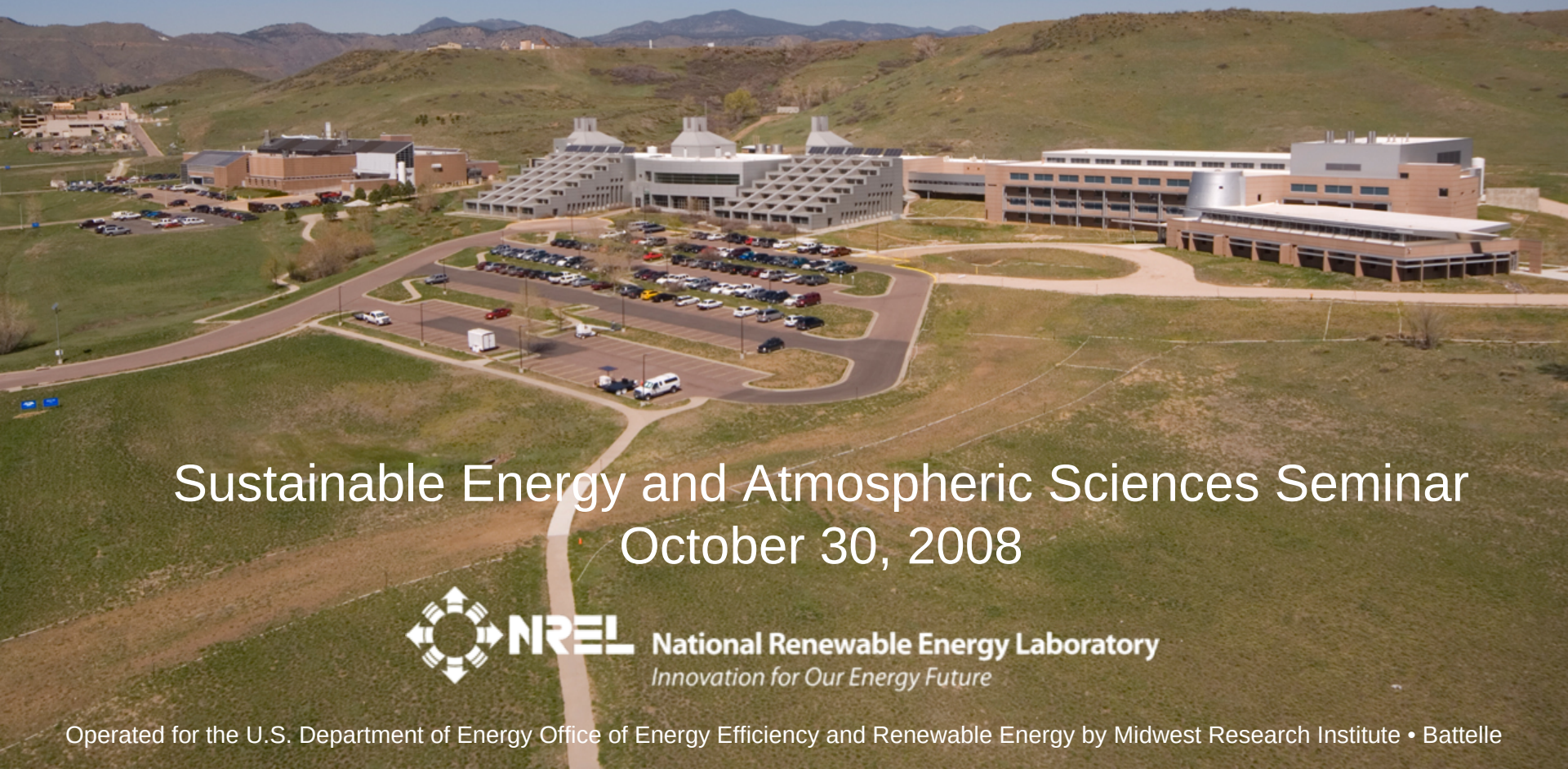
Renewable Energy: Big Potential and Big Challenges

Chuck Kutscher

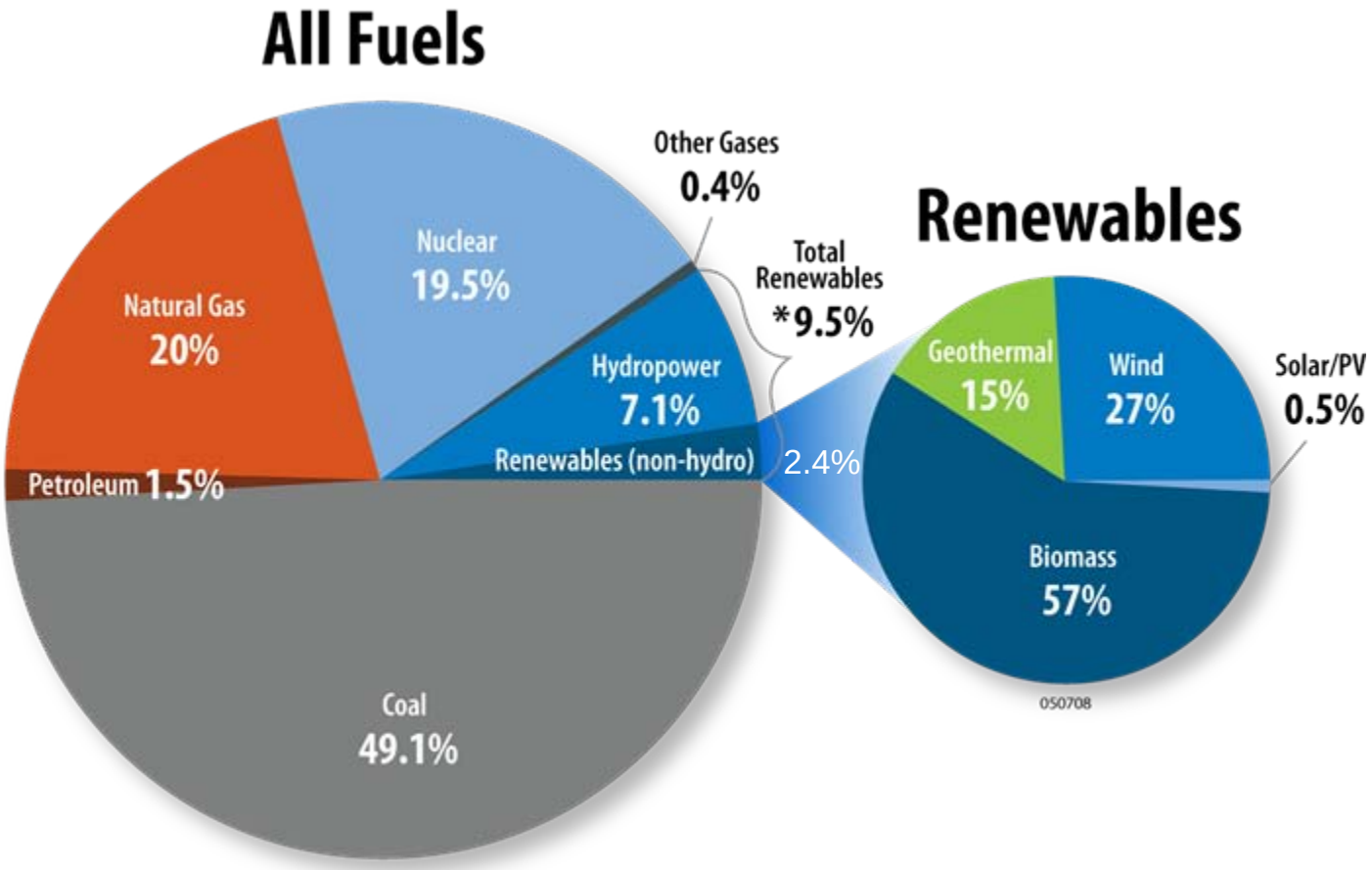


Sustainable Energy and Atmospheric Sciences Seminar
October 30, 2008

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

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

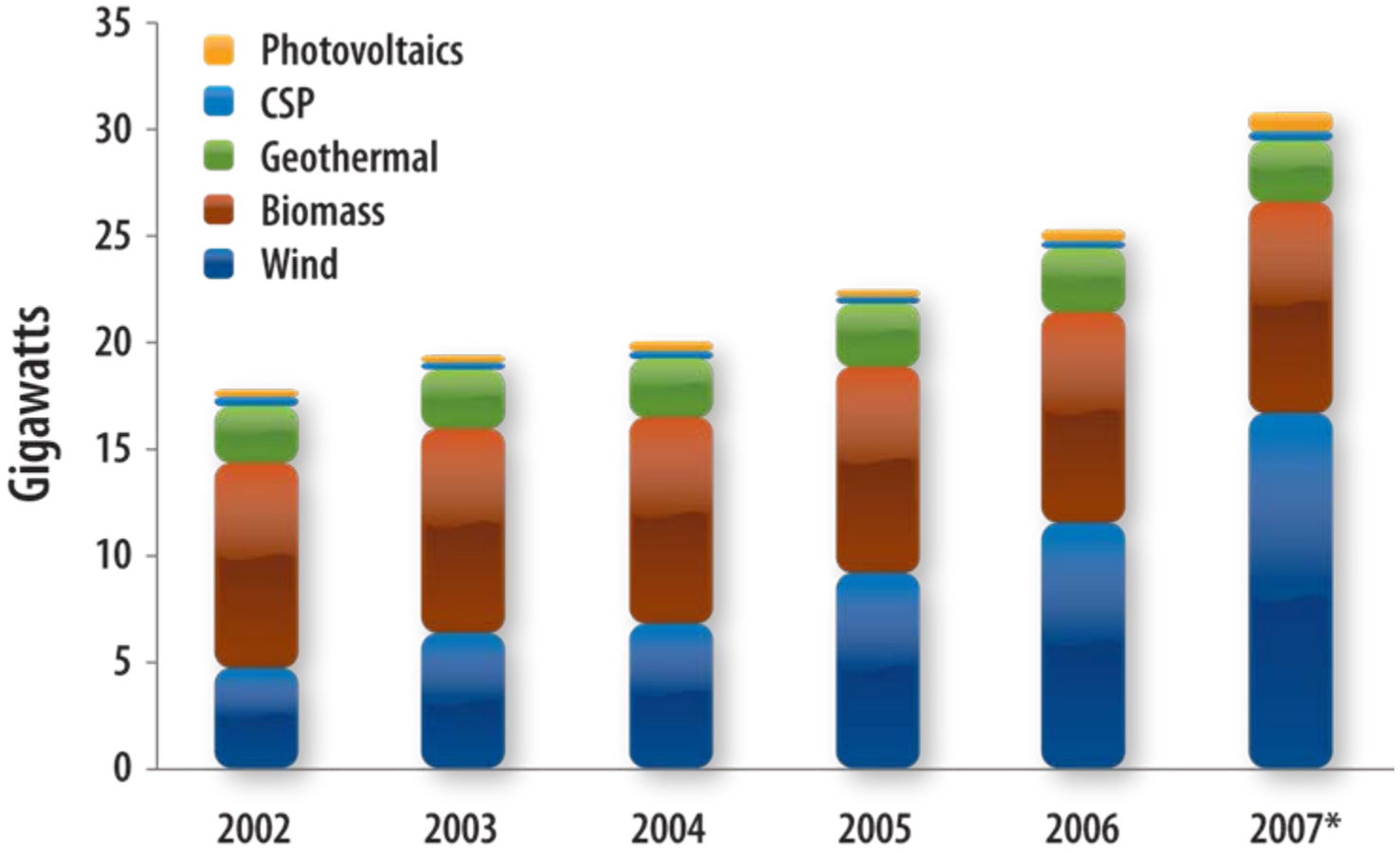
U.S. Electricity Net Generation



Net generation for 2006 = 3814 TWhr UCb

Source: EIA Annual Energy Review 2007, AEO 2008

U.S. Renewable Energy Electric Capacity



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

Buildings

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

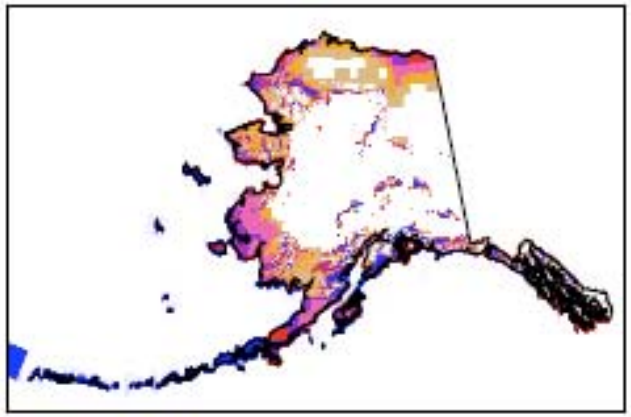
DOE Goal:
- Zero energy buildings by 2025

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

Wind

United States - Wind Resource Map

This map shows the annual average wind power estimates at 50 meters above the surface of the United States. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.



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
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 - 1600	8.8 - 11.1	19.7 - 24.8

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

U.S. Department of Energy
National Renewable Energy Laboratory

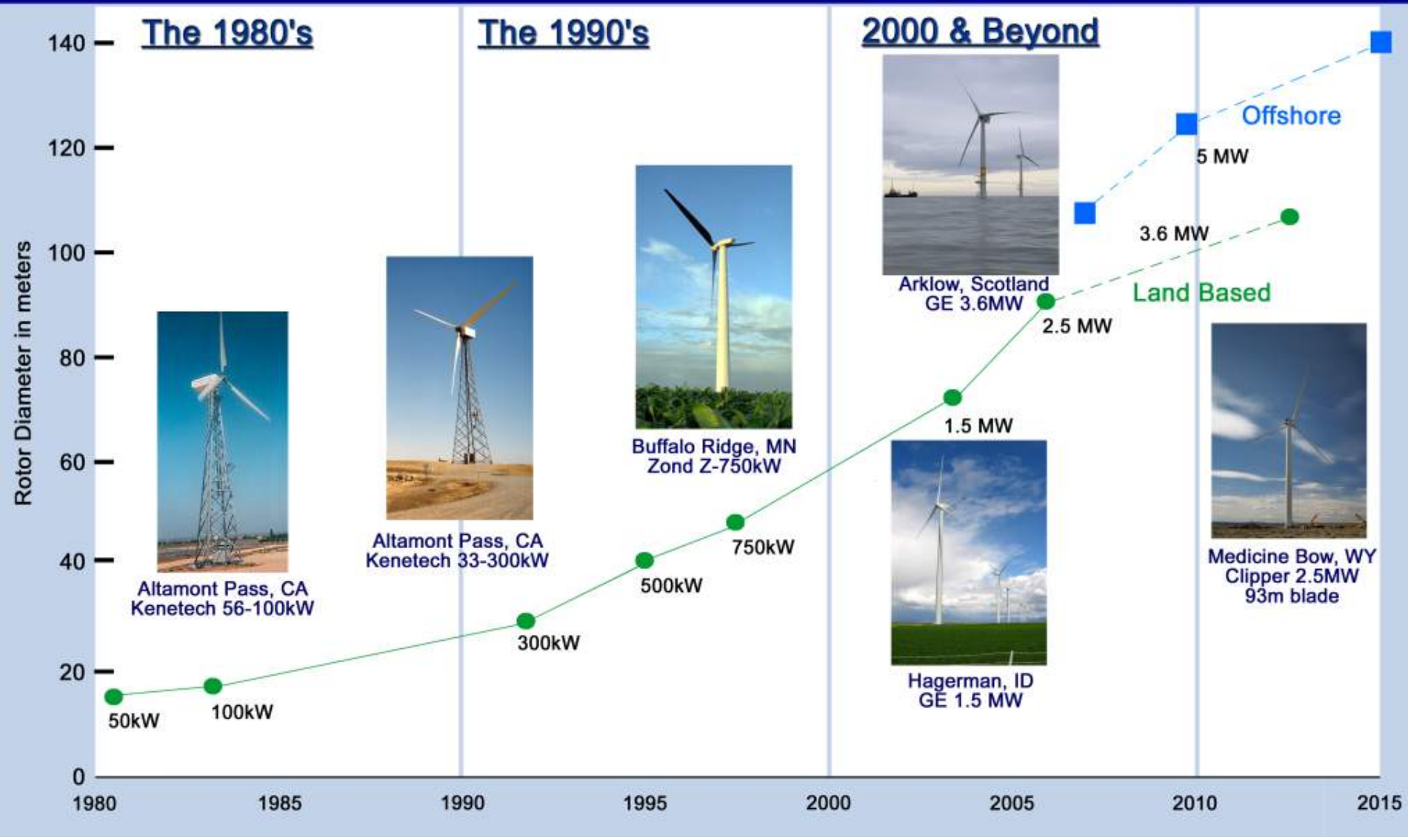
Wind

Today's Status in U.S.
- 21,000 MW installed
- Cost 6-9¢/kWh at good wind sites*

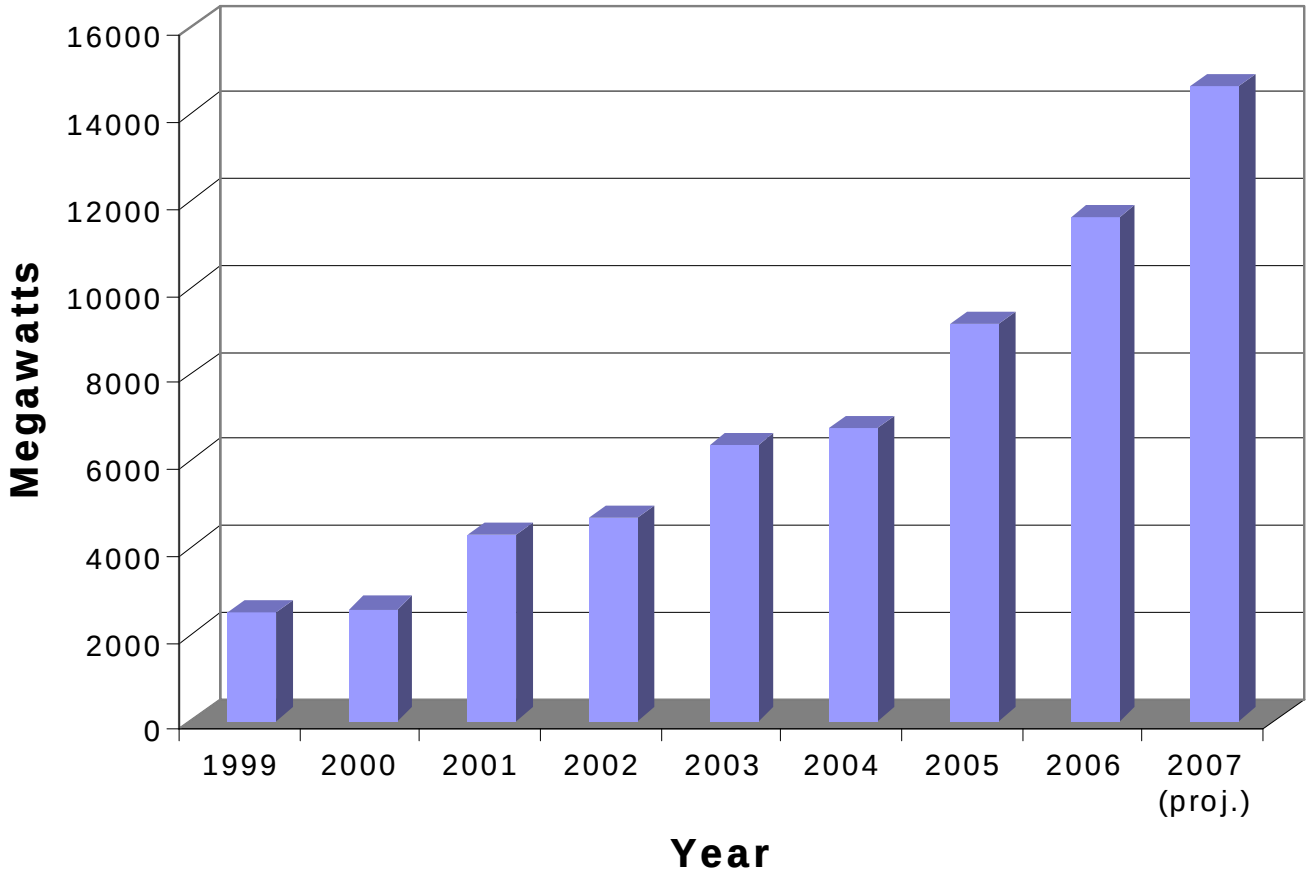
Goals
- 3.6¢/kWh at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014
- 20% of nation's electricity by 2030

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

Evolution of U.S. Commercial Wind Technology



U.S. Wind Capacity



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

Relevant Issues for Wind

- Resolve discrepancies between CFD and data
- Terrain effects
- Upwind turbine effects
- Extreme wind events

Photovoltaics (PV)

Photovoltaics

Status in U.S.

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

PV Goals

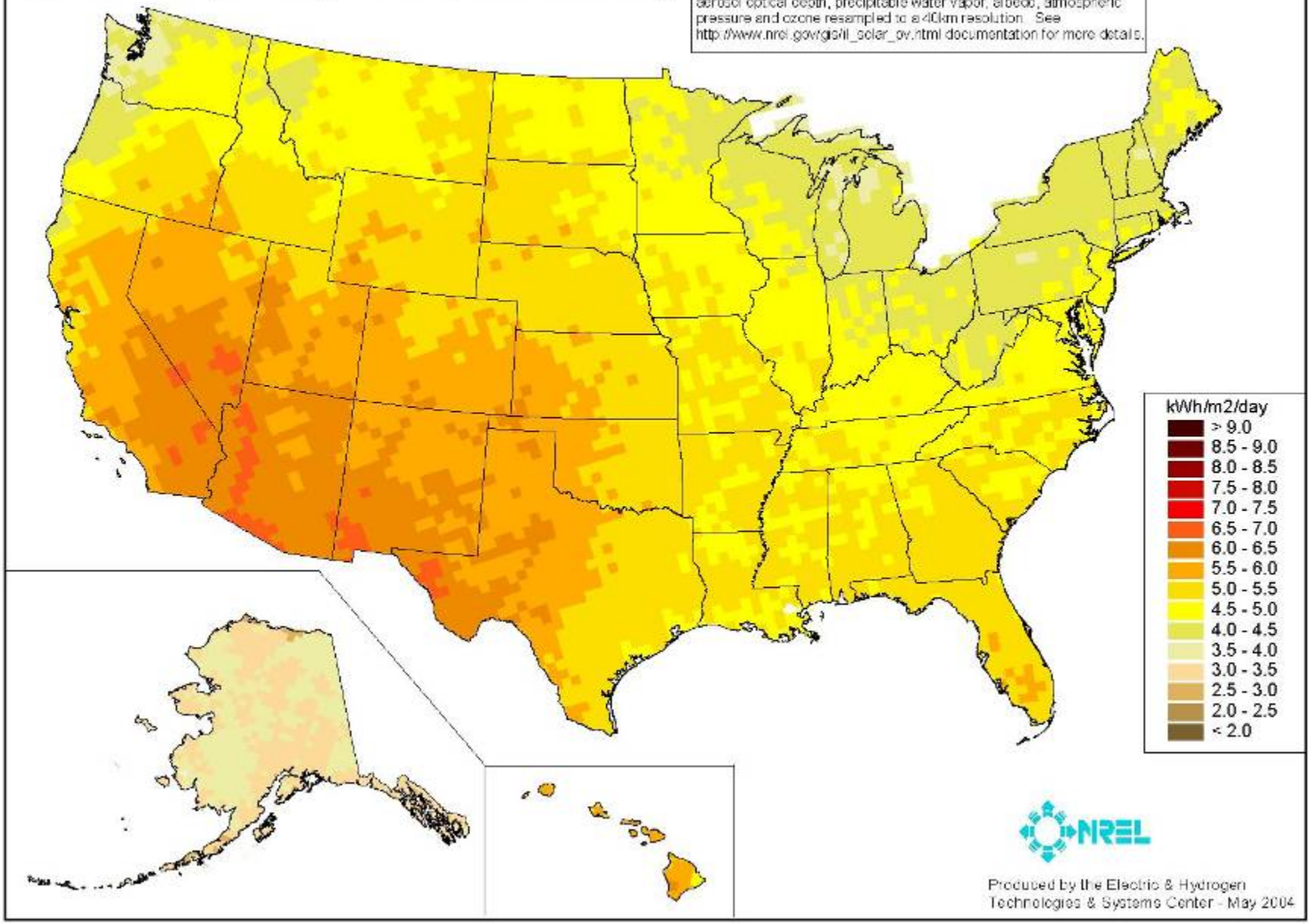
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

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

PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)

Annual

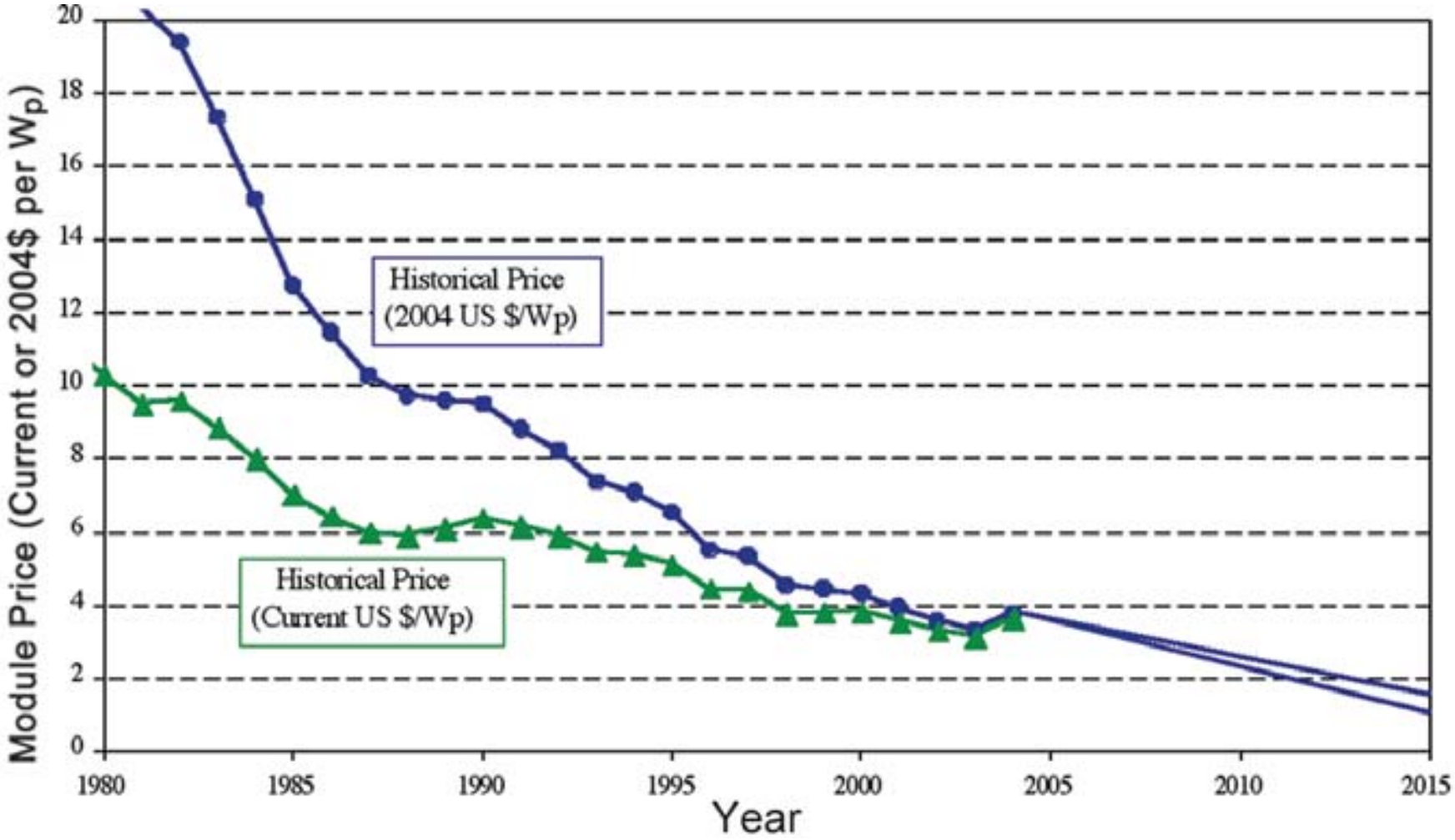
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/ll_solar_pv.html documentation for more details.



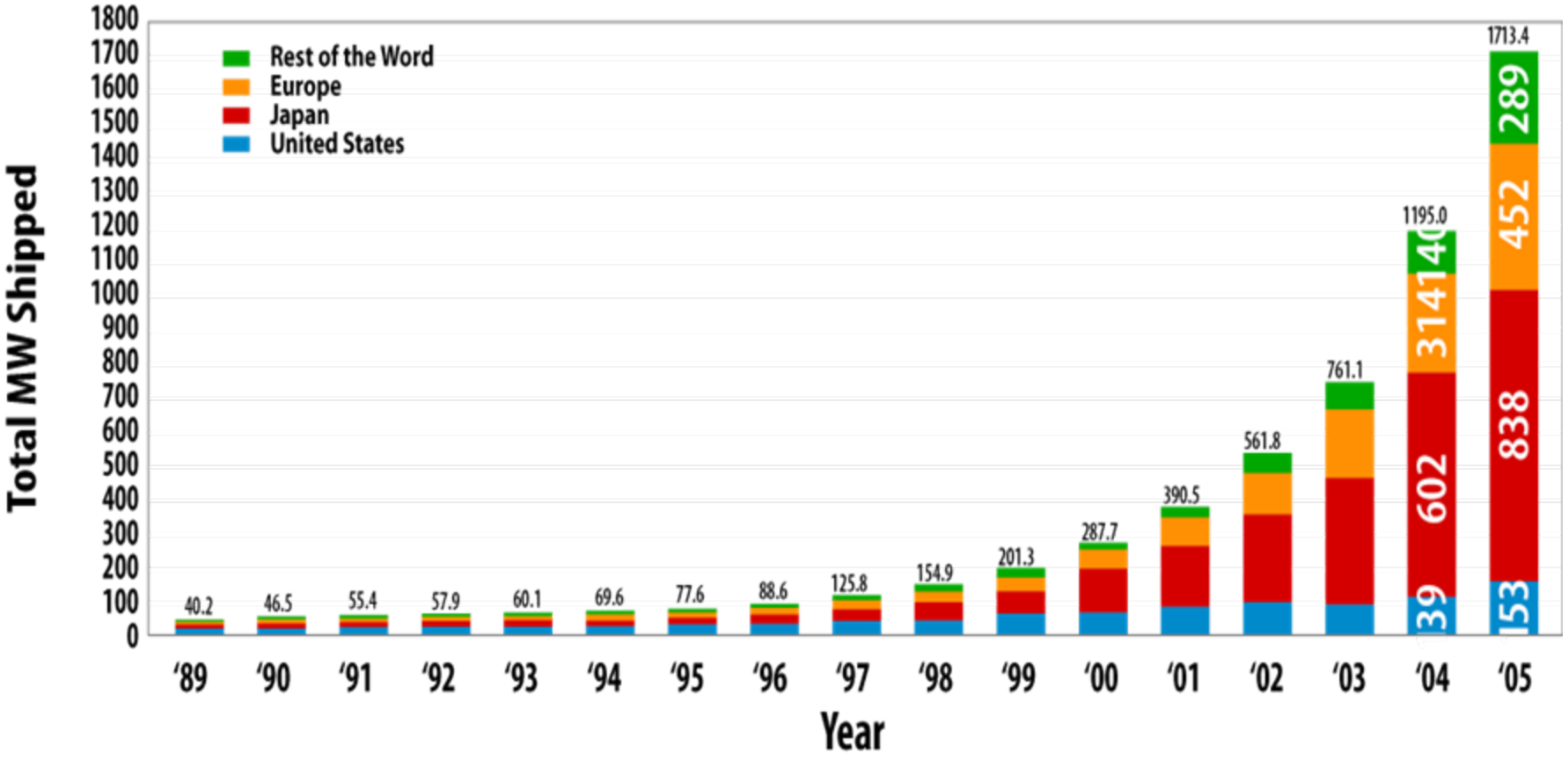
NREL

Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004

PV Module Prices

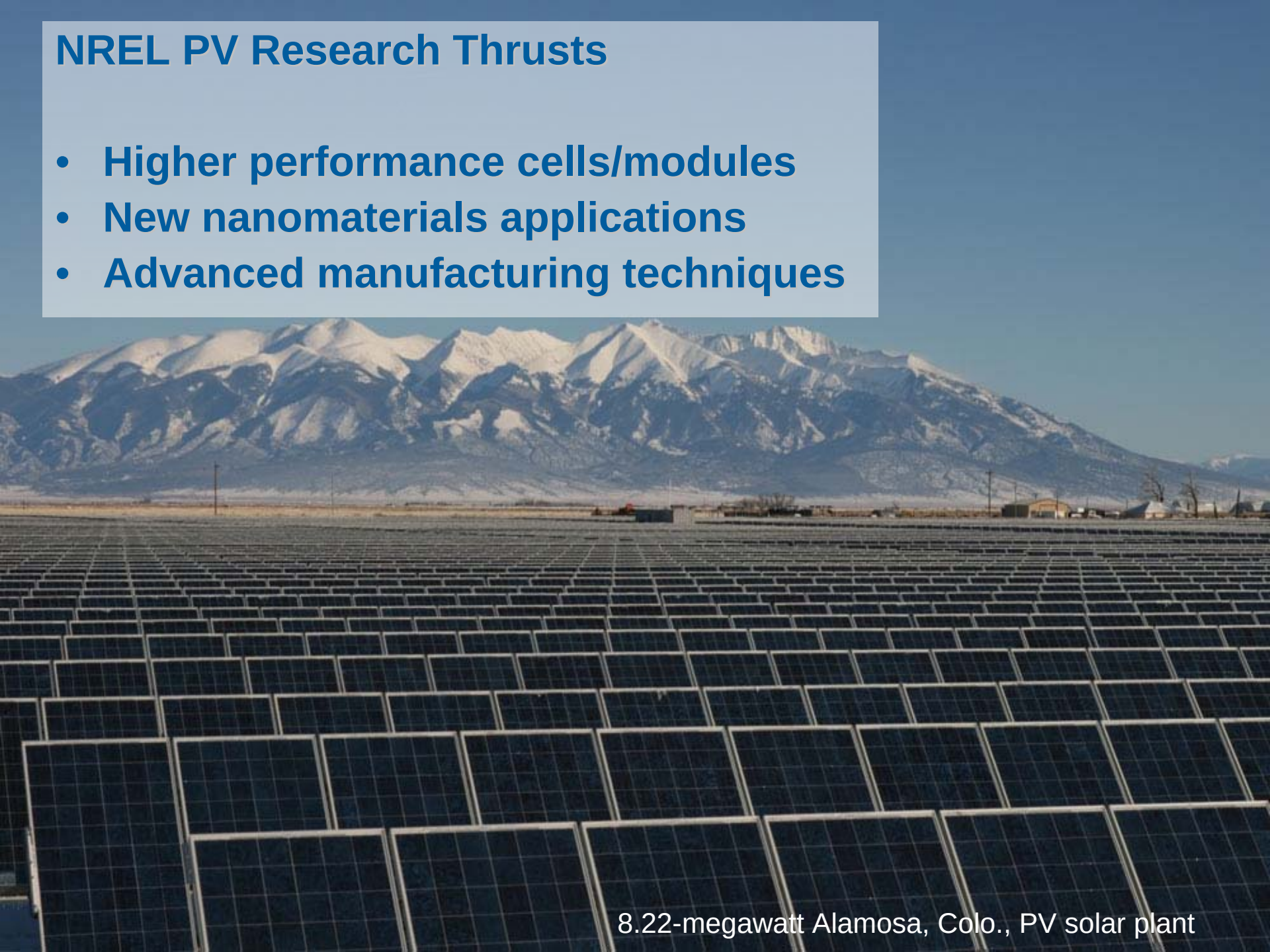


Worldwide PV Shipments



NREL PV Research Thrusts

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



8.22-megawatt Alamosa, Colo., PV solar plant

Concentrating Solar Power (CSP): The Other Solar Energy

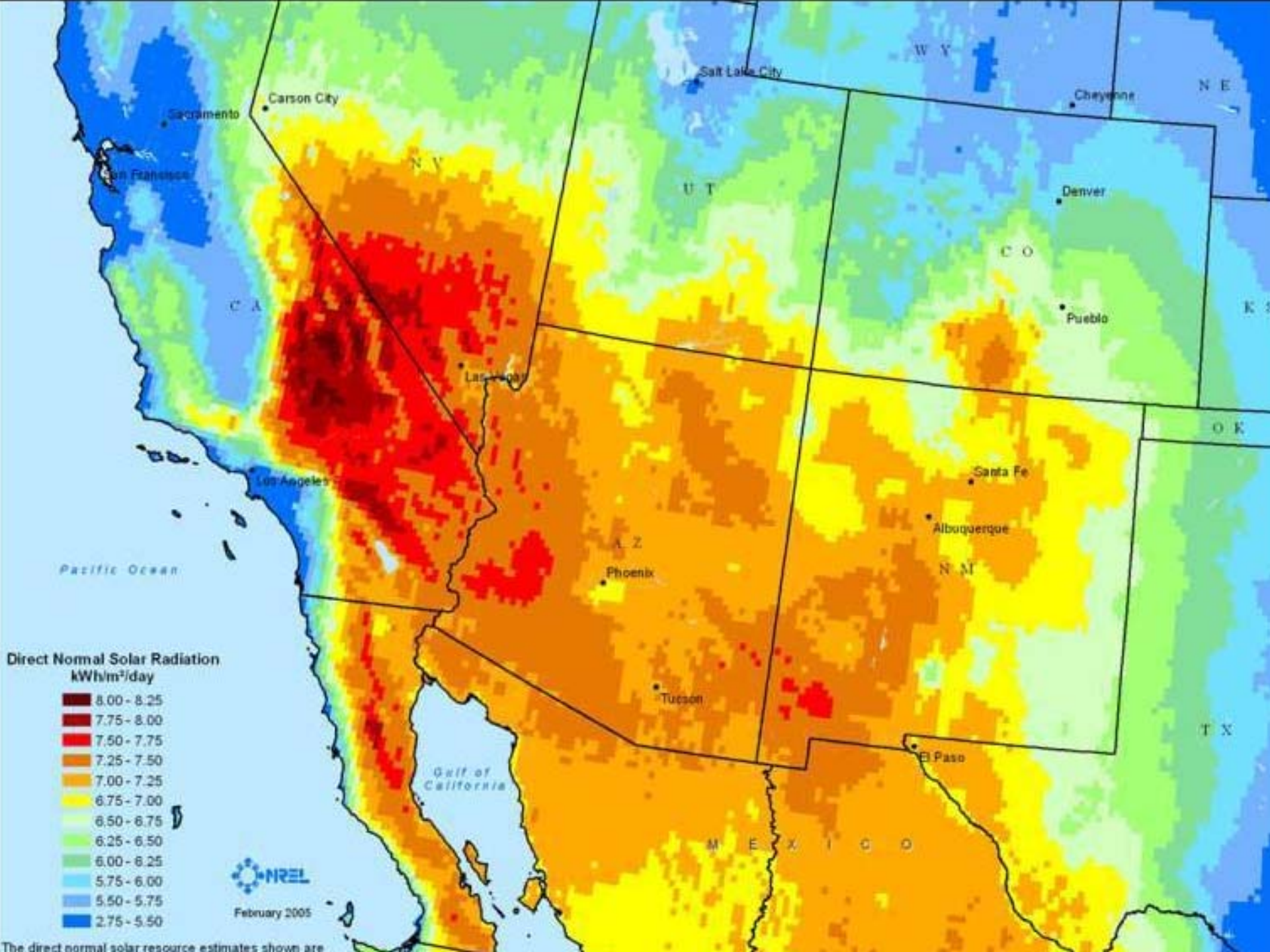
Parabolic trough

Linear Fresnel

Power tower

Dish-Stirling

354 MW Solar Electric Generating Systems (SEGS)



The direct normal solar resource estimates shown are

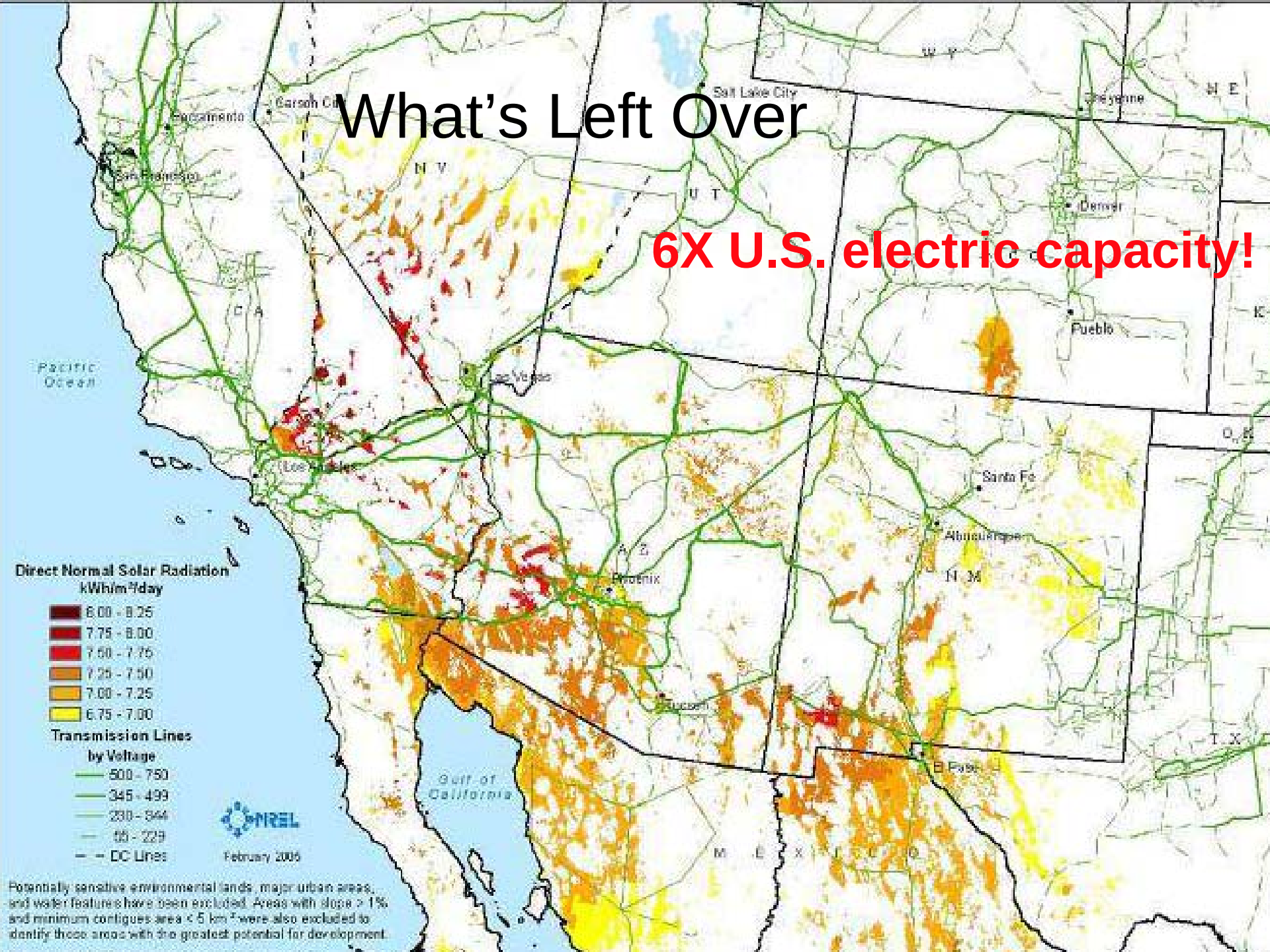
Exclude:

- Used and sensitive land

- Solar < 6.75 kWh/m^2 per day

- Ground slope > 1%

What's Left Over



CSP

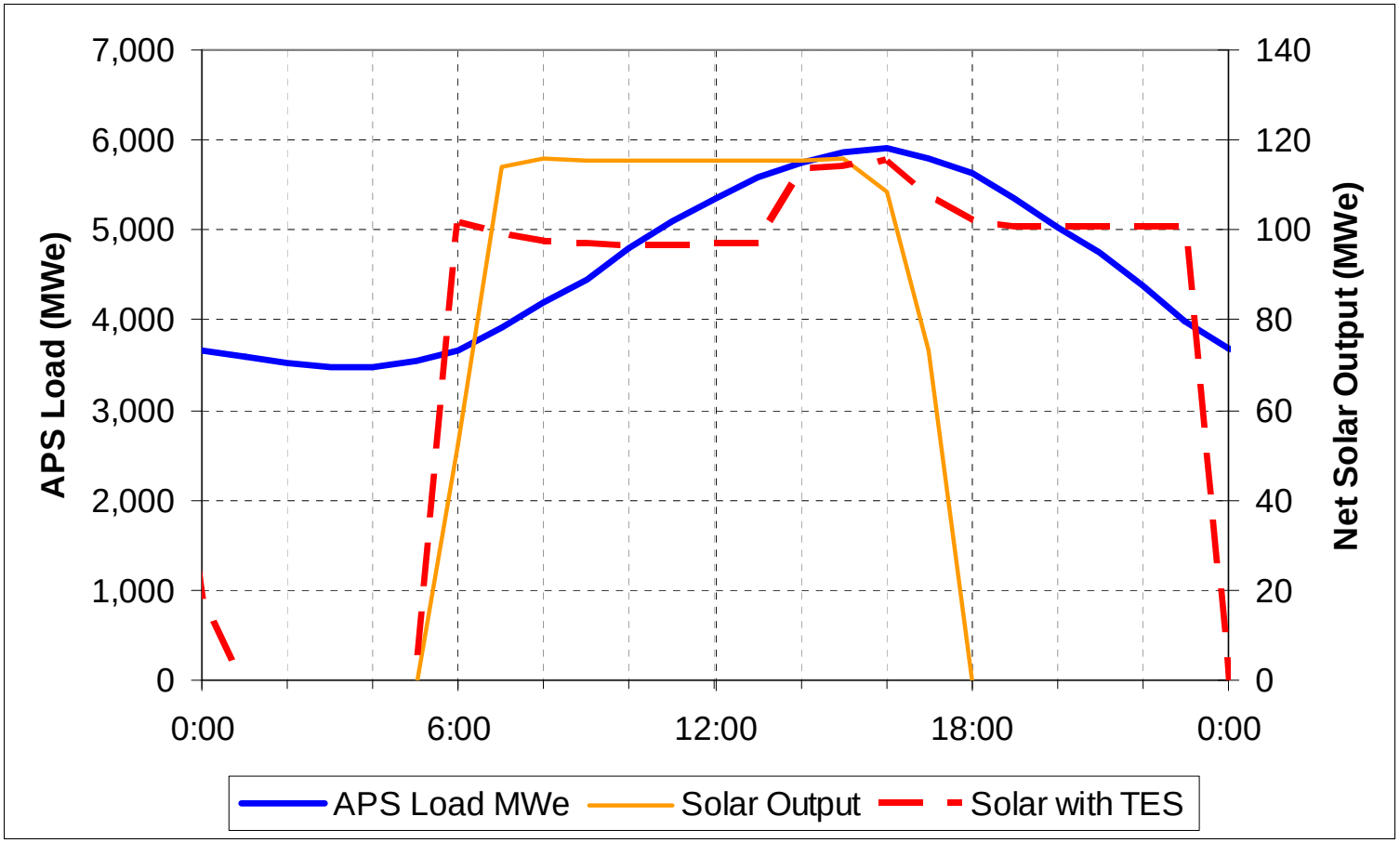
Status in U.S.

CSP
- 419 MW installed capacity
- Cost 12¢/kWh

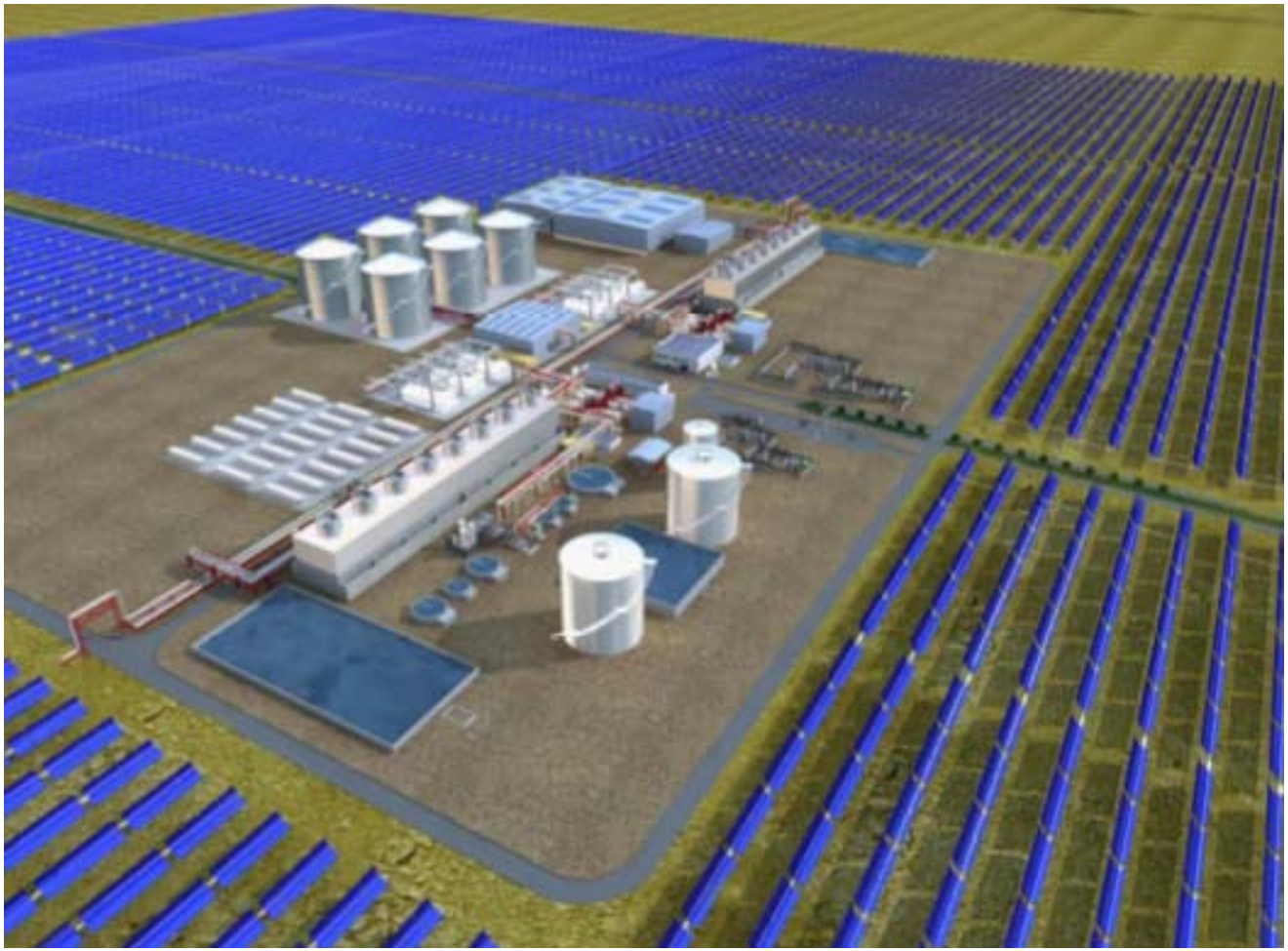
CSP
10¢/kWh by 2010
6¢/kWh by 2015

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

Parabolic Trough Output Profile Summer Day



Planned 280 MW Solana Plant with 6 hrs Storage



Artist Rendition

1500 construction jobs over two years

85 permanent jobs

APS

Renewable Energy

4,000 MW of Planned U.S. Projects

1,103 MW

1,750 MW

900 MW

177 MW

NREL CSP Research Thrusts

- Advanced absorbers, reflectors, and heat transfer fluids
- Low-cost, high-performance storage
- Next-generation solar concentrators

Relevant Issues for PV and CSP

- Better resource measurement and assessment
- Impact of large collector farms on local weather
- Changes in air and water temperatures impact efficiency

Biomass and Biofuels

Wood chips

Switch grass

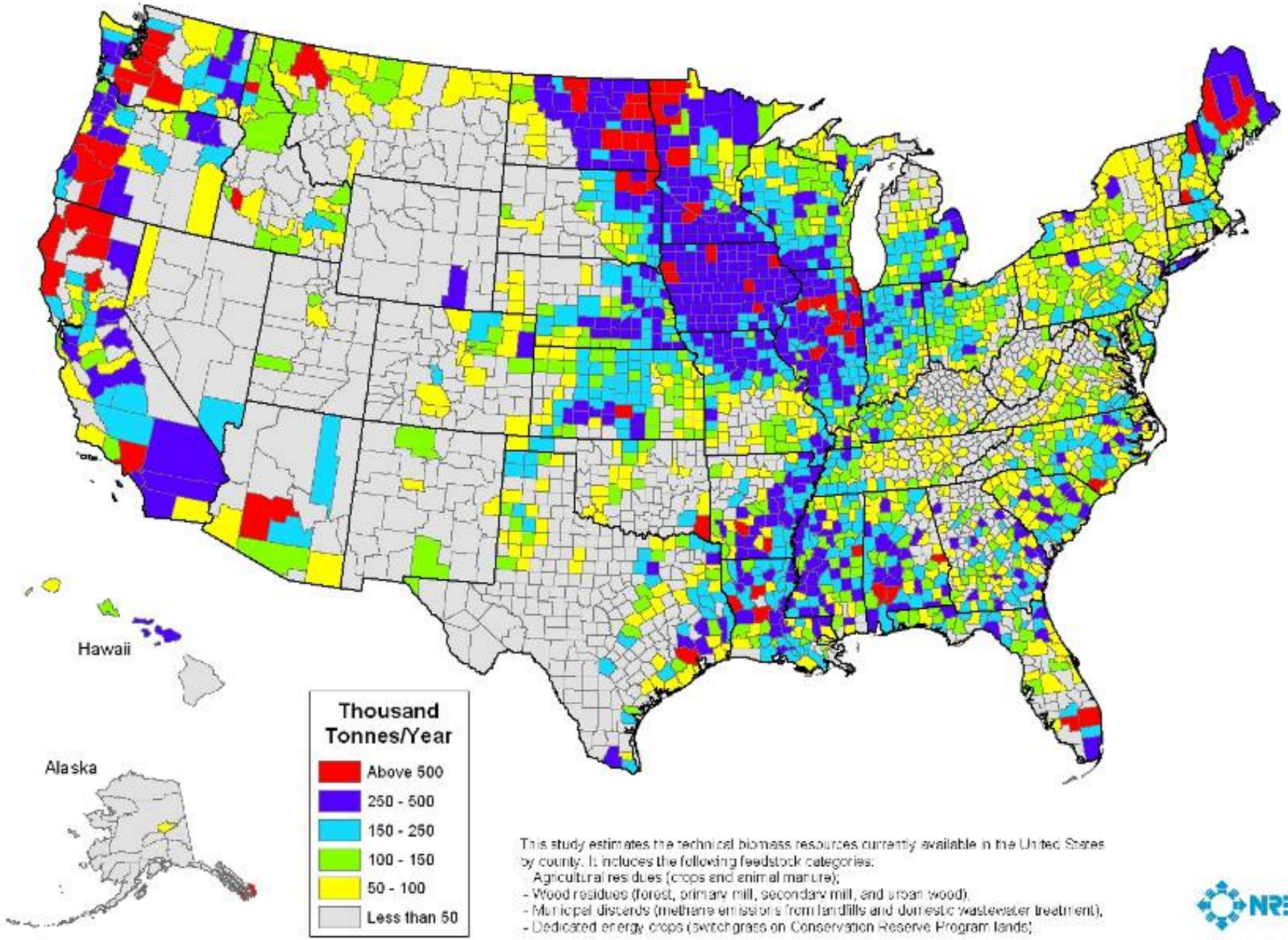
Poplars

Fats and Oils

Municipal solid waste

Corn Stover

Biomass Resources Available in the United States



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);

NREL

September 2005

Routes to Biofuels

Bio/chemical transformation

- **Ethanol from sugars**
- **Biodiesel from renewable oils**

Thermochemical reduction to “syngas” (H_2, CO)

- **Fischer-Tropsch diesel, gasoline**
- **Methanol, other alcohols**

Biofuels

Current Biofuels Status in U.S.

- Biodiesel – 1.85 billion gallons/yr capacity[1]
- Corn ethanol
  - 134 commercial plants[2]
  - 7.2 billion gal/yr. capacity[2]; 6.2 billion gal/yr planned
- Cellulosic ethanol
  - Projected commercial cost ~$3.50/gge

DOE Goals

- 2012 goal: cellulosic ethanol at $1.96/gge
- 2022 goal: 36 B gal renewable fuel

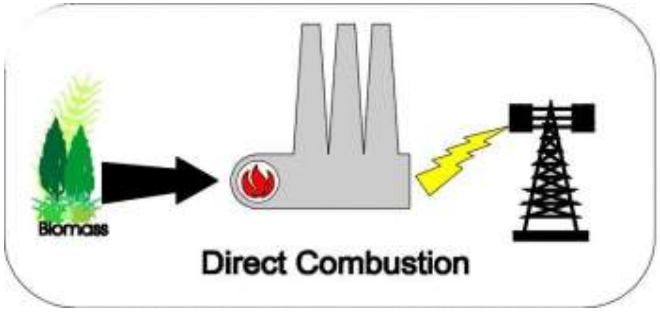
Updated February 2008
Sources: 1- National Biodiesel Board
2 - Renewable Fuels Association, all other information based on DOE and USDA sources

NREL Biofuels Research Thrusts

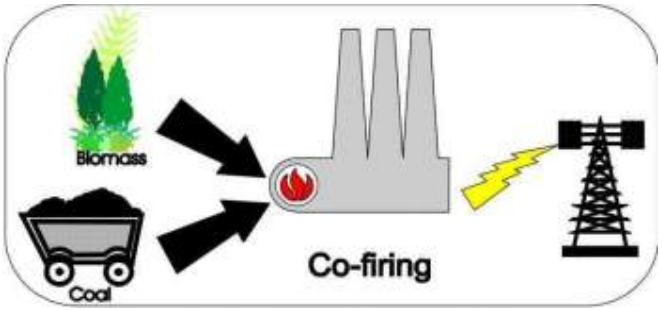
- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops

Biomass Power

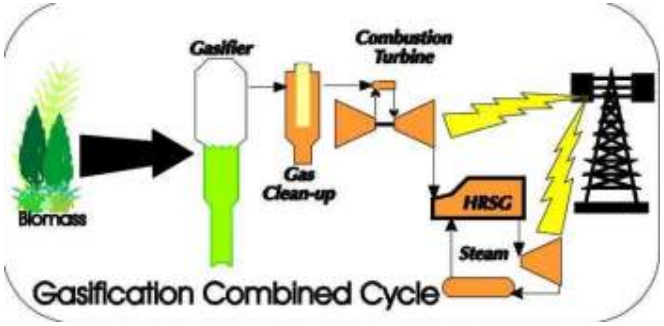
Direct combustion



Co-firing



Gasification



Biopower

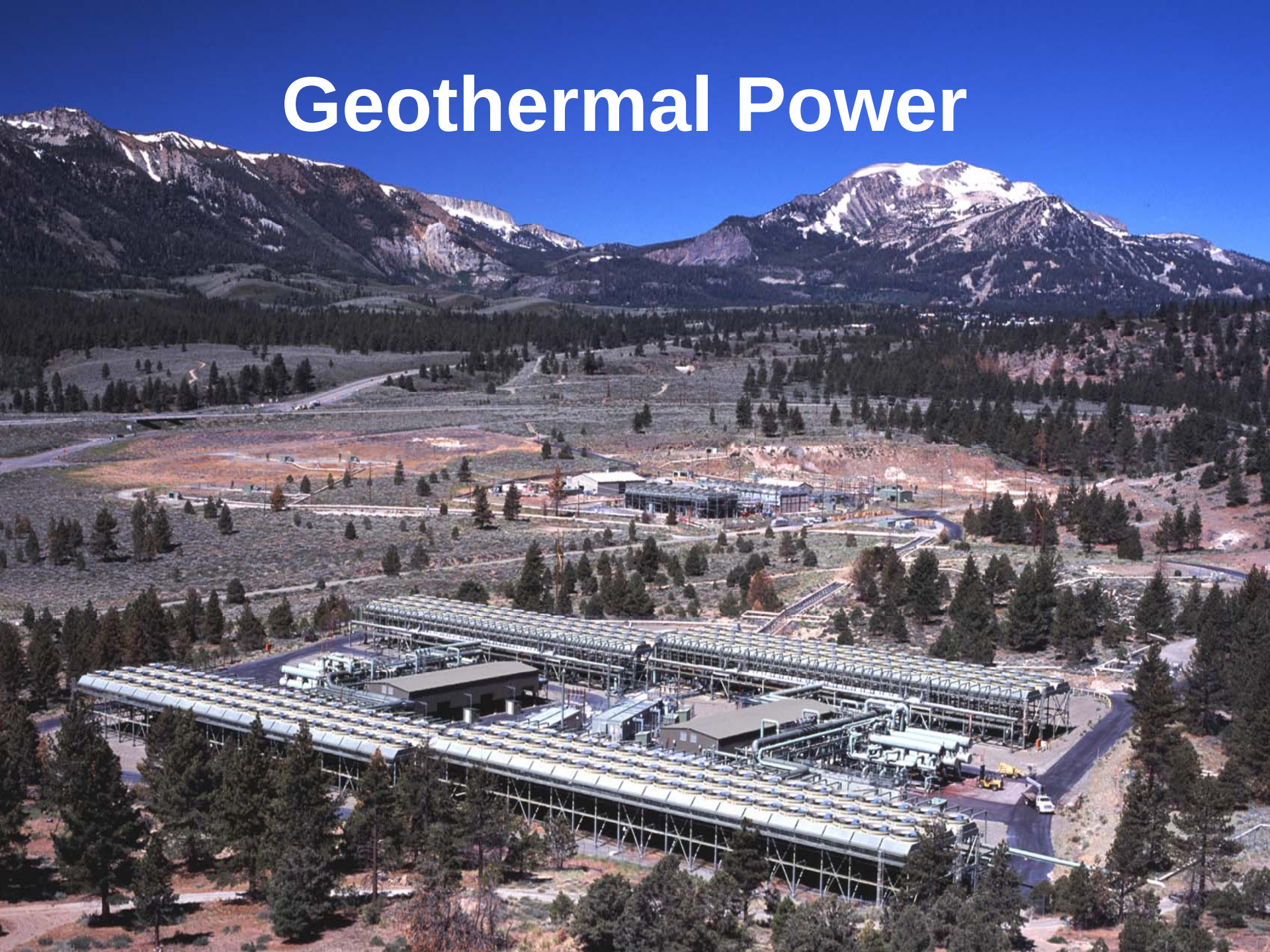
Biopower status in U.S.

- 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 TWh
- Cost – 8-10¢/kWh

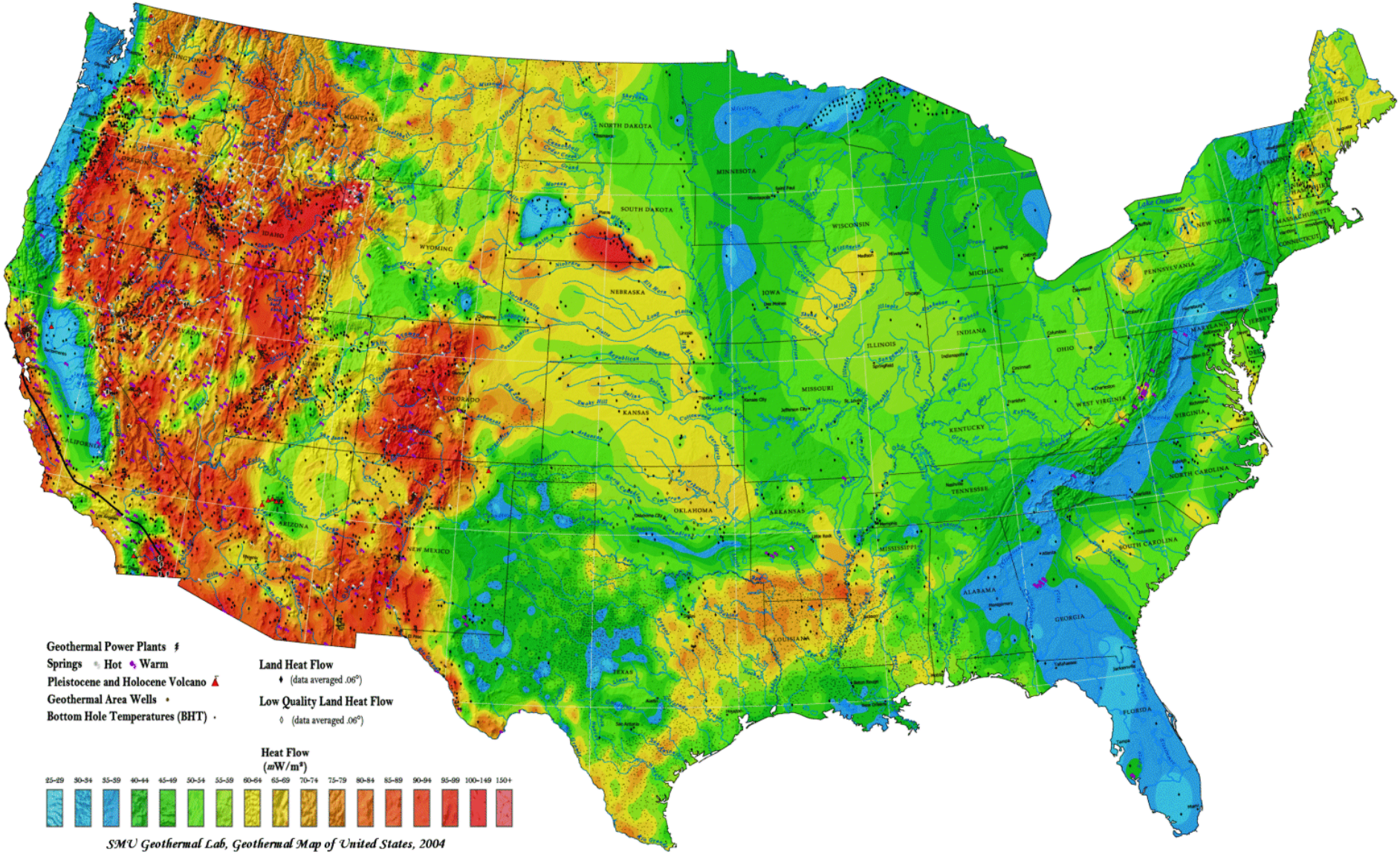
Potential

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

Geothermal Power



Geothermal Heat Flux Map



Geothermal

Today's Status in U.S.

- 2,800 MWe installed,
- 3000 MWe under development
- Cost 5-8¢/kWh with no PTC
- Base load power

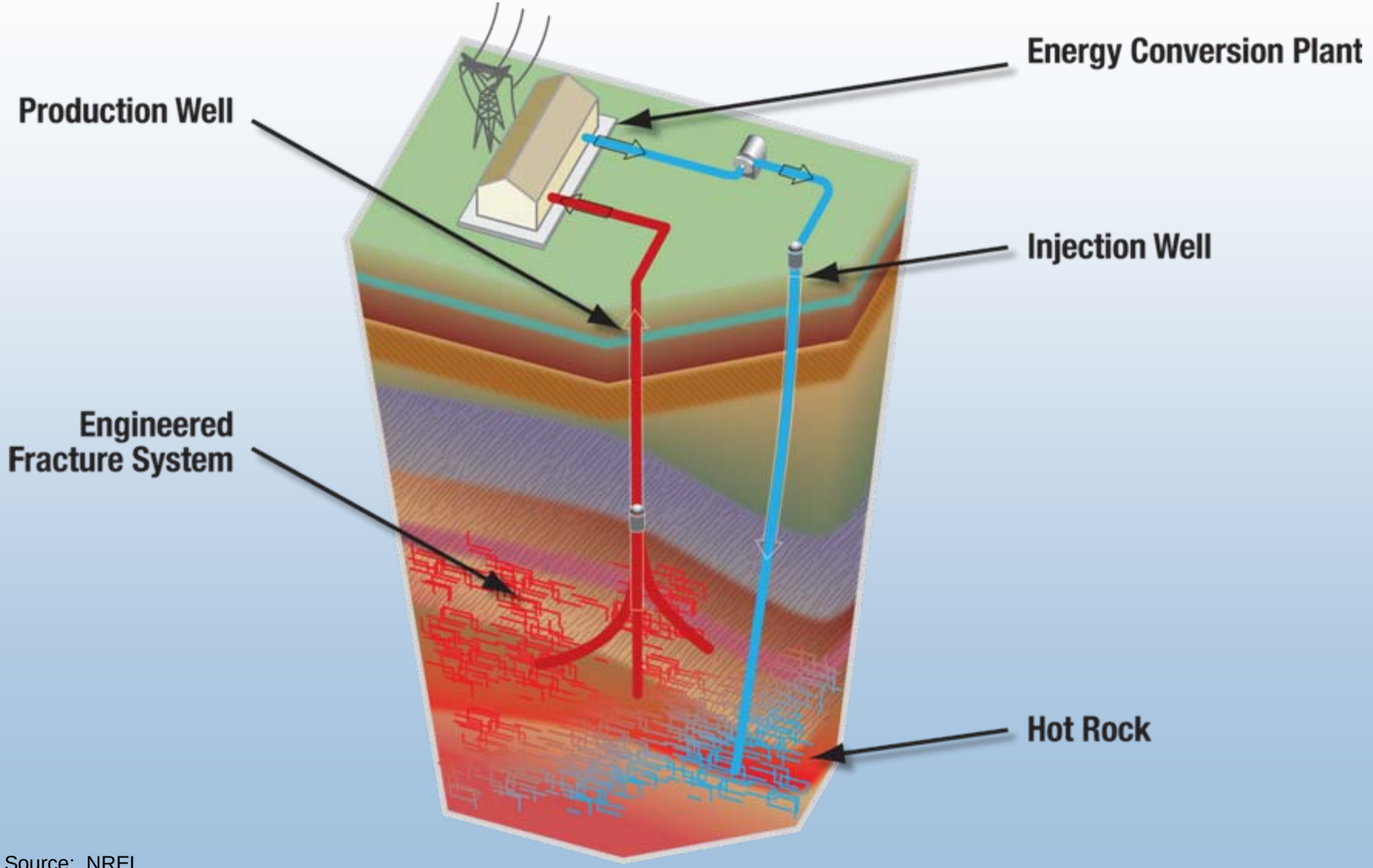
DOE Cost Goals:

- <5¢/kWh for typical hydrothermal sites
- 5¢/kWh for EGS

Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed EGS by 2050

Enhanced Geothermal System



Source: NREL

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

Plug-In Hybrid Electric Vehicles (PHEV)

Status:

- PHEV-only conversion vehicles available
- Industry building prototypes
- NREL PHEV Test Bed

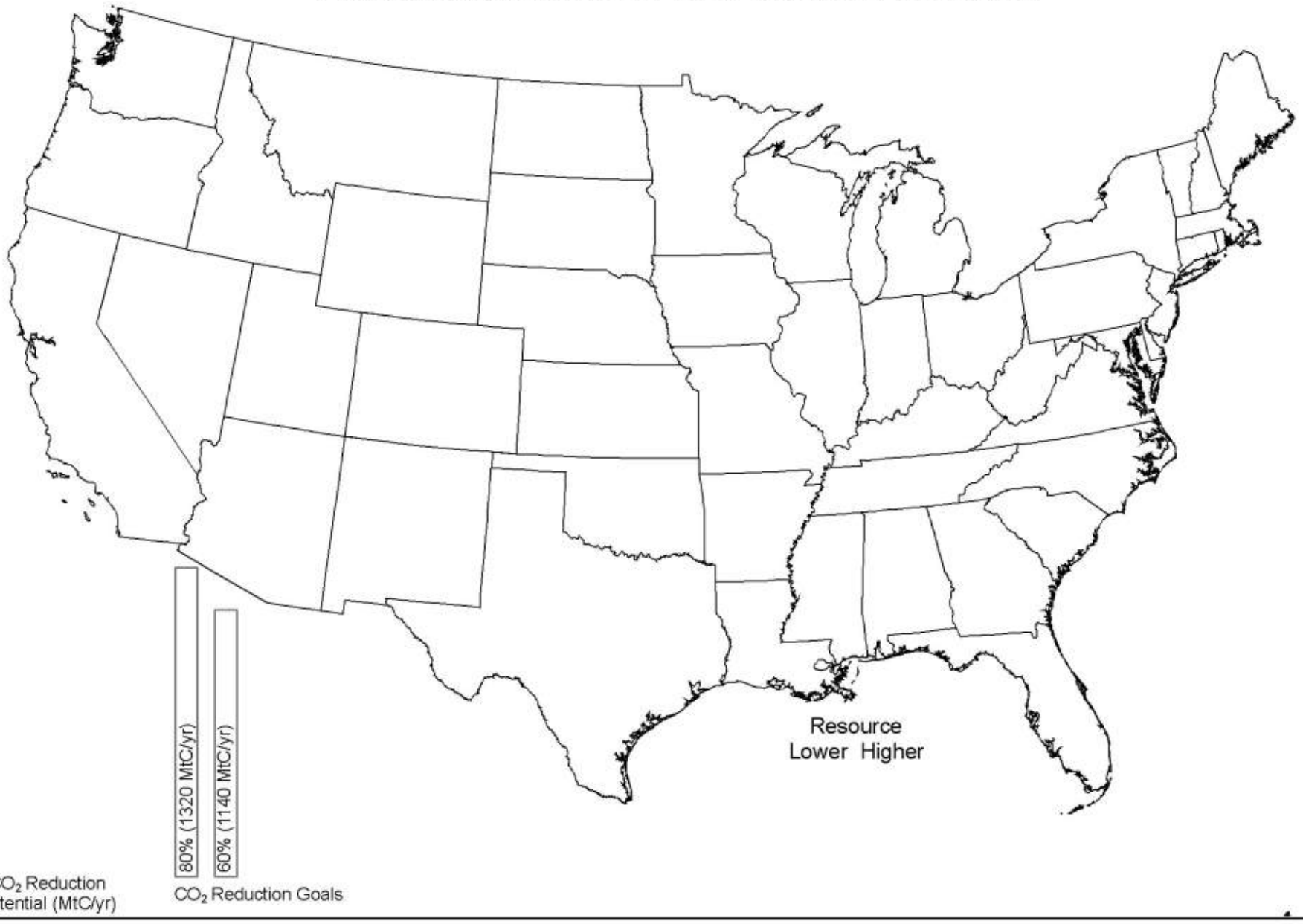
NREL Research Thrusts

- Battery life and cost
- Advanced power electronics
- Vehicle ancillary loads reduction
- Utility interconnection
- Vehicle-to-grid

American Solar Energy Society
WORKING TOWARD A SUSTAINABLE ENERGY FUTURE

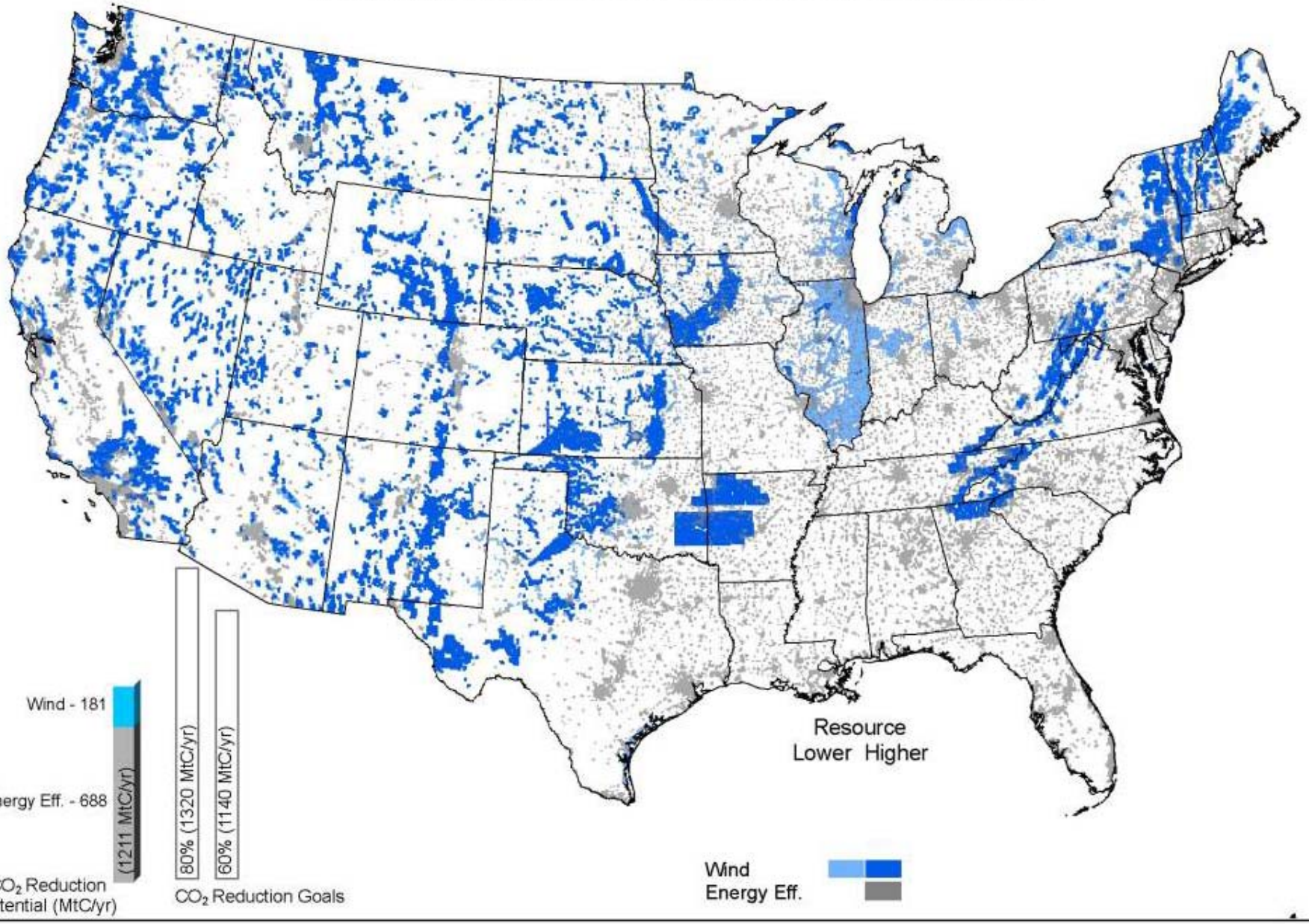
ASES Tackling Climate Change Study

Potential Reduction in U.S. Carbon Emissions

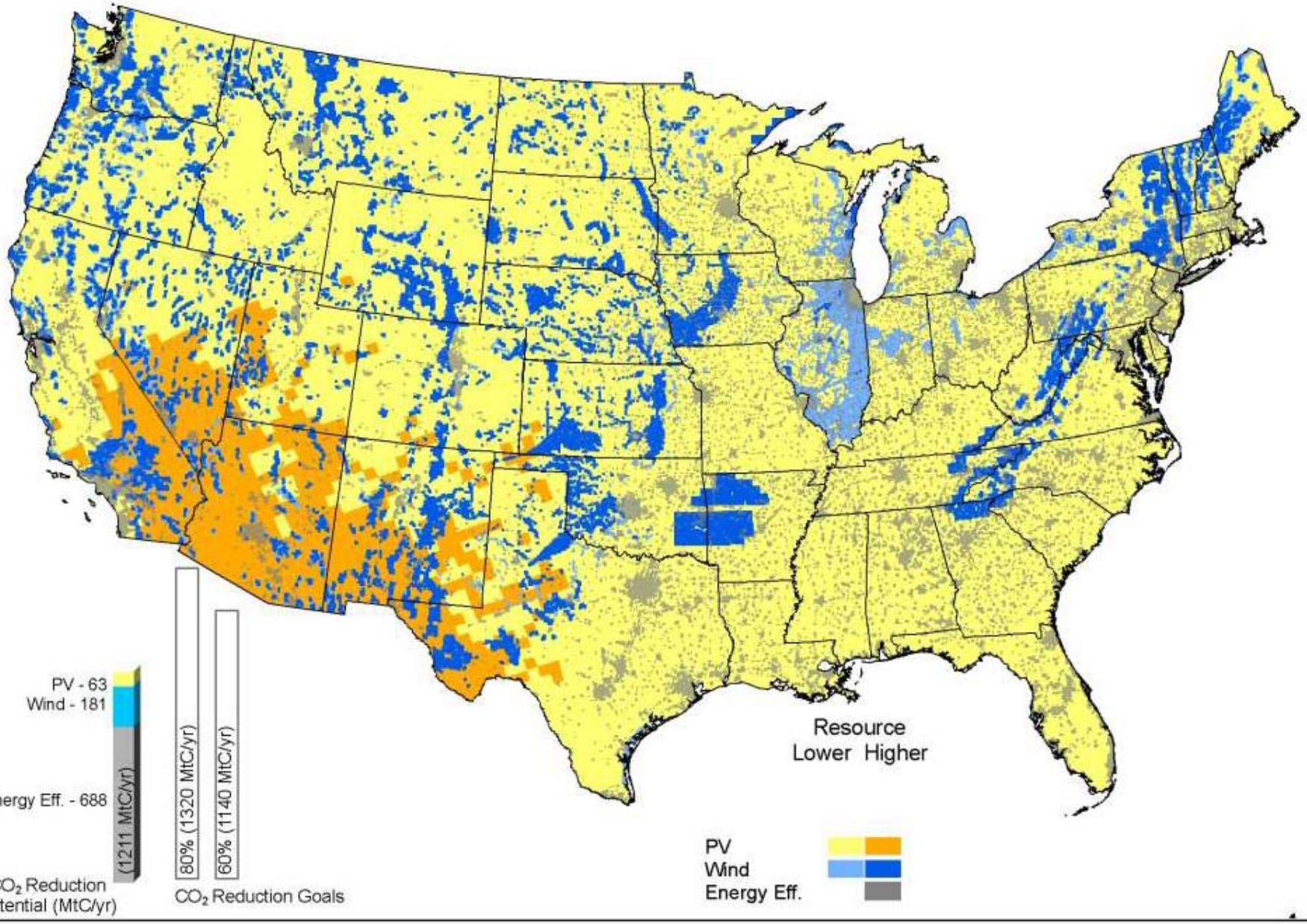


Potential Reduction in U.S. Carbon Emissions

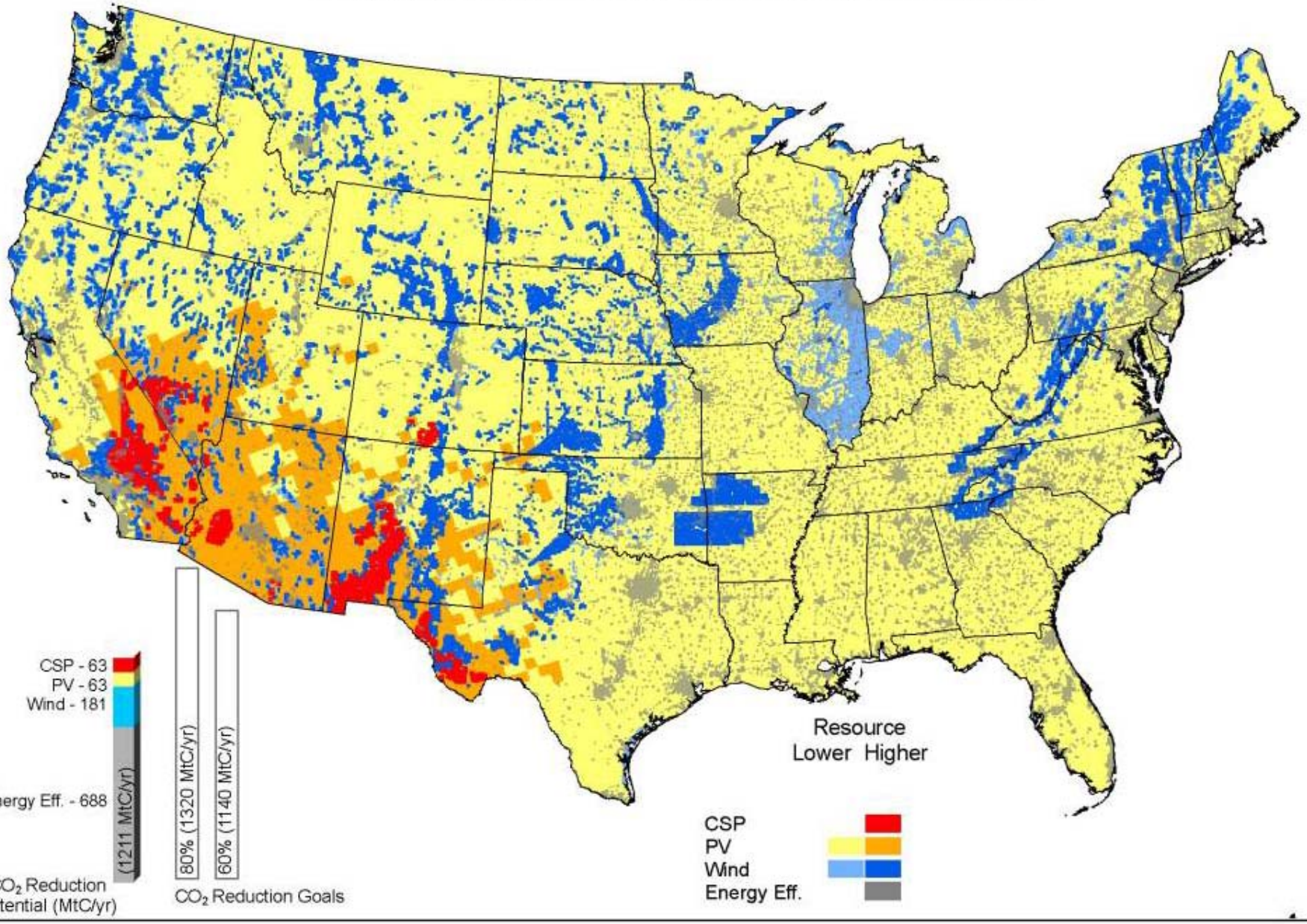
Potential Reduction in U.S. Carbon Emissions



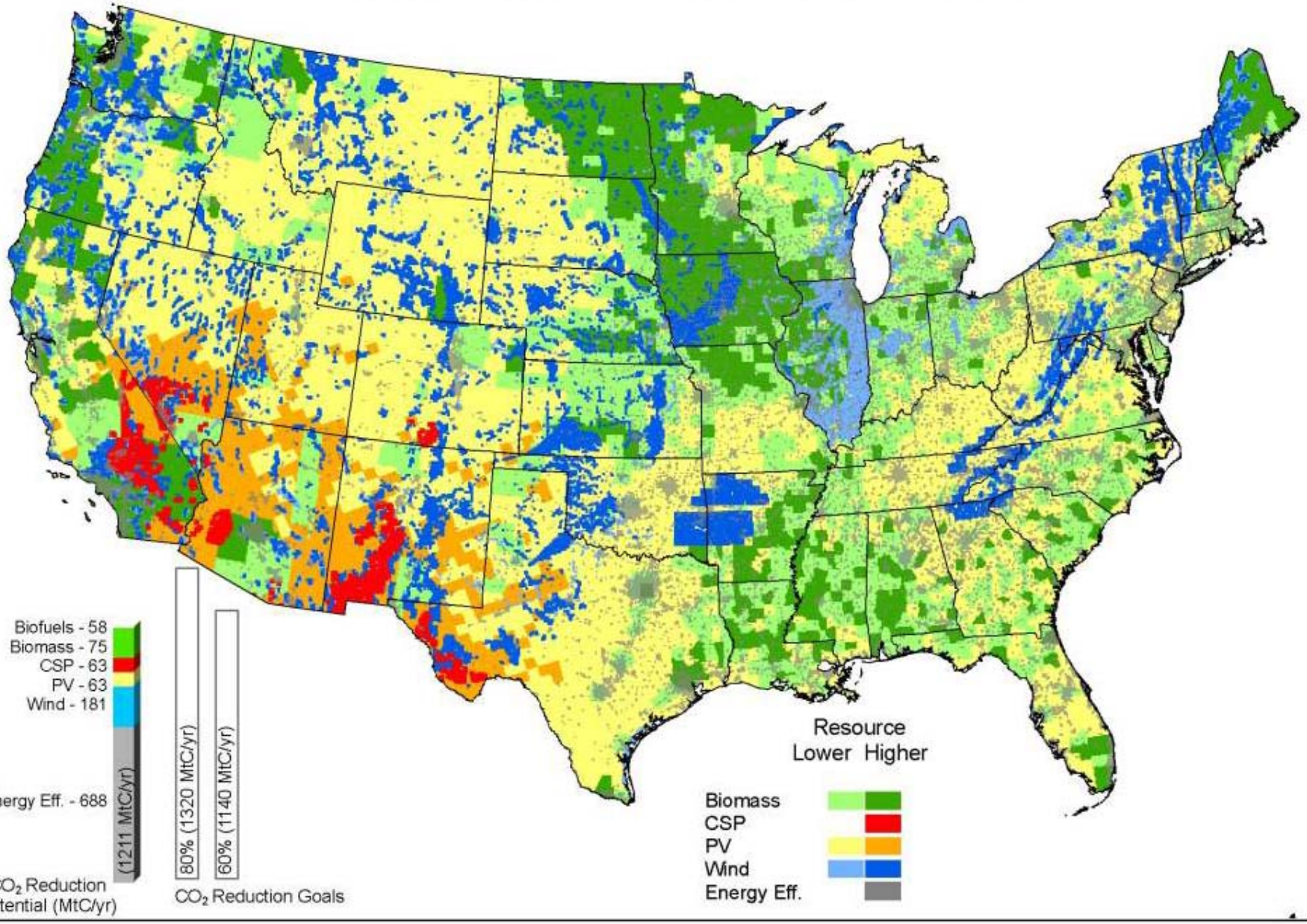
Potential Reduction in U.S. Carbon Emissions



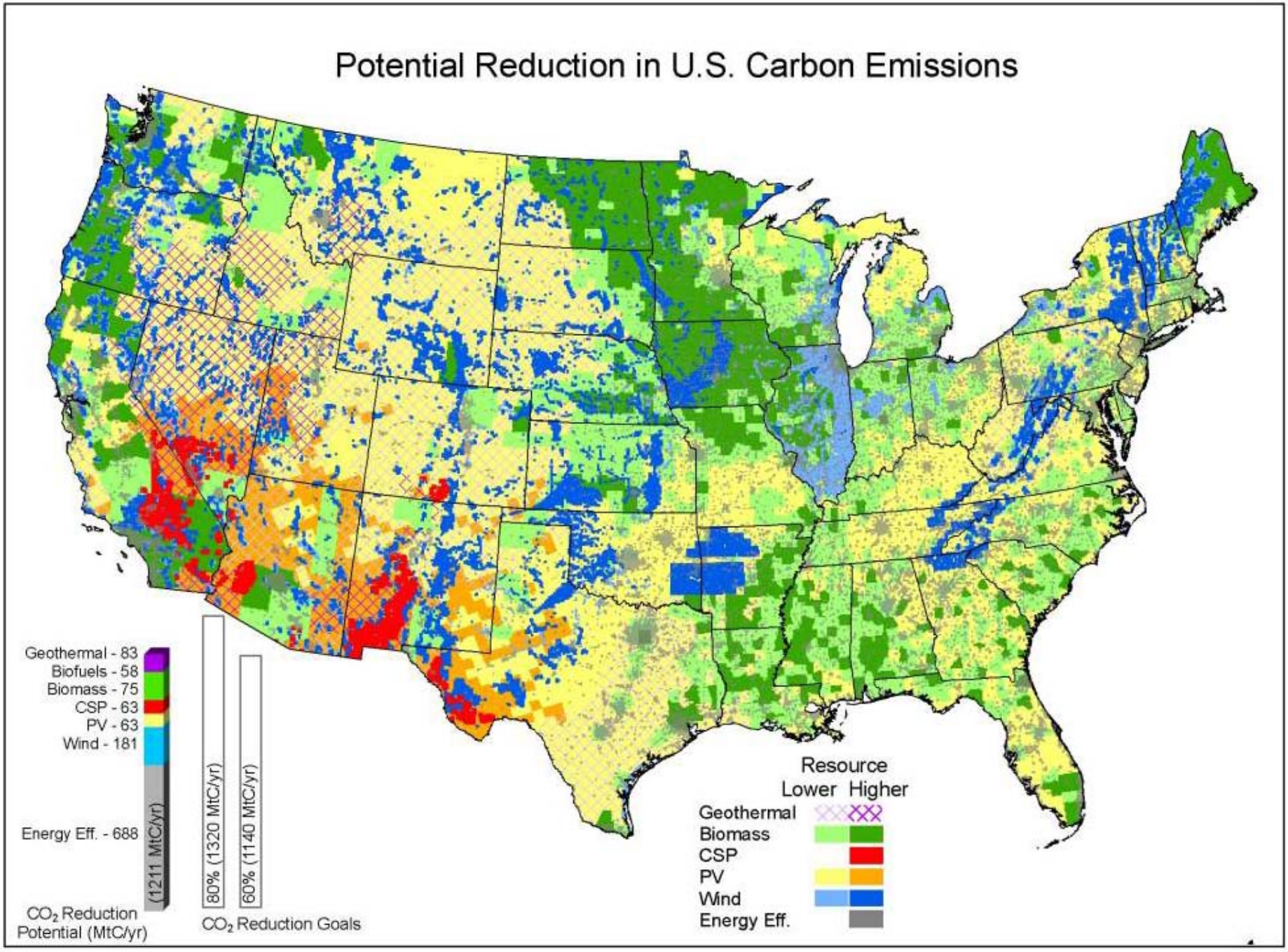
Potential Reduction in U.S. Carbon Emissions



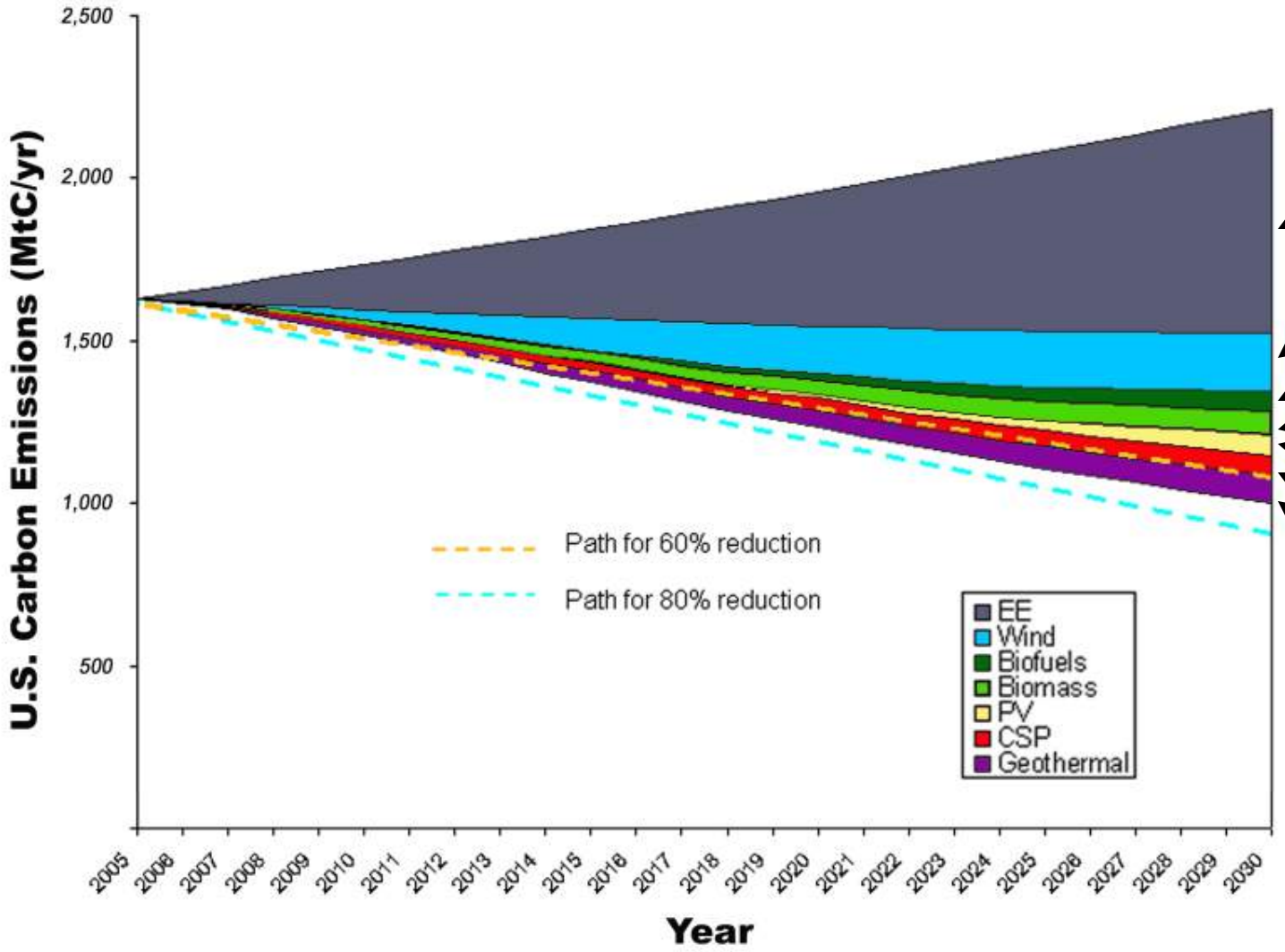
Potential Reduction in U.S. Carbon Emissions



Potential Reduction in U.S. Carbon Emissions



Potential U.S. Carbon Reductions



What does it cost?

-$108B/yr

$0B/yr

$9B/yr

$3B/yr

$5B/yr

$7B/yr

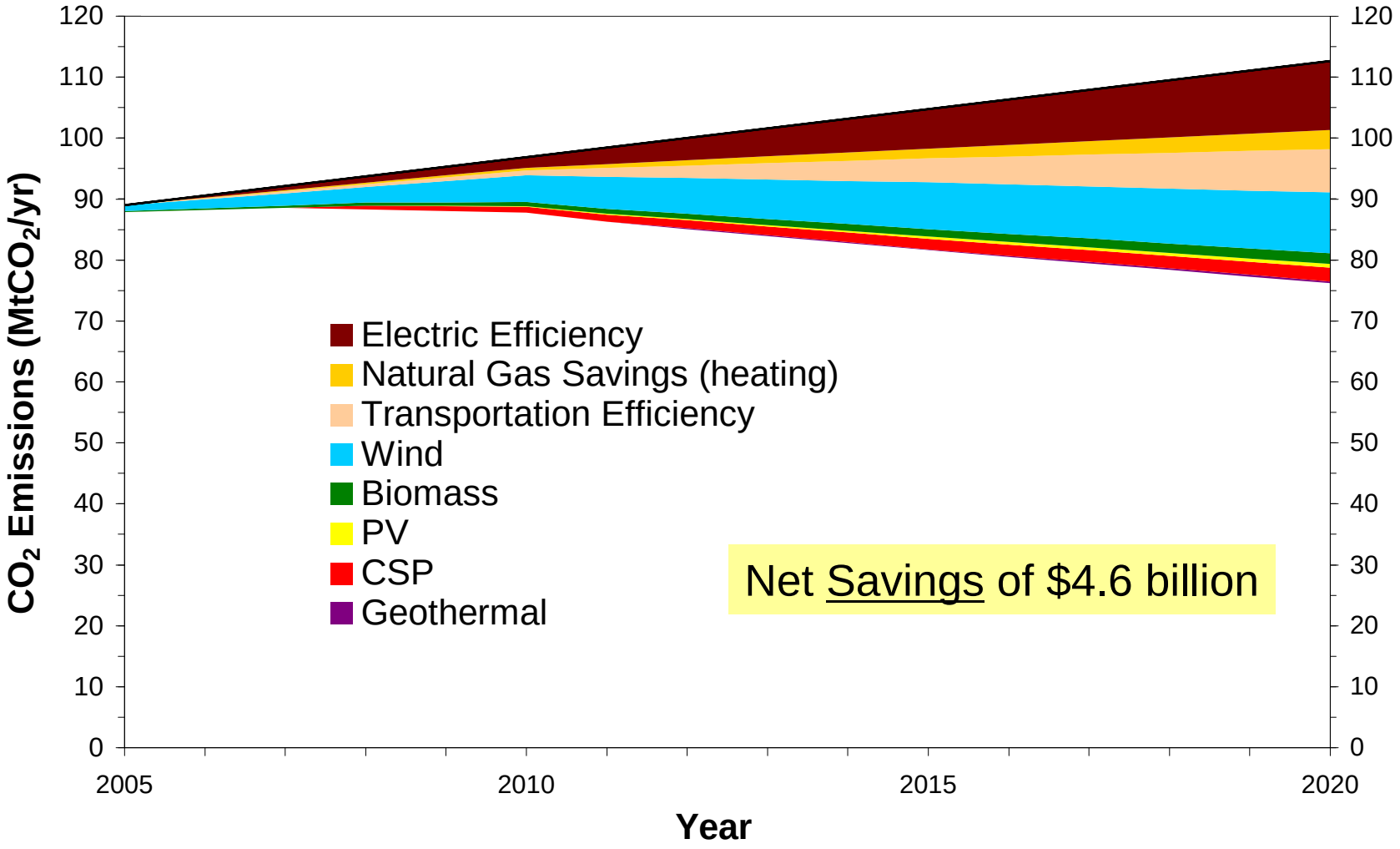
$2B/yr

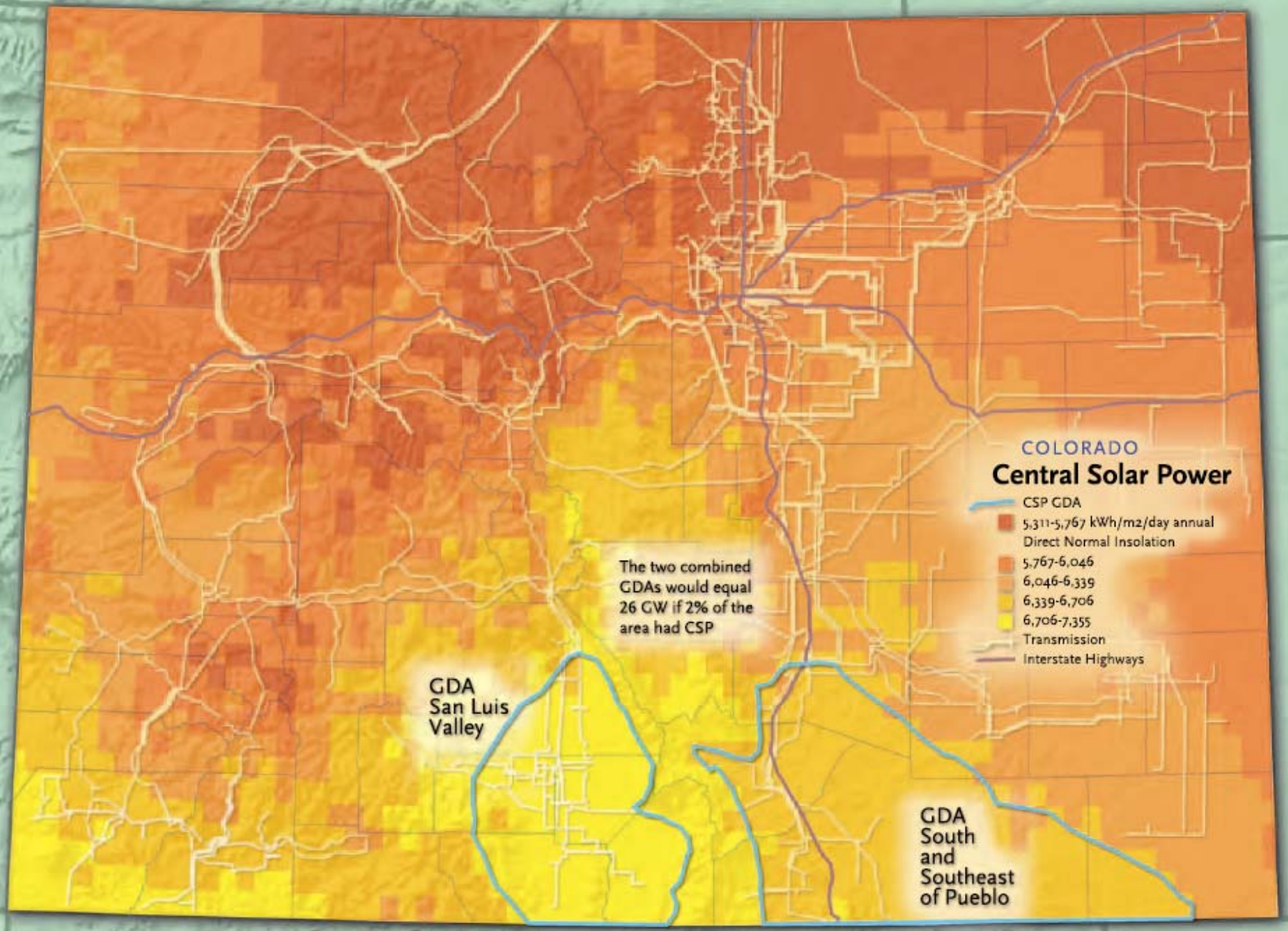
Total:
<u>Savings</u>
of $82B/yr

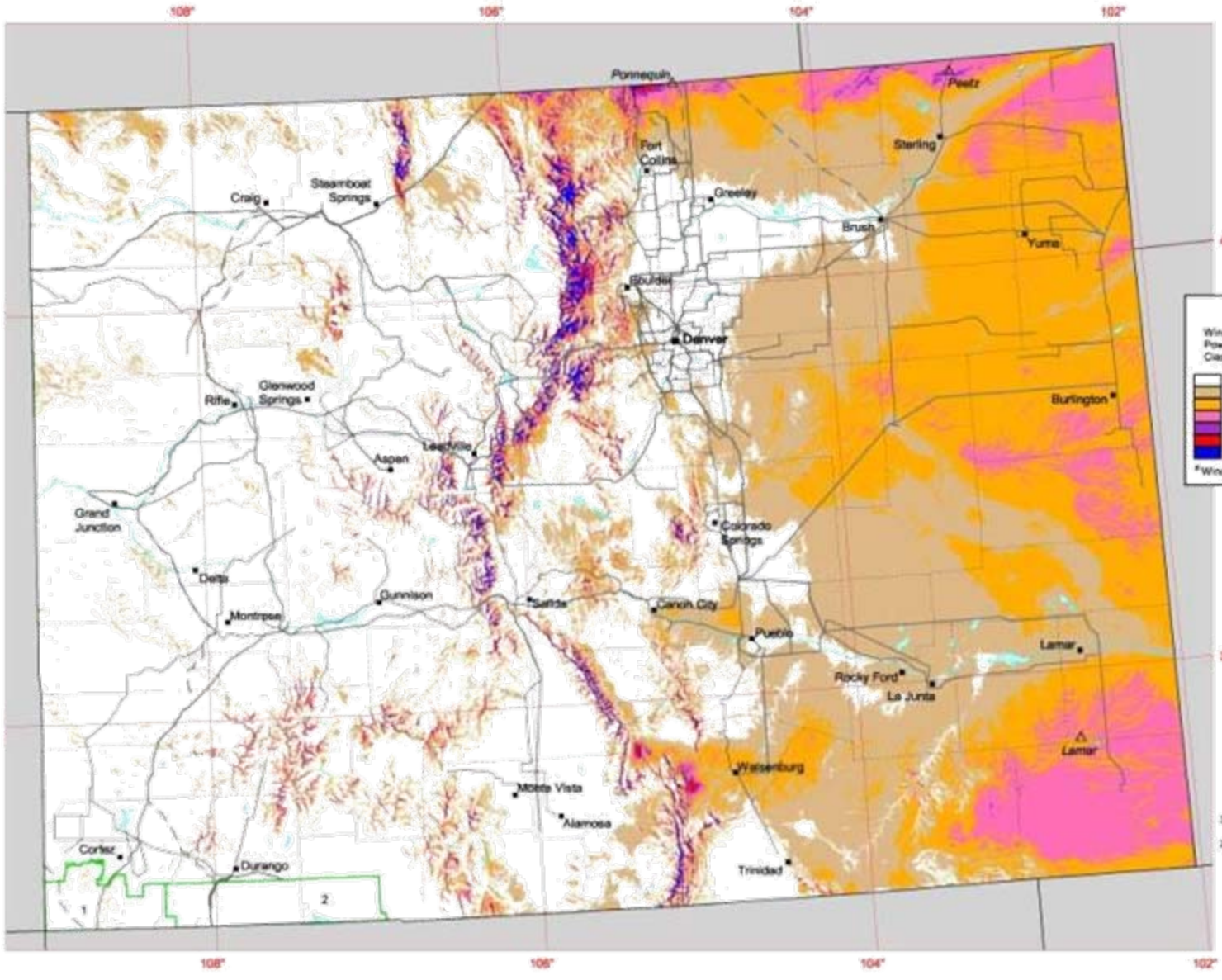
57% Energy Efficiency, 43% Renewables

What About Colorado?

Analysis of Colorado 30% RES




COLORADO
Central Solar Power
CSP GDA
5,311-5,767 kWh/m2/day annual Direct Normal Insolation
5,767-6,046
6,046-6,339
6,339-6,706
6,706-7,355
Transmission
Interstate Highways
The two combined GDAs would equal 26 GW if 2% of the area had CSP
GDA San Luis Valley
GDA South and Southeast of Pueblo



Colorado

50 m Wind Power

The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
1	Poor	0 - 200	0.0 - 5.9	0.0 - 13.2
2	Marginal	200 - 300	5.9 - 6.7	13.2 - 15.0
3	Fair	300 - 400	6.7 - 7.4	15.0 - 16.6
4	Good	400 - 500	7.4 - 7.9	16.6 - 17.7
5	Excellent	500 - 600	7.9 - 8.4	17.7 - 18.8
6	Outstanding	600 - 800	8.4 - 9.3	18.8 - 20.8
7	Superb	> 800	> 9.3	> 20.8

*Wind speeds are based on a Weibull k of 2.0 at 1500 m elevation.

Indian Reservation

1 Ute Mountain
2 Southern Ute

Transmission Line*

Voltage (kV)

115 - 161
230
345

△ Wind Farm*

* Source: POWERmap ©2004 Platts, a Division of the McGraw-Hill Companies

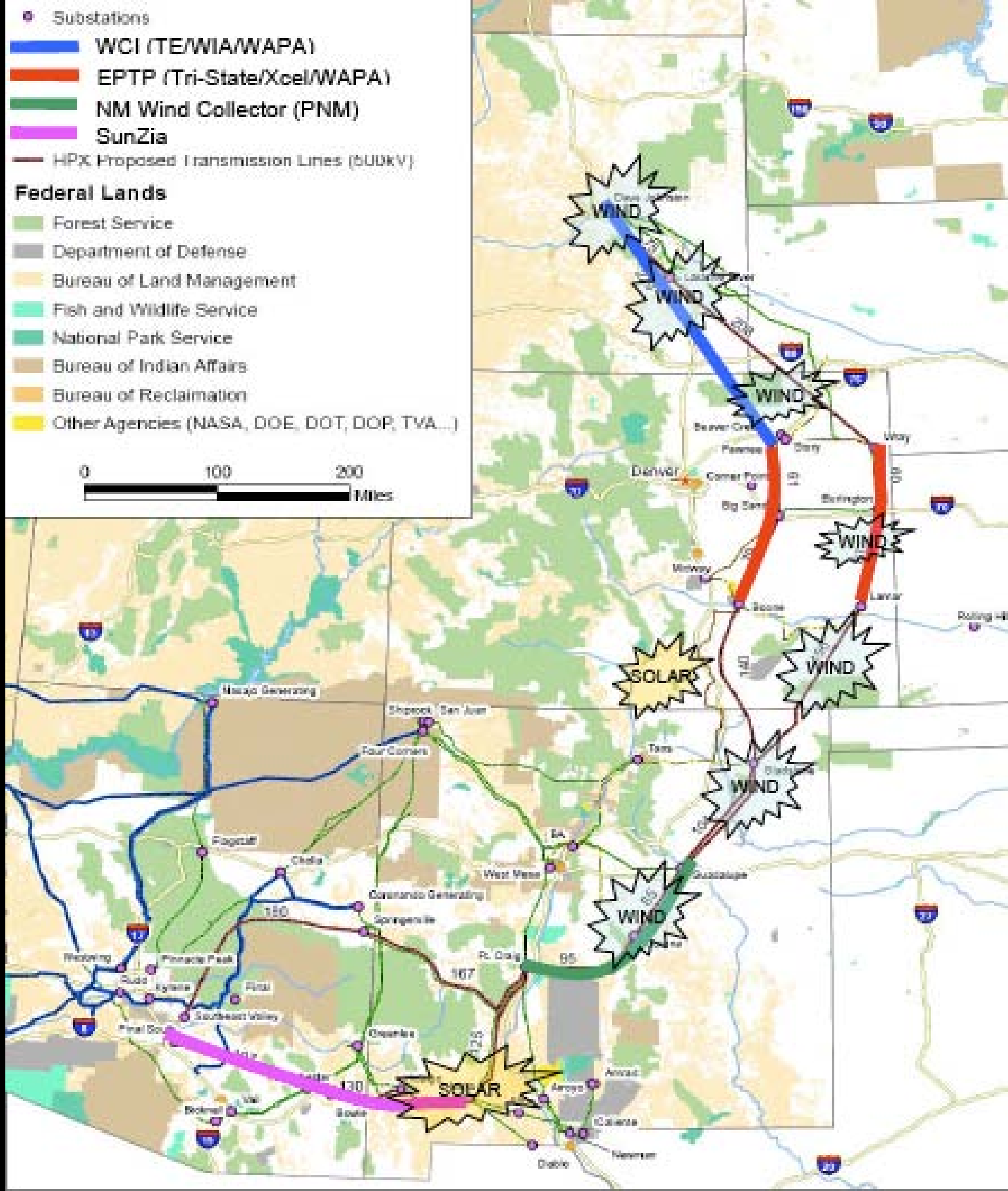
30 0 30 60 90 120 Kilometers

20 0 20 40 60 80 Miles

U.S. Department of Energy
National Renewable Energy Laboratory

NREL

30-JAN-2004 2.1.3


Substations
WCI (TE/WIA/WAPA)
EPTP (Tri-State/Xcel/WAPA)
NM Wind Collector (PNM)
SunZia
HPX Proposed Transmission Lines (500kV)
Federal Lands
Forest Service
Department of Defense
Bureau of Land Management
Fish and Wildlife Service
National Park Service
Bureau of Indian Affairs
Bureau of Reclamation
Other Agencies (NASA, DOE, DOT, DOP, TVA...)
0
100
200
Miles
WIND
WIND
WIND
WIND
WIND
WIND
WIND
SOLAR
SOLAR
Denver
Wray
Burlington
Lamar
Boone
Midway
Rolling Hills
Navajo Generating
Shiprock / San Juan
Four Corners
Flagstaff
Cholla
Coronado Generating
Springerville
West Mesa
Pinnacle Peak
Southeast Valley
Greenlee
Arroyo
Caliente
Newman
Diablo
Guadalupe
Ft. Craig
150
167
95
130

Resource Assessment

NREL Resource Assessment Tasks

Bankable Data and GIS Support

On-Site DNI Measurements

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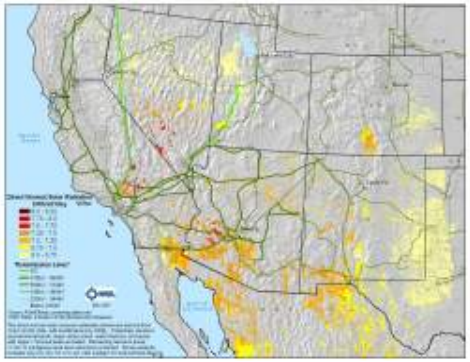
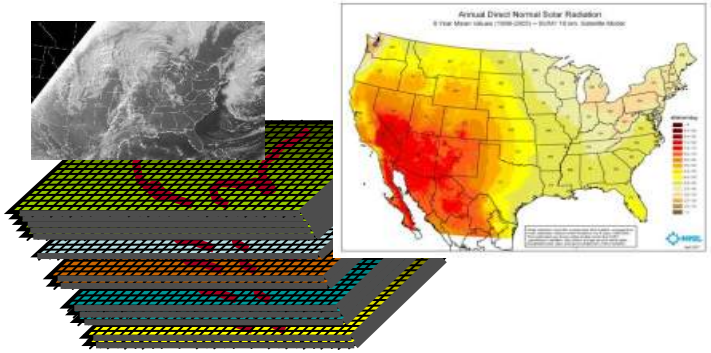


GIS Analysis

Resource Data Modeling and Forecasting

Satellite-based DNI Modeling



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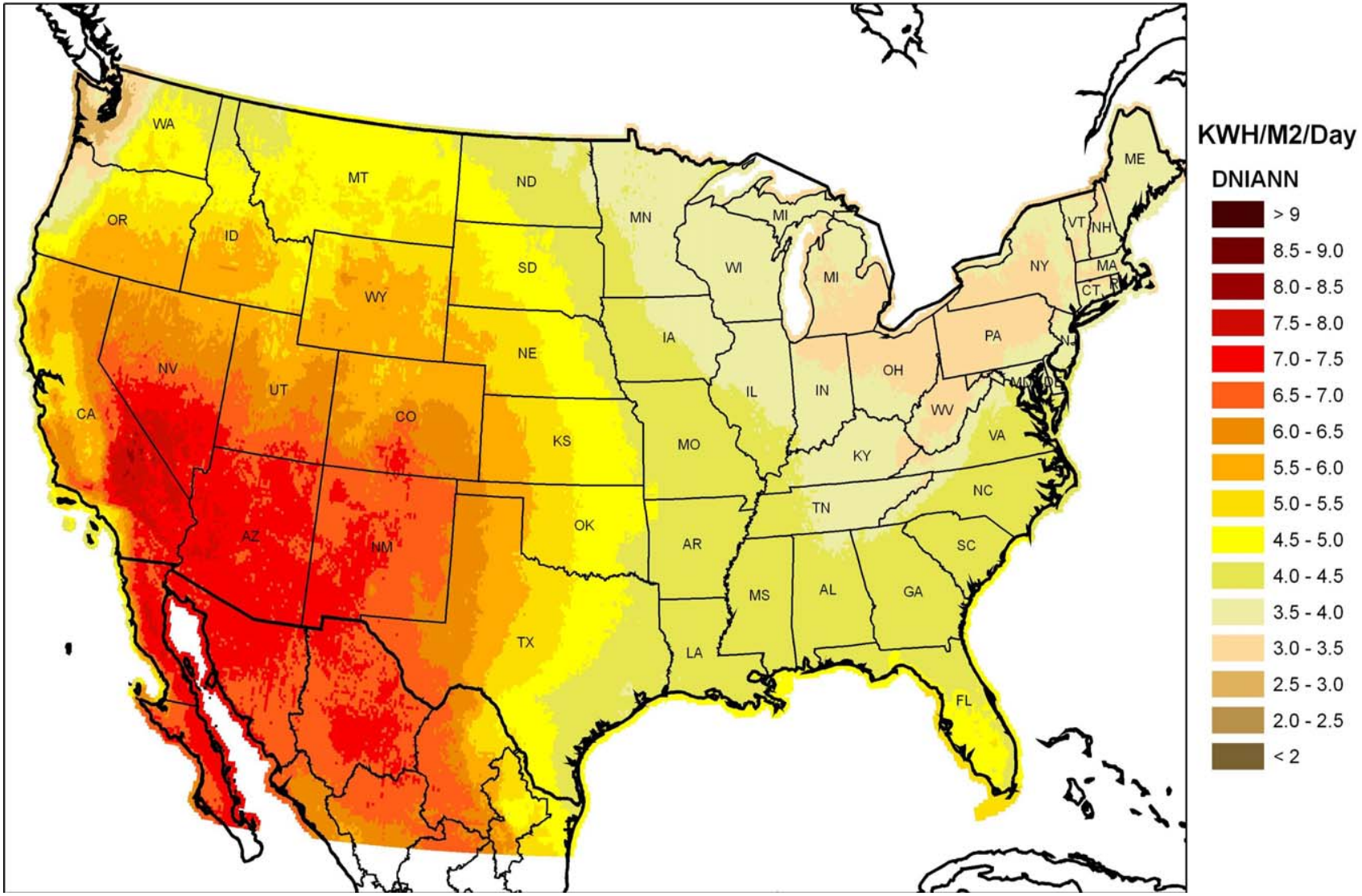
Cloud and Irradiance Forecasting

Source: Richard Perez, SUNY/Albany

Satellite Global and DNI 8 Year Maps



Measurements

~$30-50K+

Conventional three-component measurements with three radiometers on a tracker.

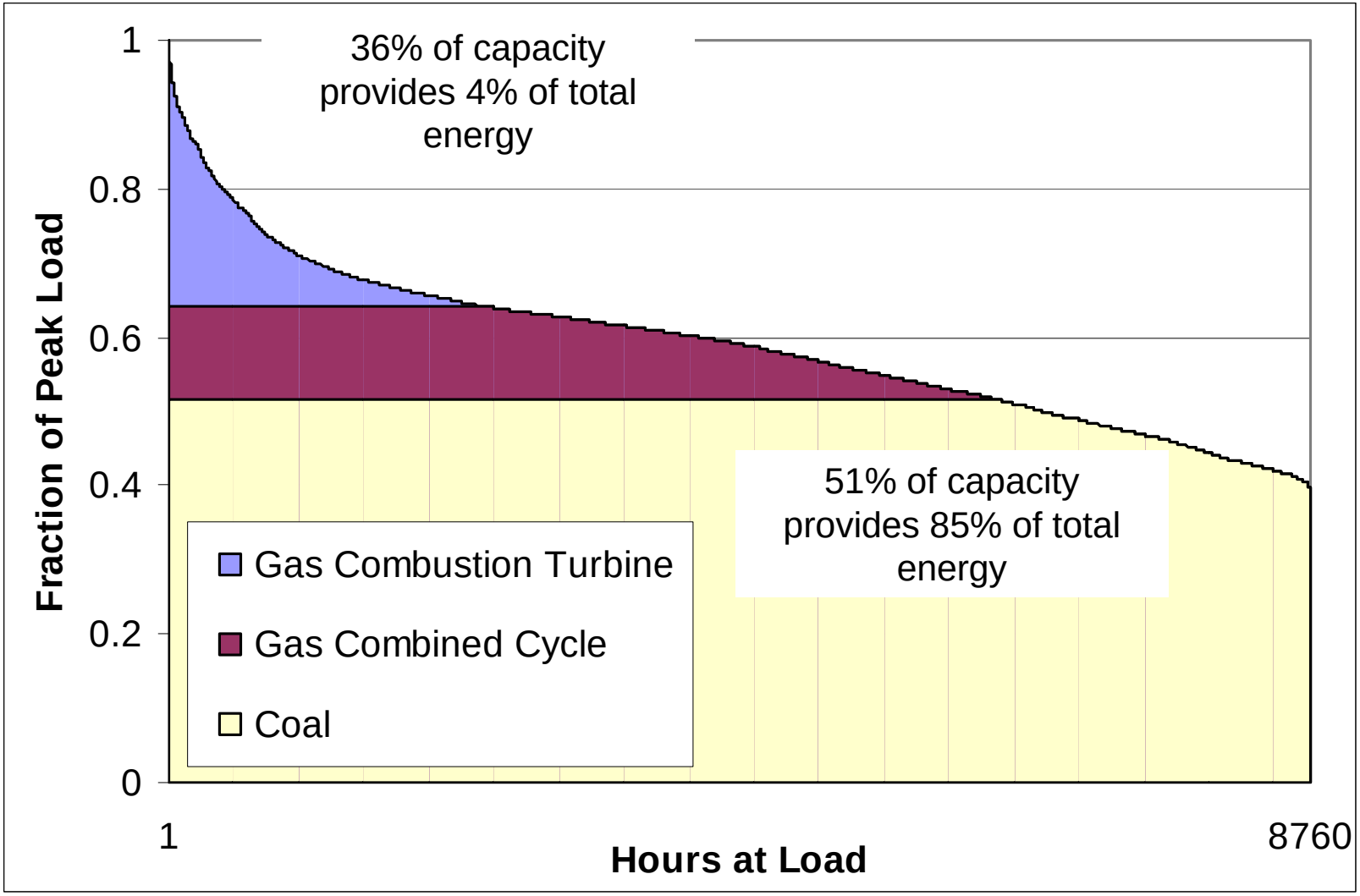
~$12K+

Rotating Shadowband – three measurements in one self-contained instrument

Includes basic meteorological instruments, data logger, modem communications, instrument mounting, and other accessories

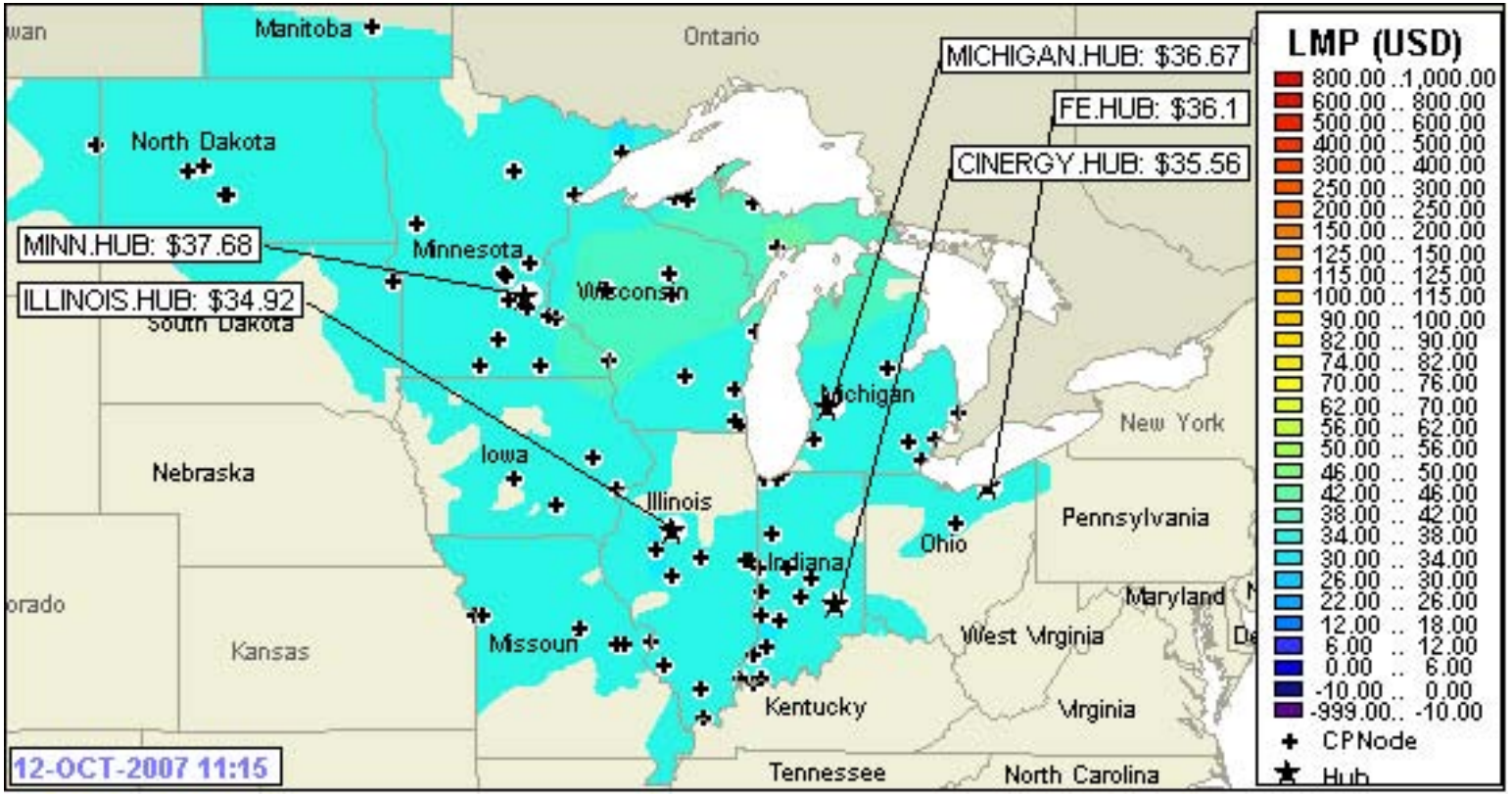
Grid Integration

Load Duration Curve

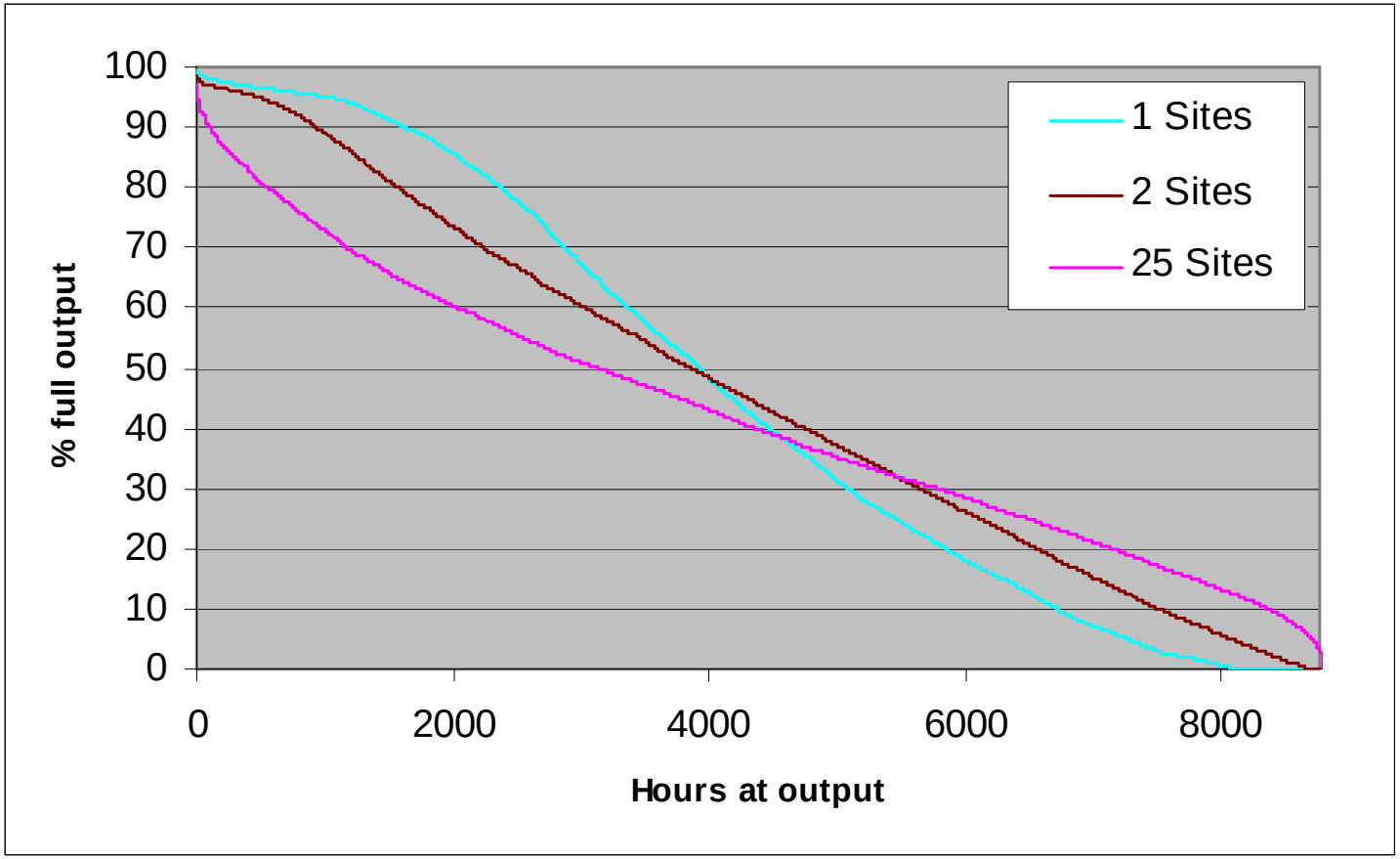


Spatial Diversity Can Mitigate Intermittency

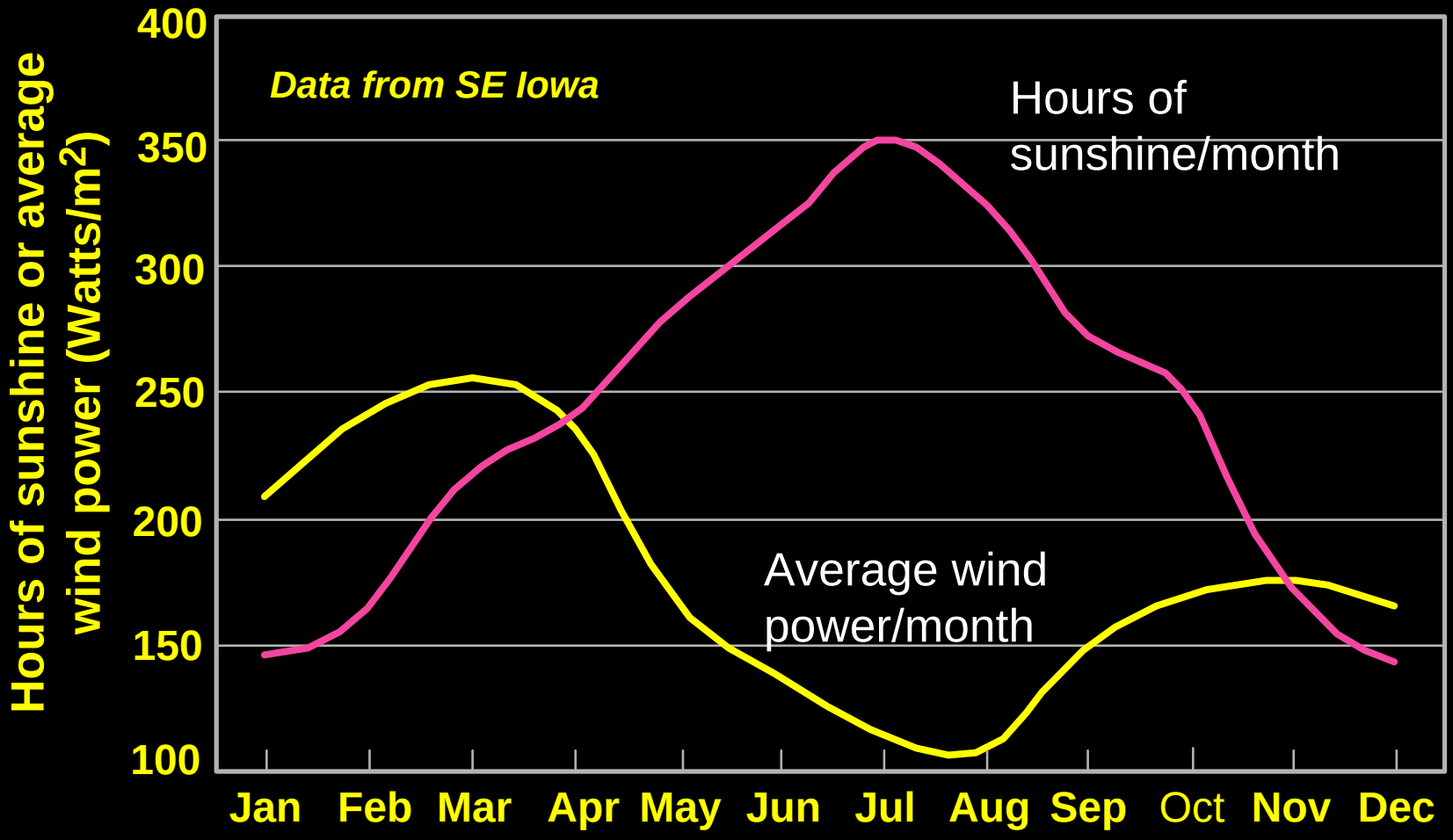
- Utility balancing areas can combine or cooperate – large electricity markets (example: Denmark/Europe)



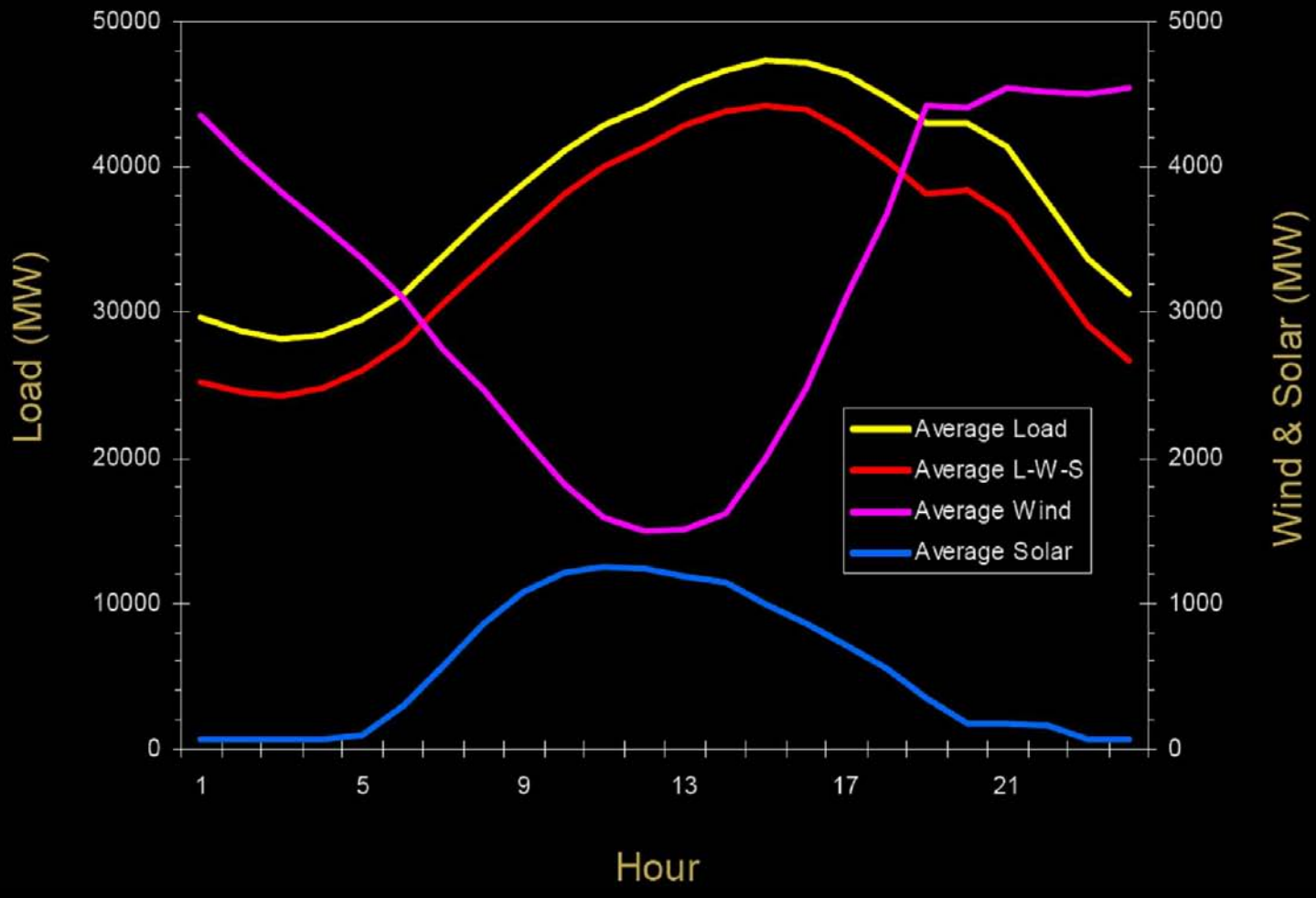
Spatial Diversity Smoothes Wind Farm Output



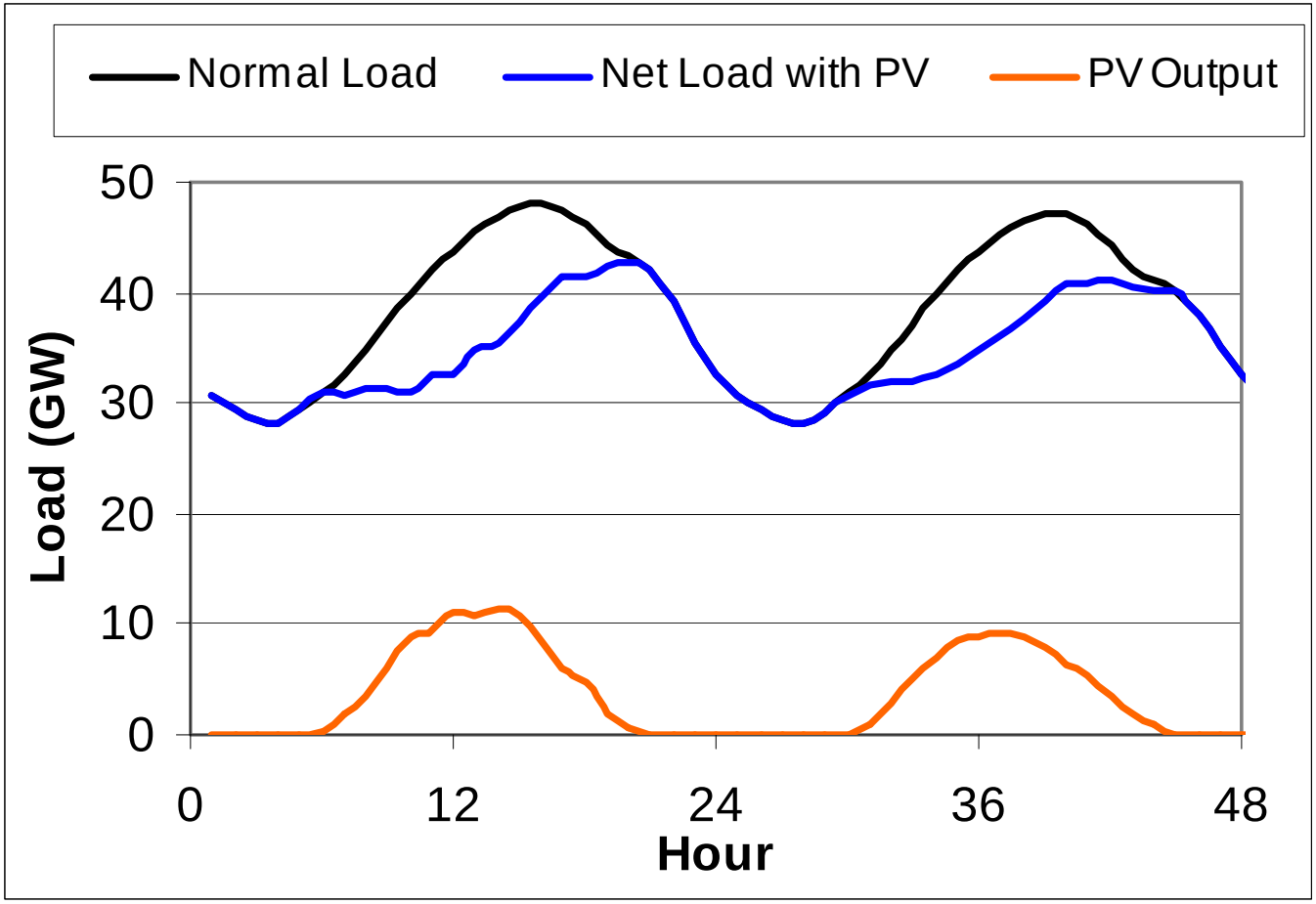
Solar and Wind Complementary: Annual



Solar and Wind Complementary: Diurnal

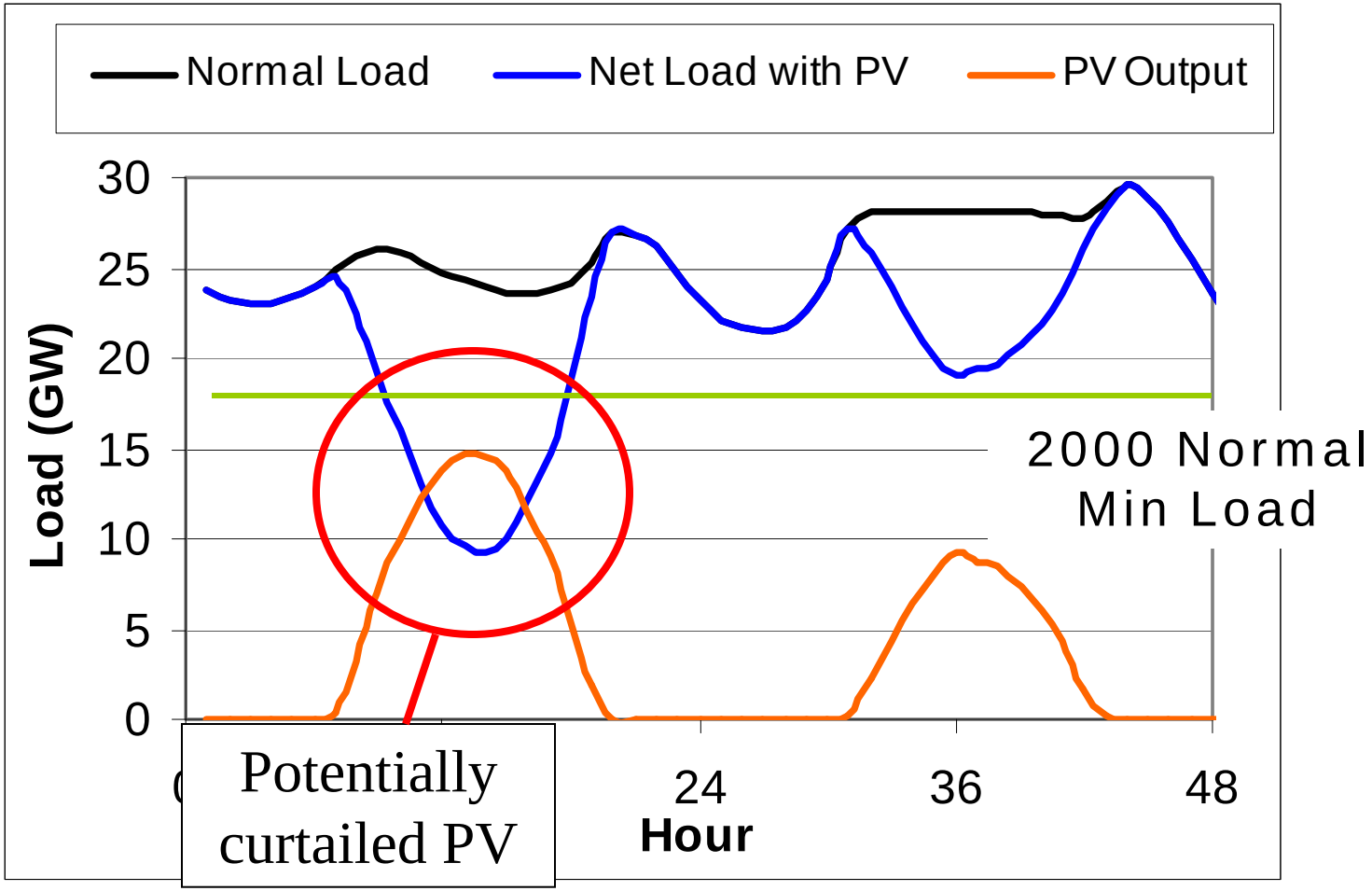


PV Coincidence With Load – Summer, ERCOT

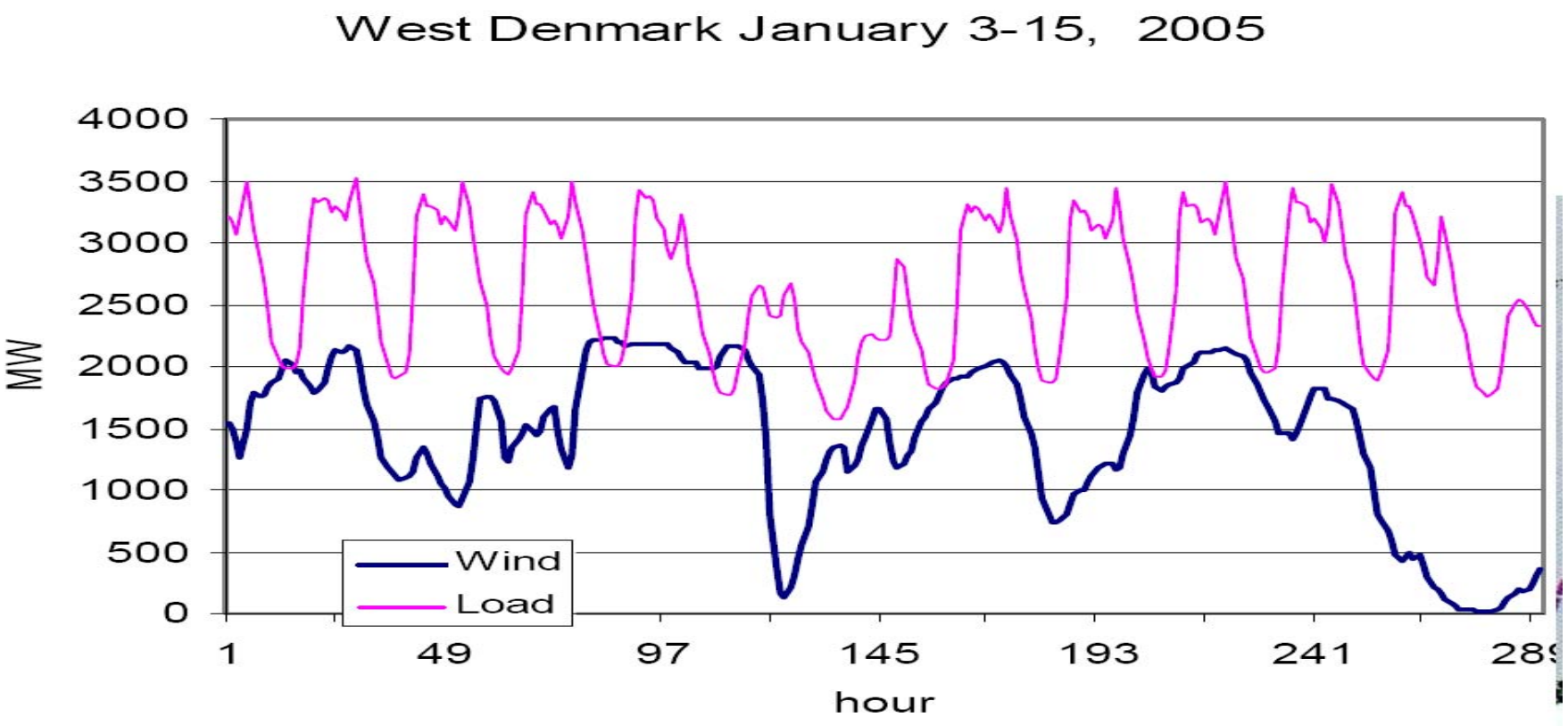


16 GW simulated PV system providing 11% of system's energy

PV Coincidence With Load - Spring



Wind Curtailment in Denmark

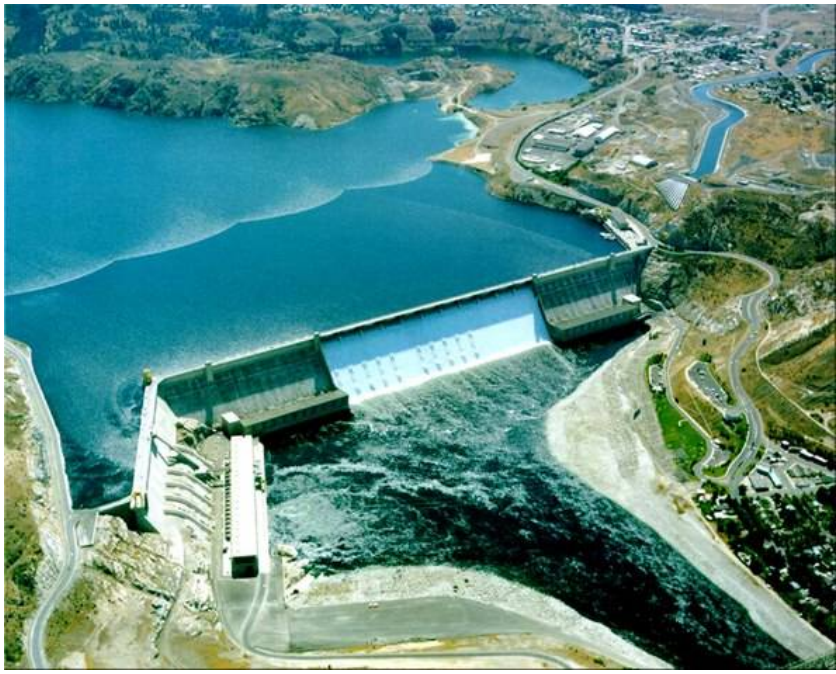


Denmark has access to large export markets

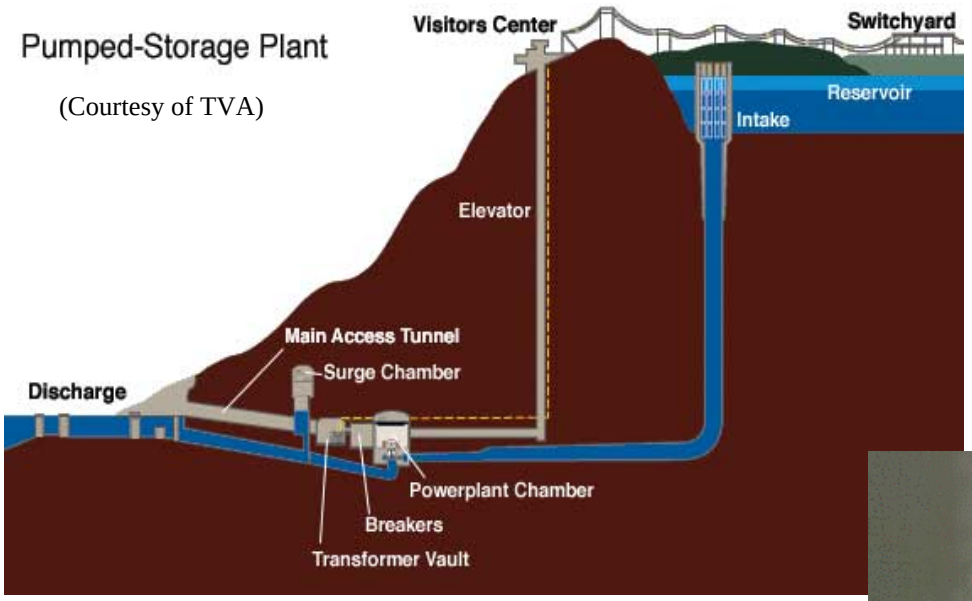
Lennart Söder,KTH, Sweden, presented at UWIG, Oct 23-25, 2006

Does wind need backup or storage?

- Increased operating reserves may be necessary, but not dedicated backup
- Although new storage has value, it may not be cost effective
- There is typically already storage on the system
  - Natural gas in the pipeline or storage facility
  - Controllable hydro
- A recent study by Xcel Energy in Colorado found
  - existing pumped storage provided $1.30/MWh offset to wind integration cost
  - Enlarging existing gas storage facility was economic at large wind penetration

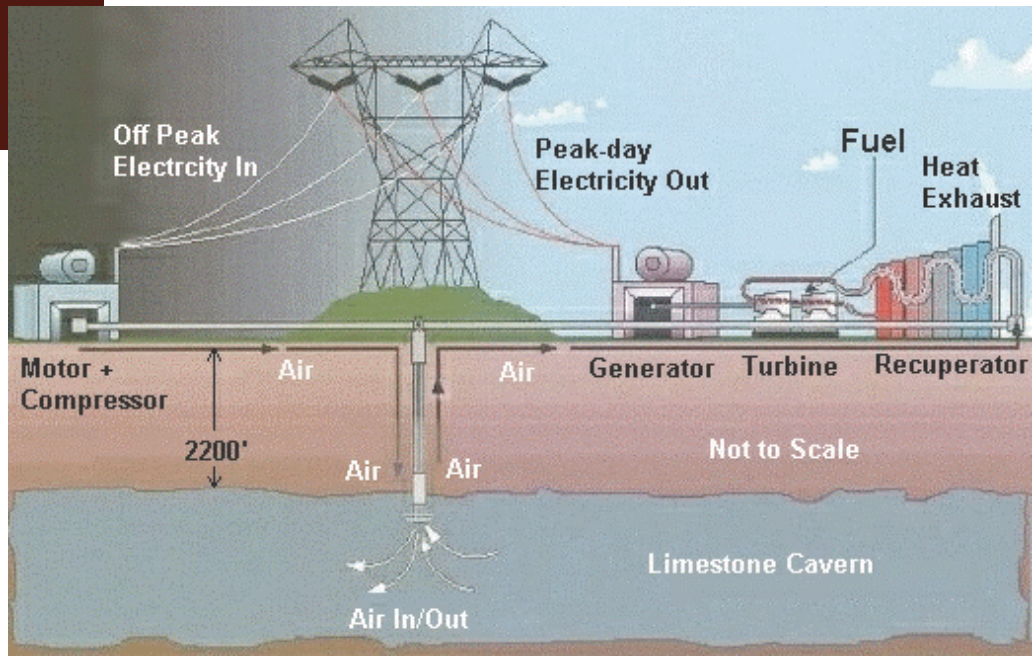


Bulk Energy Storage

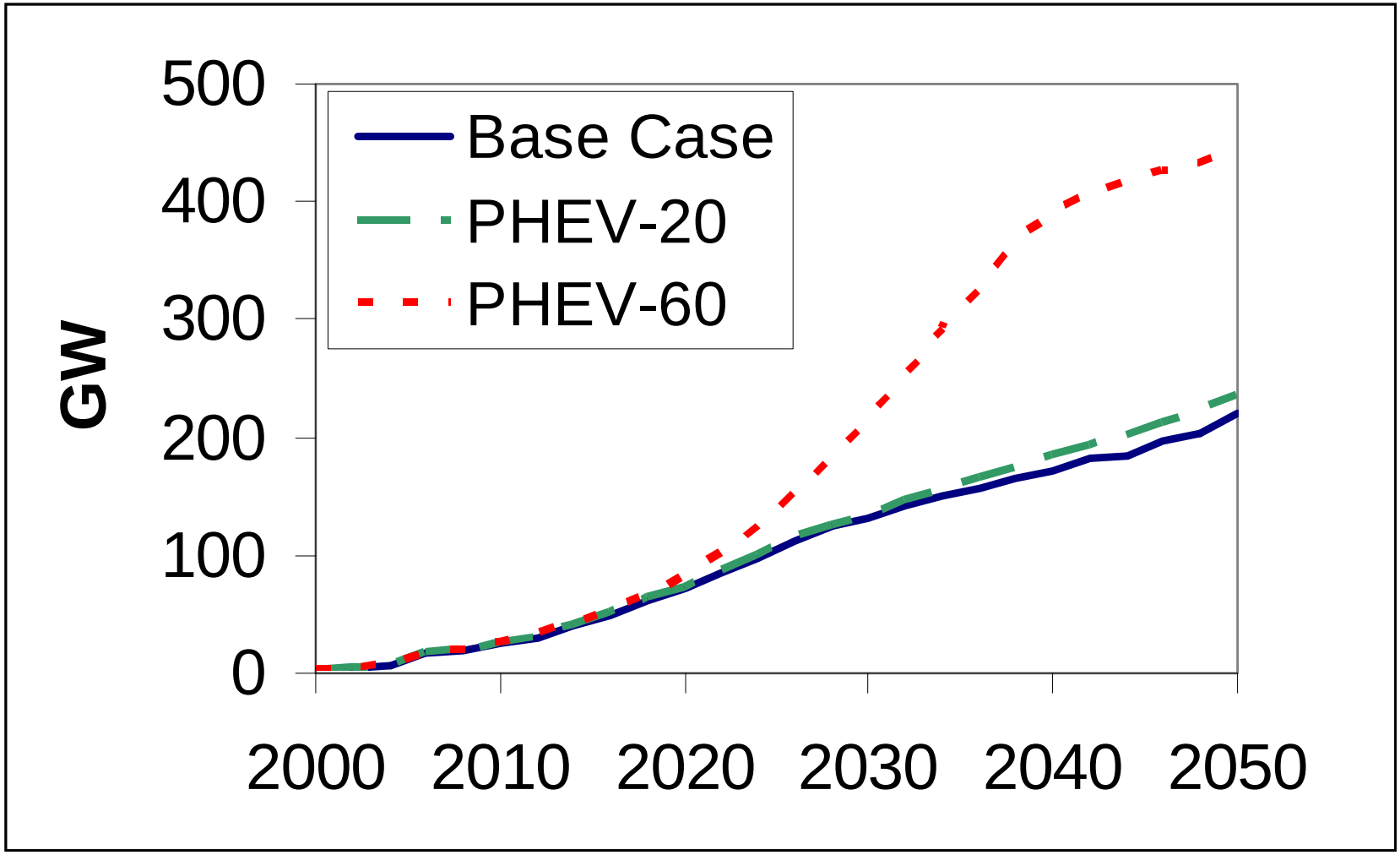


20 GW in U.S.
200 MW at Mt. Elbert

Compressed Air Energy Storage (CAES)
110 MW in U.S.



PHEVs* Can Increase Wind Penetration



* Assumes 50% PHEV-V2G penetration by 2050

Forecasting

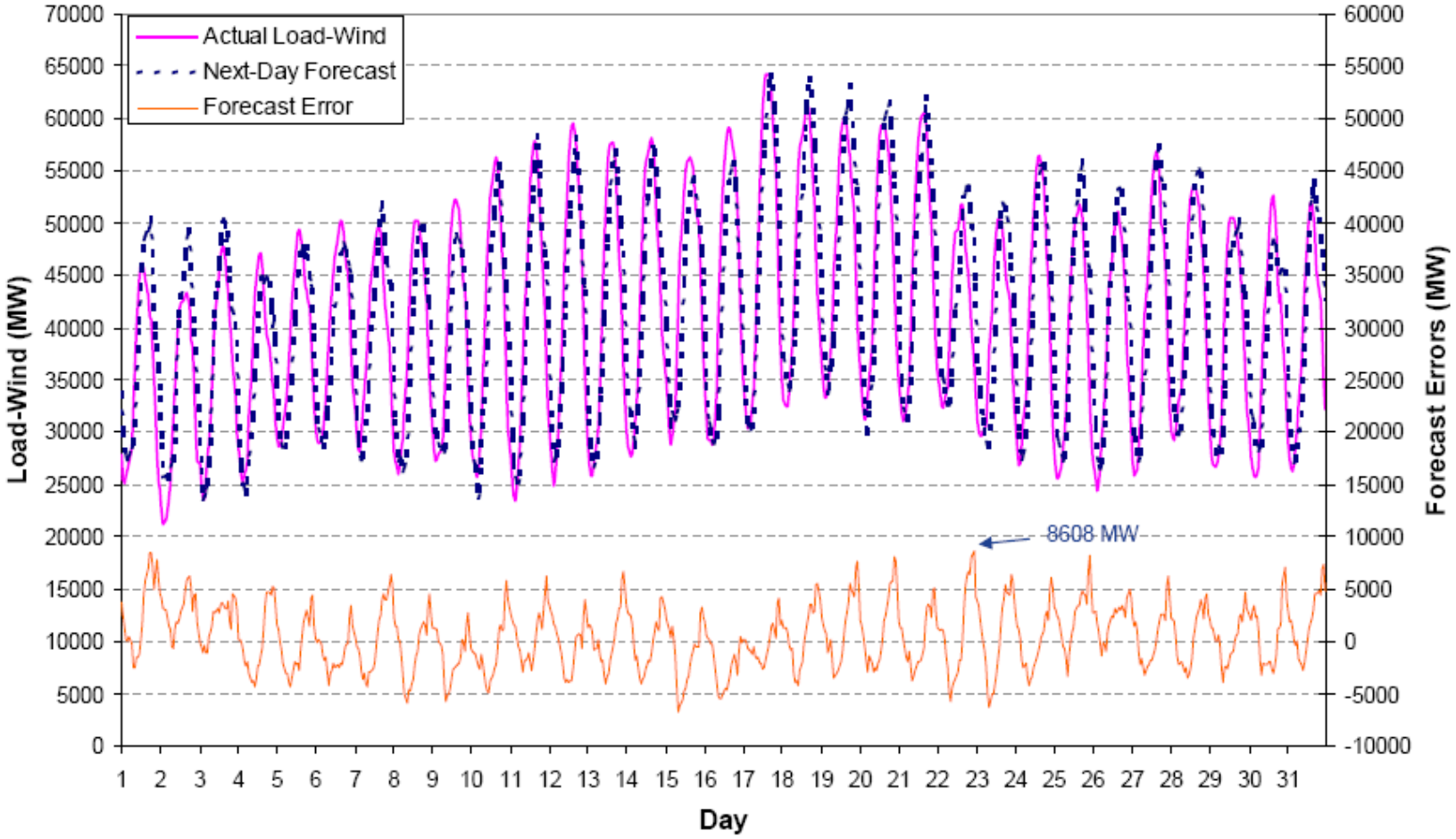
Grid Integration Costs (Arizona Public Service)

Wind Energy Penetration	1%	4%	7%	10%
Within-hour Regulating	$0.40	$0.41	$0.31	$0.37
Hour-ahead Uncertainty	$0.11	$1.88	$2.32	$2.65
Day-ahead Uncertainty	$0.39	$0.95	$0.93	$1.06

Forecasting Issues

- Xcel day-ahead wind forecast has error of 20% compared to 2.5% for load forecast
- Can we forecast extreme wind events that will shut down wind turbines?
- At what size level should forecasts be done: Wind farms? Regions? Utilities?

Forecast Error



Forecasting Requirements

- Daily plant operations (load following)
  - Hourly, 15-minute “look ahead”
  - 105-minute (CA)
- Storage/Dispatch Scheduling (day ahead, 2-3 days)
  - Determined by value of power (storage vs. grid)
- System maintenance (7-day)

Approaches for Solar Resource Predictions

Short-Term (0-6 hours)

- Use of on-site meteorological and sky-cover observations
- Satellite-based cloud movement data

Medium-Term (> 6-hours to 3-days)

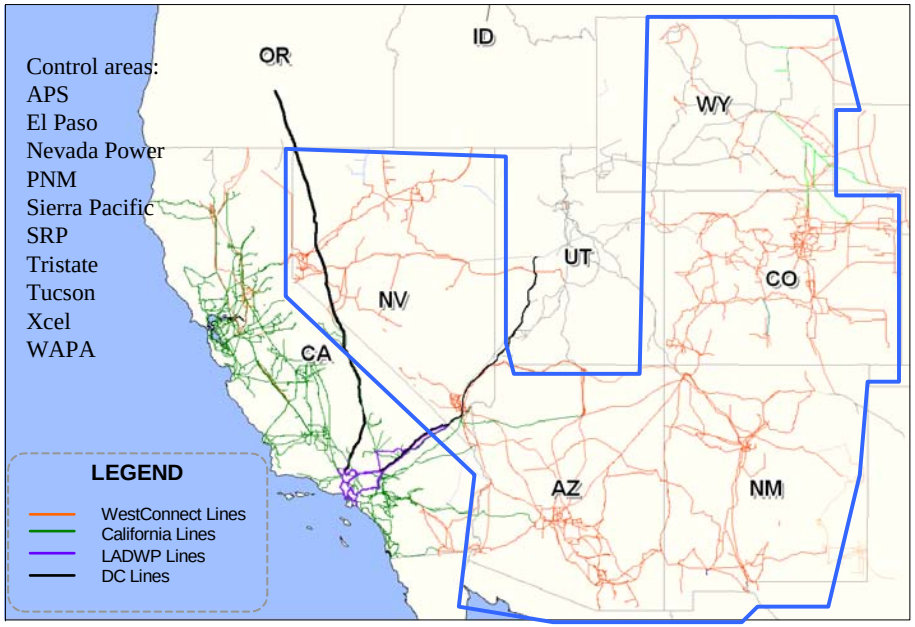
- Numerical weather prediction models
- Downscaling using mesoscale models

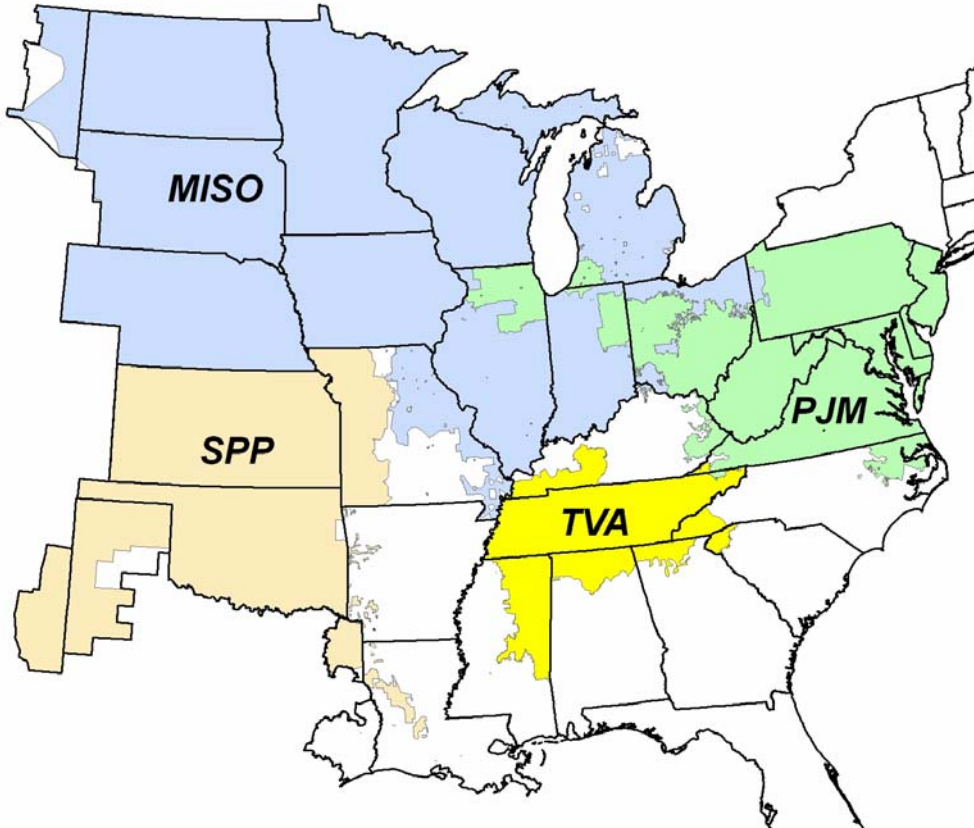
Long-term (weekly, seasonal annual, interannual)

- NOAA, NASA Climate prediction models
- GCM analyses published in IPCC reports
- Extrapolation of long-term weather records

Large-Scale Studies in Progress

- Western Wind & Solar Integration Study
  - 30% Wind in footprint, 20% in WECC
- Eastern Wind Integration Study





Climate Change Impacts on Energy Use

- Increase in cooling power needs
- Increase in peak summer cooling loads
- More air conditioning needed in North

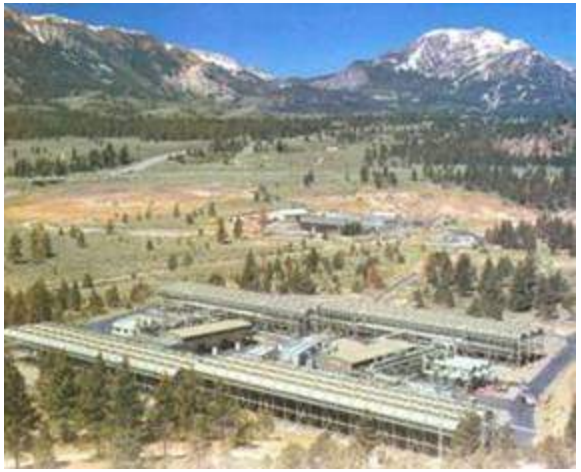
Effects of Climate Change on Energy Production and Use in the United States, U.S. Climate Change Science Program, 2007

Climate Change Impacts on Power Plants

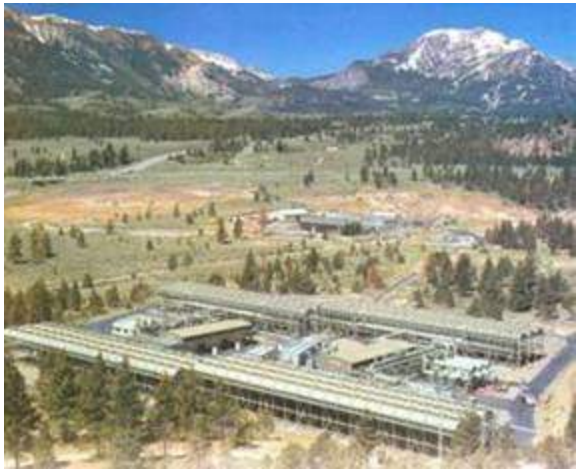
- Decrease in cooling water quantity and quality
- Increase in air temperature for heat rejection

Climate Change Impacts on Renewable Energy

- Loss of reservoir volume
- Agricultural impacts
- More intense wind events
- Changes in solar radiation
- Drop in plant power efficiency, especially in summer



Lots of solutions to climate change!



Plenty of challenges to tackle!