National Renewable Energy Laboratory
Innovation for Our Energy Future

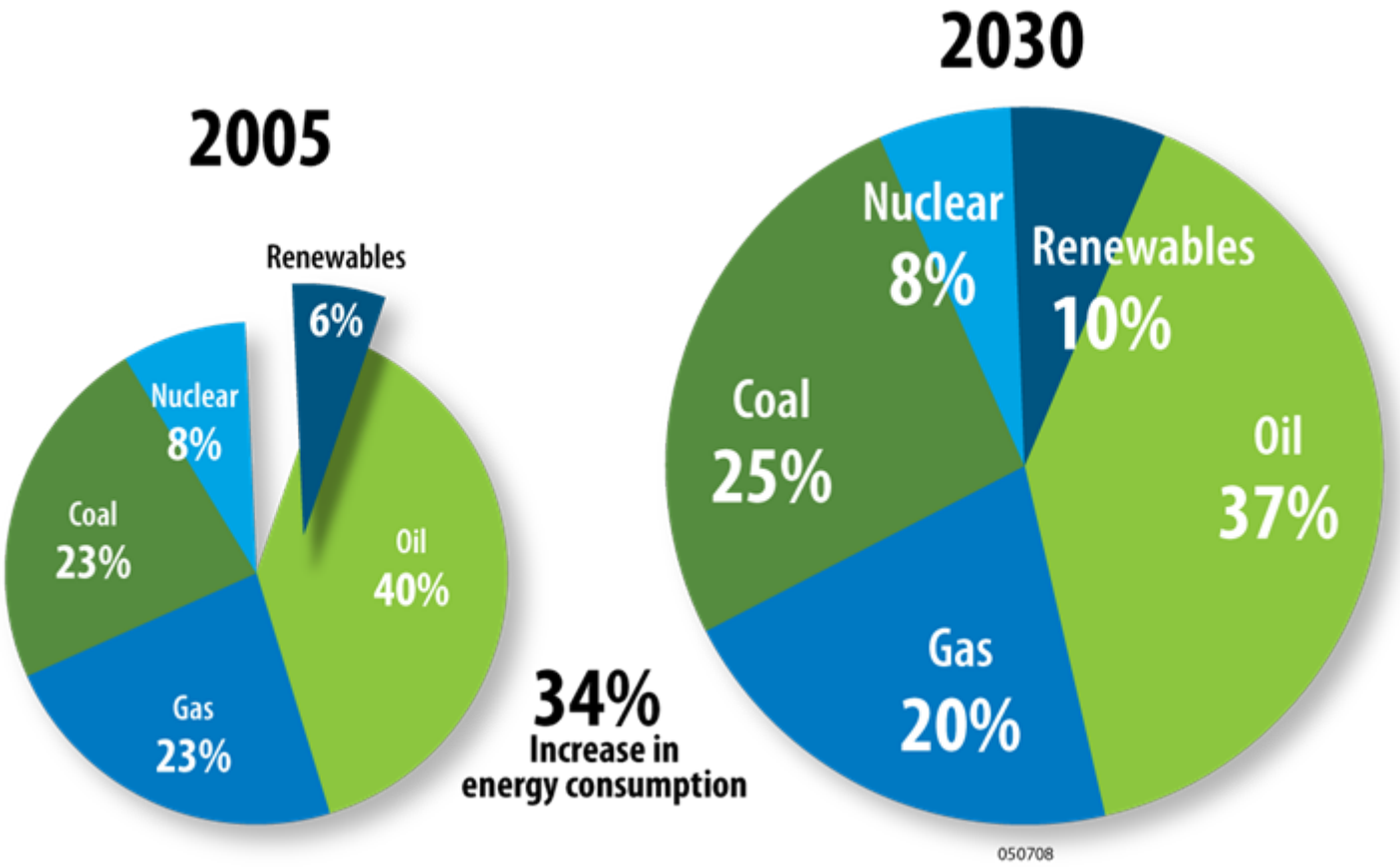
Renewable Energy and Utilities: A Perspective from NREL

PGE Board Meeting

Dr. Dan E. Arvizu
Laboratory Director

June 17, 2008

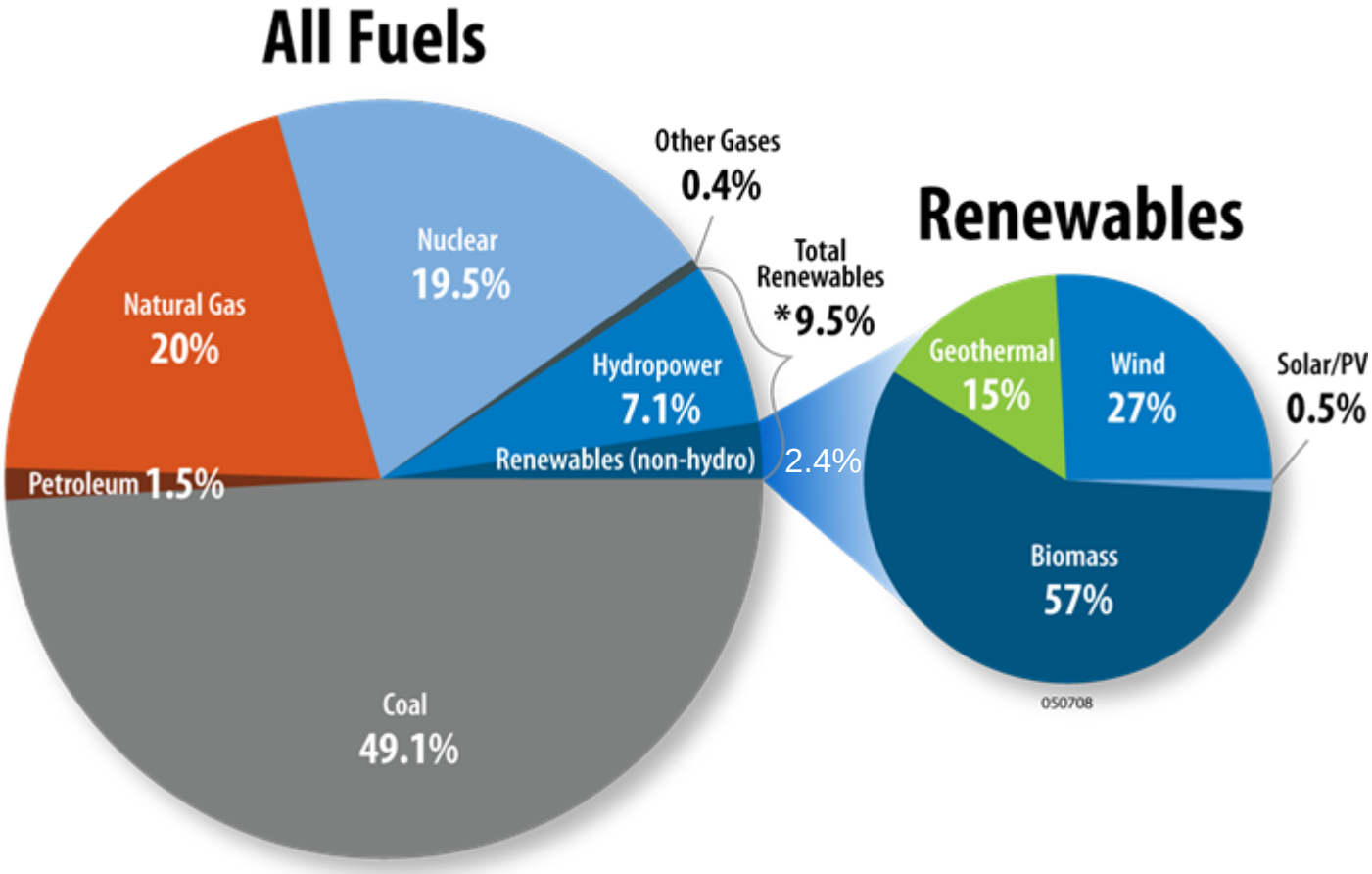
U.S. Energy Consumption and the Role of Renewable Energy



Source: Energy Information Administration,
Annual Energy Outlook 2008 (revised early release), Table 1

What Are the Major Renewables?

U.S. Electricity Net Generation

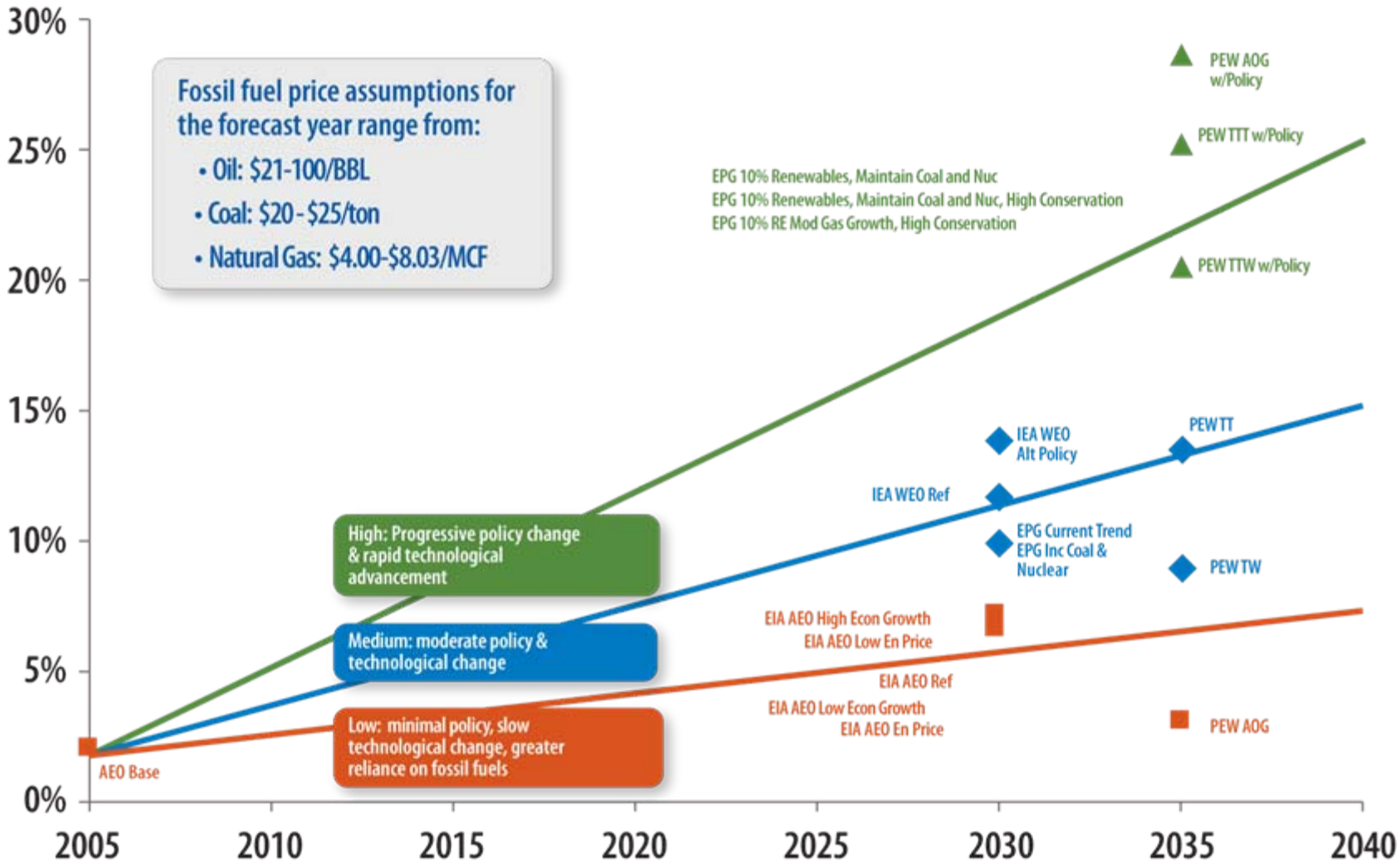


Net generation for 2006 = 3814 TWhr UCb

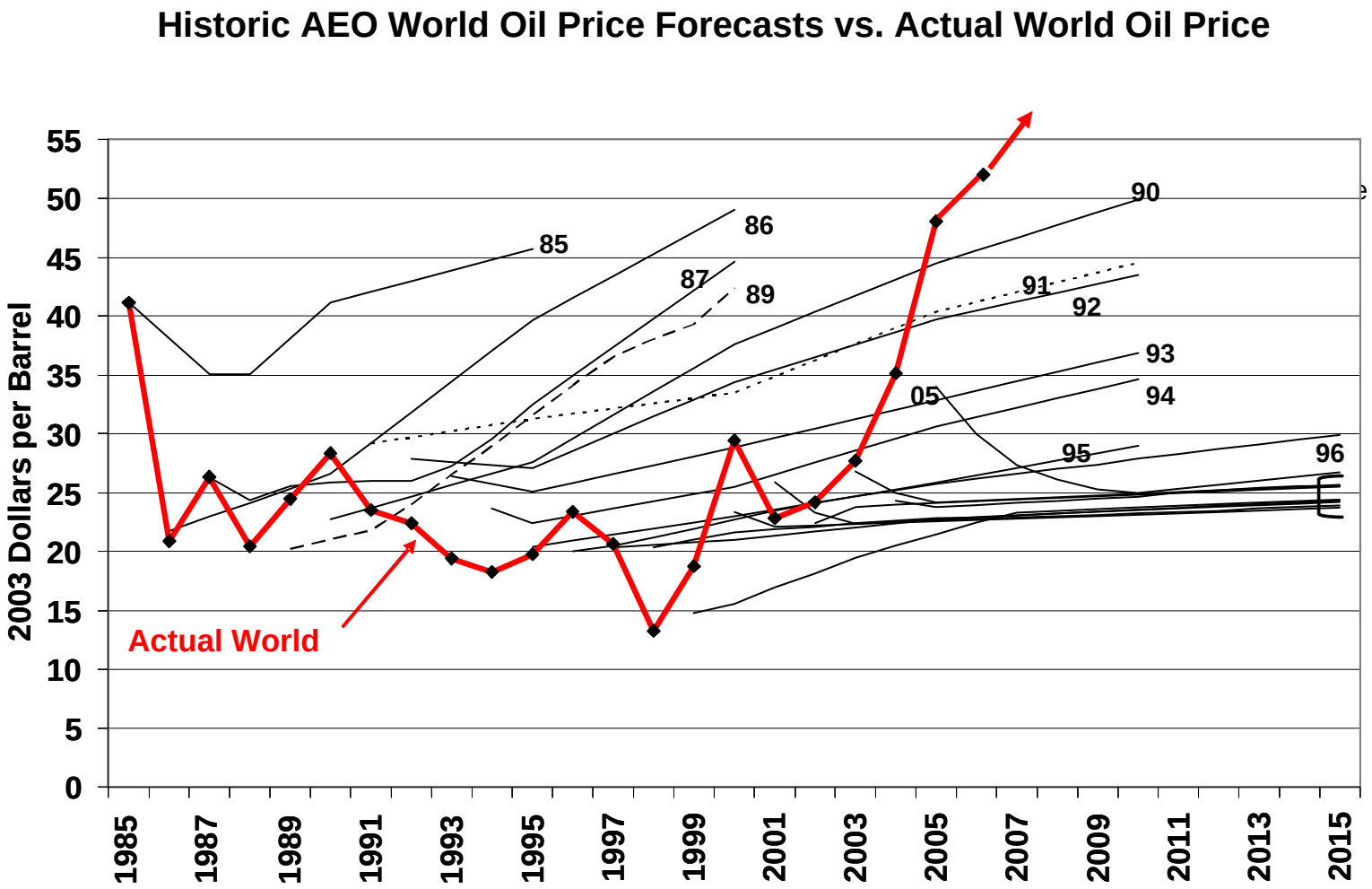
Source: EIA Annual Energy Review 2007, AEO 2008

U.S. Renewable Energy Contributions

Percent of Total Electric Generating Capacity



Econometric Modeling is Imprecise



Sources: EIA *Annual Energy Outlooks* (2006 is Early Release)

Setting the Bar Higher

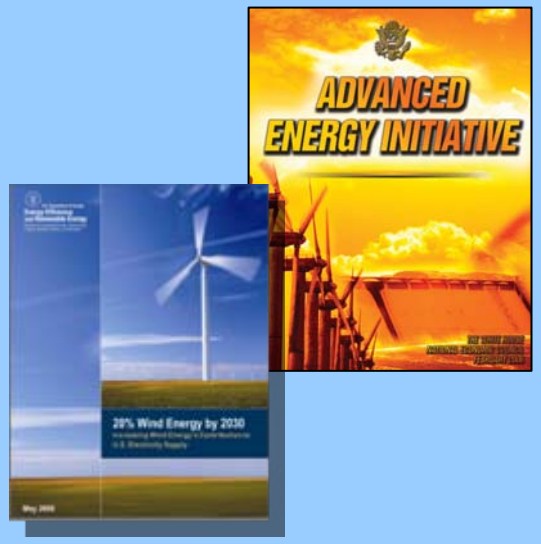
Electricity – Gigawatt-Scale Renewables

Solar Goal

PV cost of electricity parity by 2015

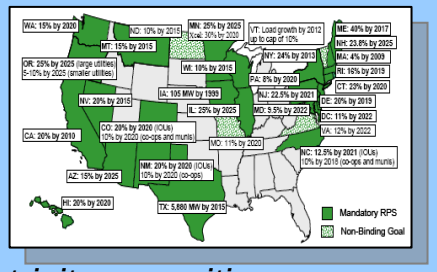
Wind Vision

20% U.S. wind electricity by 2030



Buildings

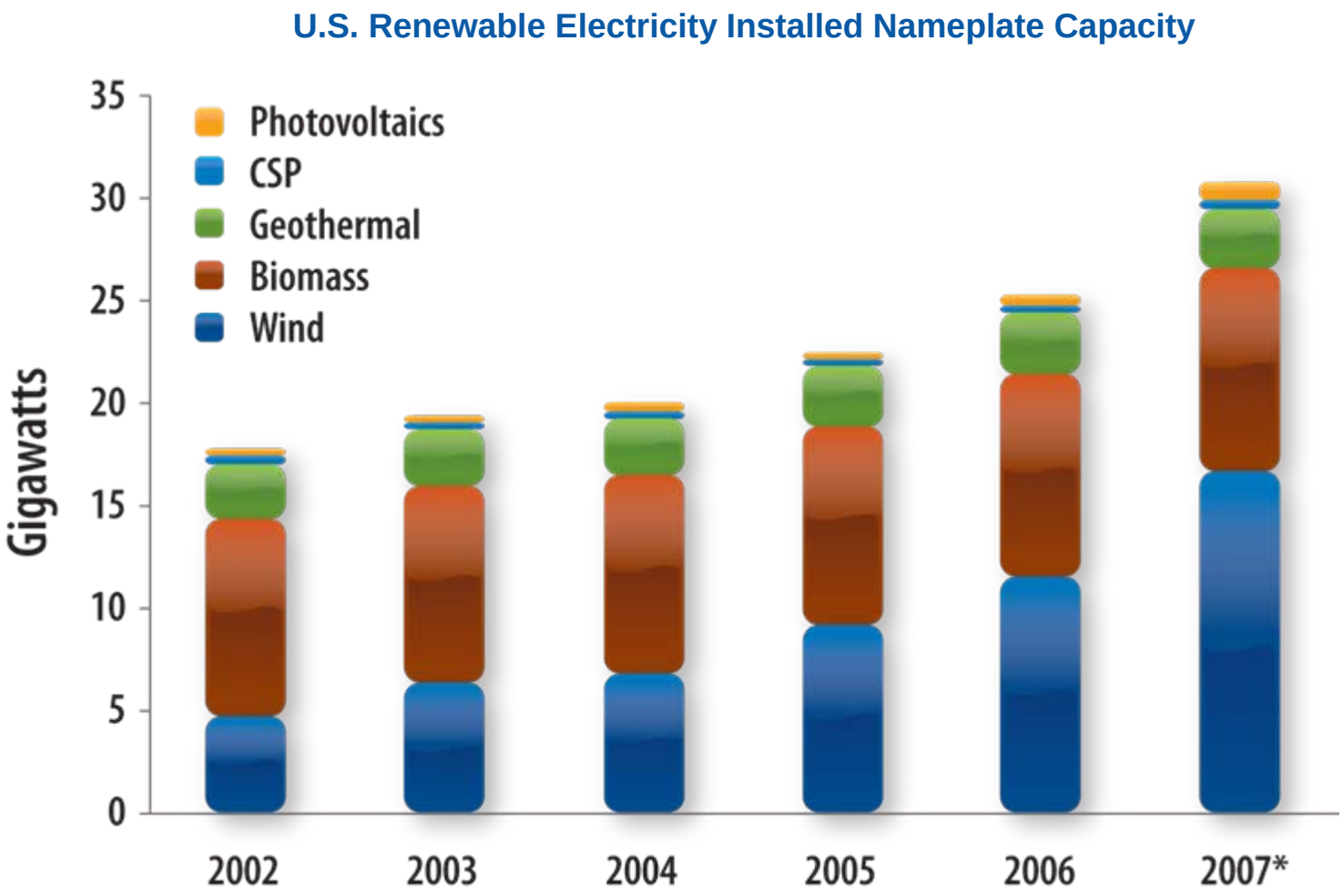
Net-Zero Energy at low incremental cost by 2025



State RPS Goals

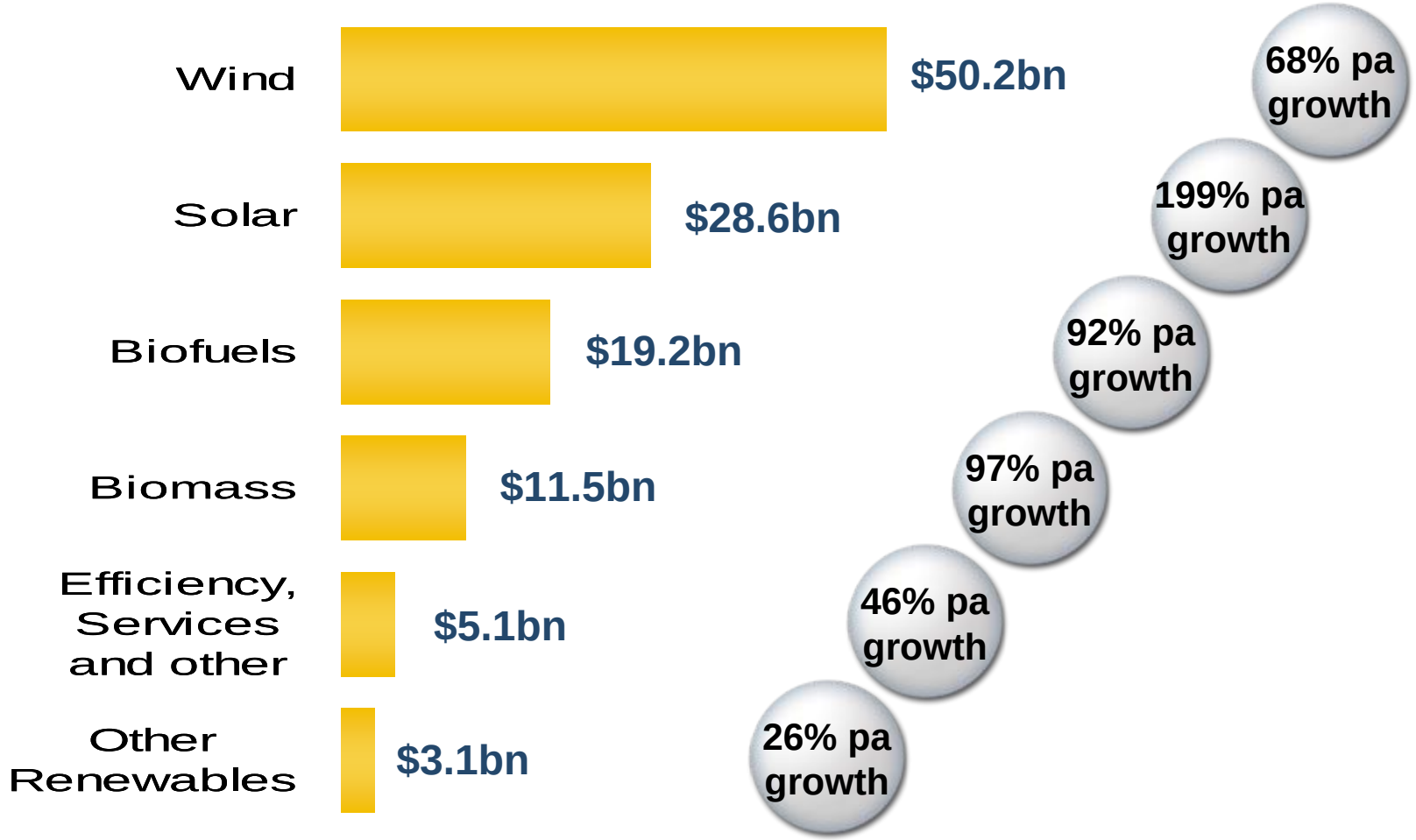
Renewable electricity capacities

Dynamic External Environment is Accelerating Speed and Scale of Renewable Energy



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

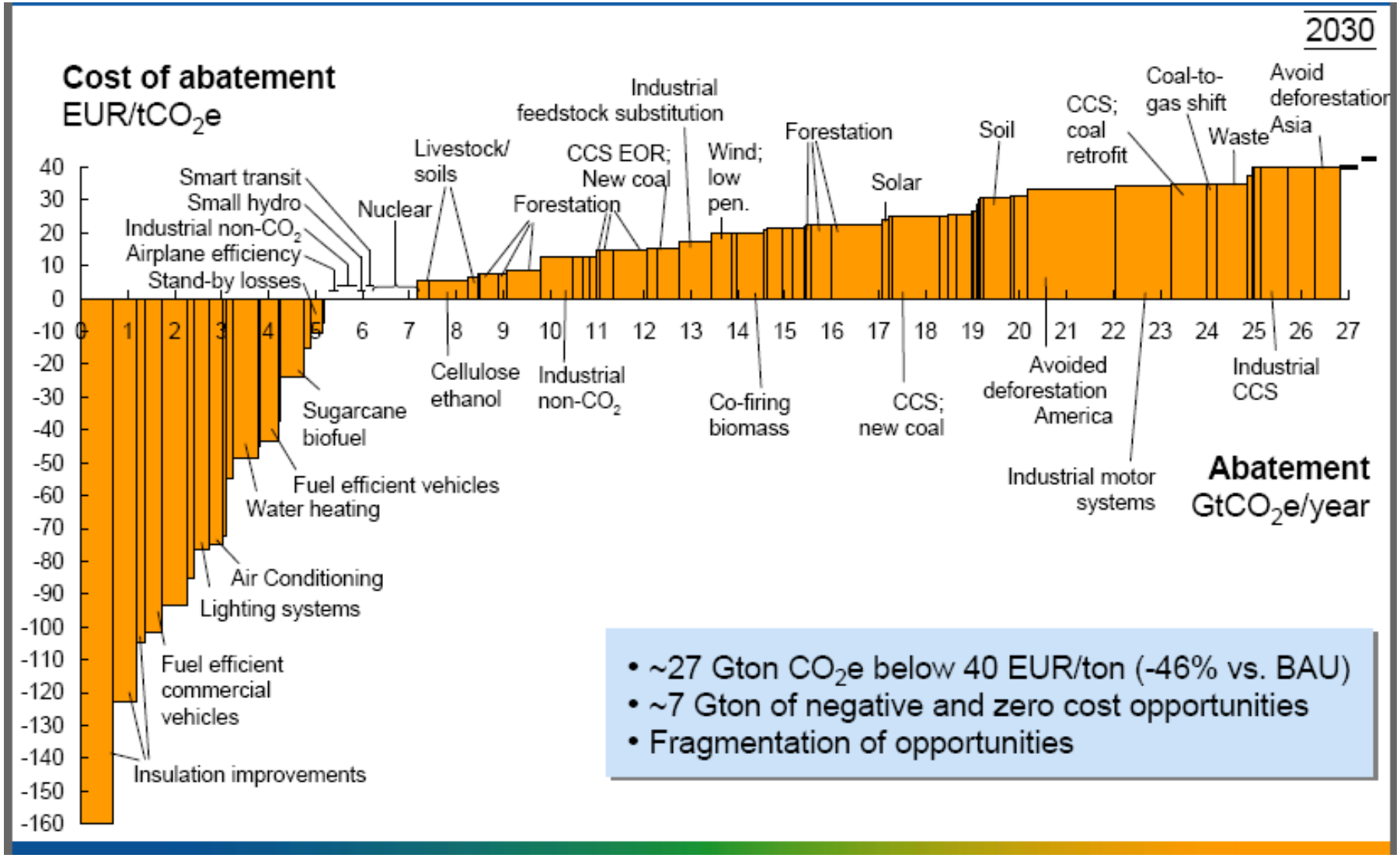
New Investment 2007 and Average Growth 2005-07 – By Sector



Note: VC/PE, Public Markets and Asset Finance only. Excludes re-investment adjustment

Source: New Energy Finance

Global cost curve of GHG abatement opportunities beyond business as usual



Source: Vattenfall AB, Global Mapping of Greenhouse Gas Abatement Opportunities, 1/07

Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

- Wind and water
- Solar
- Biomass
- Geothermal

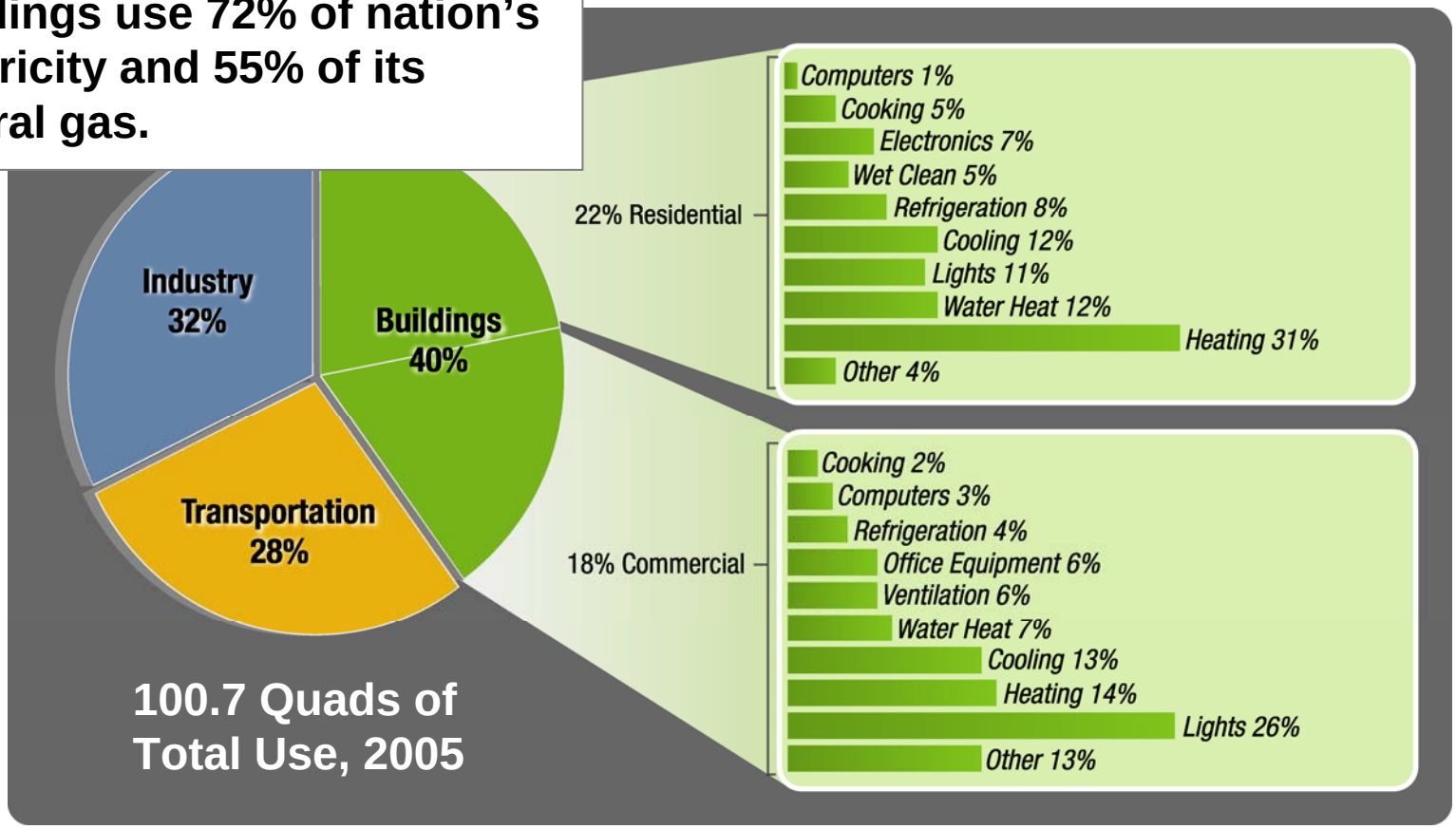
Energy Delivery and Storage

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

Foundational Science and Advanced Analytics

Buildings Matter

Buildings use 72% of nation's electricity and 55% of its natural gas.



Buildings construction/renovation contributed 9.5% to US GDP and employs approximately 8 million people. Buildings' utility bills totaled $370 Billion in 2005.

Source: *Buildings Energy Data Book 2007*

Buildings

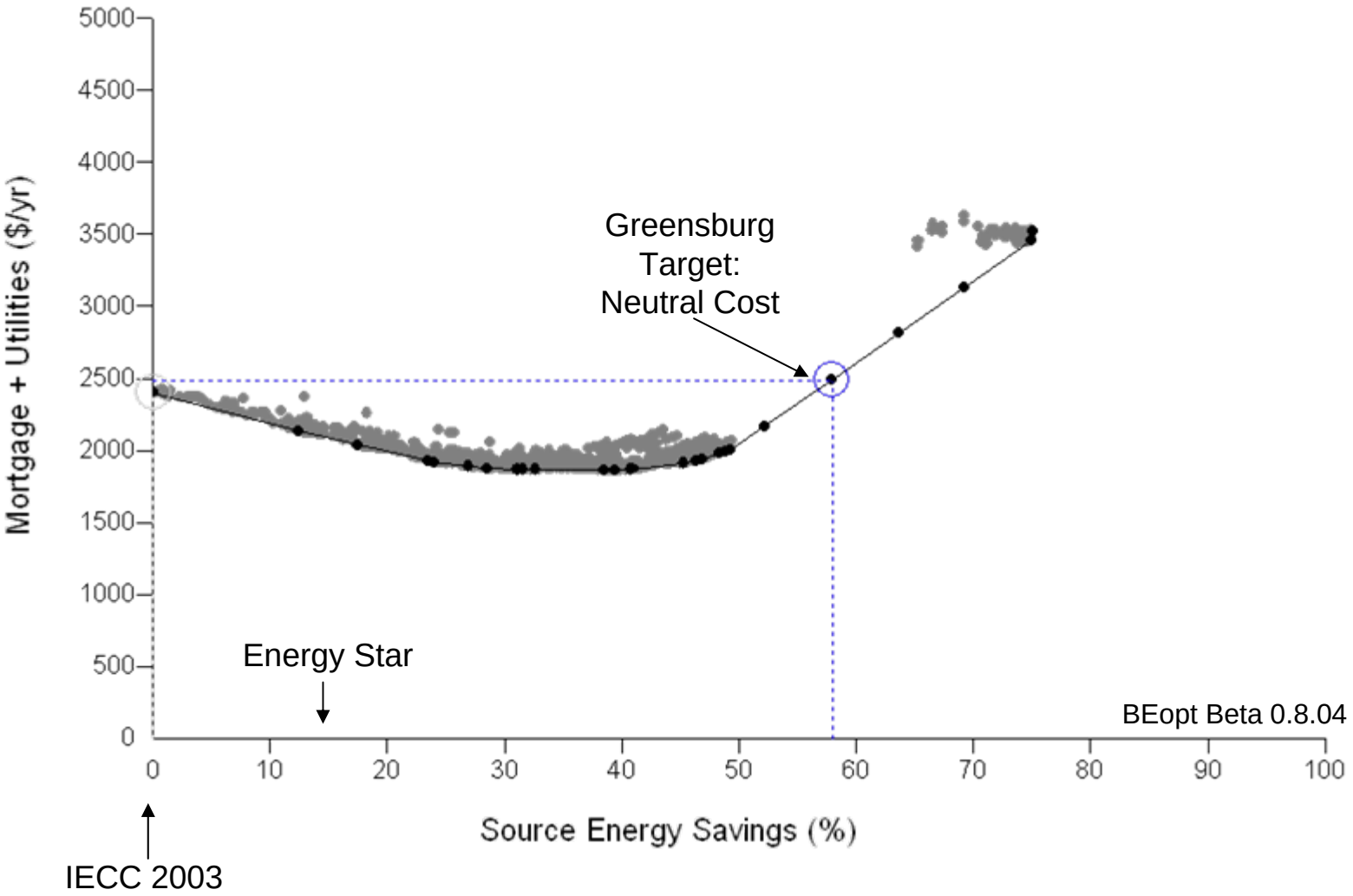
Status U.S. Buildings:
- 40% of primary energy
- 72% of electricity
- 38% of carbon emissions

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

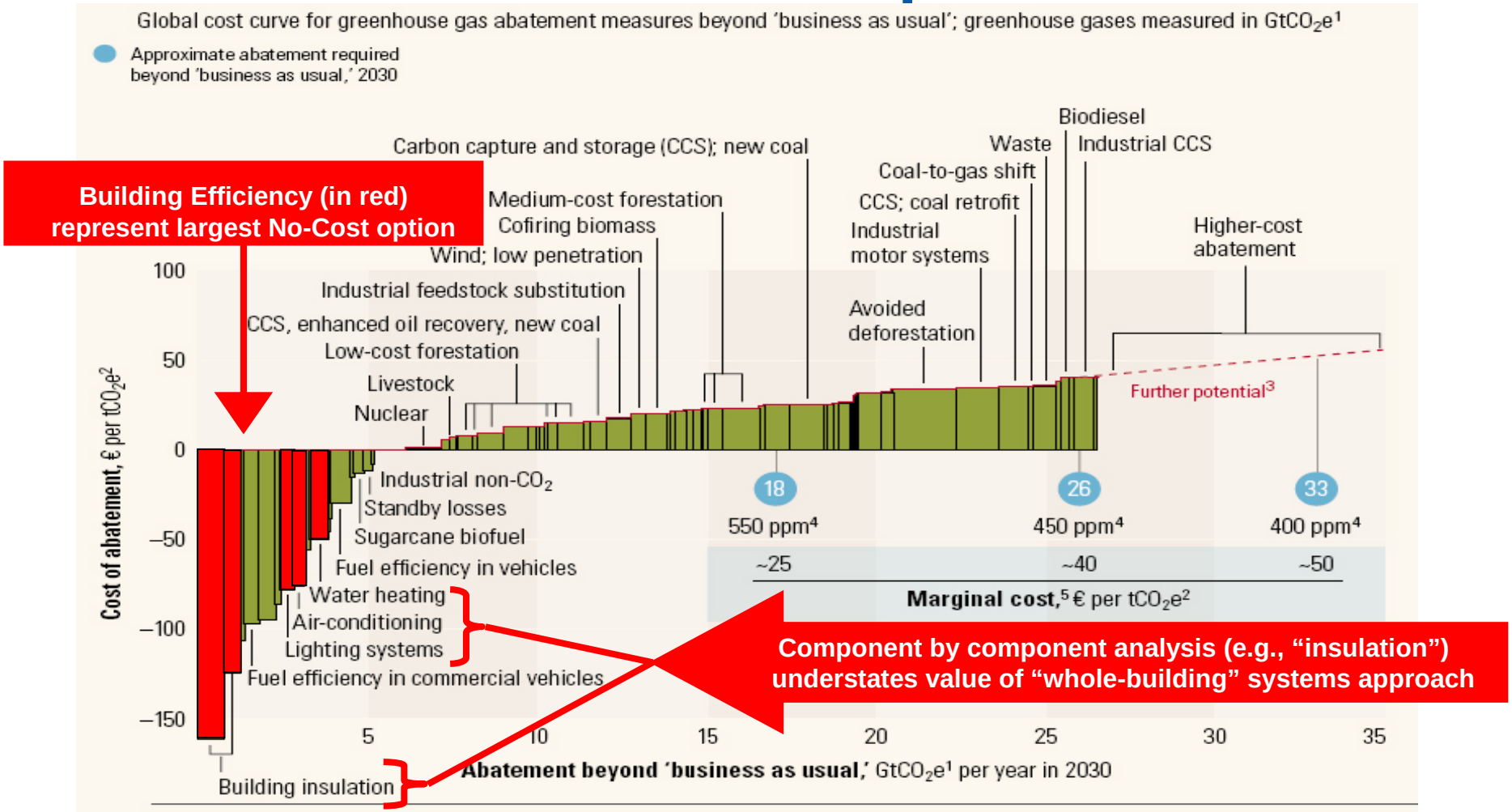
April 10, 2008

Neutral Cost Point Example
Greensburg, Kansas



(2000 ft2, 2-story, 16% window to floor area ratio, unconditioned basement)

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

Barriers to Adoption of Commercial Building Energy Efficiency

- Utility Barriers
  - Profits coupled to increased sales of energy
  - Regulatory structures inflexible and change slowly

- Technical Barriers
  - Lack of adequate measurement and verification
  - Inherent complexity of integrated approaches (e.g., daylighting)
  - Integrated building control systems have poor user interfaces
  - Good indoor environmental quality (IEQ) requires more than code ventilation requirements
  - Significant variation in building types and end uses
  - Plug and process loads not well understood or addressed

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

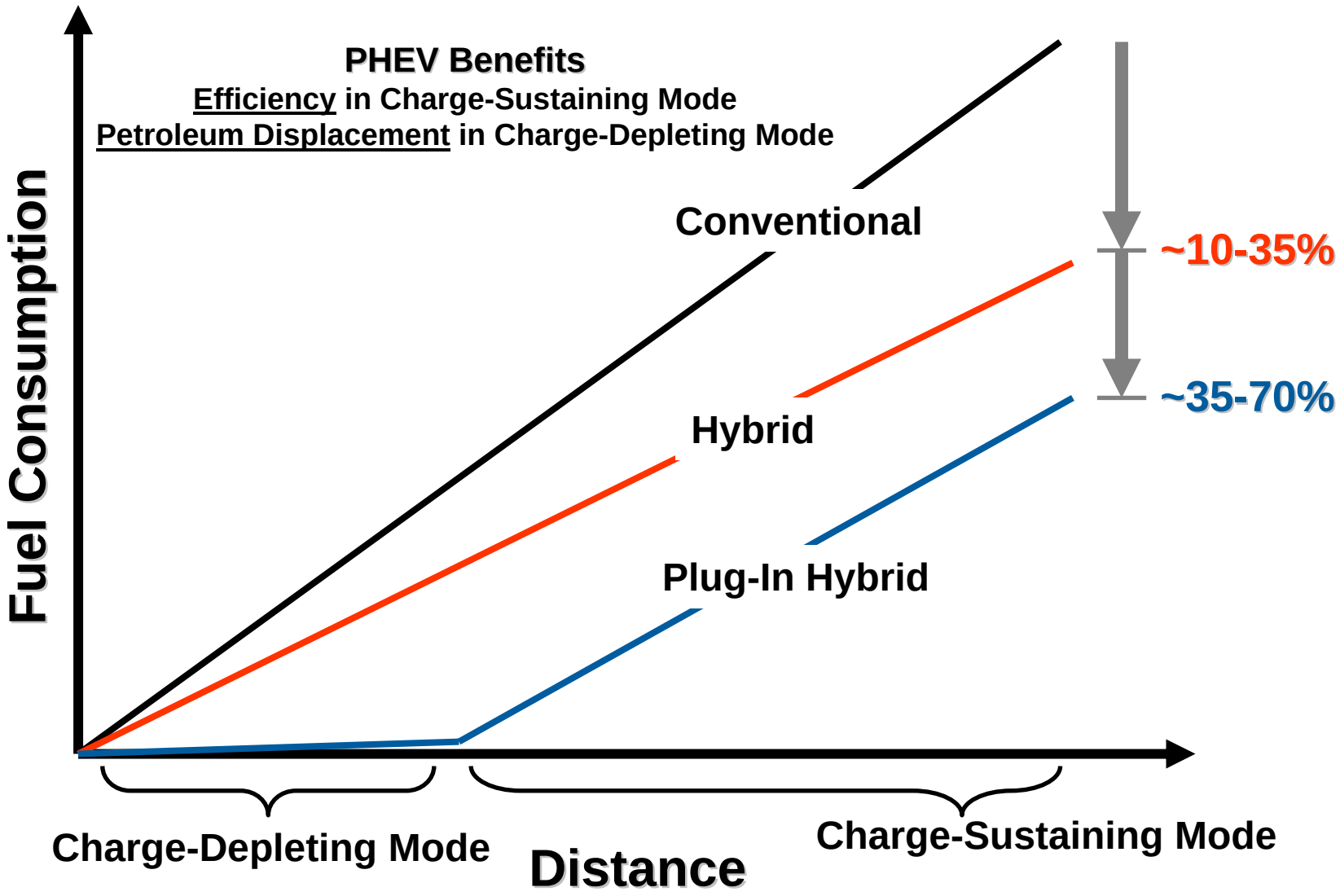
Key Challenges

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

Challenges for Plug-Ins

- Improving batteries
  - Cost
  - Calendar and cycle life
  - Safety of Li-Ion
  - Cold temperature performance
  - Volume and packaging
- Reducing power electronics cost and volume
- Developing efficient chargers
- Standardizing plugs for charging
- Avoiding negative peak time charging impacts

PHEV Benefits Tied to Usage Pattern



Science at the Leading Edge of Energy Efficiency Research

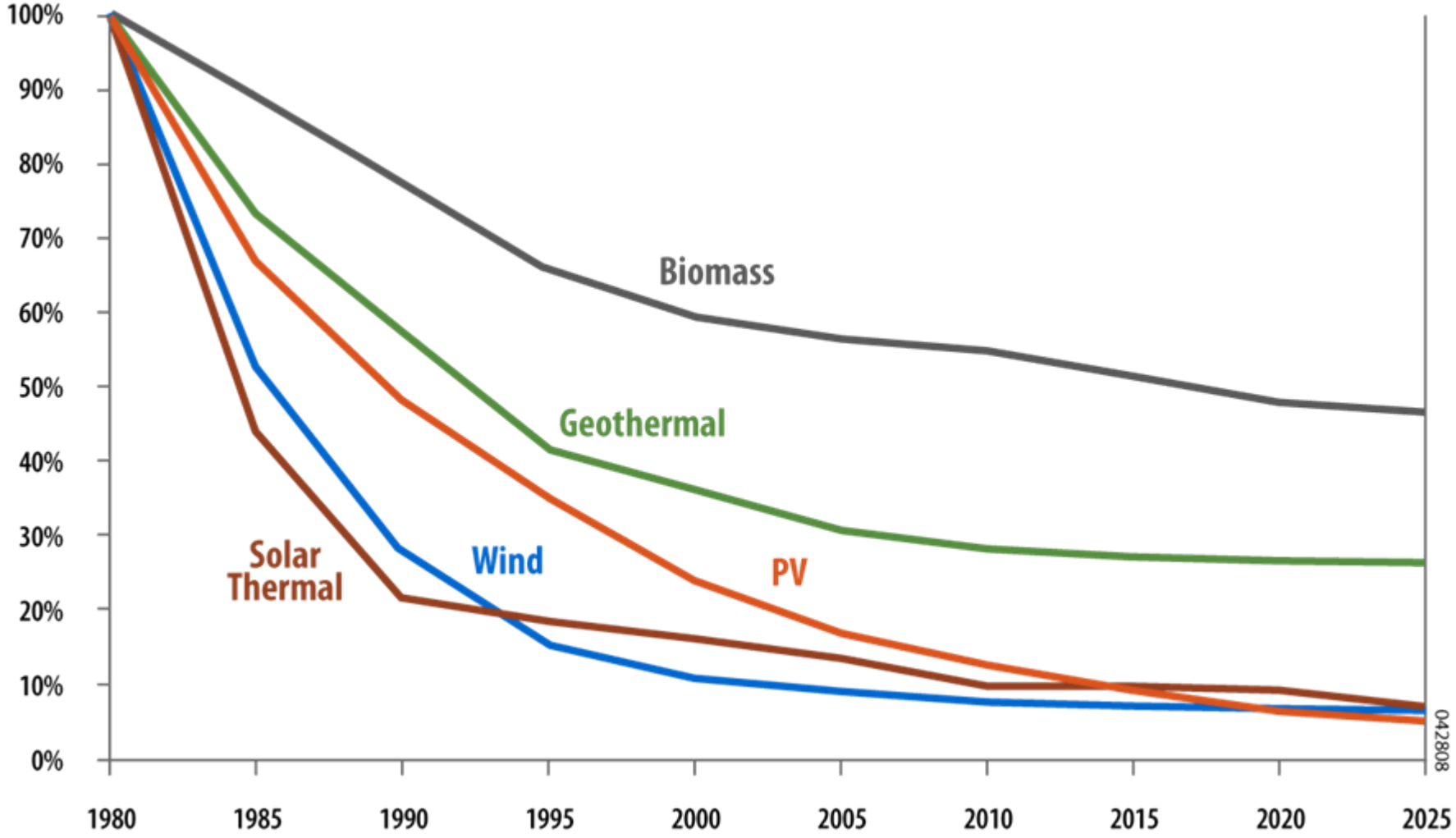
Significant improvements are anticipated through:

- Super-strong lightweight materials
- Smart roofs
- Solid state lighting
- Superconducting

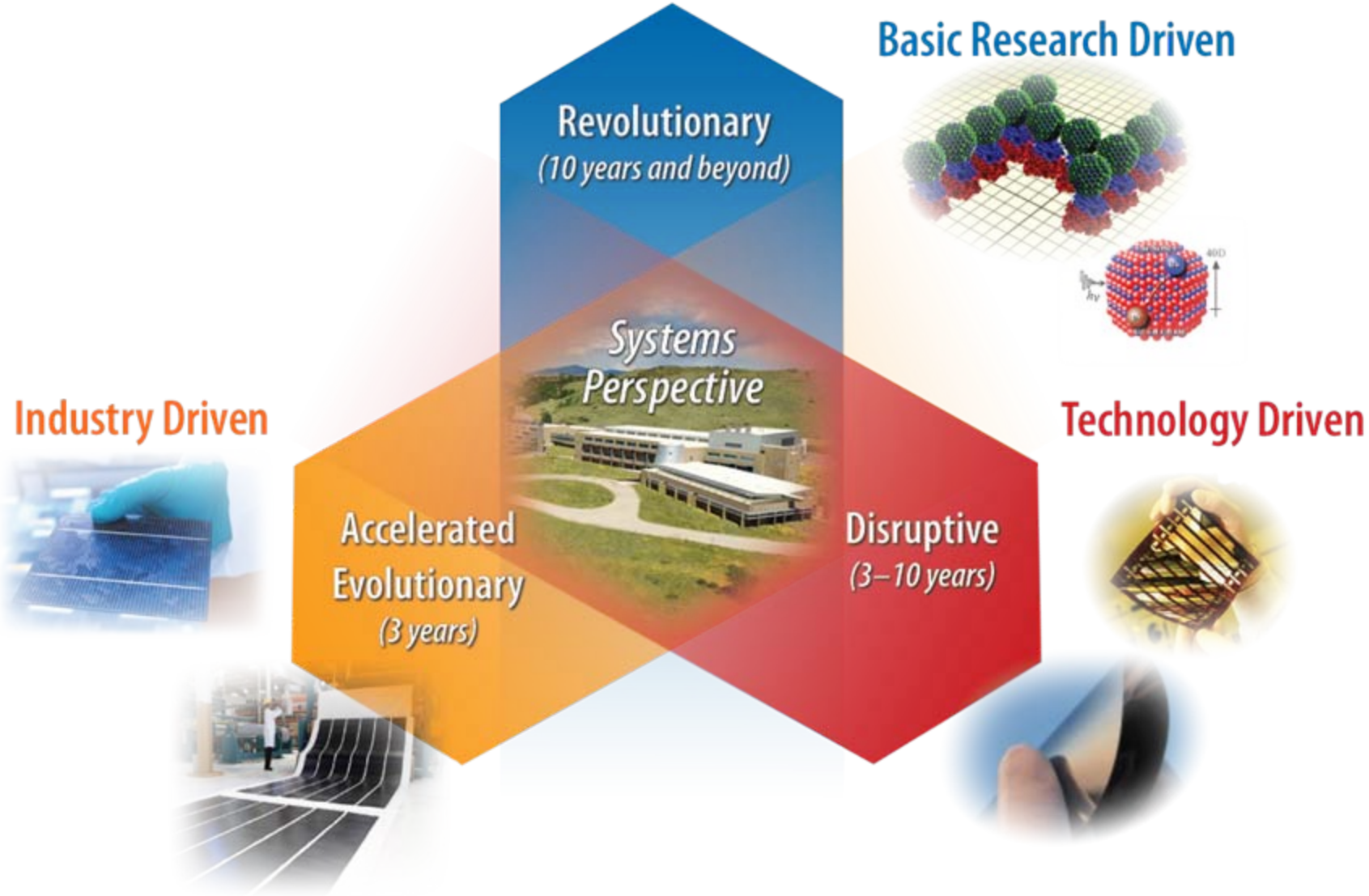
New discoveries will have broad impact on daily life

Source: Oak Ridge National Laboratory

Past Investments Have Dramatically Reduced Costs



Maxmizing Impact



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

Integrating Wind Into Power Systems

New studies find integrating wind into power systems is manageable, but not costless

Date	Study	Wind Capacity Penetration	Cost ($/MWh)				
			Regulation	Load Following	Unit Commitment	Gas Supply	TOTAL
2003	Xcel-UWIG	3.5%	0	0.41	1.44	na	1.85
2003	We Energies	4%	1.12	0.09	0.69	na	1.90
2003	We Energies	29%	1.02	0.15	1.75	na	2.92
2004	Xcel-MNDOC	15%	0.23	na	4.37	na	4.60
2005	PacifiCorp	20%	0	1.6	3	na	4.60
2006	CA RPS (multi-year)	4%	0.45*	trace	na	na	0.45
2006	Xcel-PSCo	10%	0.2	na	2.26	1.26	3.72
2006	Xcel-PSCo	15%	0.2	na	3.32	1.45	4.97
2006	MN-MISO 20%	31%	na	na	na	na	4.41**

** 3-year average* *** highest over 3-year evaluation period*

Key Results from Major Wind Integration Studies Completed 2003-2006

Some Additional Reserves May Need to be Committed

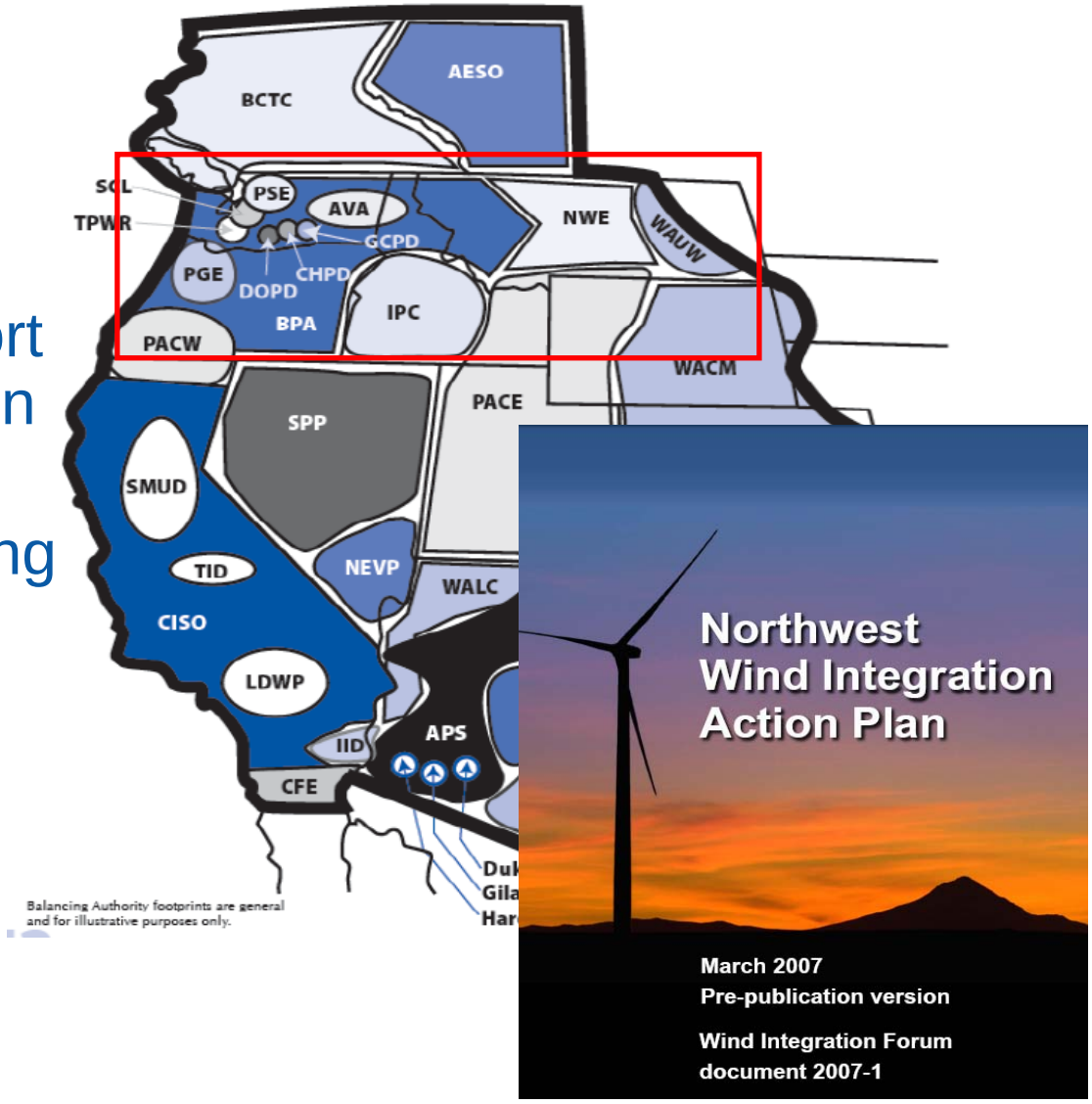
Reserve Category	Base		15% Wind		20% Wind		25% Wind	
	MW	%	MW	%	MW	%	MW	%
Regulating	**137**	**0.65%**	**149**	**0.71%**	**153**	**0.73%**	**157**	**0.75%**
Spinning	**330**	**1.57%**	**330**	**1.57%**	**330**	**1.57%**	**330**	**1.57%**
Non-Spin	**330**	**1.57%**	**330**	**1.57%**	**330**	**1.57%**	**330**	**1.57%**
Load Following	**100**	**0.48%**	**110**	**0.52%**	**114**	**0.54%**	**124**	**0.59%**
Operating Reserve Margin	**152**	**0.73%**	**310**	**1.48%**	**408**	**1.94%**	**538**	**2.56%**
Total Operating Reserves	**1049**	**5.00%**	**1229**	**5.86%**	**1335**	**6.36%**	**1479**	**7.05%**

Source MN DOC

Estimated Operating Reserve Requirement for MN BAs – 2020 Load

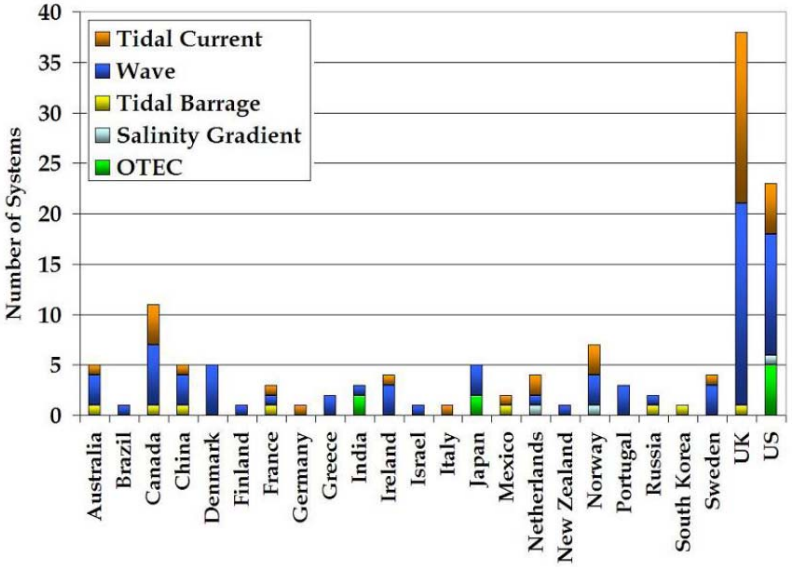
NREL Wind Systems Integration Team is Assisting NW Utilities

- Northwest Wind Integration Action Plan/Forum
- Large stakeholder effort to examine wind; action items developed
- Separate effort assisting BPA develop a wind integration rate



Marine Energy

Marine Technology Development by Country

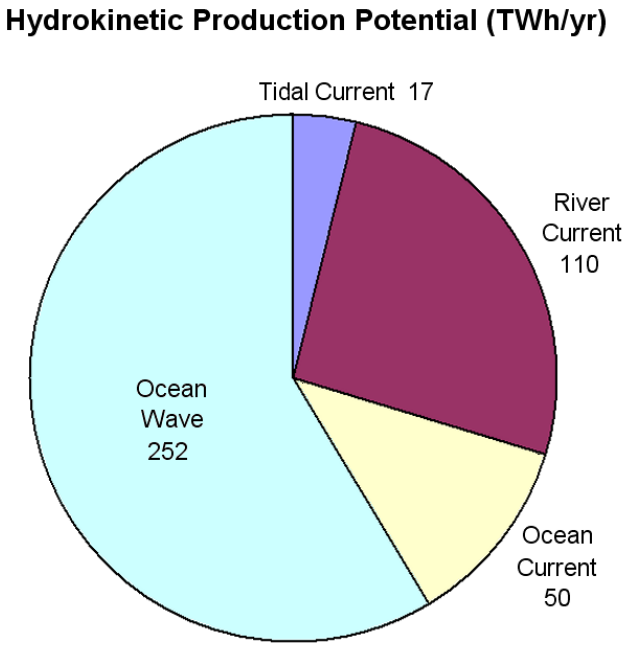


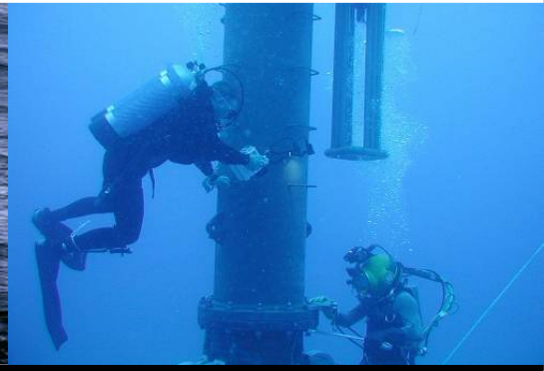
Source: International Energy Agency – Ocean Energy Systems and Powertech

- According to IEA the number of companies developing marine energy devices increased from 35 to 81 between 2003 to 2006
- Wave and Tidal current devices dominate
- Most companies are small and under capitalized
- Most are at the conceptual or scale model testing phase
- Very few have progressed to the long term, full scale ocean testing phase
- No companies are in commercial production yet
- Federal funding began in FY2008 at $10M to DOE from EIS 2007

Marine Energy Technical Challenges

- Resource is dispersed regionally among a few states and has not yet been fully quantified
- Regulatory barriers are impeding technology development – projects face old hydro permitting schemes
- Technology is not proven; there is no basis for evaluating different concepts.
- Environmental sensitivities & competing use impacts need to be quantified





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

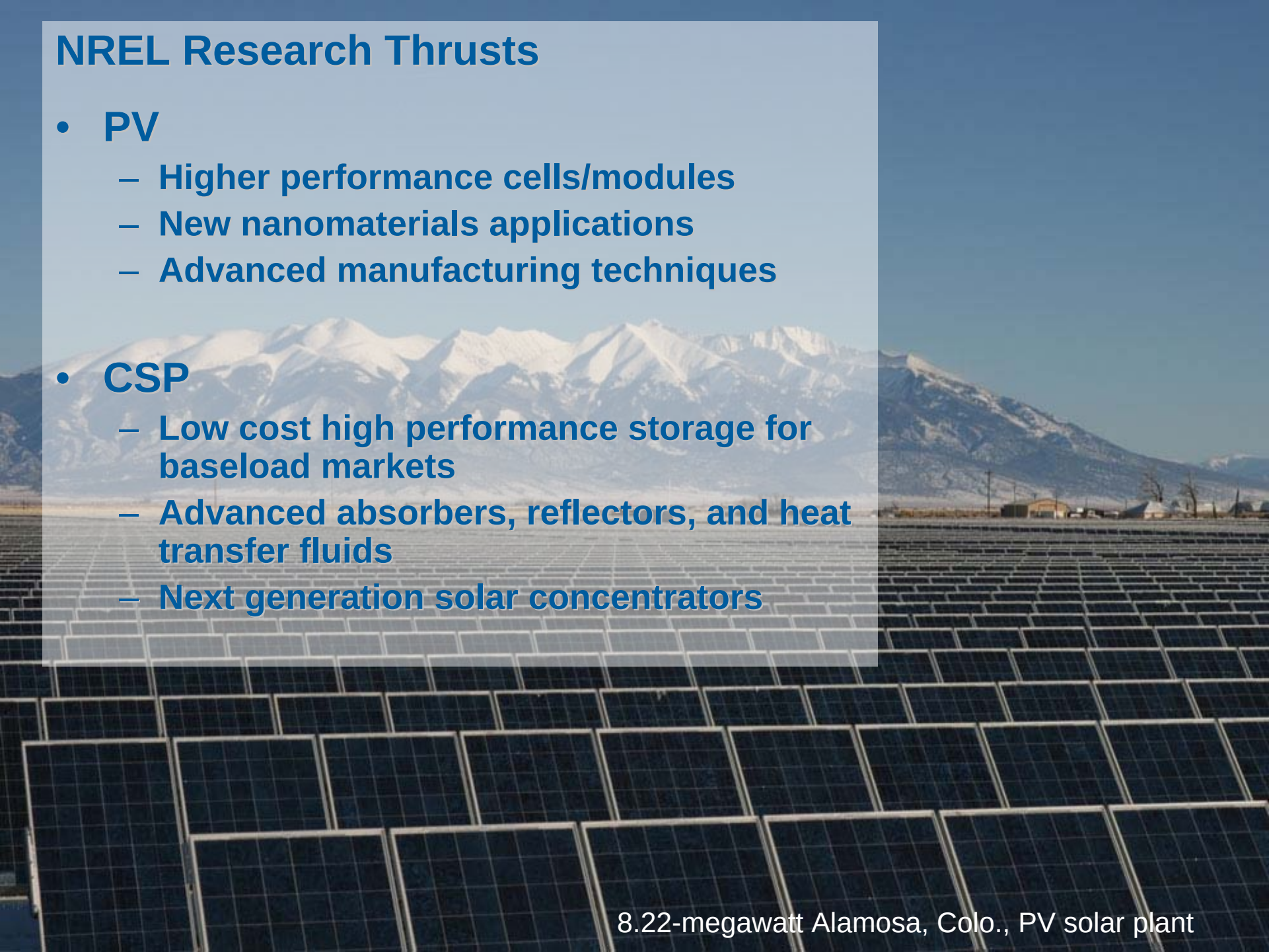
CSP
8.5 ¢/kWh by 2010
6 ¢/kWh by 2015

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

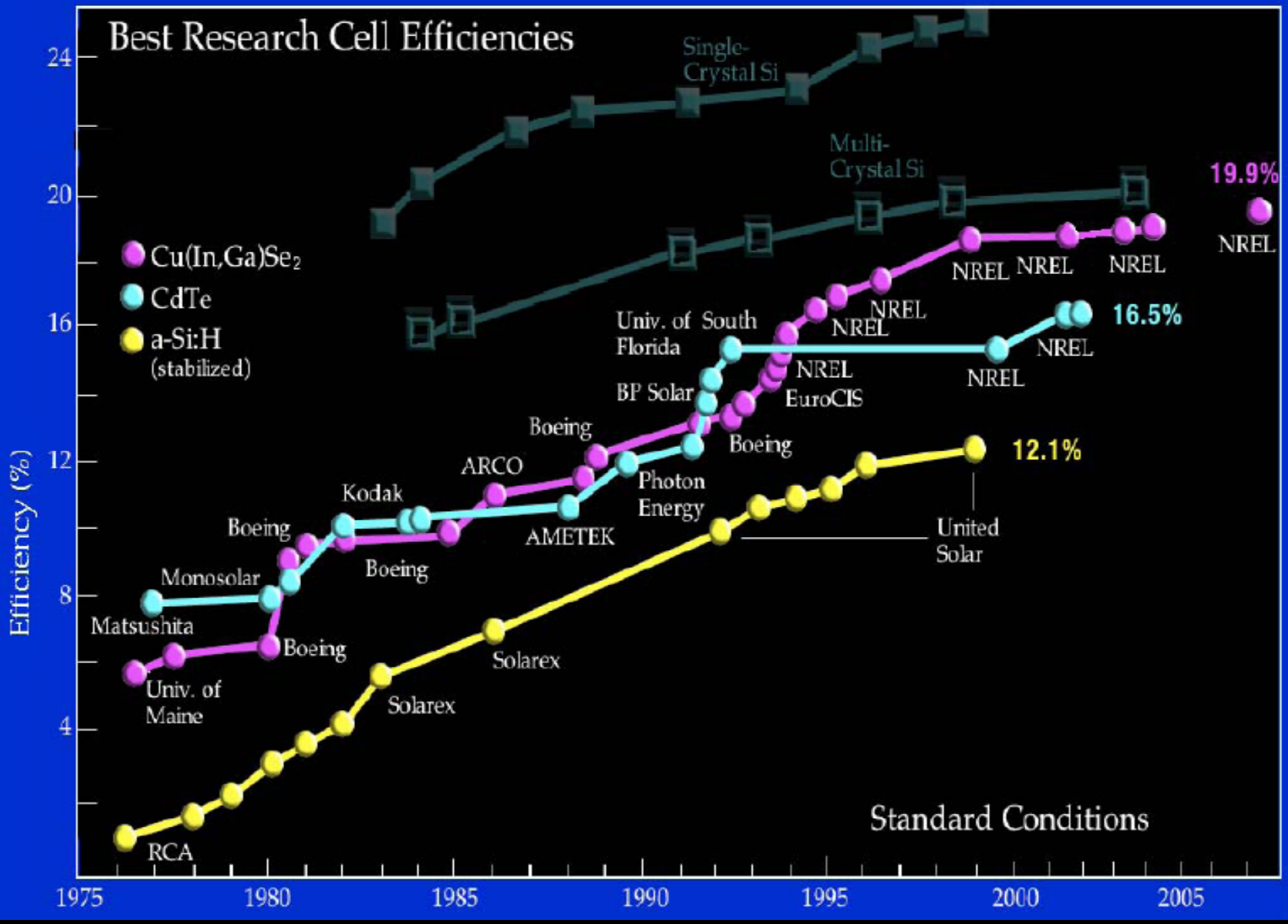
NREL Research Thrusts

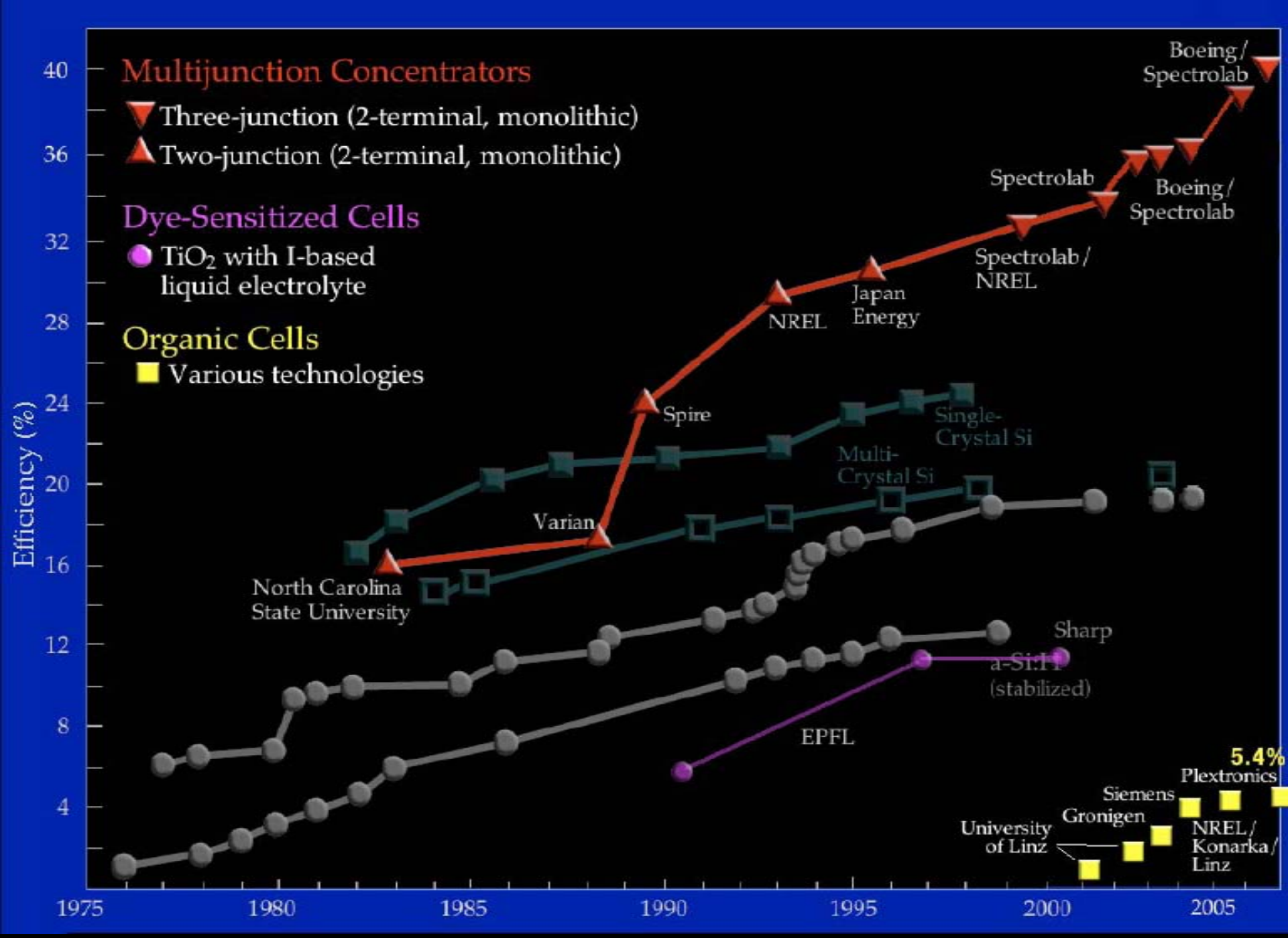
- **PV**
  - Higher performance cells/modules
  - New nanomaterials applications
  - Advanced manufacturing techniques

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

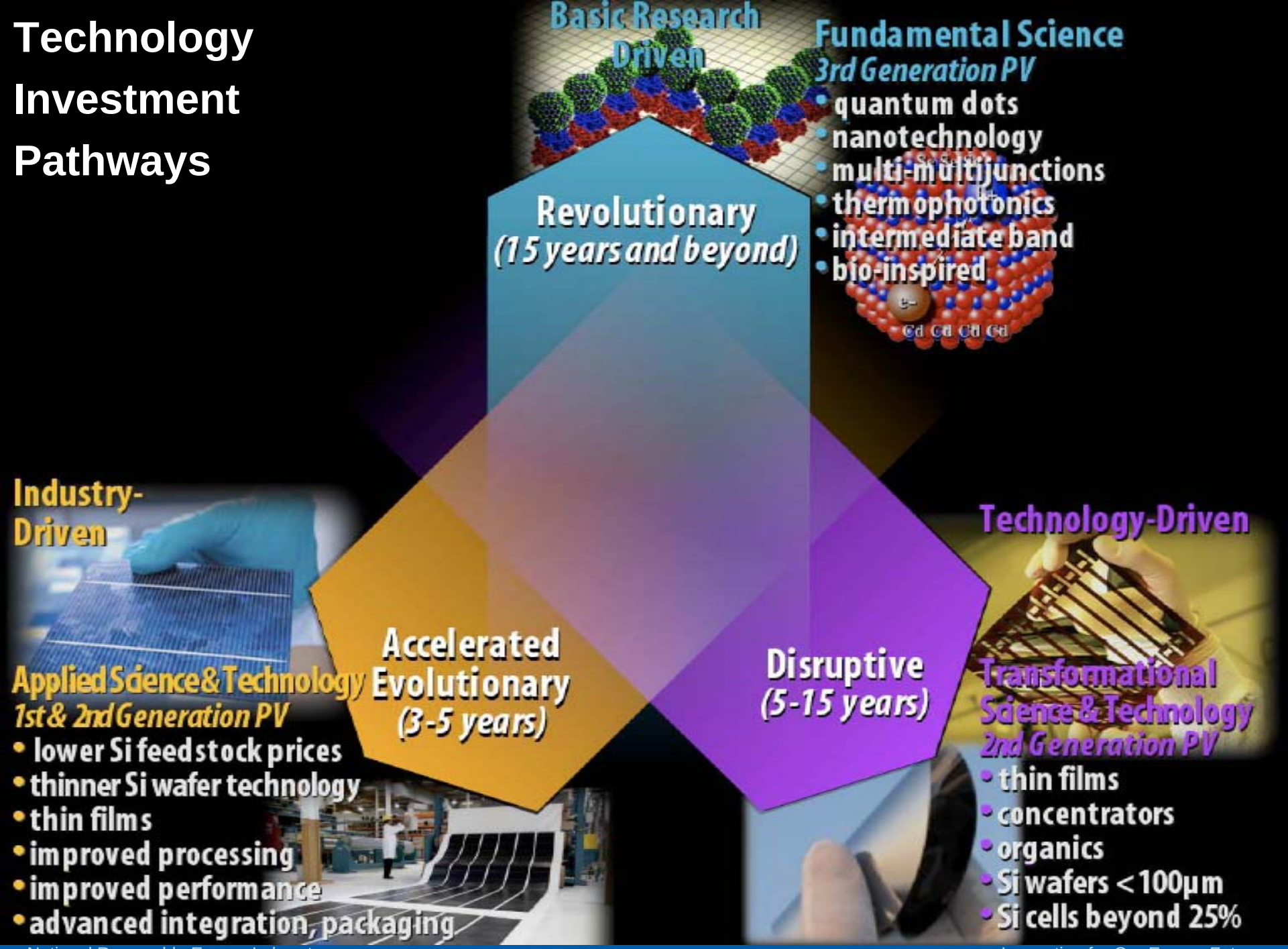


8.22-megawatt Alamosa, Colo., PV solar plant


Best Research Cell Efficiencies
Single-Crystal Si
Multi-Crystal Si
Cu(In,Ga)Se2
CdTe
a-Si:H (stabilized)
19.9%
NREL
NREL
NREL
NREL
NREL
NREL
NREL
16.5%
NREL
NREL
NREL
EuroCIS
Univ. of South Florida
BP Solar
Boeing
Boeing
ARCO
Photon Energy
AMETEK
Kodak
Boeing
Boeing
Monosolar
Matsushita
Boeing
Univ. of Maine
Solarex
Solarex
RCA
12.1%
United Solar
Standard Conditions
Efficiency (%)
24
20
16
12
8
4
1975
1980
1985
1990
1995
2000
2005


Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
Dye-Sensitized Cells
TiO2 with I-based liquid electrolyte
Organic Cells
Various technologies
Efficiency (%)
40
36
32
28
24
20
16
12
8
4
1975
1980
1985
1990
1995
2000
2005
Boeing / Spectrolab
Spectrolab
Boeing / Spectrolab
Spectrolab / NREL
Japan Energy
NREL
Spire
Single-Crystal Si
Multi-Crystal Si
Varian
North Carolina State University
Sharp
a-Si:H (stabilized)
EPFL
5.4%
Plextronics
Siemens
Gronigen
University of Linz
NREL / Konarka / Linz

Technology Investment Pathways



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

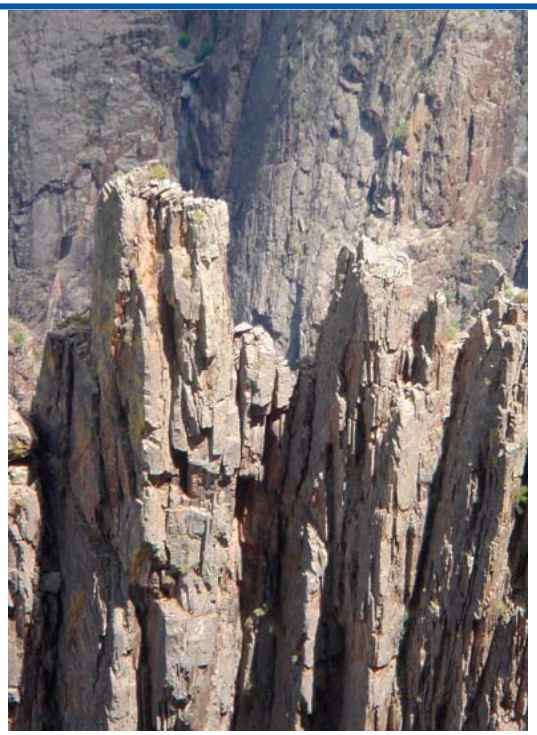
Long Term Potential:

- 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

Enhanced Geothermal Systems Challenges



Technical

- Site selection - exploration techniques for EGS
  - EGS paradigm shift from hydrothermal
- Creating EGS in variety of geologic environments
  - Create a subsurface fracture system to enable extraction of heat
    - Sufficient flow rates (80 kg/sec)
    - Heat exchange volume (recoverable energy) and surface area (recovery rate)
    - Minimal loss of injected fluid
- Few EGS field experiments yet conducted worldwide
  - Experimental evidence of EGS well productivity, heat exchange volume, and longevity is lacking

Geologic variability and uncertainty create technical challenges

Biofuels

Current Biofuels Status

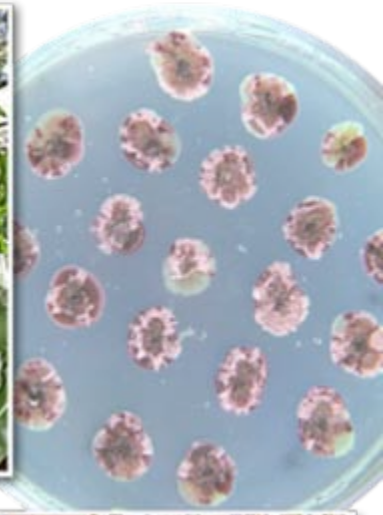
- Biodiesel – 165 companies; 1.85 billion gallons/yr capacity[1]
- Corn ethanol
  - 134 commercial plants[2]
  - 7.2 billion gal/yr. capacity[2]
  - Additional 6.2 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
  - Projected commercial cost ~$3.50/gge

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)

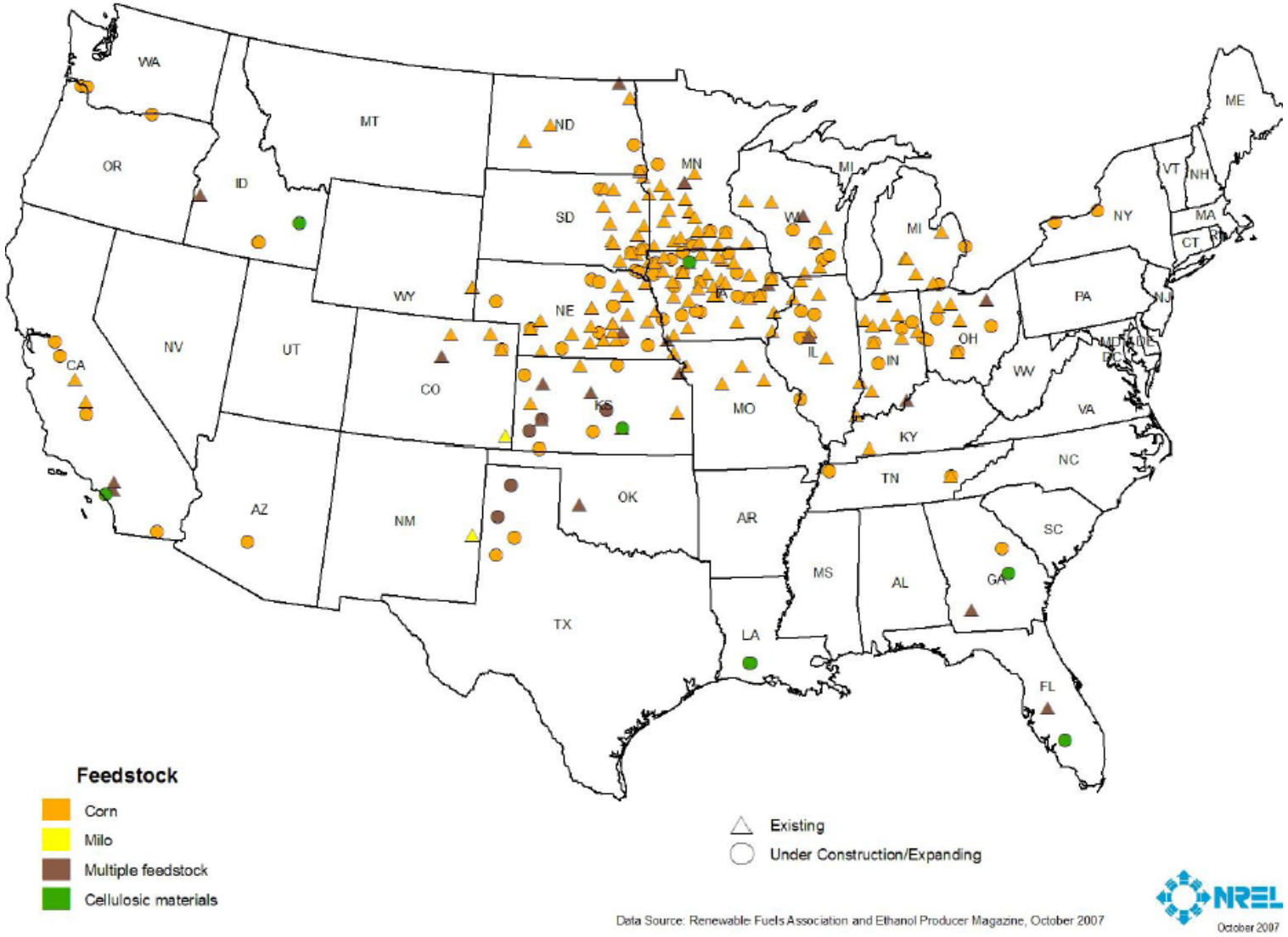
NREL Research Thrusts

- 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

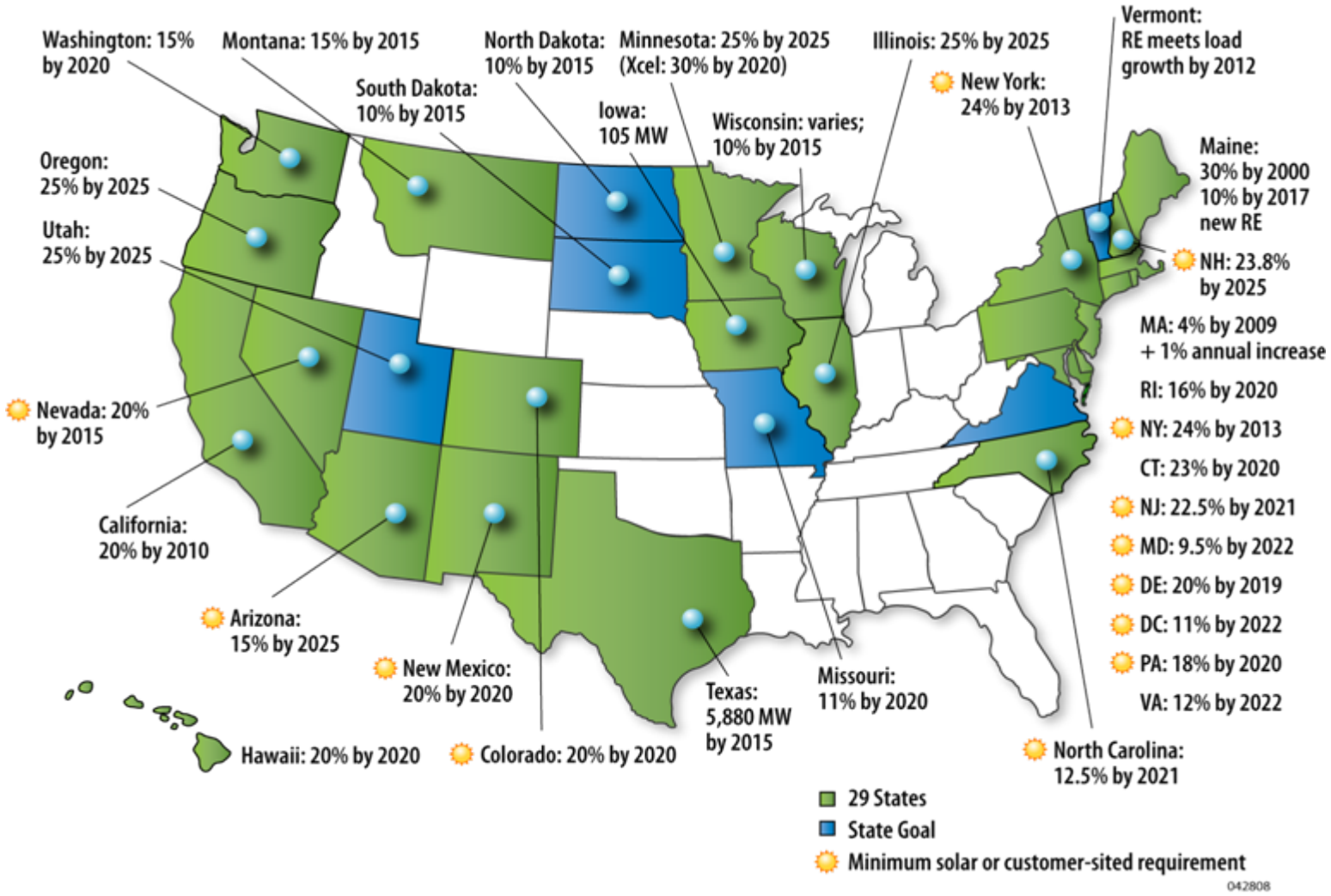
U.S. Ethanol Biorefineries



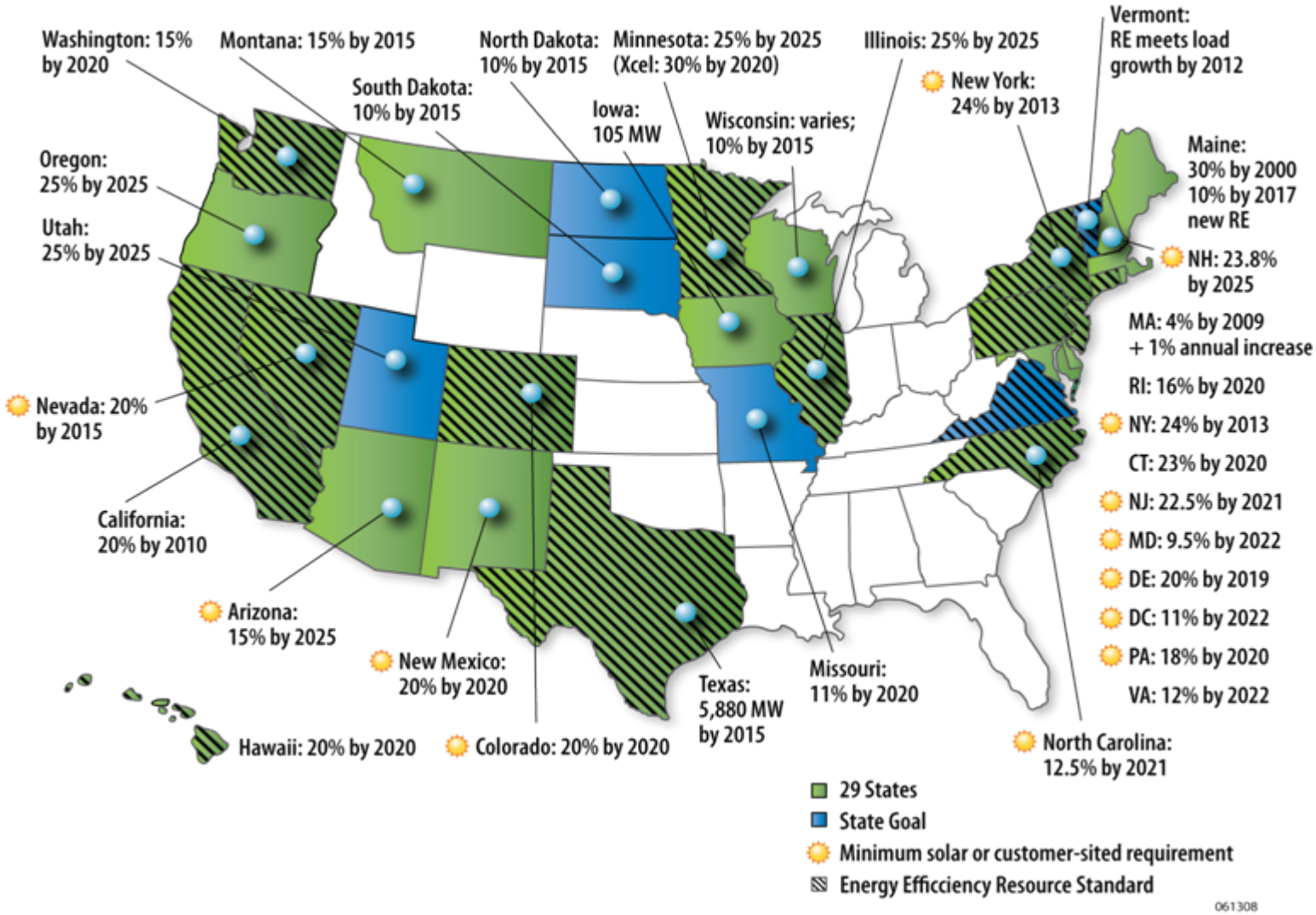
An Integrated Approach is Required

Policies, Transmission and Regulatory Acceptance

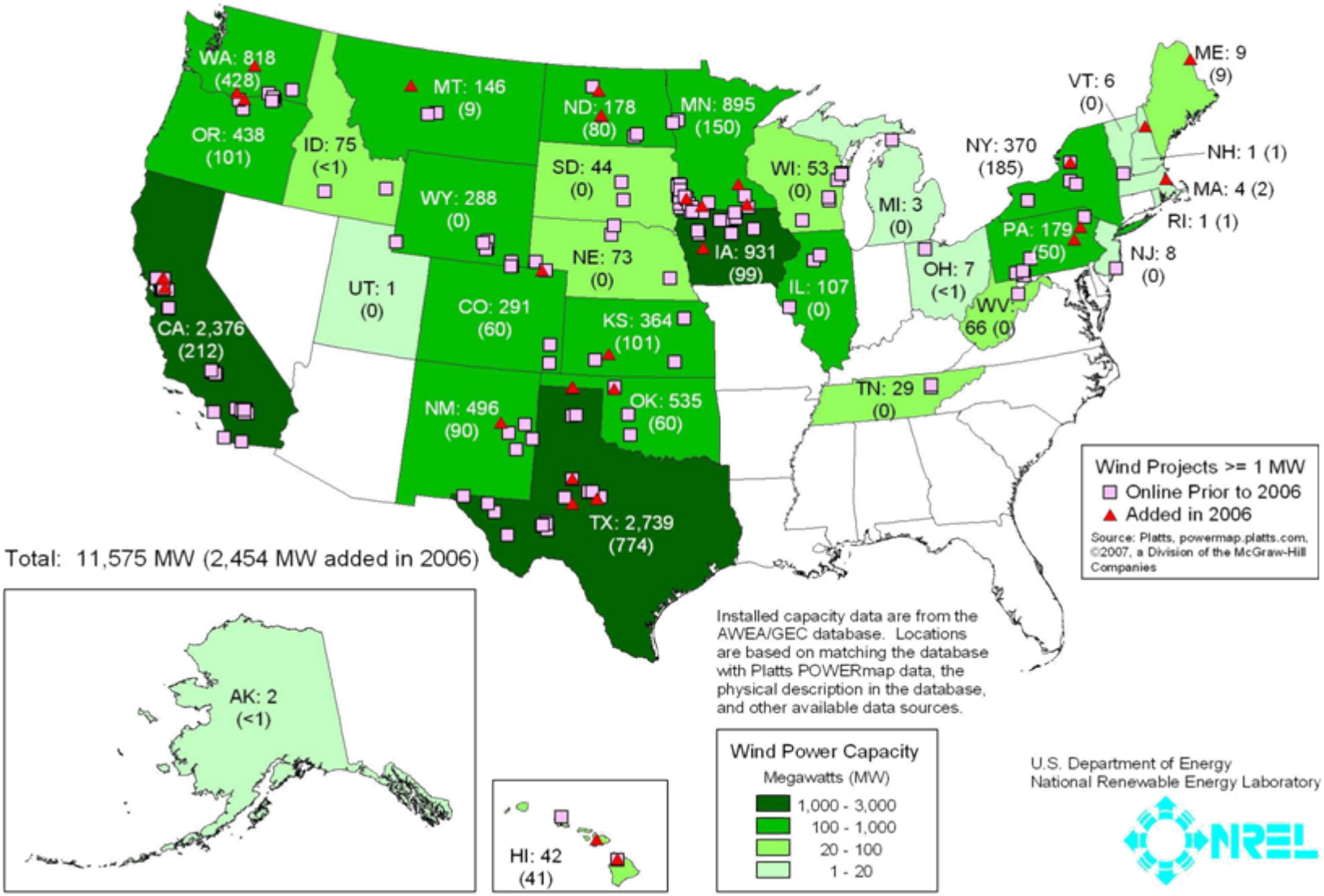
Renewable Portfolio Standards



Energy Efficiency Resource Standards

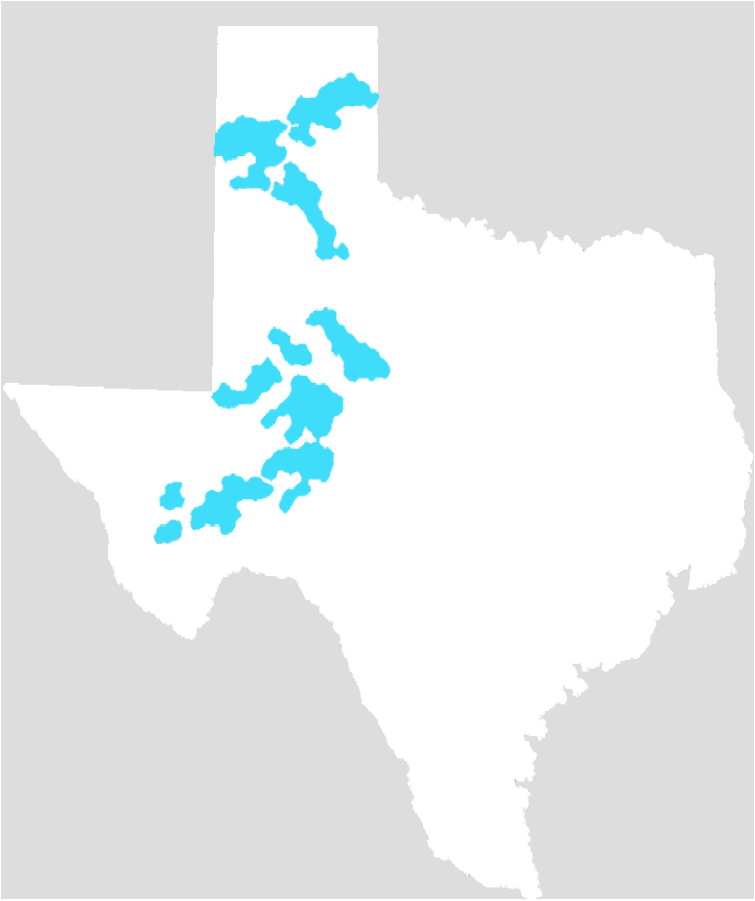


Installed Wind Capacity



Transmission: Texas CREZs

- Statutory directives
  - After getting technical advice, PUC legally designates CREZs (where and how big)
  - CREZ designation settles question of need
  - CREZ designation guarantees cost recovery
- Likely plans would cost $4-$5 billion and add up to 11.5 GW of new wind power



Western Governor's Association Area

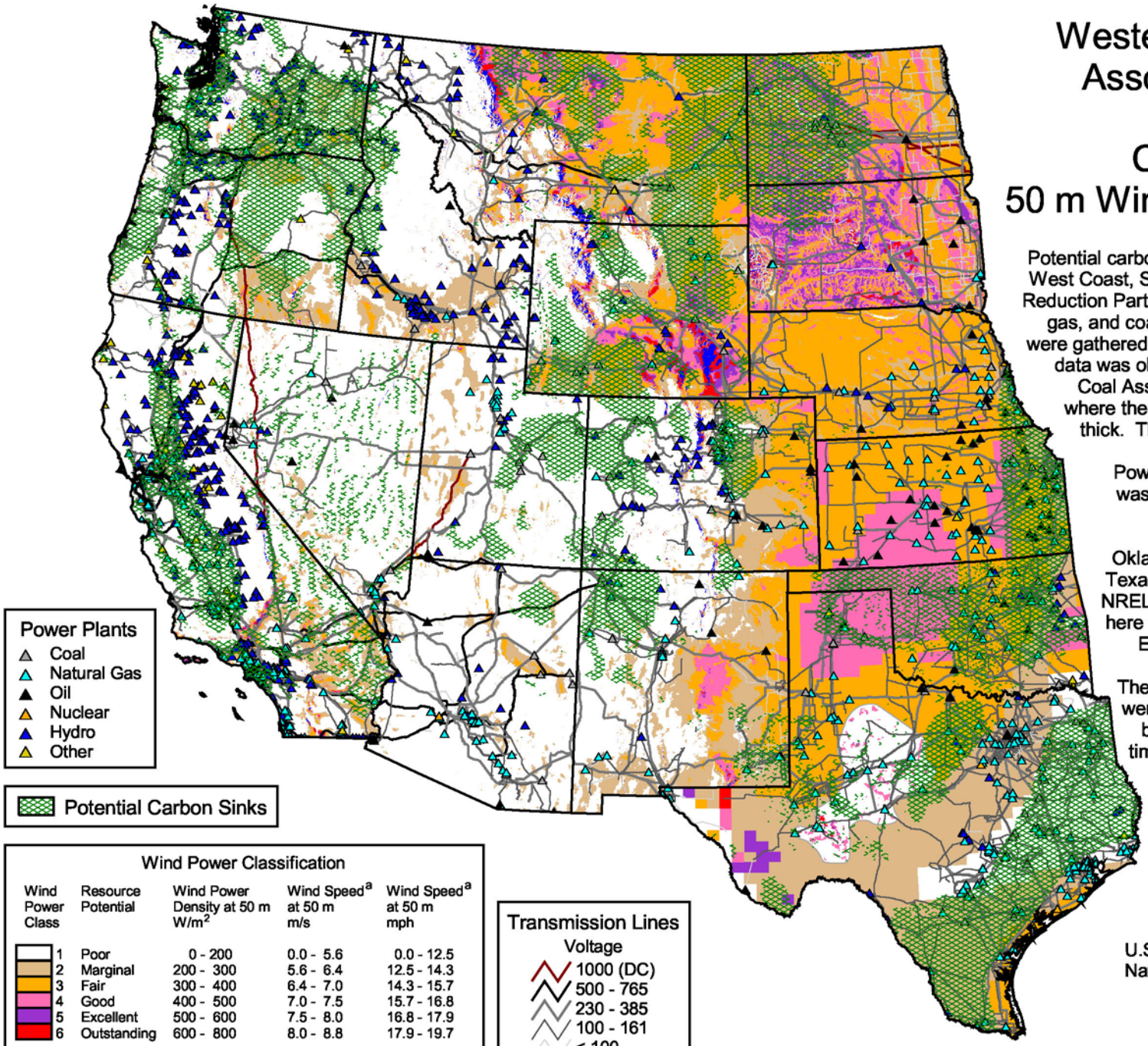
Composite 50 m Wind Resource Data

Potential carbon sink data was obtained from the West Coast, Southwest, and Plains Carbon CO2 Reduction Partnerships. This data represents oil, gas, and coal fields. The oil and gas field data were gathered from state agencies; the coal bed data was obtained from the U.S.G.S. National Coal Assessment website, excluding areas where the coal was identified as being <10 ft thick. This data is still under development.

Power plant and transmission line data was obtained from Platts POWERmap and POWERdat products, ©2005.

Oklahoma, Kansas, and the majority of Texas have not yet been re-modeled by NREL. The resource information shown here was obtained from the 1987 "Wind Energy Resource Atlas of the U.S.".

The high resolution wind assessments were conducted on a state or regional basis from 1999 to 2004. Over that time, the methodology and resolution of the data varied due to changes in the modeling process. The fine resolution of these datasets may prevent many good wind resource areas from appearing when viewed at this scale.



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
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
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

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

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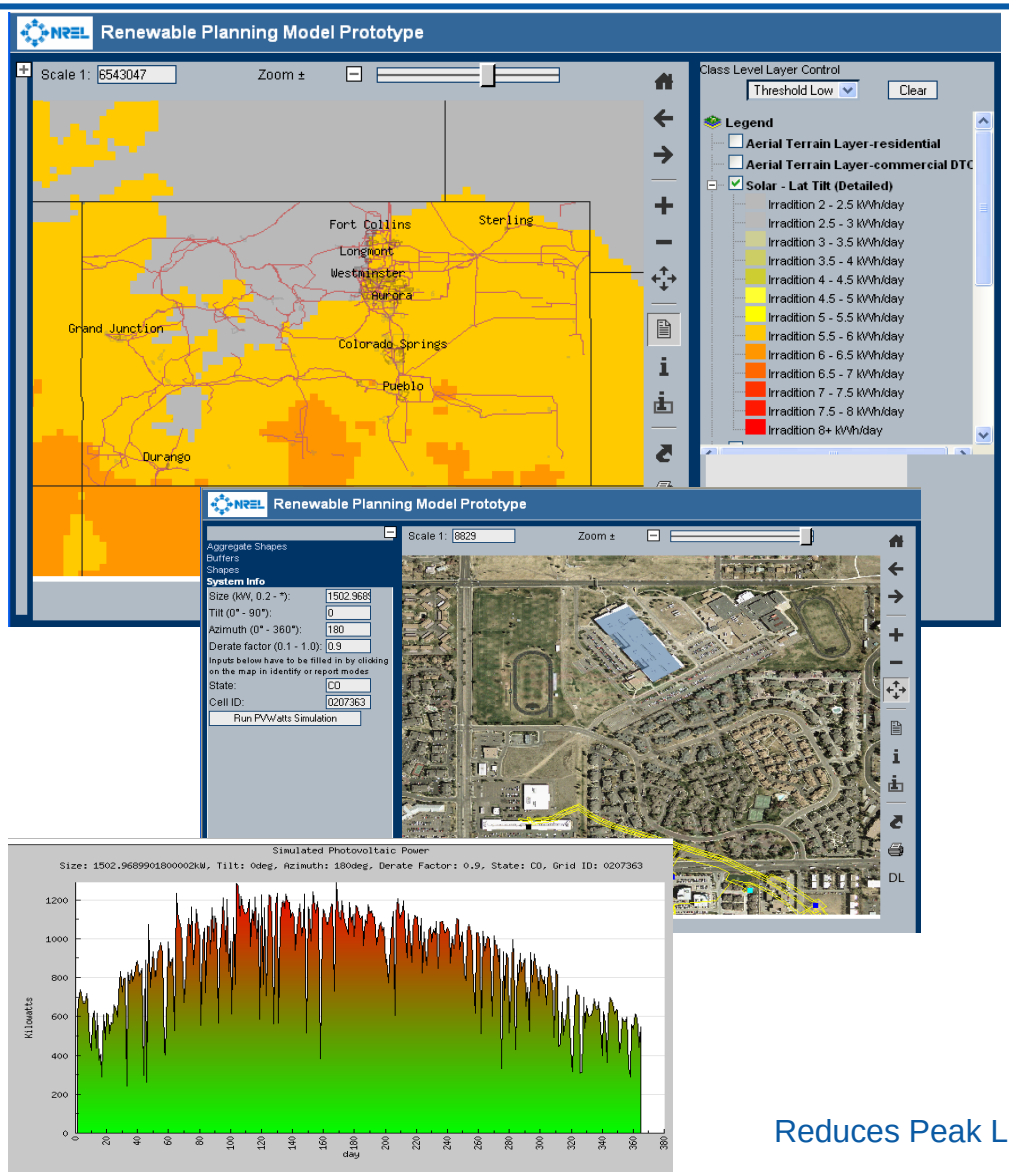
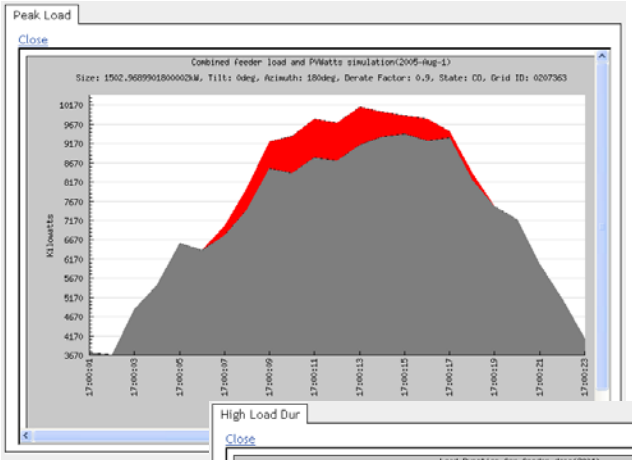
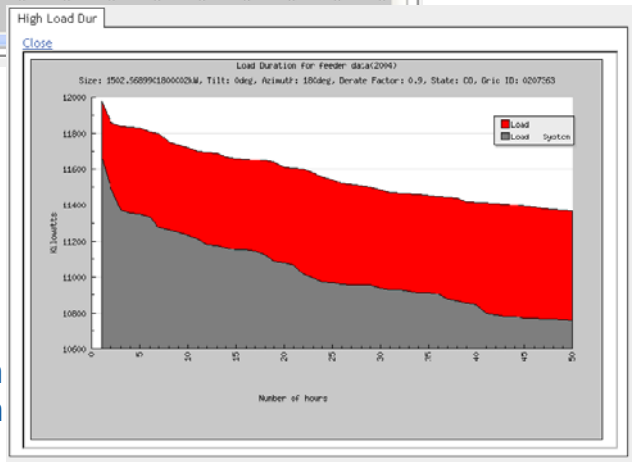
Renewable Planning Model



Interactive assessment and basic analysis tool to assist in locating feasible areas and understanding the impacts of renewable power systems.



PV System Reduces Daily Load



PV System Reduces Peak Load on System

Energy Systems Integration Facility (ESIF)

Full Systems Evaluation: Integrating Electricity, Fuels, Thermal, Storage, and End-use

Solar

- Interconnection
- Power electronics
- Building integration
- Thermal and PV system
- Optimization

Buildings

- Sensors & controls
- PV design and integration
- Modeling and simulation
- System integration

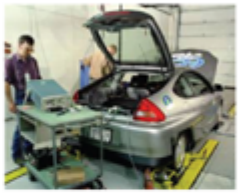
Hydrogen

- Hydrogen/electric interfaces
- RE electrolyzers
- Storage systems
- Standards
- Fuel cell integration
- Fueling systems

Wind

- Models, methods for wind interaction
- Mini-grid analysis

FreedomCAR

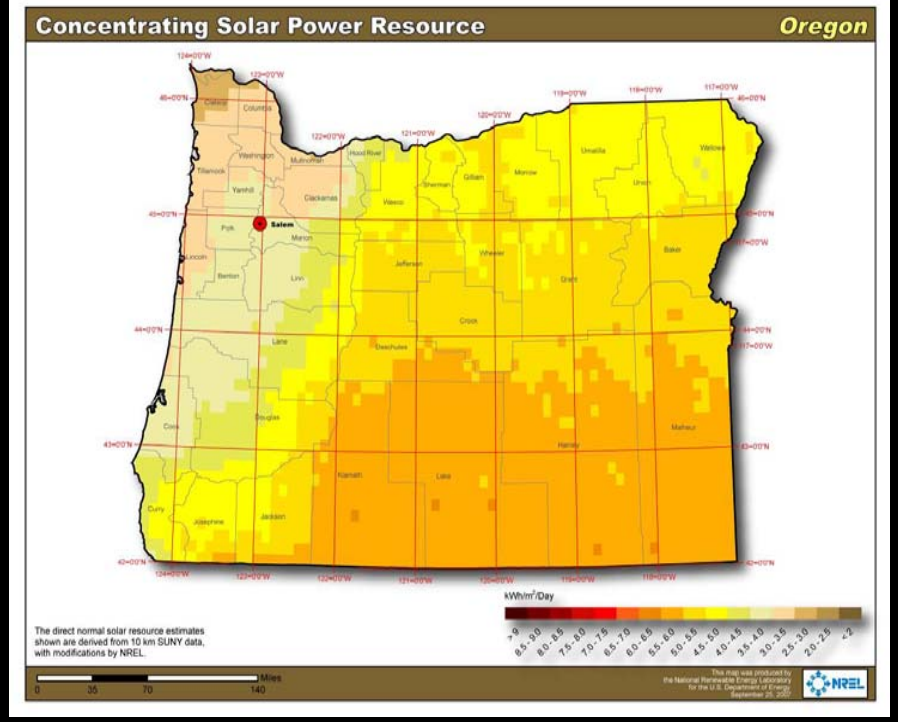


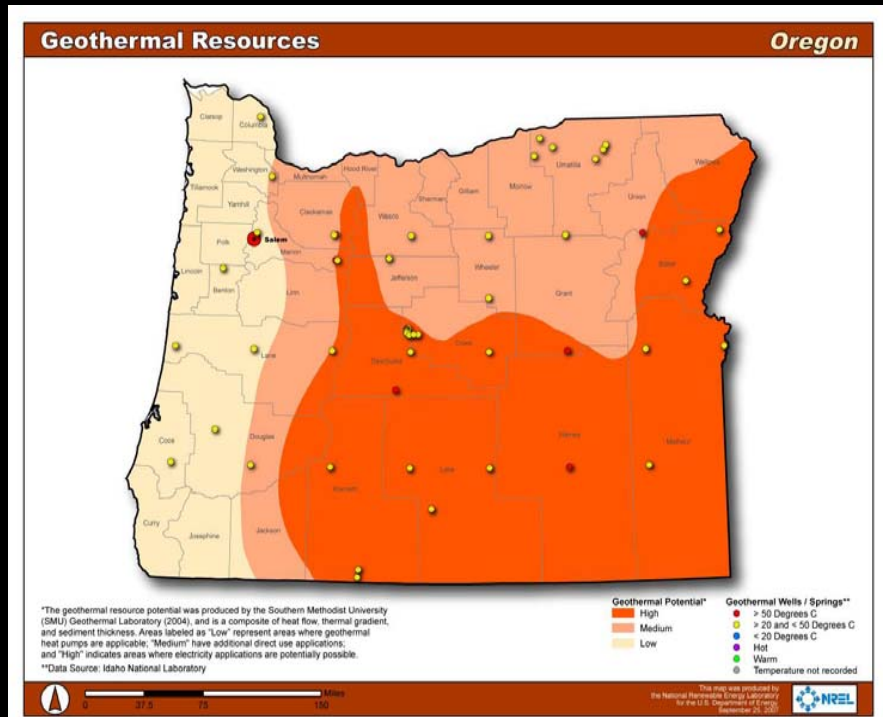
- Plug-in-hybrids and vehicle-to-grid
- Battery thermal management
- Power electronics

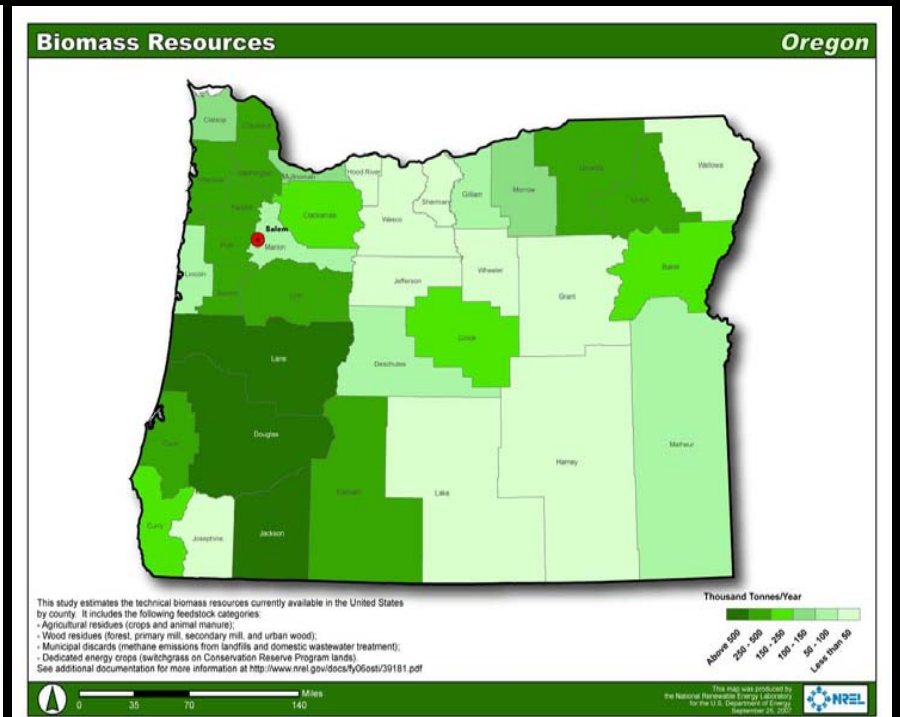
Biomass

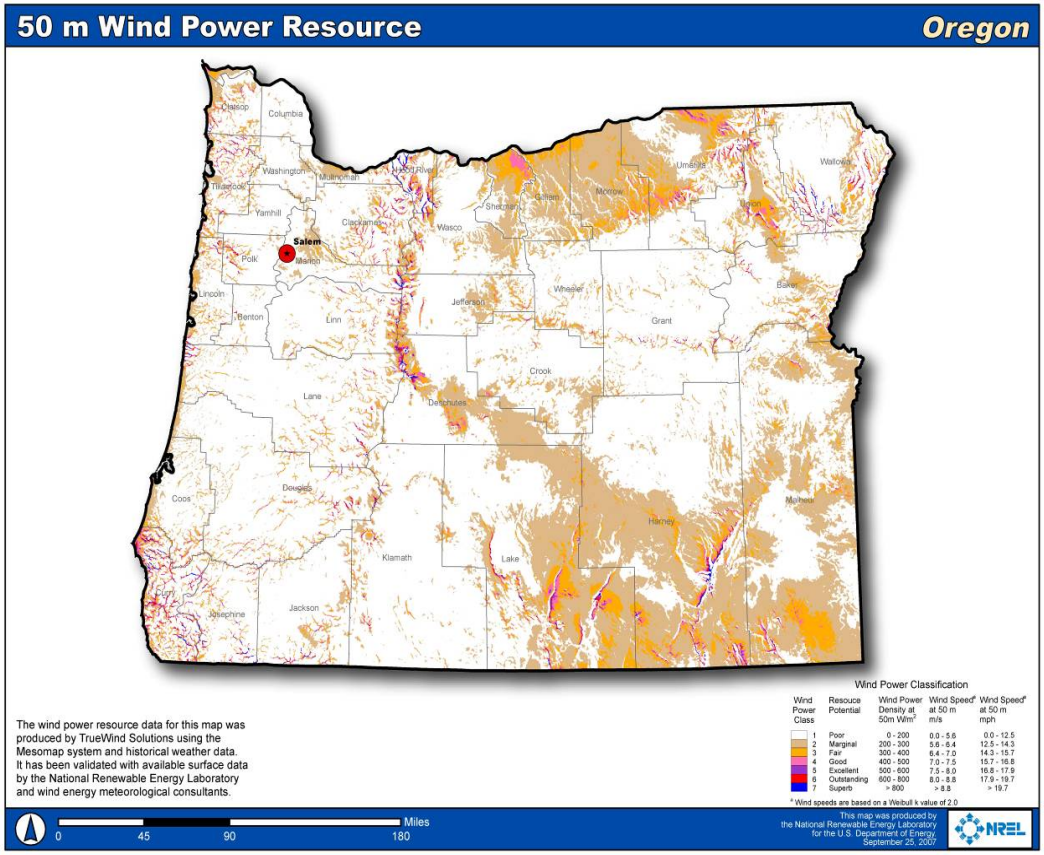
- Biofueled gensets and engines

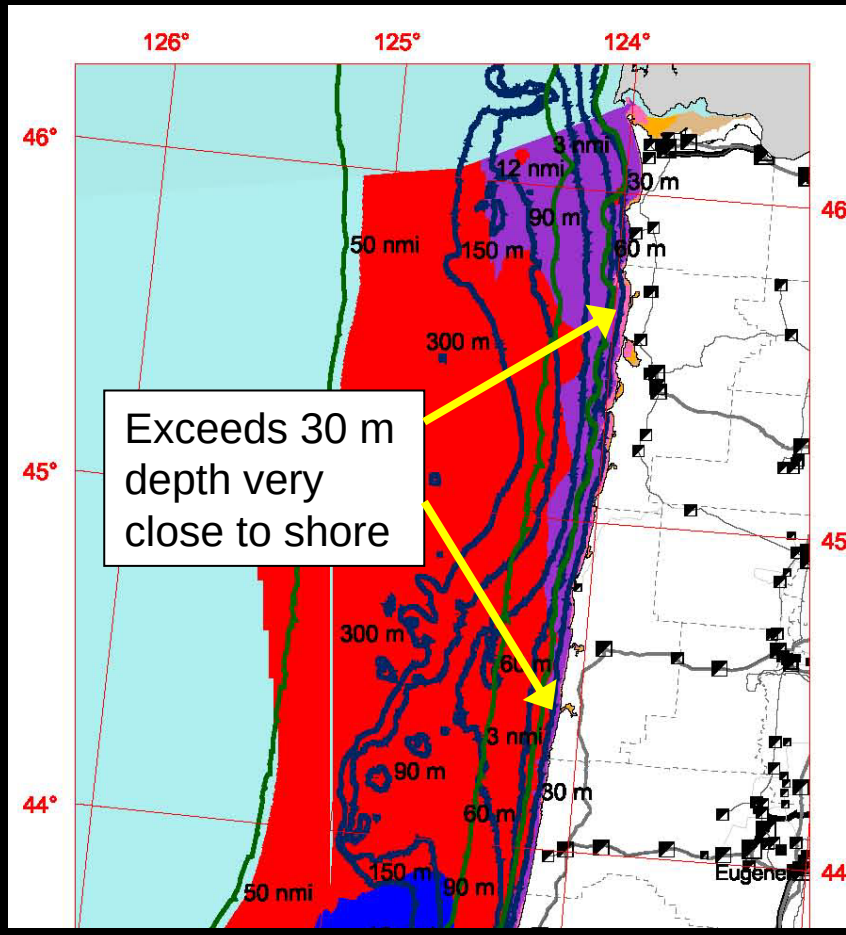
Oregon Resources and NREL Activities


Concentrating Solar Power Resource
Oregon
Salem
kWh/m²/Day
The direct normal solar resource estimates shown are derived from 10 km SUNY data, with modifications by NREL.
Miles
0 35 70 140
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy September 25, 2007
NREL


Geothermal Resources
Oregon
Salem
Geo
*The geothermal resource potential was produced by the Southern Methodist University (SMU) Geothermal Laboratory (2004), and is a composite of heat flow, thermal gradient, and sediment thickness. Areas labeled as "Low" represent areas where geothermal heat pumps are applicable; "Medium" have additional direct use applications; and "High" indicates areas where electricity applications are potentially possible.
**Data Source: Idaho National Laboratory
Geothermal Potential*
High
Medium
Low
Geothermal Wells / Springs**
> 50 Degrees C
> 20 and < 50 Degrees C
< 20 Degrees C
Hot
Warm
Temperature not recorded
Miles
0 37.5 75 150
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy September 25, 2007
NREL


Biomass Resources
Oregon
Salem
This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:
- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops (switchgrass on Conservation Reserve Program lands).
See additional documentation for more information at http://www.nrel.gov/docs/fy06osti/39181.pdf
Thousand Tonnes/Year
Above 500
250 - 500
150 - 250
100 - 150
50 - 100
Less than 50
Miles
0 35 70 140
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy September 25, 2007
NREL

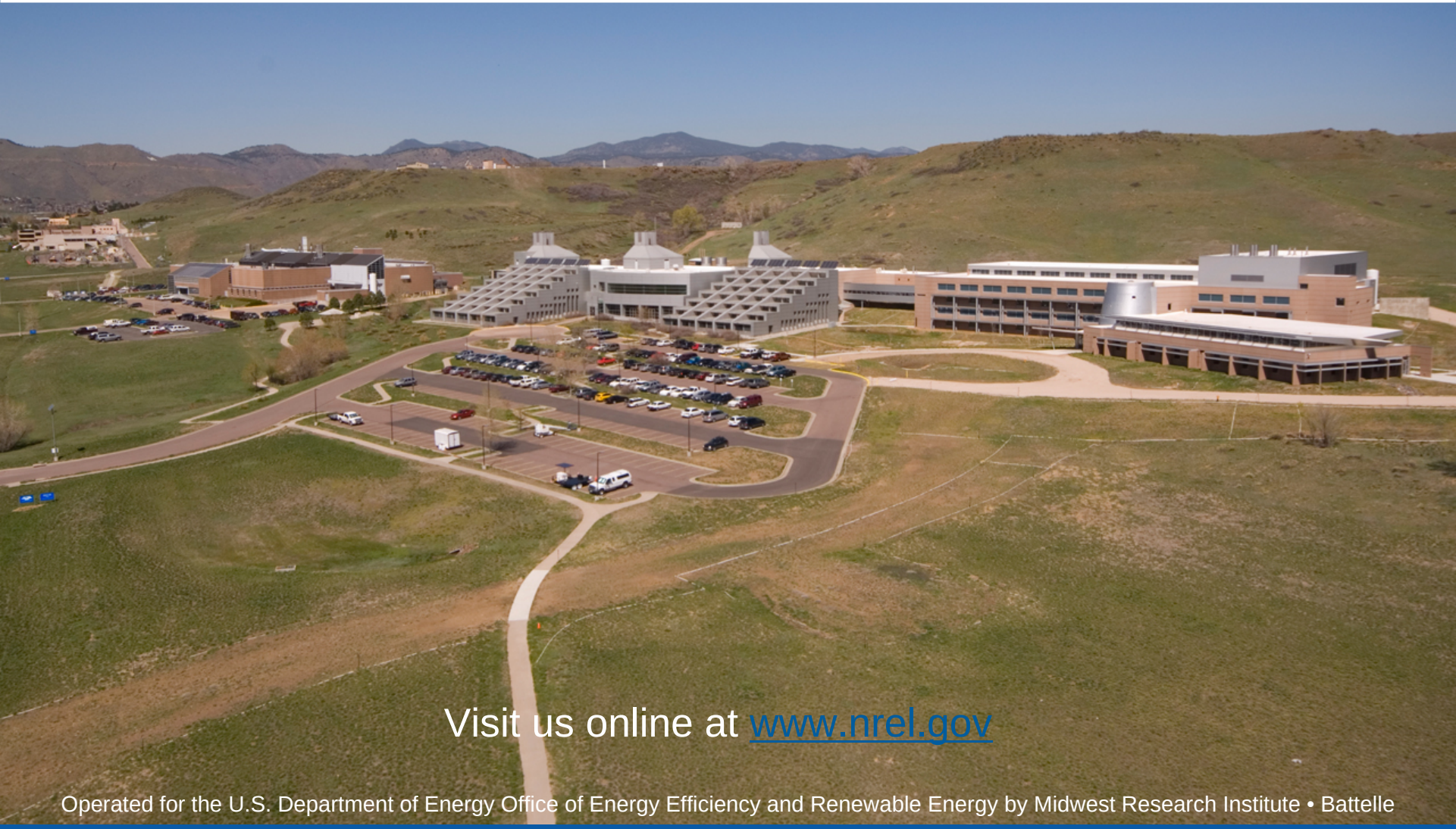




Northern Oregon Offshore Wind

National Renewable Energy Laboratory

Innovation for Our Energy Future



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