Tackling Climate Change in the U.S.

Potential Carbon Emissions Reductions from Energy Efficiency and Renewable Energy by 2030

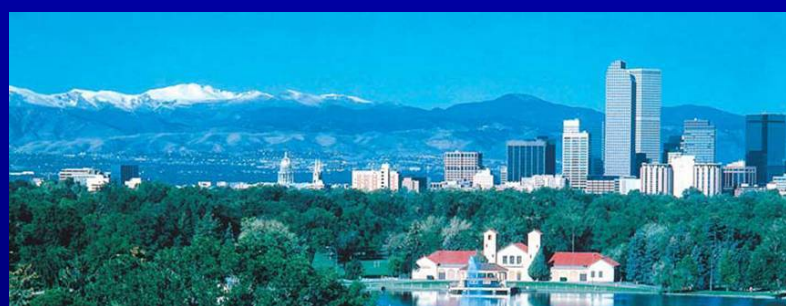
Parabolic Trough Workshop
March 8, 2007

Chuck Kutscher
NREL

American Solar Energy Society

WORKING TOWARD A SUSTAINABLE ENERGY FUTURE

SOLAR 2006, Denver
"Renewable Energy: Key to Climate Recovery"



Climate Change Review/Update

Global Warming:
A Personal Perspective

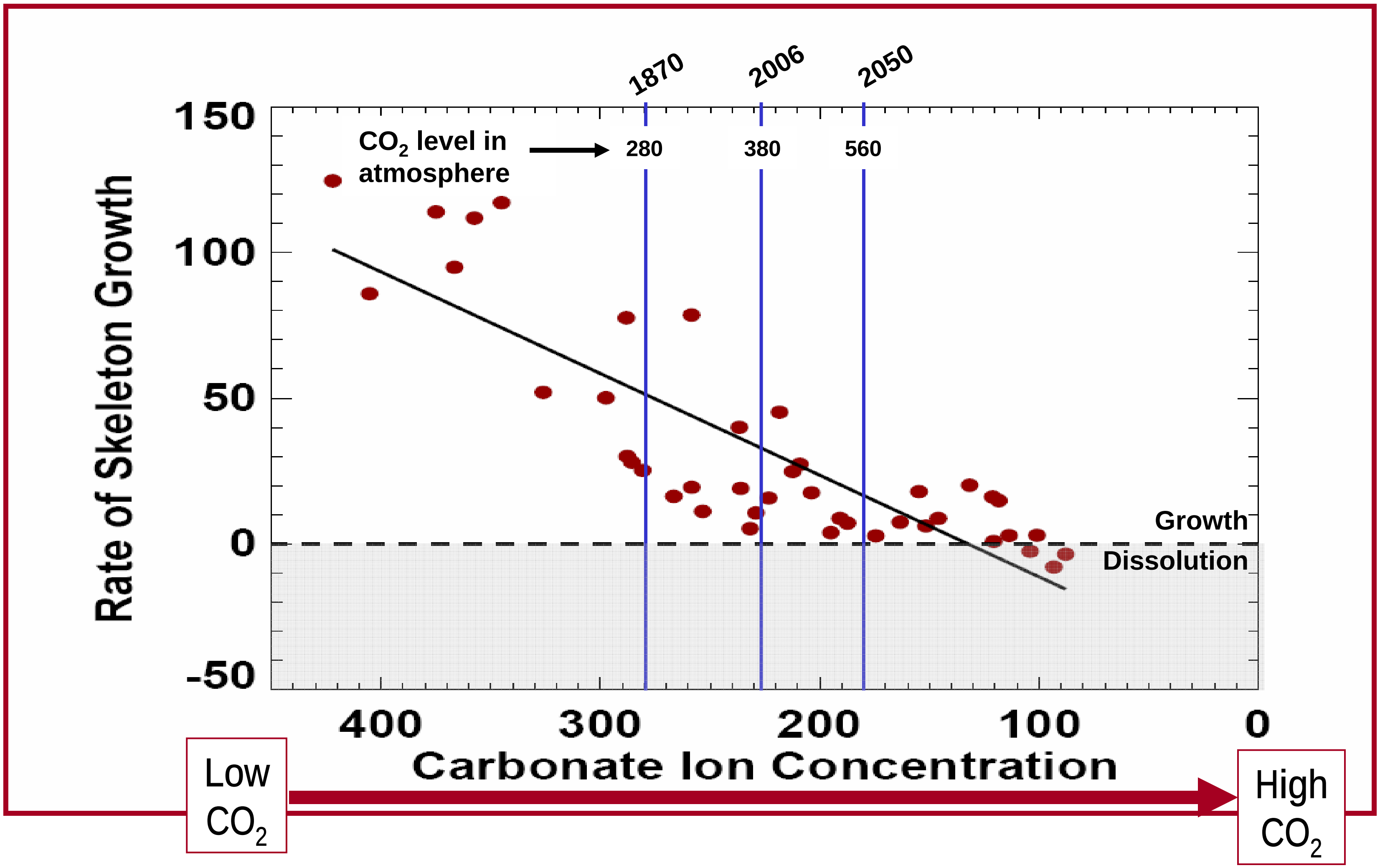
March 31, 2006 Headline:

Caribbean coral suffers record die-off

World's coral reef loss 'an underwater holocaust'

Living Coral Reefs Provide Better Protection From Tsunami Waves

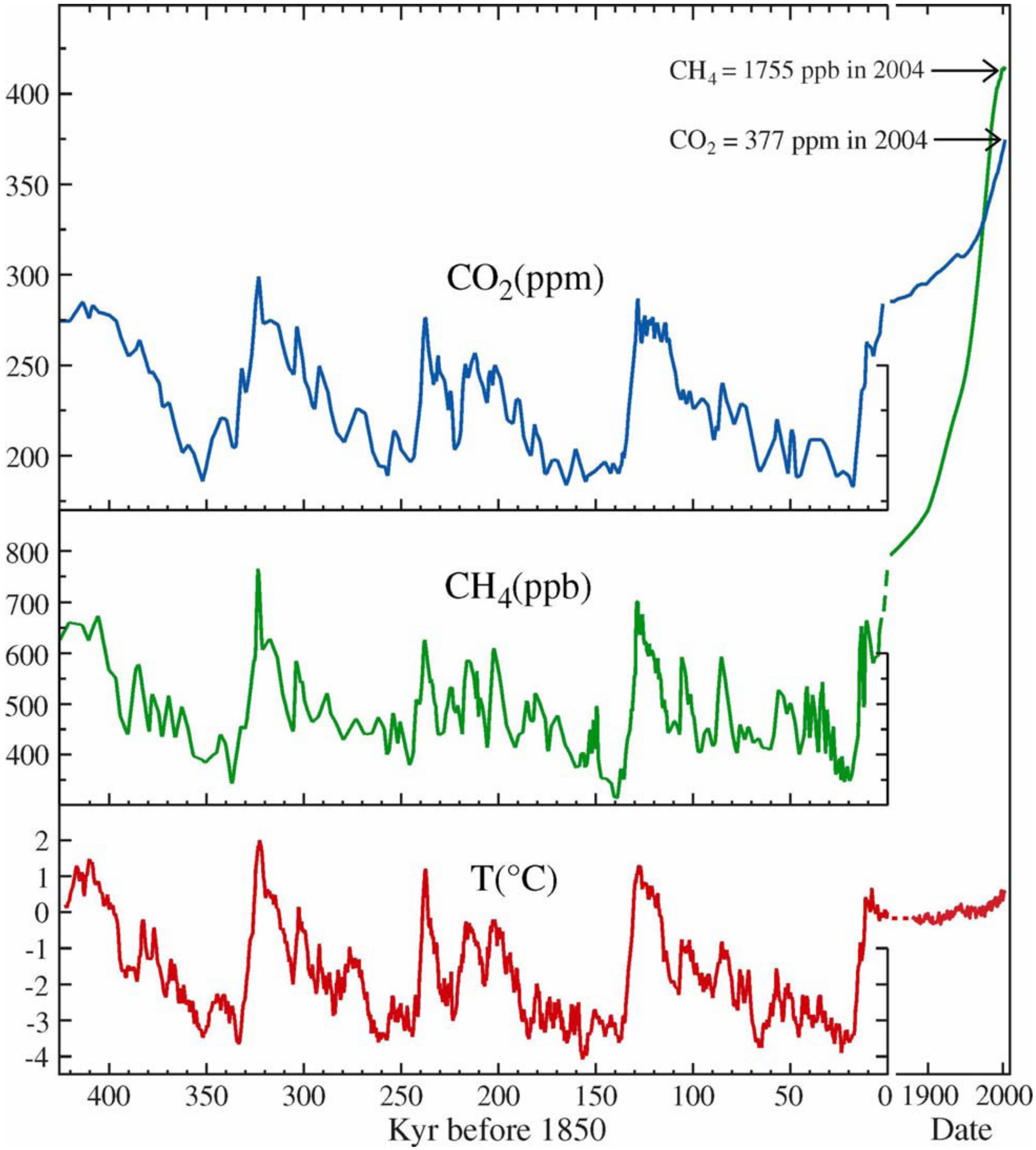
Impact of CO_2 on Coral



Data from Chris Langdon

Proof of Human-Induced Climate Change

- Paleoclimatic data (ice cores and other evidence)
- Agreement between rapidly improved climate models from around the world
- Measurement evidence



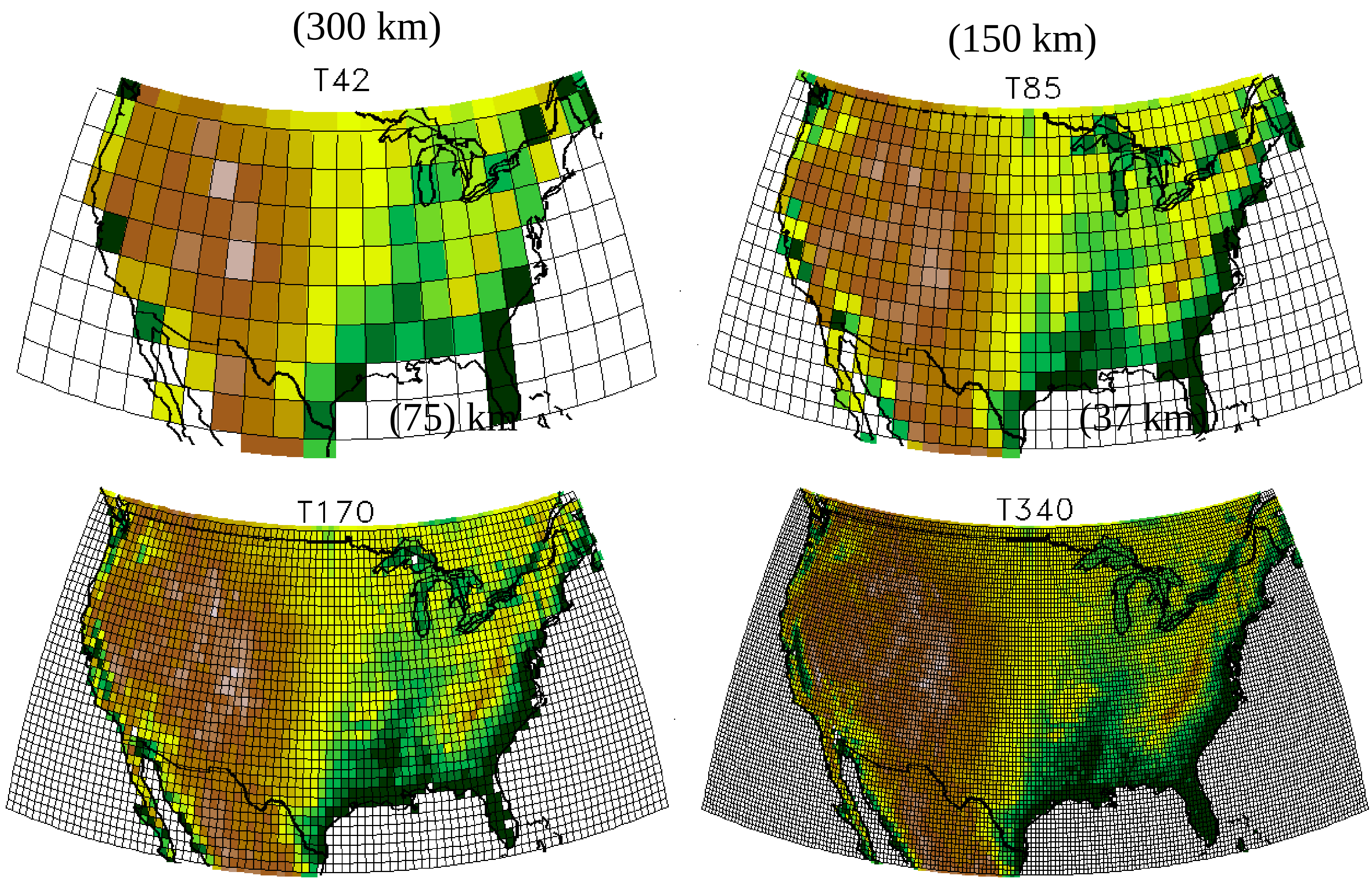
Ice Core Data

CO_2 today:
380 ppm

Rising 2 ppm/yr

Source: James Hansen

Improved Model Resolution

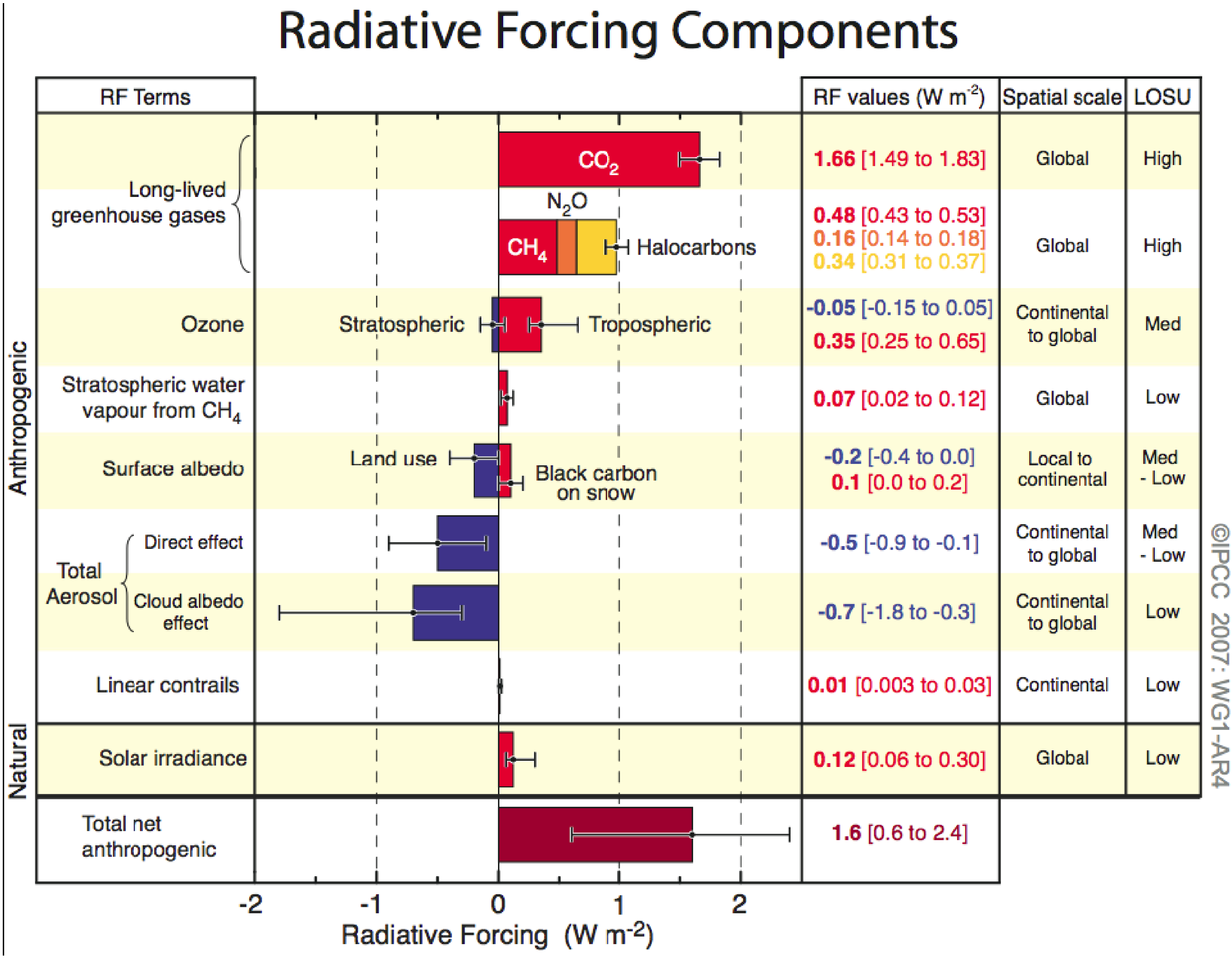


Courtesy of Warren Washington

Timeline of Climate Model Development

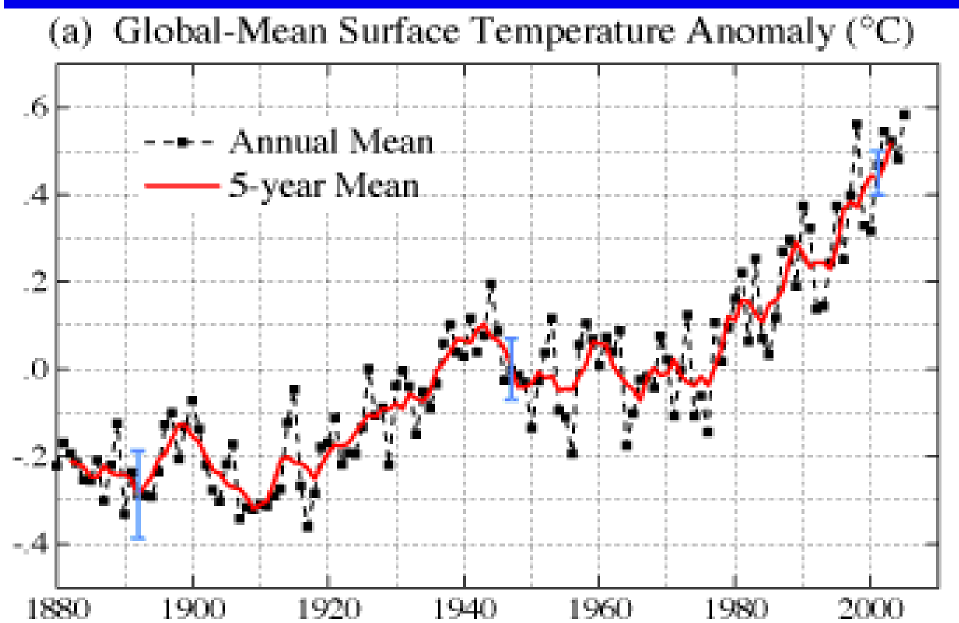
Mid-1960s	Mid 1970s-1980s	1990s	Present Day	2000-2010
Atmosphere/ Land Surface	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation
Ocean	Ocean	Ocean	Ocean	Ocean
	Sea Ice	Sea Ice	Sea Ice	Sea Ice
	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model
		Sulfate Aerosol	Sulfate Aerosol	Sulfate Aerosol
		Carbon Cycle	Carbon Cycle	Carbon Cycle
			Dust/Sea Spray/Carbon Aerosols	Dust/Sea Spray/Carbon Aerosols
			Interactive Vegetation	Interactive Vegetation
			Biogeochemical Cycles	Biogeochemical Cycles
				Ice Sheet

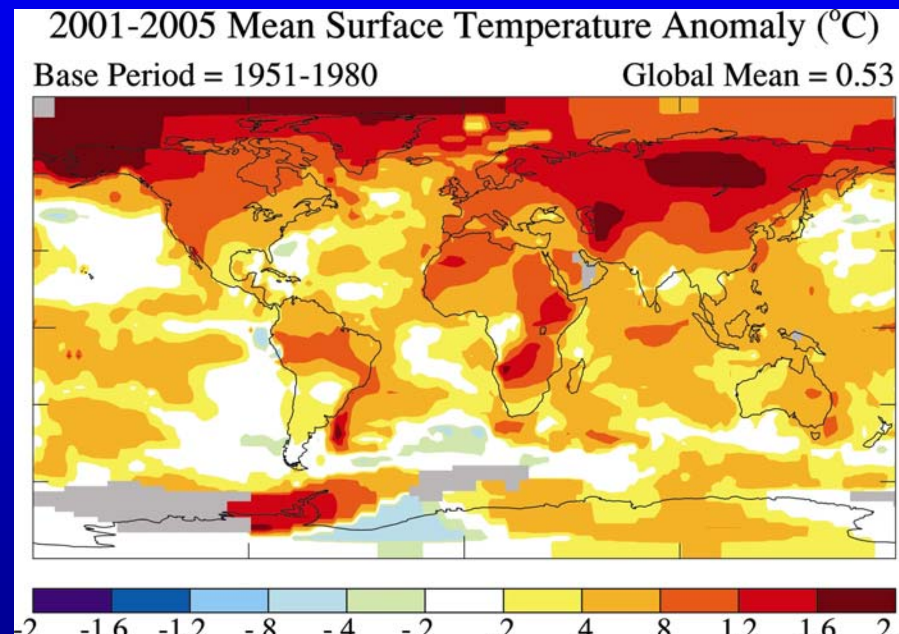
Courtesy of Warren Washington



Radiative Forcing Components
RF Terms
RF values (W m-2)
Spatial scale
LOSU
Anthropogenic
Natural
Long-lived greenhouse gases
CO2
1.66 [1.49 to 1.83]
Global
High
N2O
CH4
Halocarbons
0.48 [0.43 to 0.53]
0.16 [0.14 to 0.18]
0.34 [0.31 to 0.37]
Global
High
Ozone
Stratospheric
Tropospheric
-0.05 [-0.15 to 0.05]
0.35 [0.25 to 0.65]
Continental to global
Med
Stratospheric water vapour from CH4
0.07 [0.02 to 0.12]
Global
Low
Surface albedo
Land use
Black carbon on snow
-0.2 [-0.4 to 0.0]
0.1 [0.0 to 0.2]
Local to continental
Med - Low
Total Aerosol
Direct effect
-0.5 [-0.9 to -0.1]
Continental to global
Med - Low
Cloud albedo effect
-0.7 [-1.8 to -0.3]
Continental to global
Low
Linear contrails
0.01 [0.003 to 0.03]
Continental
Low
Solar irradiance
0.12 [0.06 to 0.30]
Global
Low
Total net anthropogenic
1.6 [0.6 to 2.4]
-2
-1
0
1
2
Radiative Forcing (W m-2)
©IPCC 2007: WG1-AR4

2005 Warmest Year on Record

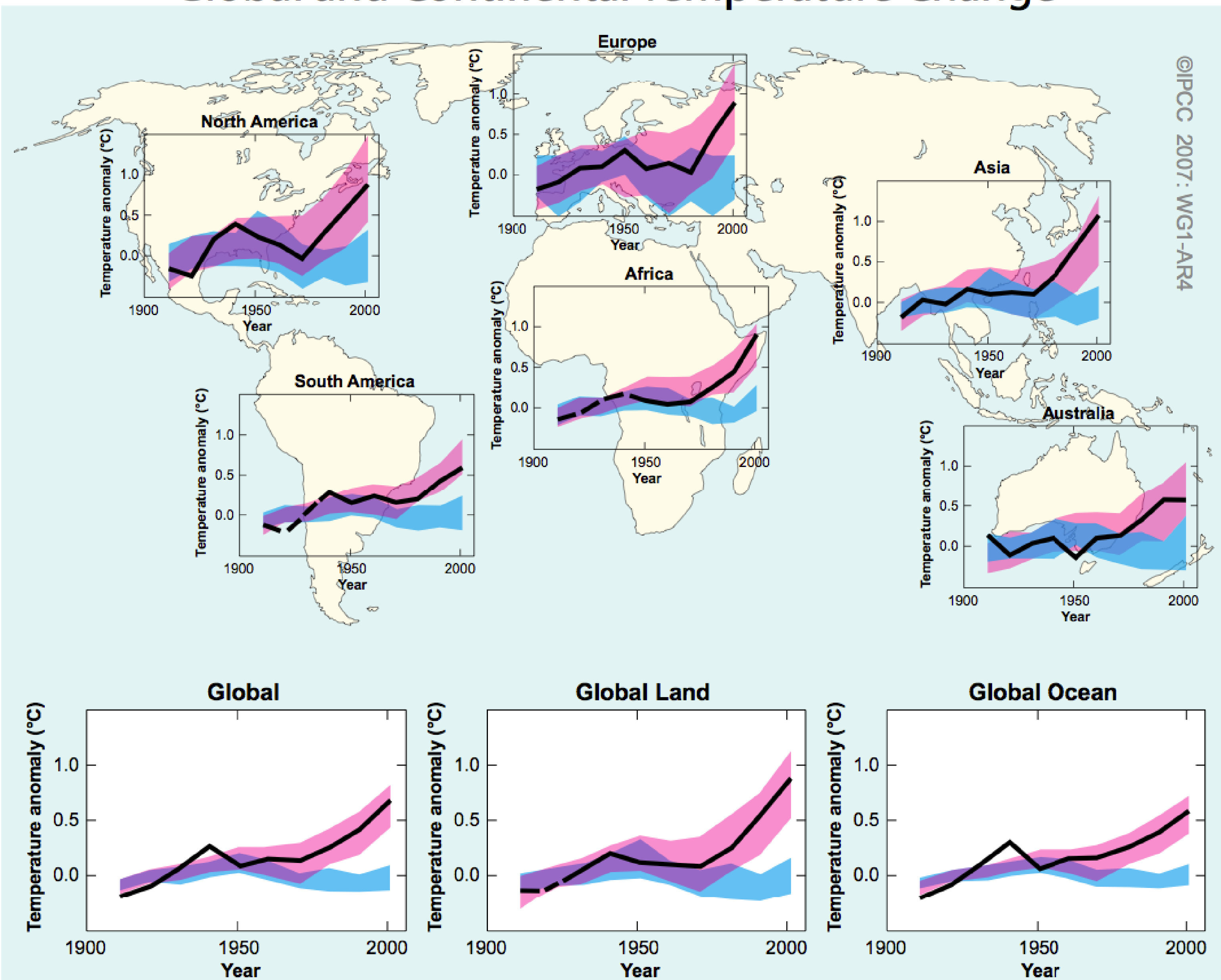




Source: J. Hansen, Goddard

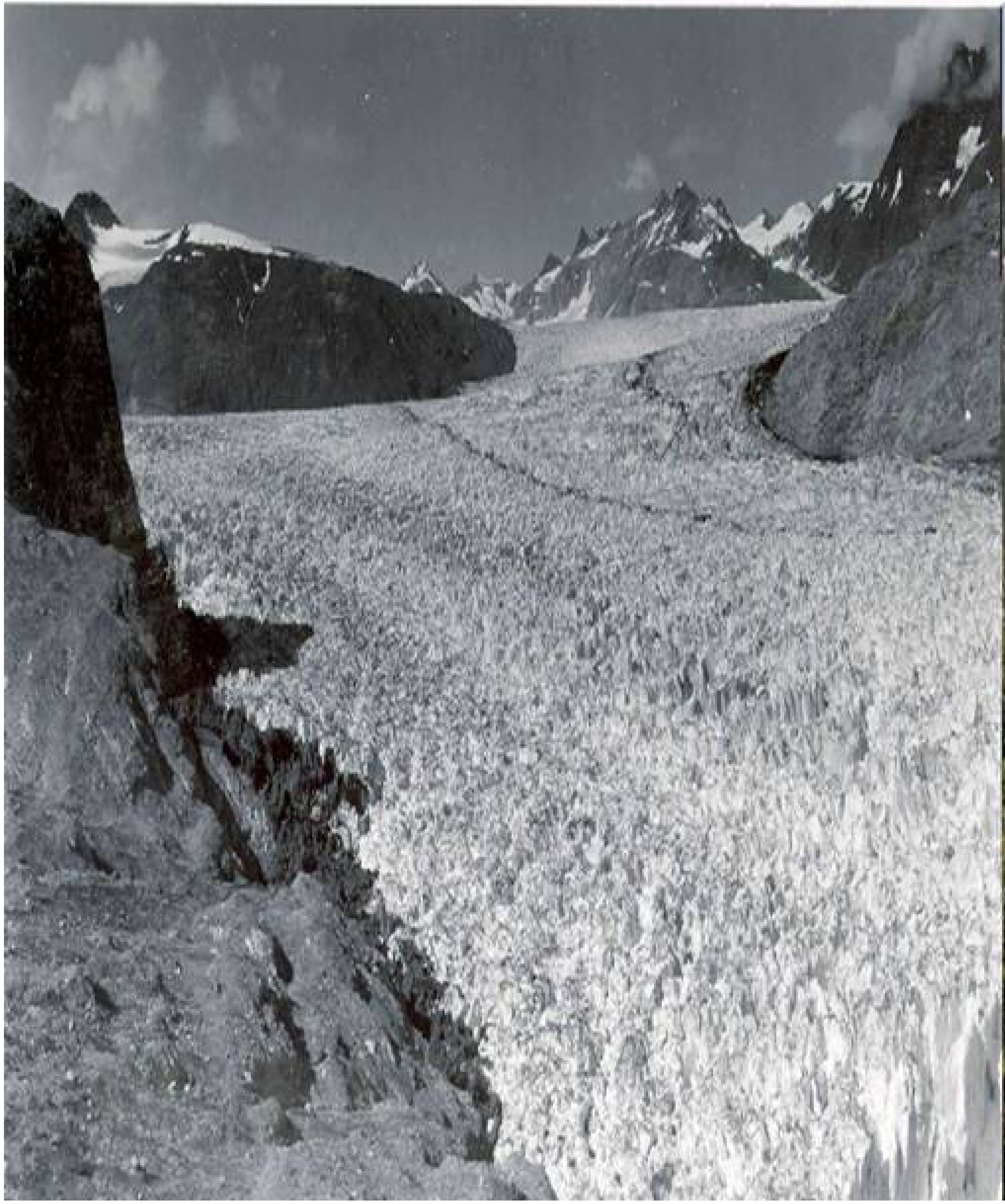
Warming of 0.2°C/decade over last 30 years

Global and Continental Temperature Change



Muir Glacier, SE Alaska

August 1941 (photo by William Field)



August 2004 (photo by Bruce Molnia)

Glacier National Park, Grinnel Glacier

Photo: Fred Kiser, Glacier National Park archives

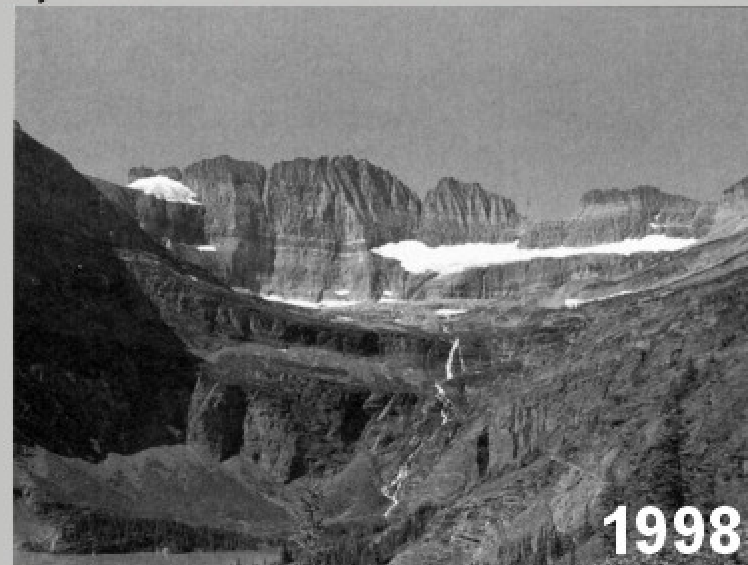


Photo: Karen Holzer, US Geological Survey

Glacier National Park, Boulder Glacier

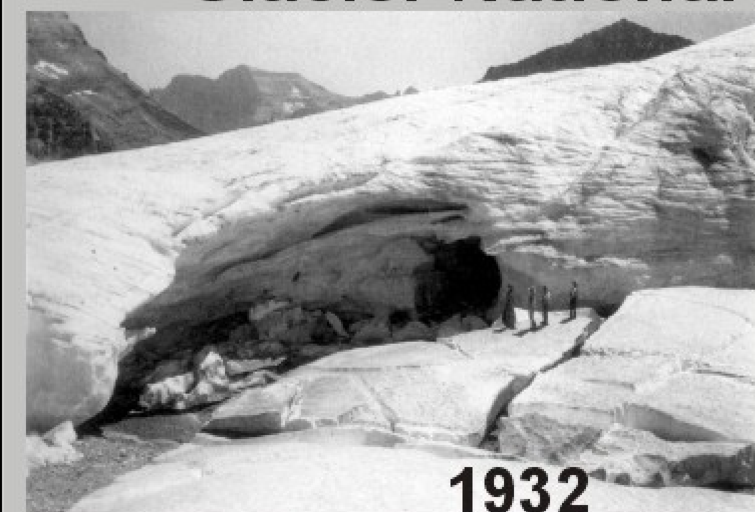


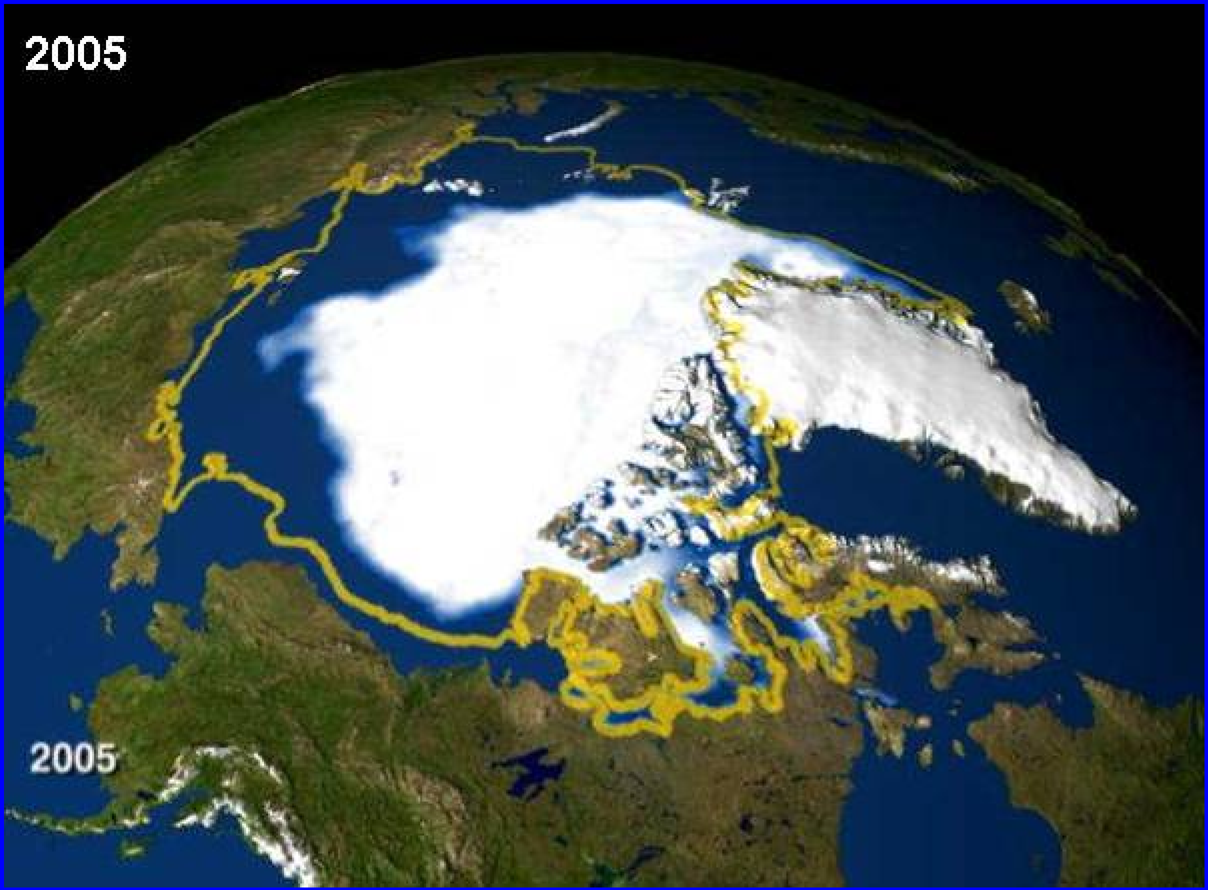
Photo: George Grant, Glacier National Park archives

Photo: Jerry DeSanto, National Park Service

Source: *BioScience*, Vol. 53 No. 2, Feb 2003

Perennial Sea Ice Cover

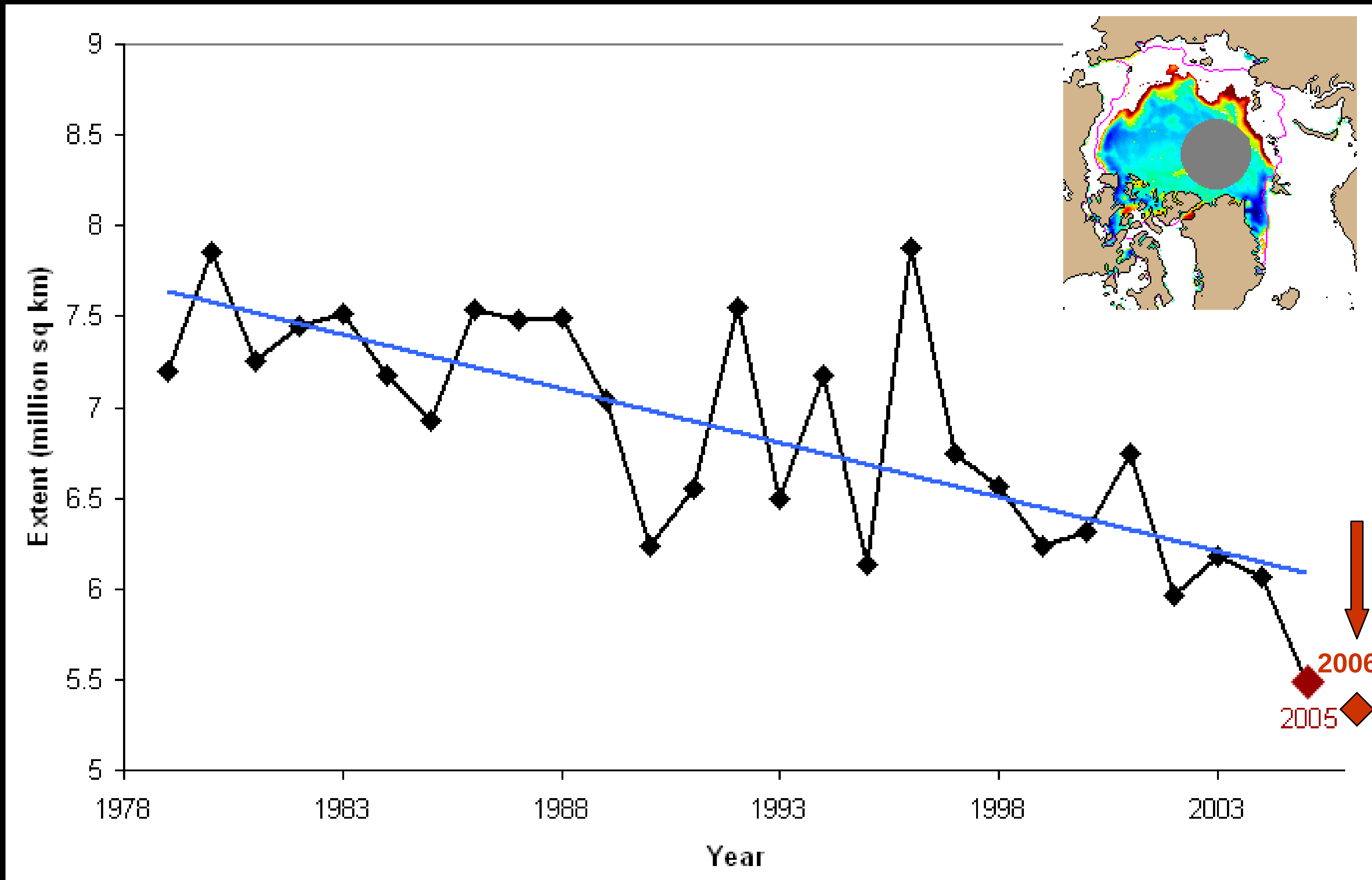
- Significant reduction in perennial sea ice cover over the last 25 years (10% per decade)
- Submarine data indicate 40% thinner ice than in the several decades before the mid-1990s



Yellow Line is the 1979-2004 average

Source: GSFC Scientific Visualization Studio and J. Comiso

Arctic Sea Ice Decline Intensifies



Courtesy of Warren Washington

September 28, 2005

Consequences of Global Warming

- Sea level rise, storm surge, flooding of coastlines
- Early runoff, summer droughts/famine, wildfires
- More frequent weather extremes, e.g., heat waves and heavy precipitation events
- Increased hurricane intensity
- Loss of mountain glaciers and drinking water
- Spread of tropical diseases, increased plant and crop disease
- Extinction of plants, corals, and other animal species

Latest IPCC Report

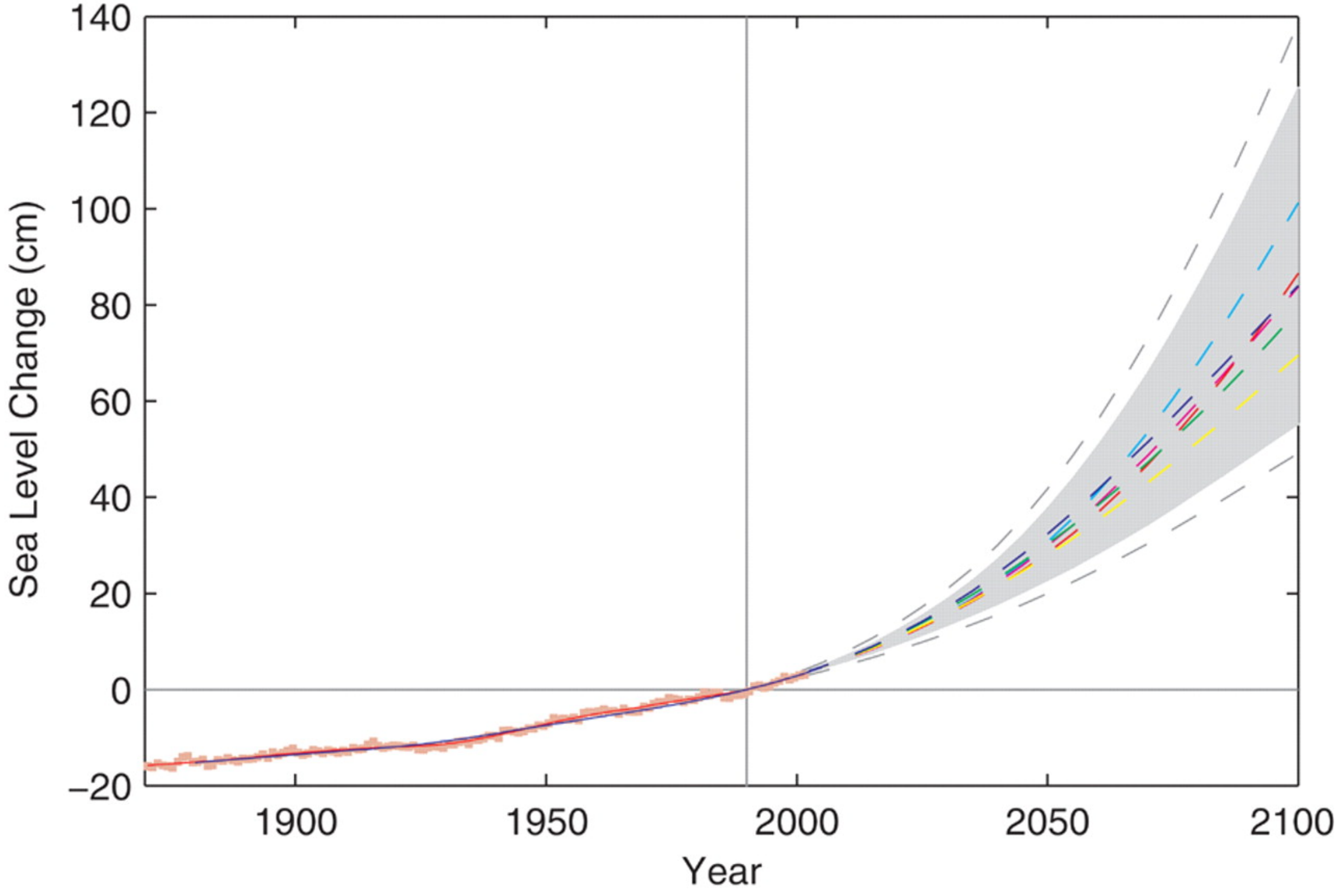
- "*Warming of the climate is unequivocal.*"
- *"Most of the observed increase…since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."*
- *"Warmth of the last half-century is unusual in at least the previous 1300 years."*

Latest IPCC Report Temperature and Sea Level Projections

- Best estimate for temperature increase this century is 1.8°C to 4.0°C

- Range of sea level rise this century is 0.18 m to 0.59 m

Fig. 4. Past sea level and sea-level projections from 1990 to 2100 based on global mean temperature projections of the IPCC TAR

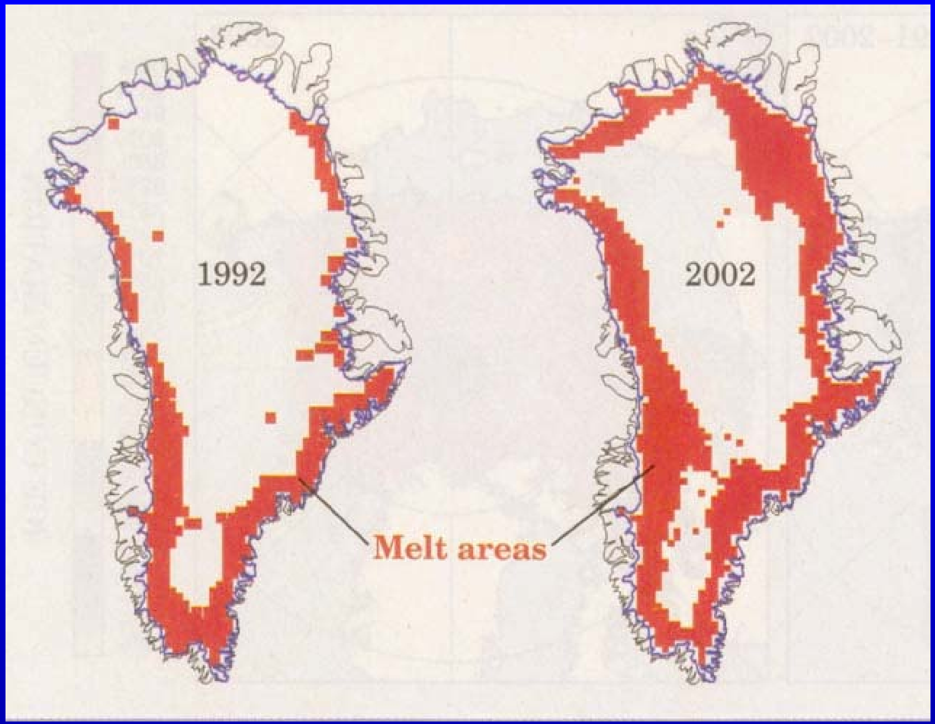


S. Rahmstorf Science 315, 368 -370 (2007)

Based on linear relationship between temperature and rate of sea level rise

Published by AAAS

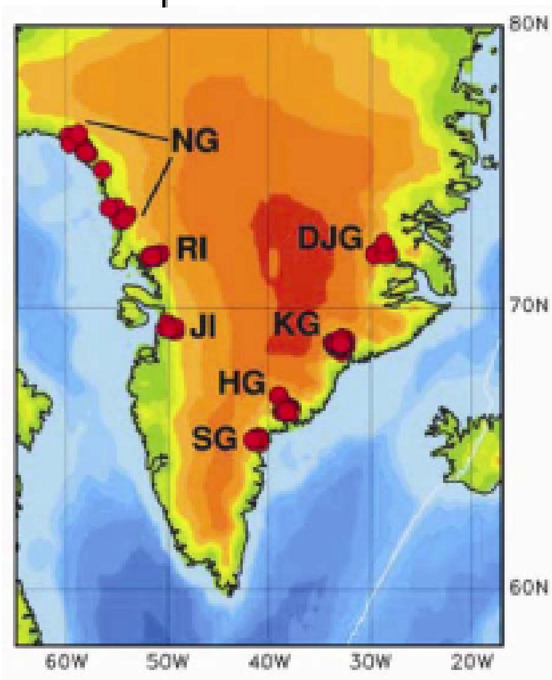
What the Latest IPCC Study Does NOT Include: "Dynamical Processes Related to Ice Flow"



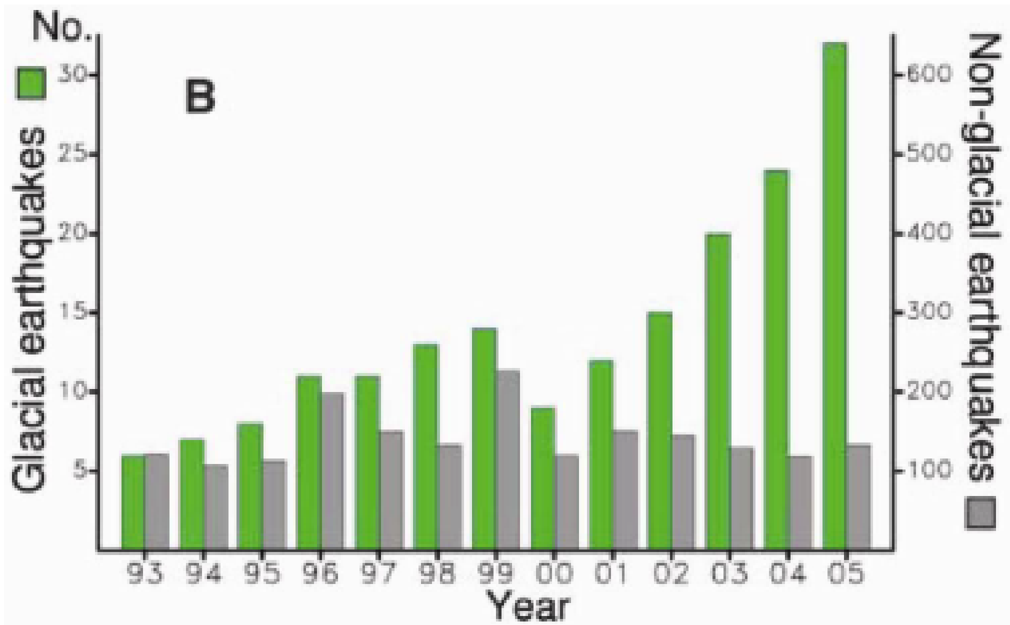
Melting of ice sheets is
a wet, dynamic process!

Glacial Earthquakes on Greenland

Earthquake Locations



Annual Number of Quakes*

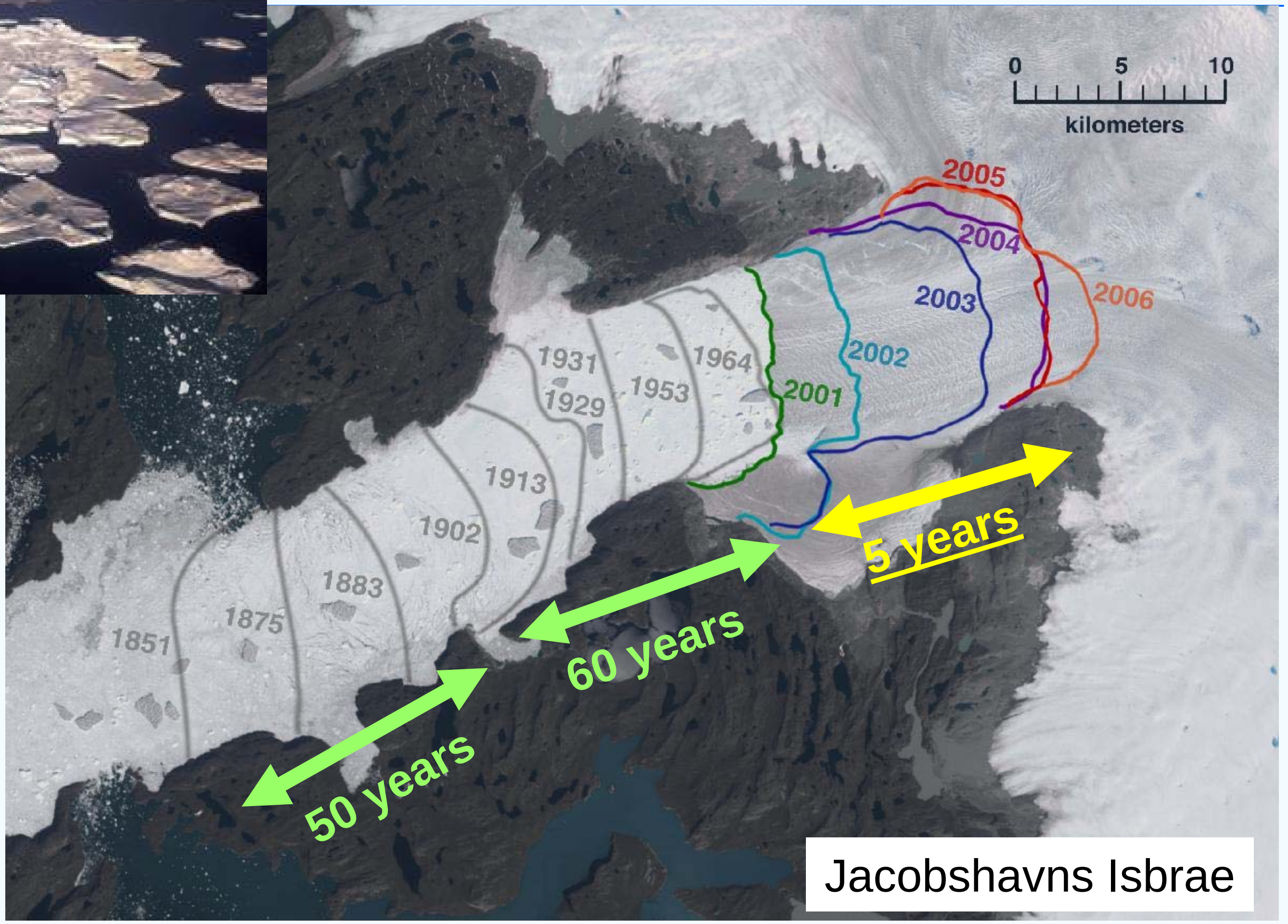


* 2005 bars capture only first 10 months of 2005

Location and frequency of glacial earthquakes on Greenland.
Seismic magnitudes are in range 4.6 to 5.1.

Source: Ekstrom, Nettles and Tsai, *Science*, **311**, 1756, 2006.

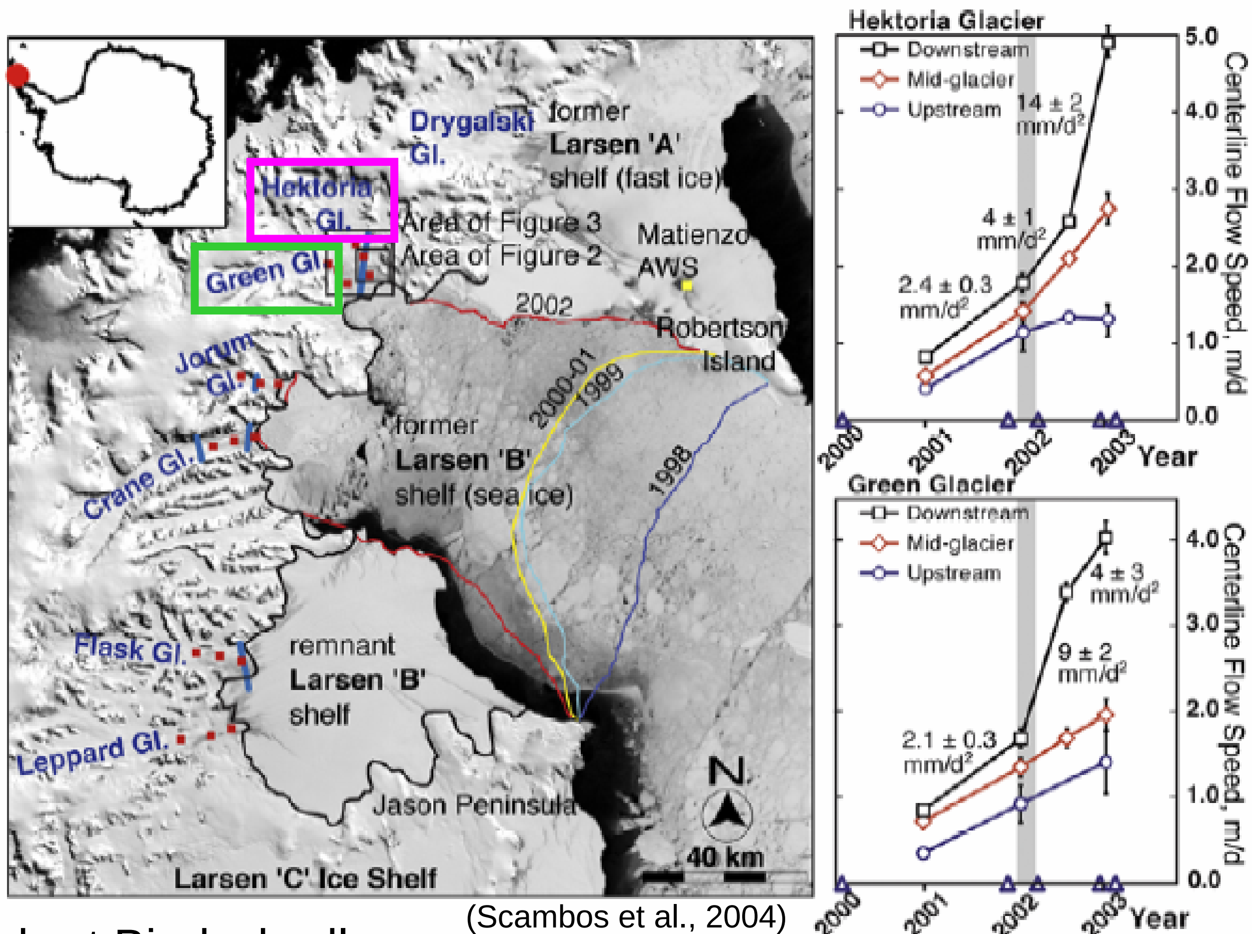
Rapid Retreat



Iceberg-choked fjord created by rapid retreat

Courtesy of Robert Bindschadler

Ice Shelf Buttressing



(Scambos et al., 2004)

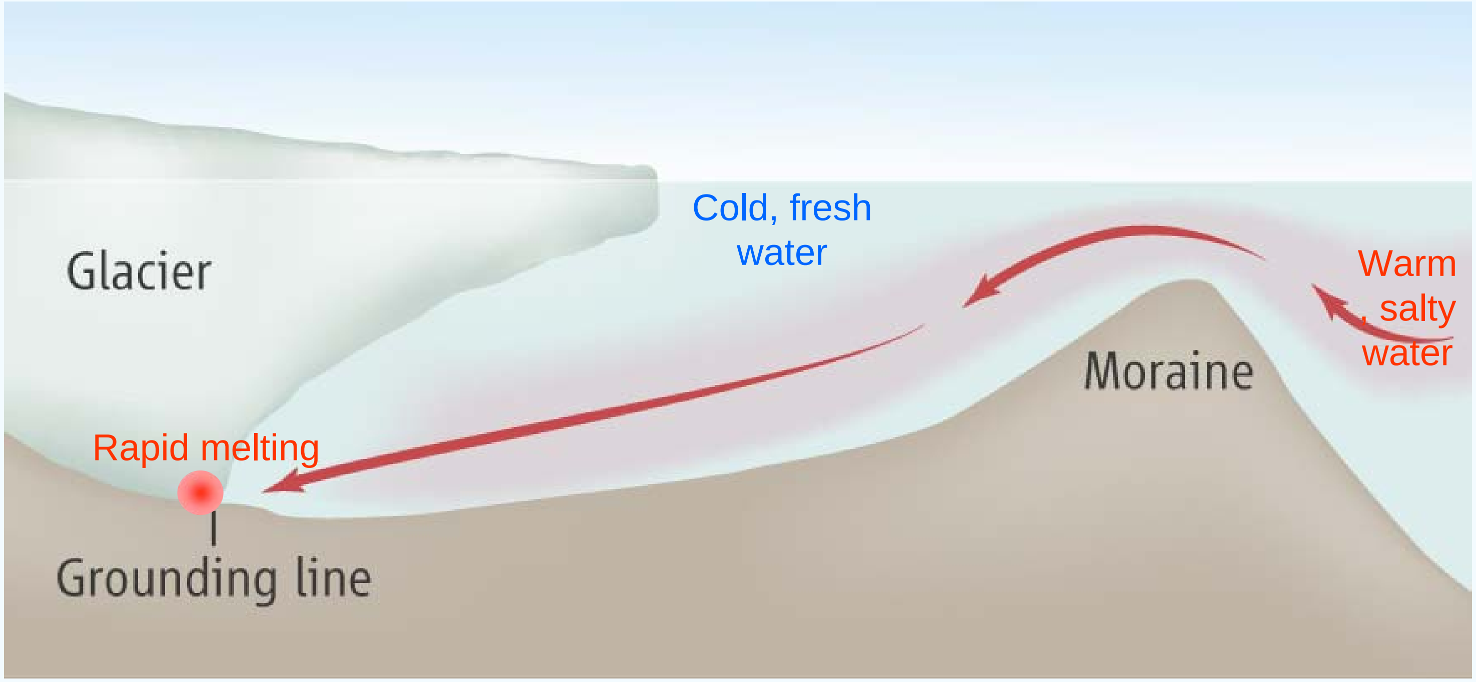
up to 510% faster in 2 years

up to 400% faster in 2 years

Courtesy of Robert Bindschadler

Formerly buttressed glaciers accelerate

Warm Water Access:



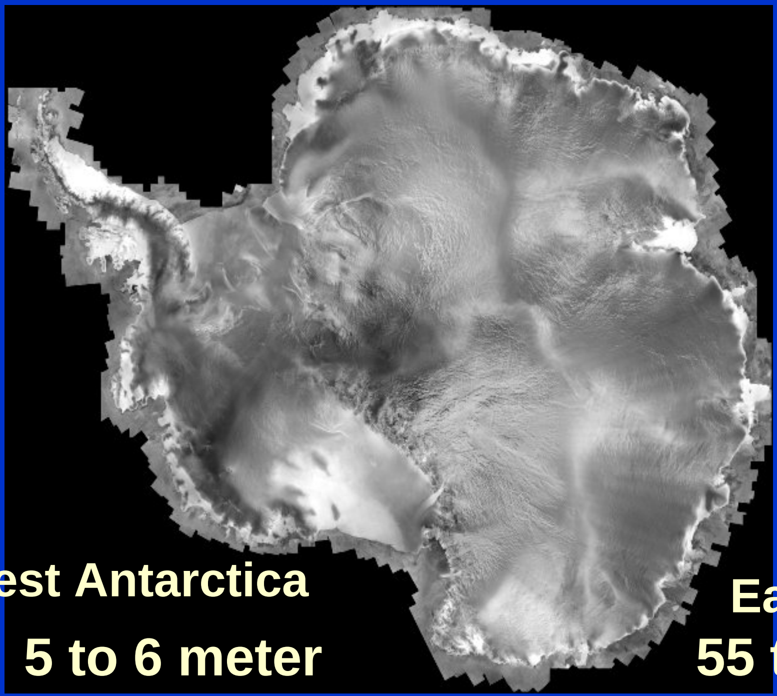
Melting basal ice: ➔reduces basal friction

➔reduces buttressing effect of floating ice shelf

Courtesy of Robert Bindschadler

Sea level is currently rising 2-3 mm a year.

Antarctica



West Antarctica

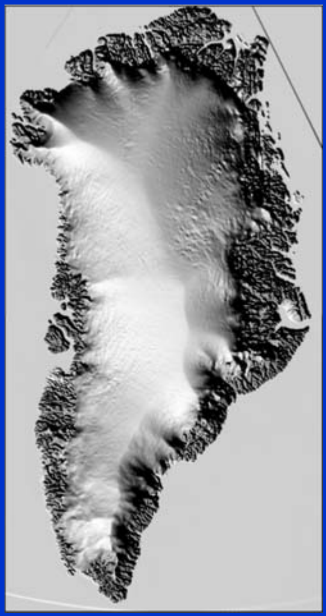
5 to 6 meter sea level rise

East Antarctica

55 to 60 meter sea level rise

Greenland

6 to 7 meter sea level rise



Courtesy of Robert Bindschadler

James Hansen: *“The last time a large ice sheet melted, sea level went up at a rate of five meters per century. That's one meter every 20 years.”*

Hansen believes a sea level rise of several meters by 2100 is likely under business-as-usual.

Global Warming Summary

- ✓ It's bad
- ✓ It's caused primarily by burning fossil fuels
- ✓ It's getting worse—fast
- ✓ It's cheaper to address it than to pay for consequences
- ✓ We're running out of time

Source: World Resources 2000-2001 Time Magazine – 9 April 2001

What We Have to Do

To limit sea level rise to 1 m and species loss to 20% this century:

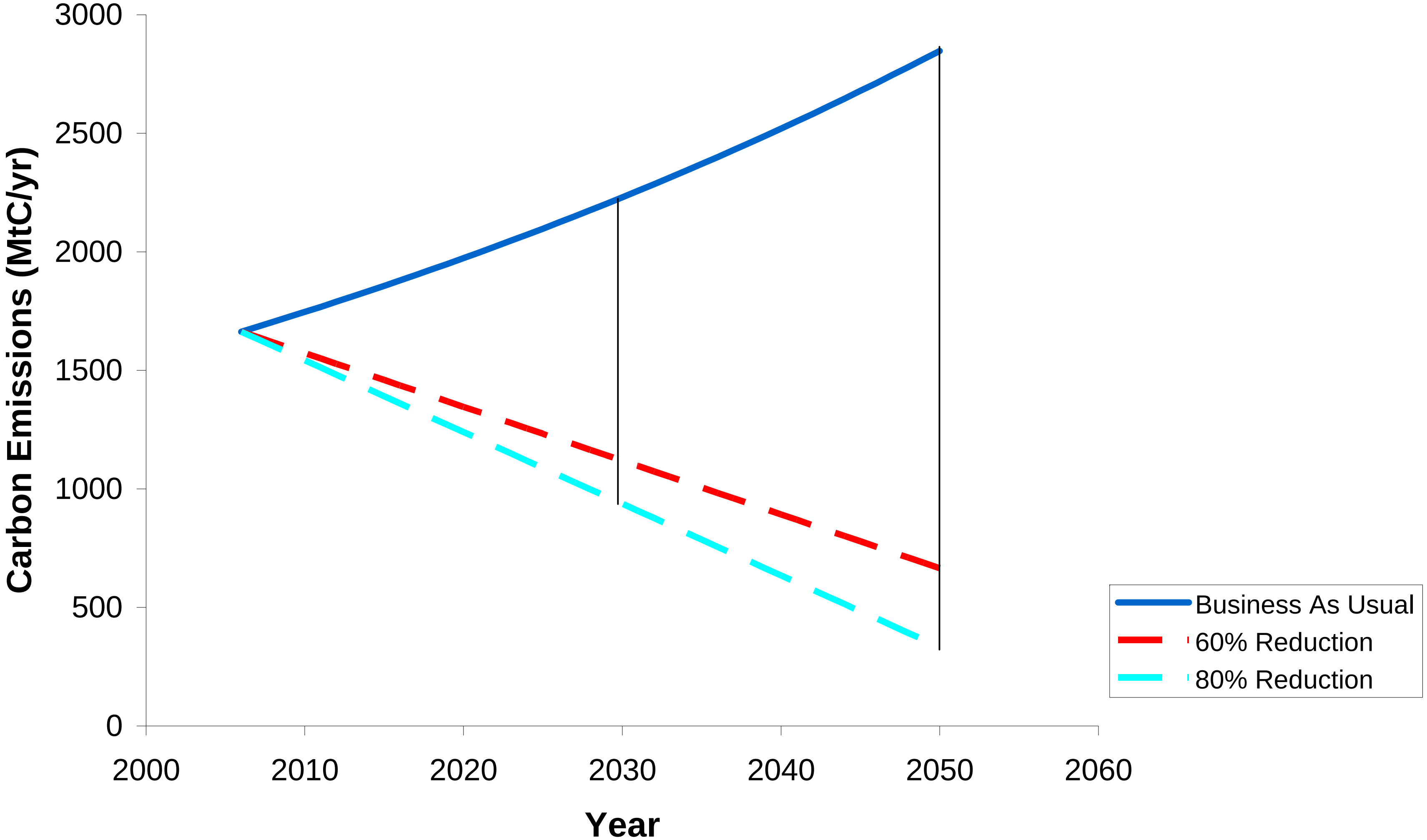
- Limit additional warming to 1°C relative to 2000 (~0.5°C is already built in)

- Stabilize atmospheric CO_2 at 450–500 ppm

- Reduce U.S. carbon emissions 60%–80% by mid-century

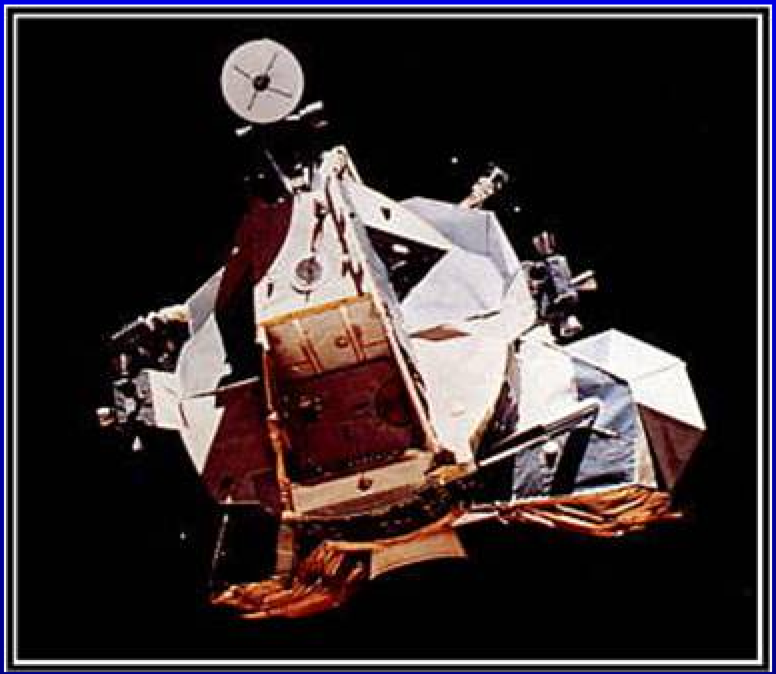
Note: With 60% reduction, our per capita emissions go from 5.5x world average to 2x world average.

U.S. Carbon Reduction Triangles



Total savings needed by 2030: 1,100 - 1,300 MtC/yr

“Houston, we have a problem.”



Key Options

- Energy Efficiency
- Renewable Energy
- IGCC with carbon capture and storage
- Nuclear power

How Much Can Energy Efficiency and Renewables Provide in the U.S.?

An Aggressive Climate-Driven Scenario for 2030

Approach

- Series of nine papers by volunteer experts
- Bottom-up engineer’s approach (with systems analysis support)
- Non-funded; built upon existing studies
- Presented at SOLAR 2006
- Reviewed and revised

Areas Studied

- Energy Efficiency (Buildings, Transportation, Industry)
- Concentrating Solar Power (CSP)
- Photovoltaics (PV)
- Wind Power
- Biomass
- Biofuels
- Geothermal

Not covered: active solar space and process heat, offshore wind, ocean power, electric storage for wind or PV

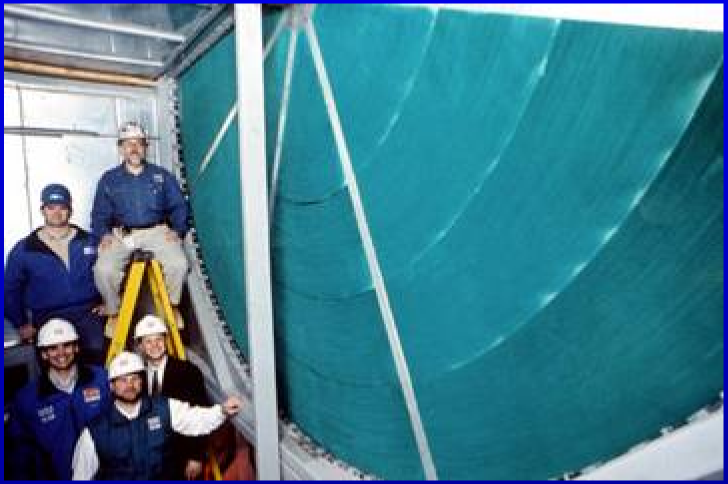
Summary of Carbon Savings

Energy Efficiency

- **Buildings** (40%) – envelope design, daylighting, better lights, building and appliance efficiency standards
- **Transportation** (30%) - lighter weight vehicles, public transportation, better propulsion
- **Industry** (30%) – heat recovery, better motors, CHP

Energy Efficiency Savings

- Electricity: 20% savings off 2030 projection
  165 - 270 MtC/yr, 0 – 4 ¢/kWh
- Oil and gas:
  470 MtC/yr, $0 - $5/MBtu



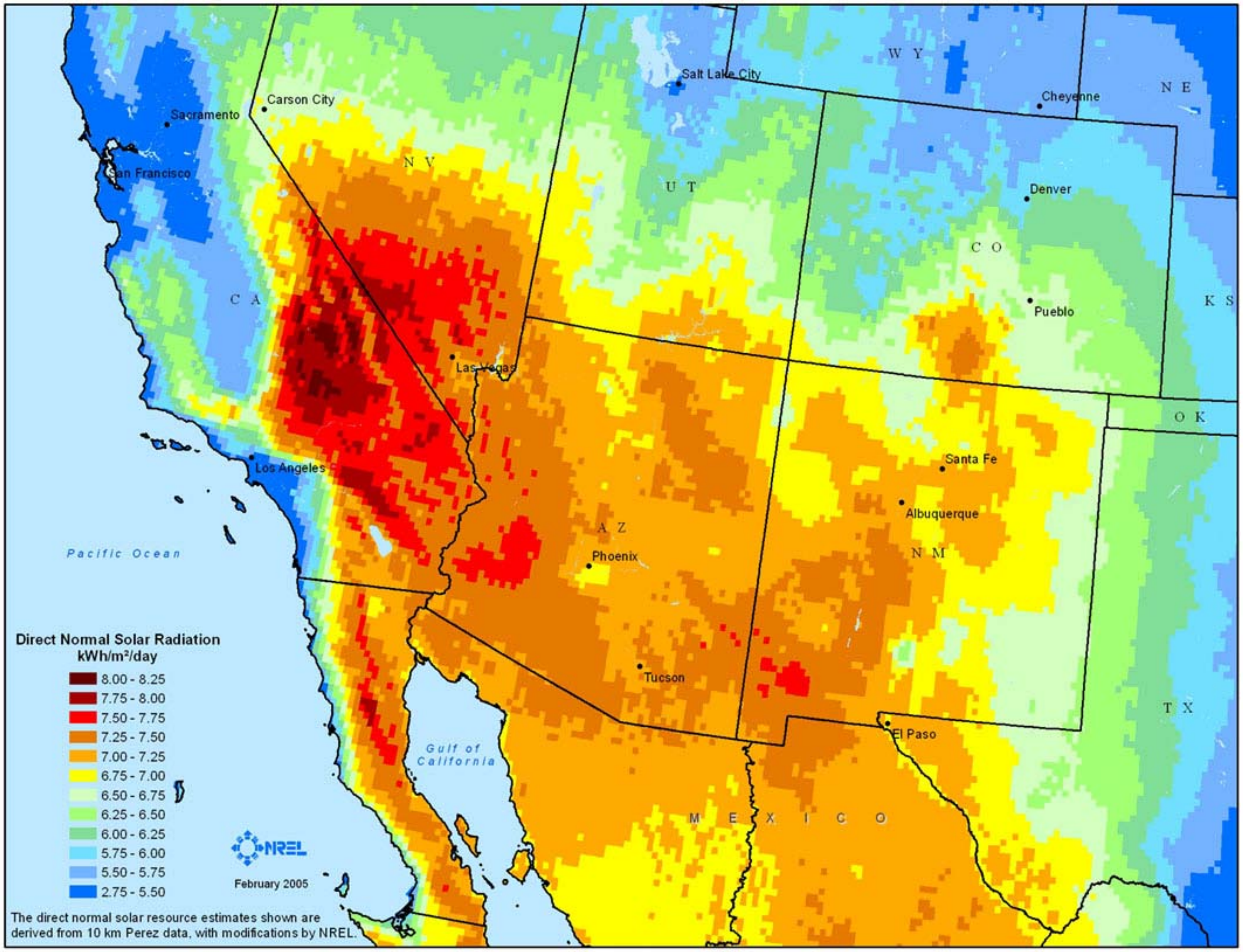
Total: 635 - 740 MtC/yr

Electricity-to-carbon conversions

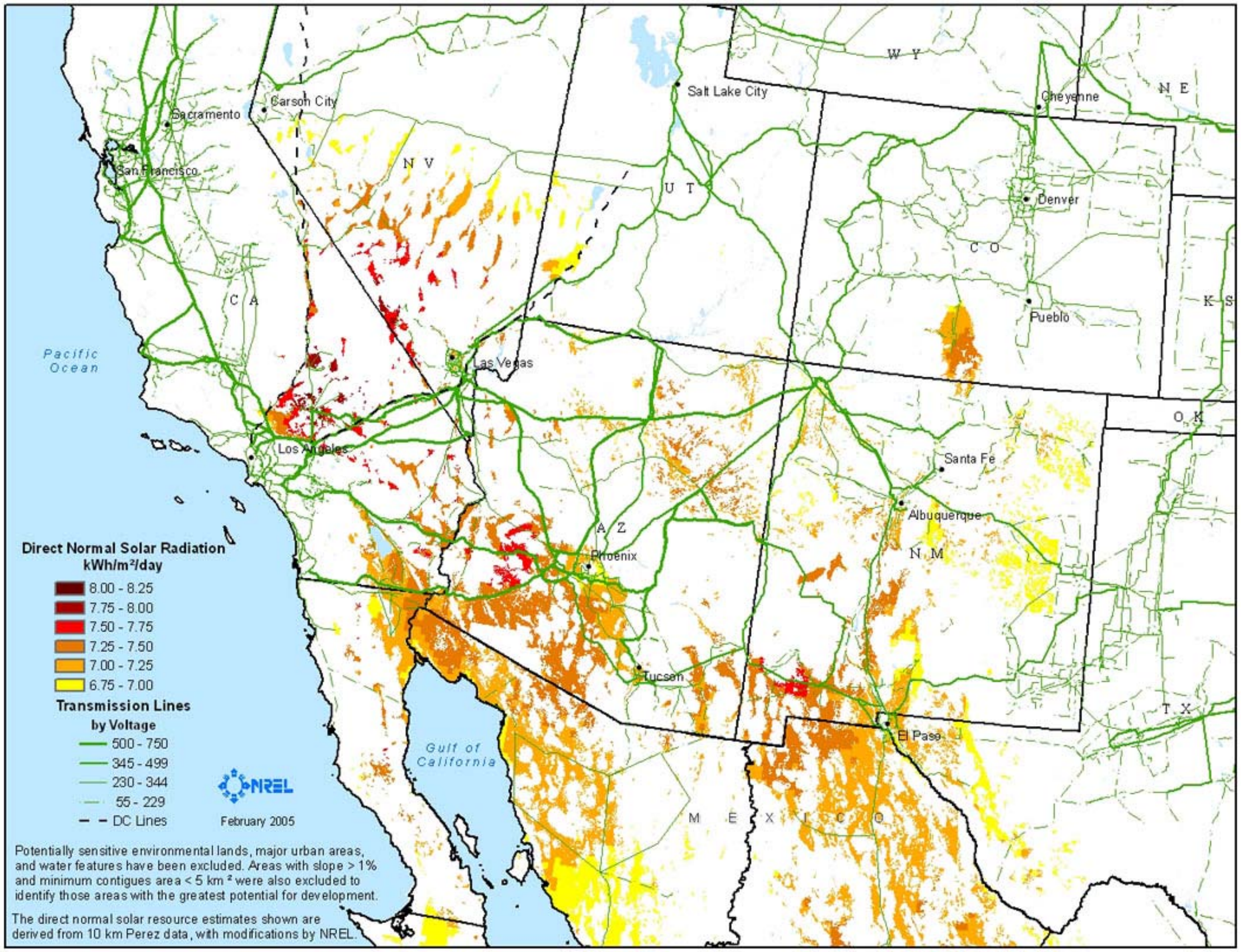
National average:	160 tons C/GWh
Coal:	260 tons C/GWh

Concentrating Solar Power

Southwest CSP Resource



Southwest Solar Resources (With all Filters)
Result: 7,000 GW (7X U.S. capacity)!



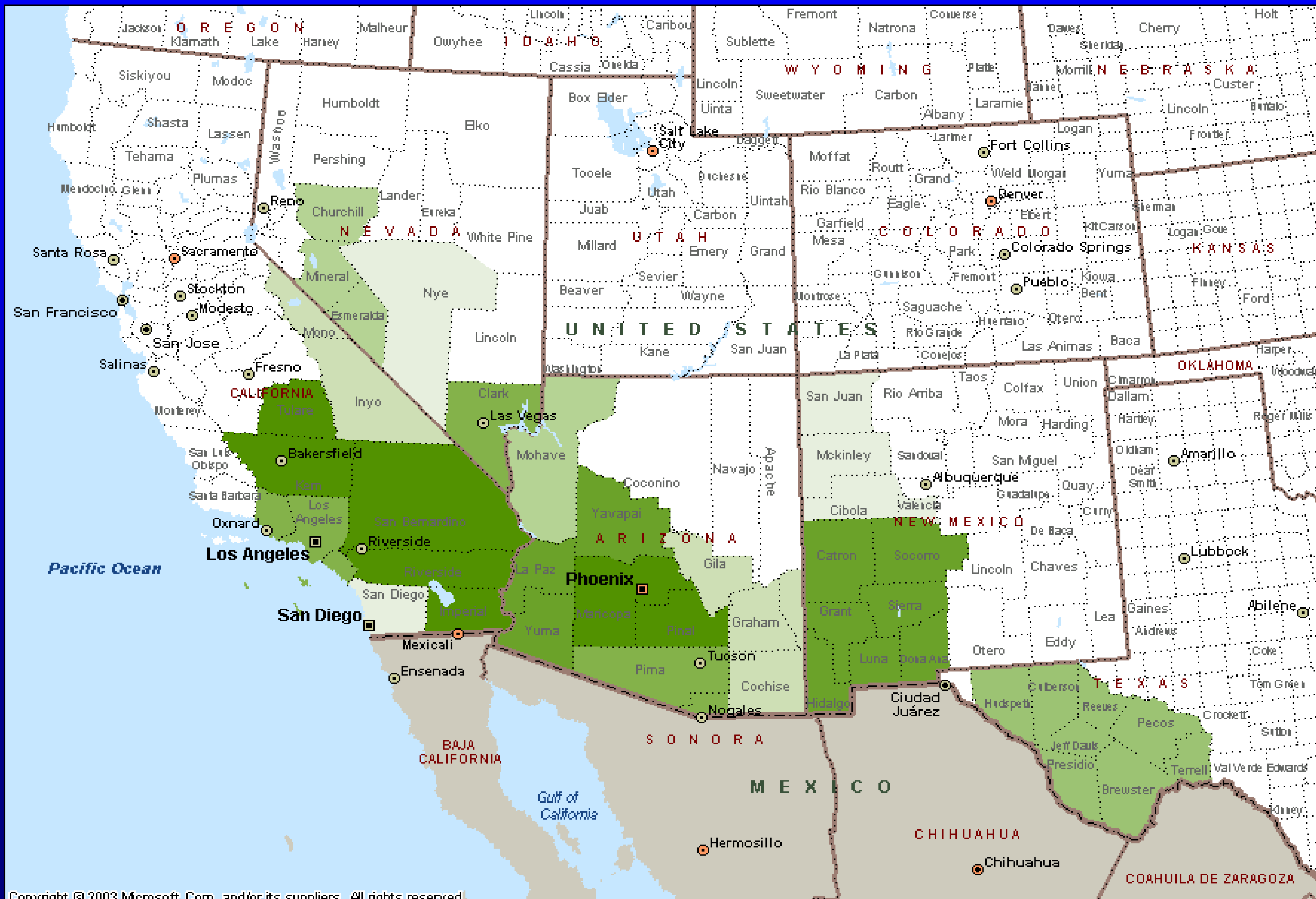
Source: Western Governors' Association study

CSP Savings

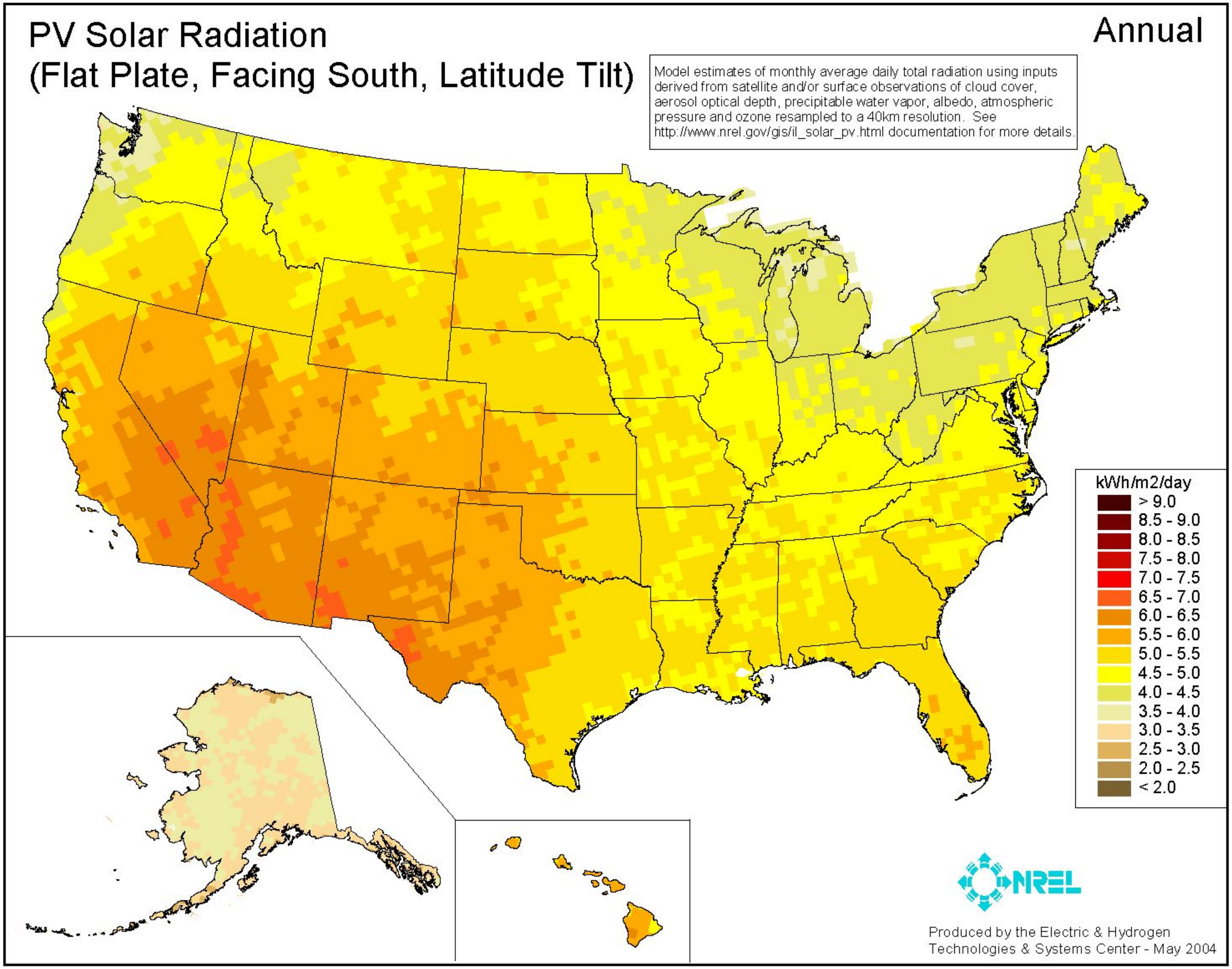
- Dispatchable power with 6 hr of storage, 43% capacity factor, 5 acres per MW
- Optimal sites near transmission: 200 GW
- With 30% ITC and CO_2 valued at $35/ton: 80 GW
- 50 - 80 MtC/yr, 6 to 16 ¢/kWh

80 GW x 8760 h/yr x 0.43 x 260 MtC/GWh = 80 MtC/yr

Deployment of 80 GW of CSP




PV

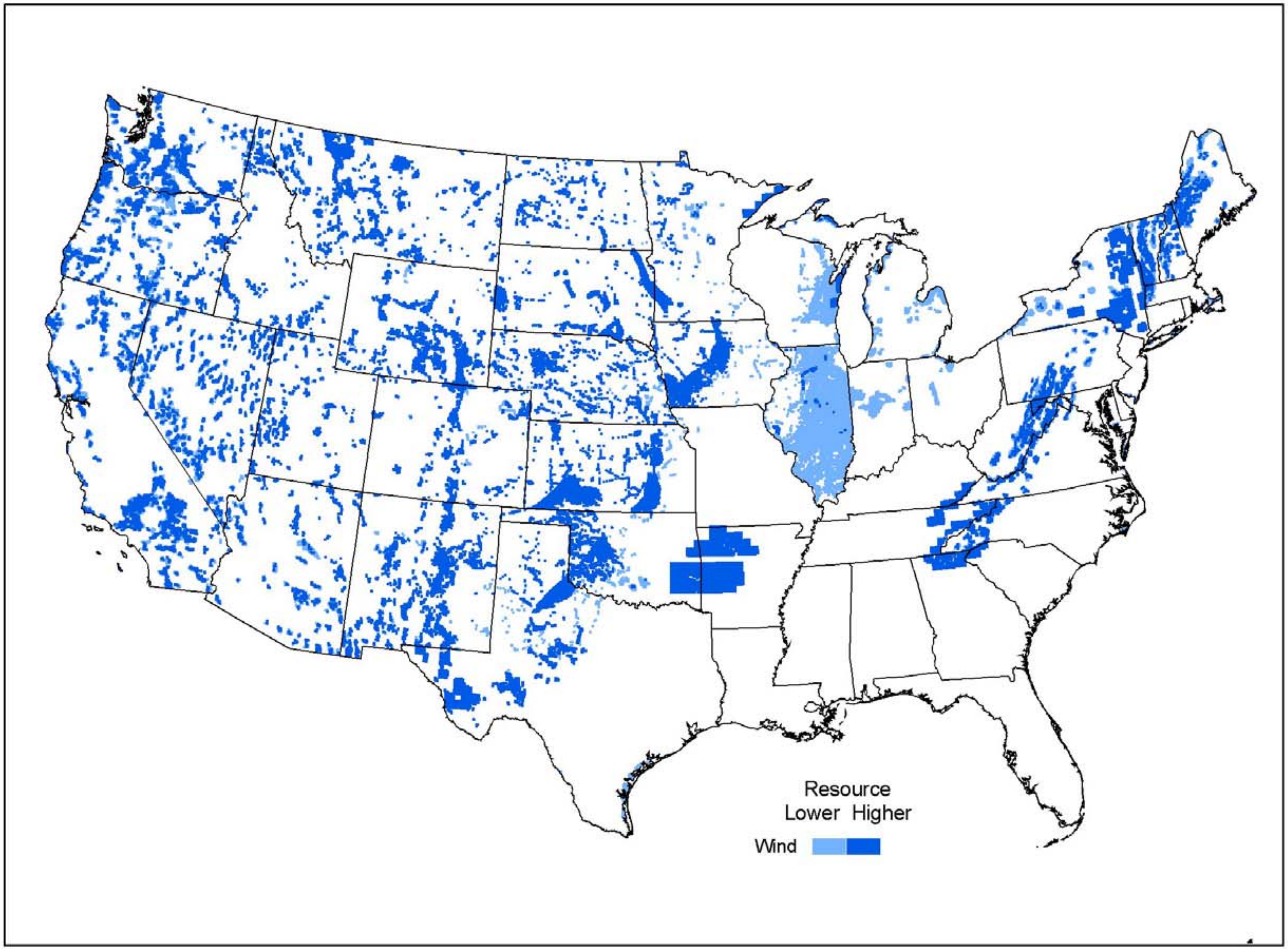

PV Solar Radiation
(Flat Plate, Facing South, Latitude Tilt)
Annual
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_solar_pv.html documentation for more details.
kWh/m2/day
> 9.0
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2.0
NREL
Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004

PV Savings

- Based on lower estimate of practical roof area—6 billion m^2
- Limiting to 10% grid penetration yields 275 GW_p
- Manufacturability limit: 200 GW_p, 17% capacity factor, 50 - 80 MtC/yr, 6 to 28 ¢/kWh (retail)


Wind

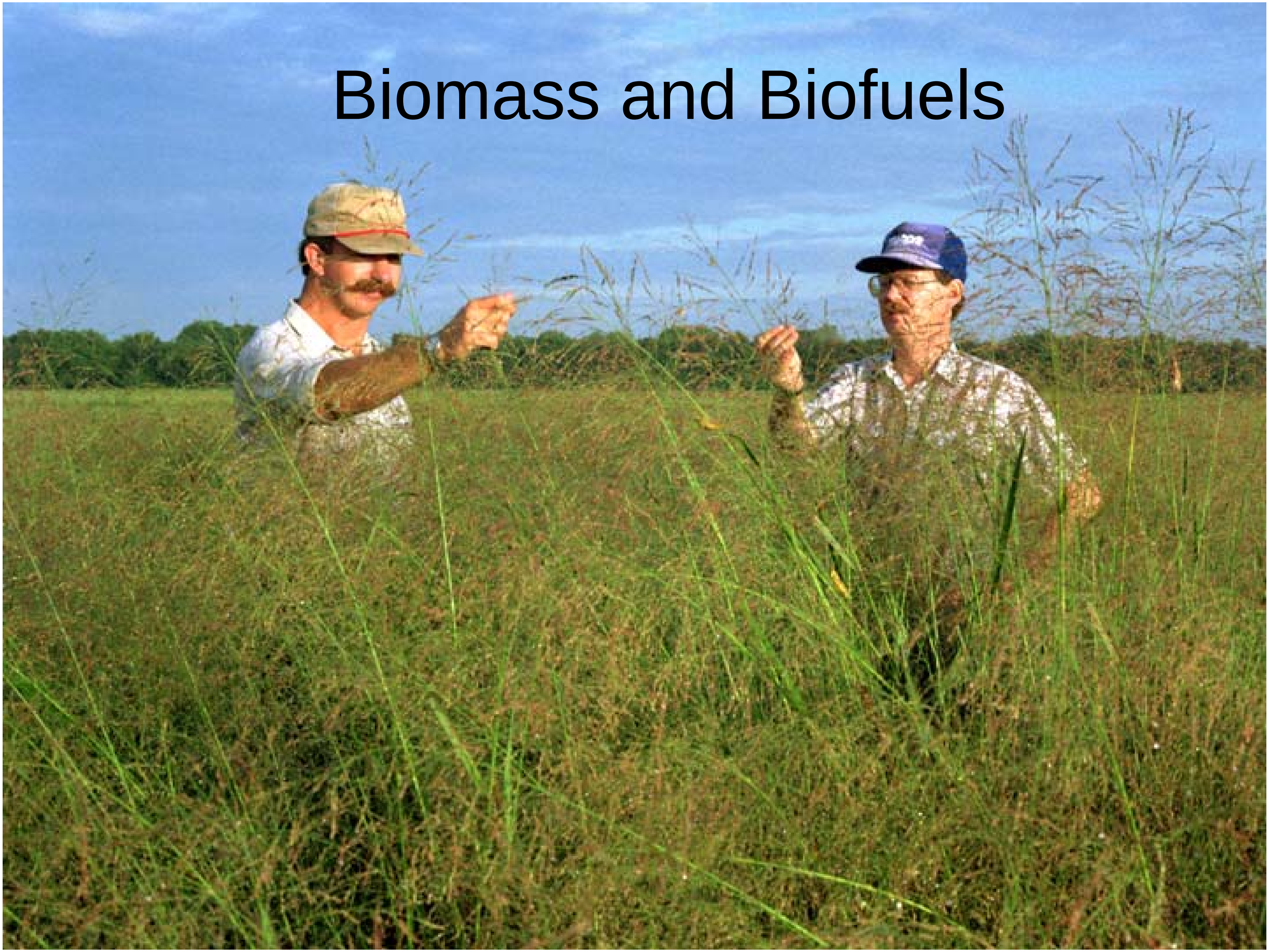
U.S. Wind Resource

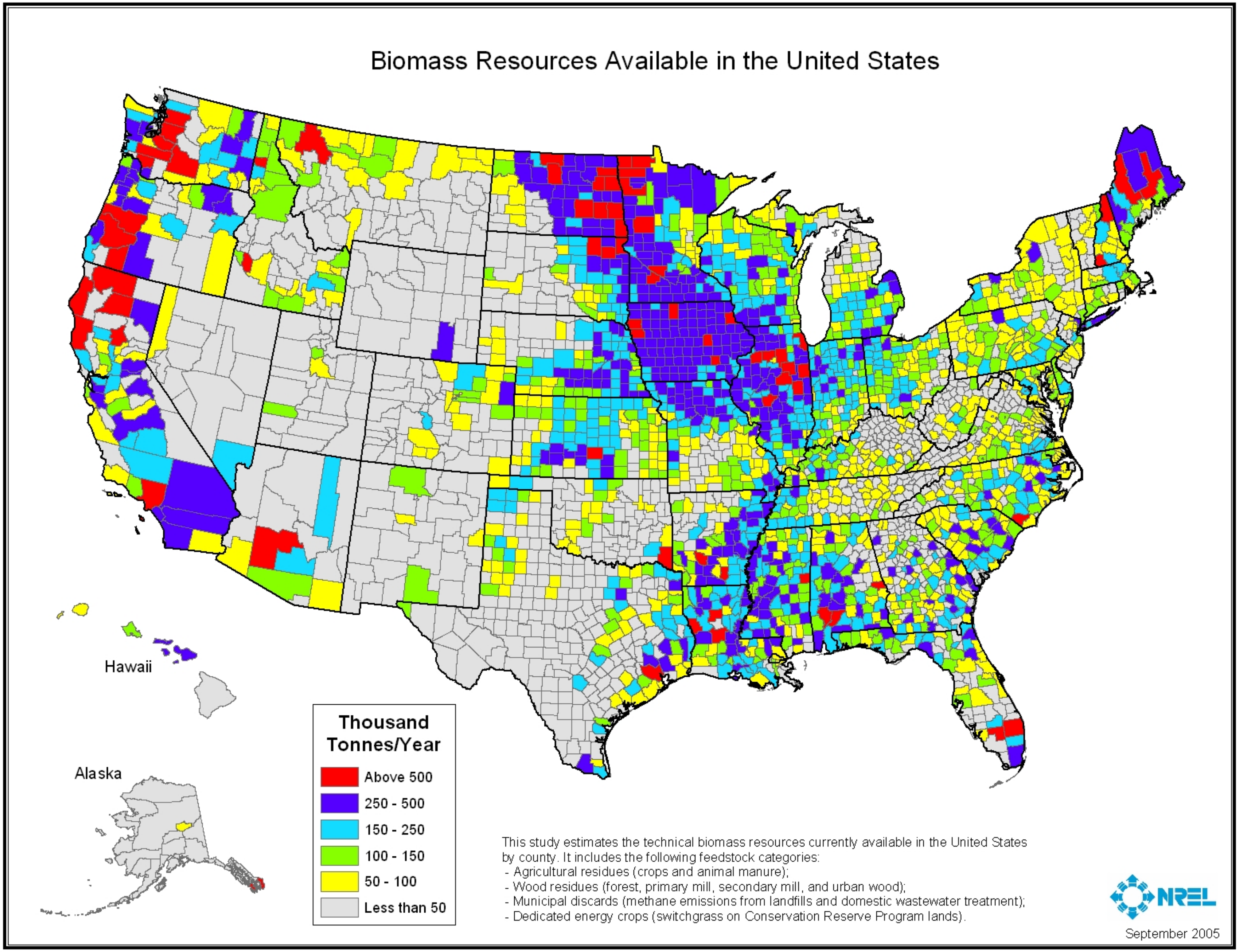


Wind Savings

- Market simulation model, PTC w/ gradual phase-out
- Limiting to 20% grid energy yields 245 GW, 40% capacity factor
- 140 – 225 MtC/yr, 3 to 7 ¢/kWh

Biomass and Biofuels



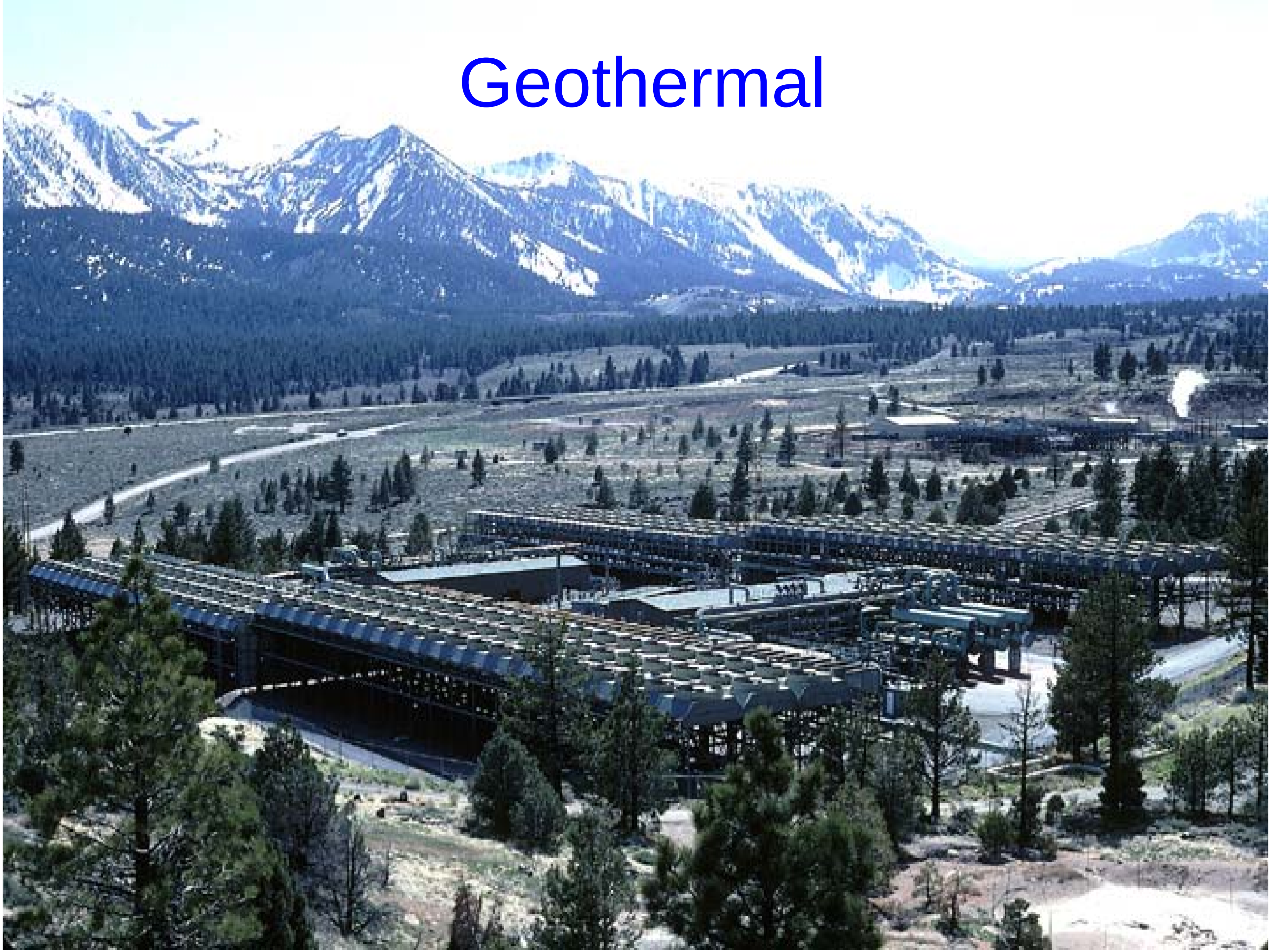

Biomass Resources Available in the United States
Hawaii
Alaska
Thousand Tonnes/Year
Above 500
250 - 500
150 - 250
100 - 150
50 - 100
Less than 50
This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:
- 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

Biofuels & Biomass Savings

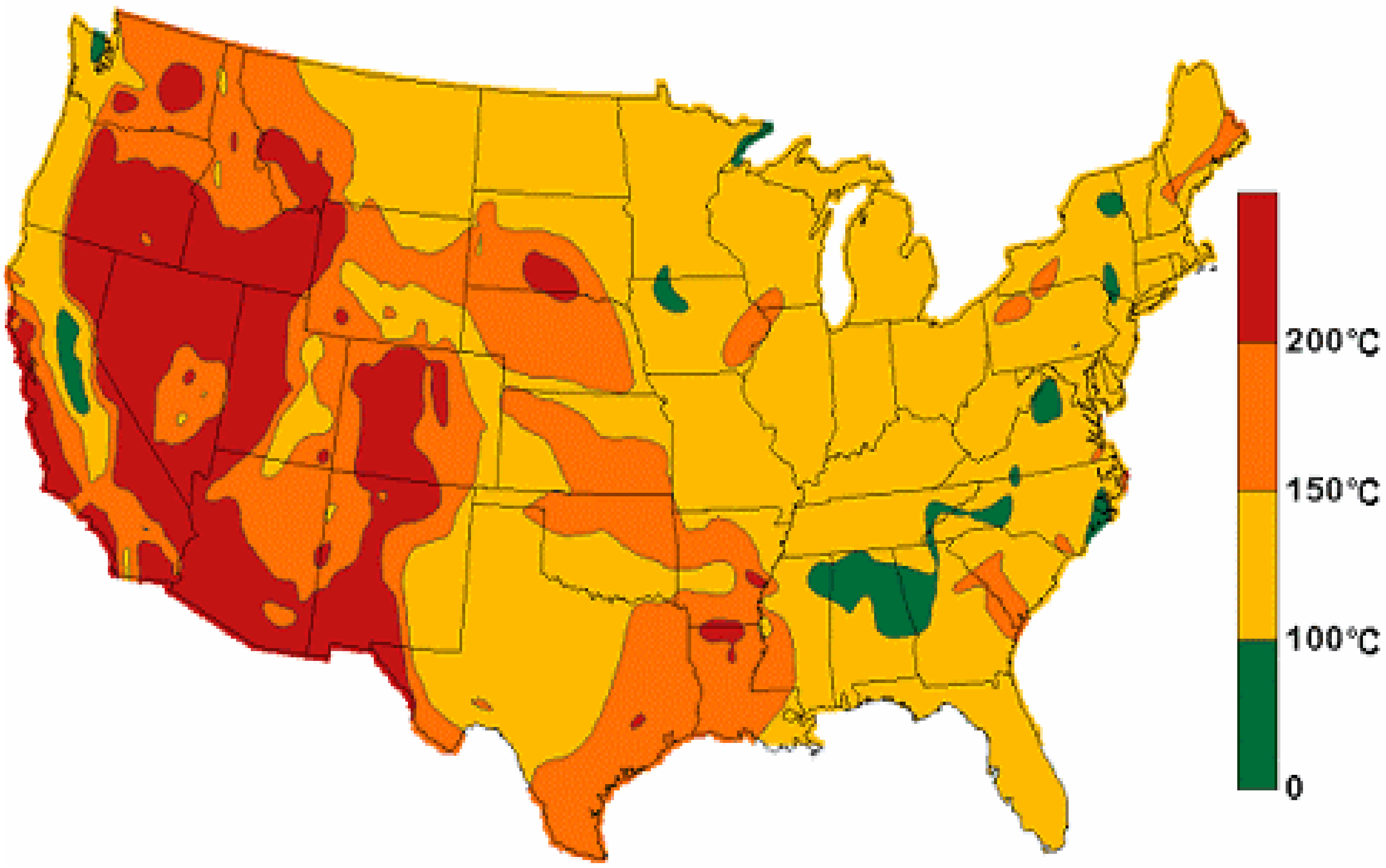
- Biofuels
  - ethanol from crop residues & energy crops
  - saves 28 billion gallons of gas in 2030 or 20% of today's consumption
  - 58 MtC/yr, $0.90 to $3.75/gal gas. equiv.

- Biomass
  - Remaining USDA billion ton estimate
  - electricity production: 45 GW, 90% capacity factor
  - 60 - 90 MtC/yr, 5-8 ¢/kWh

Geothermal



Temperatures at 6 km Depth



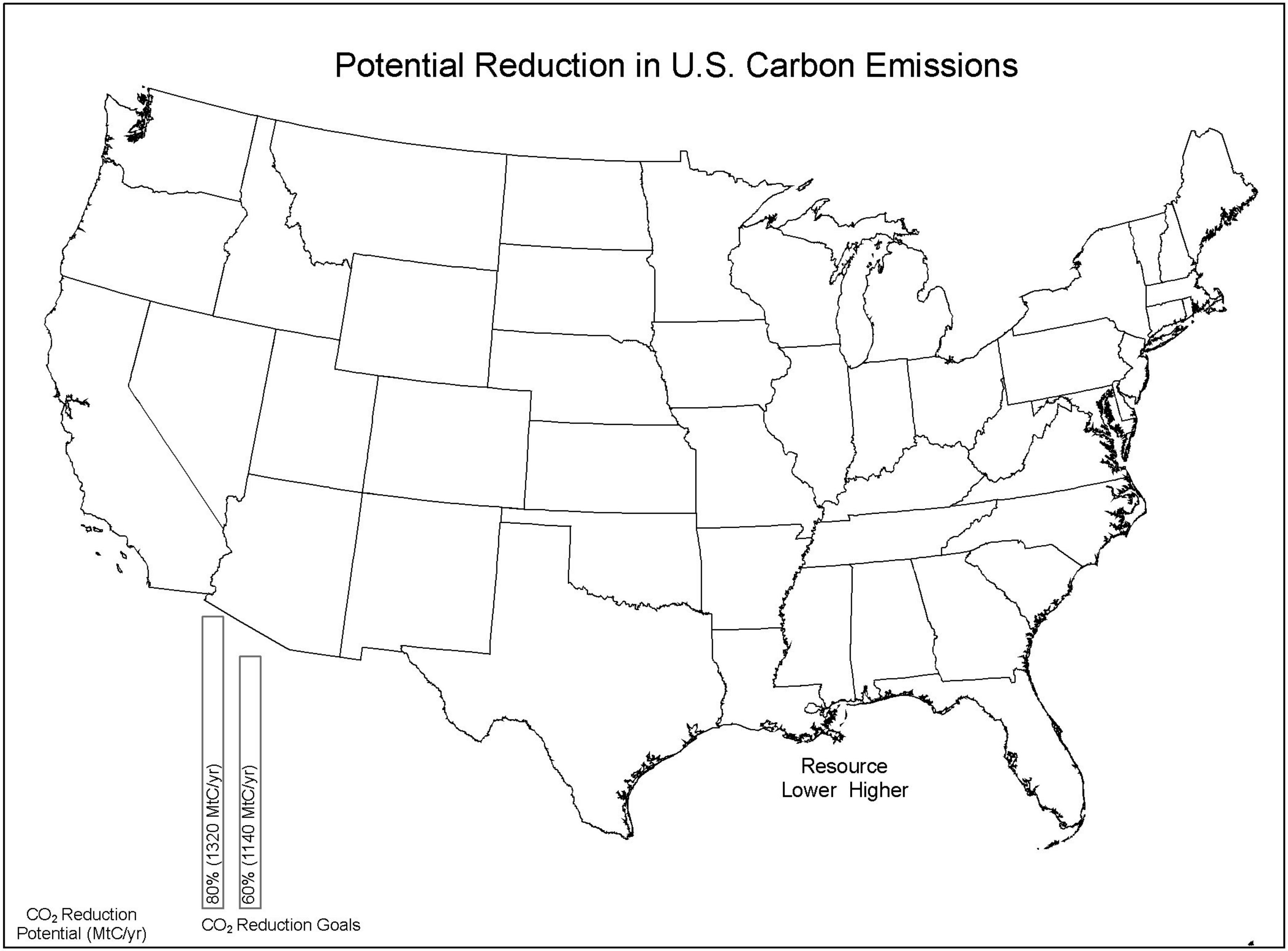
Geothermal Savings

- Assumes binary-cycle plants, continued DOE R&D
- 25% existing resources, 25% expanded, 50% from oil & gas wells
- National Energy Modeling System: 50 GW, 90% capacity factor
- 65 – 100 MtC/yr, 5 to 10 ¢/kWh

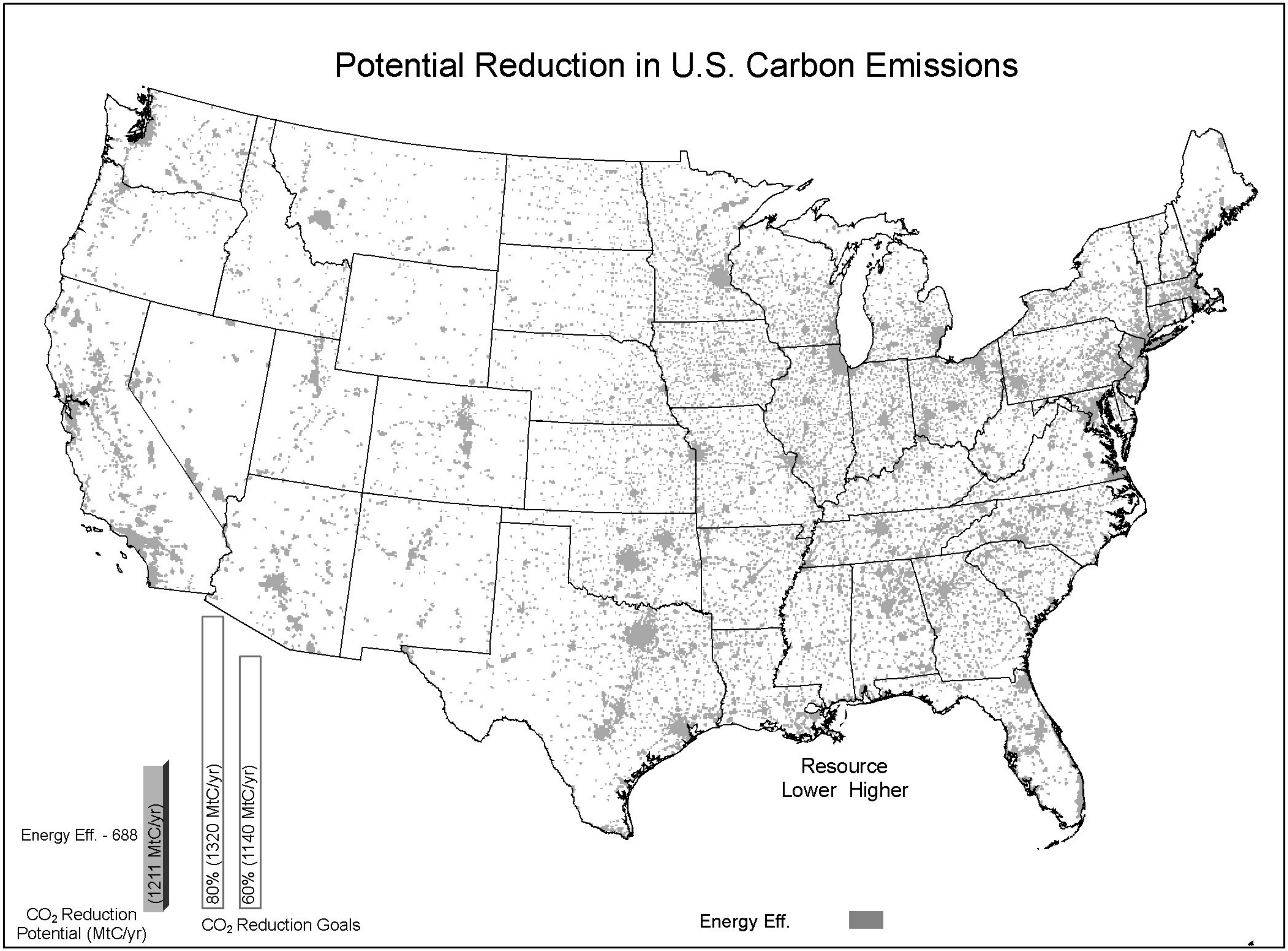
Putting It All Together

Renewable Energy ▸ Key to Climate Recovery

Denver Solar 2006

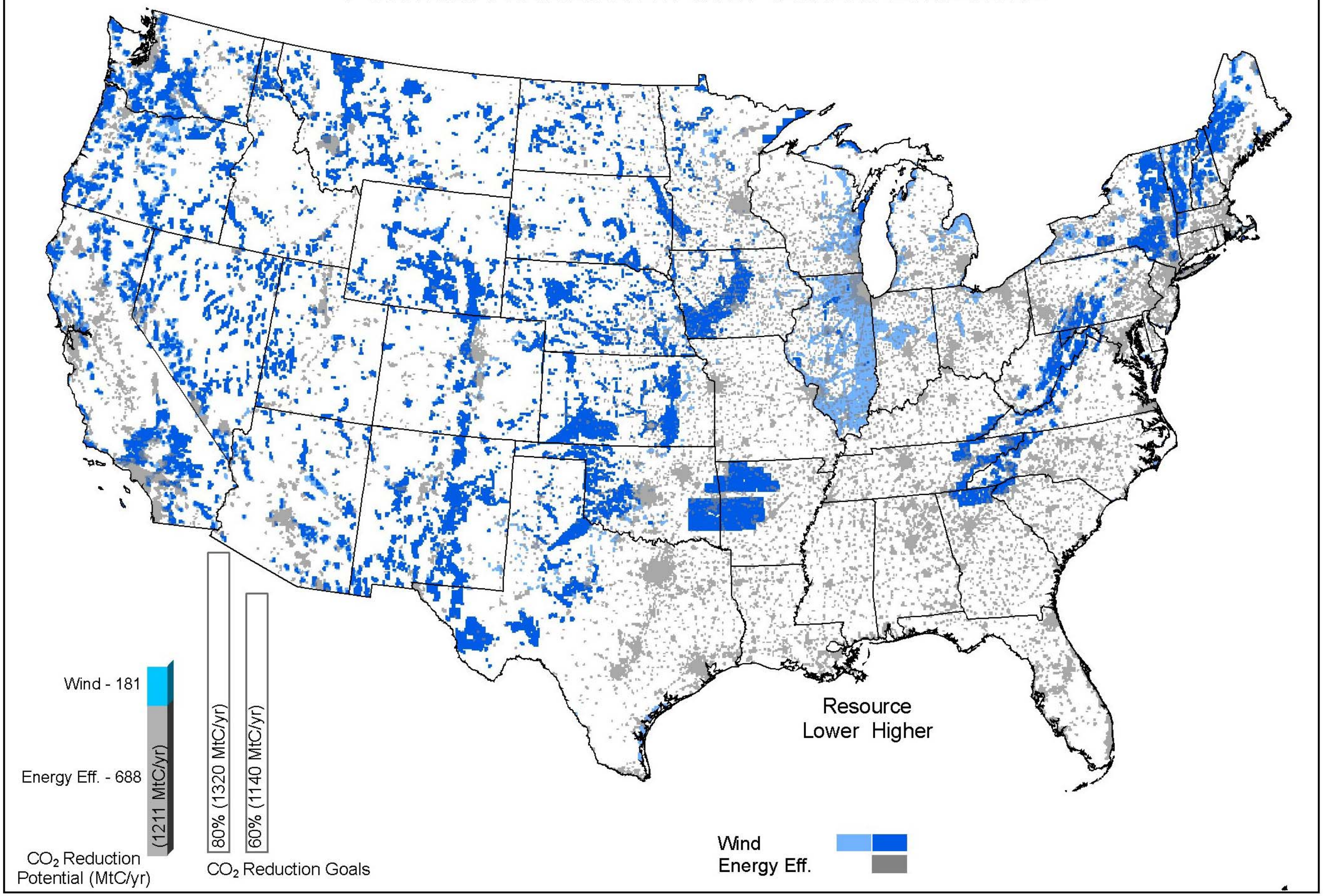


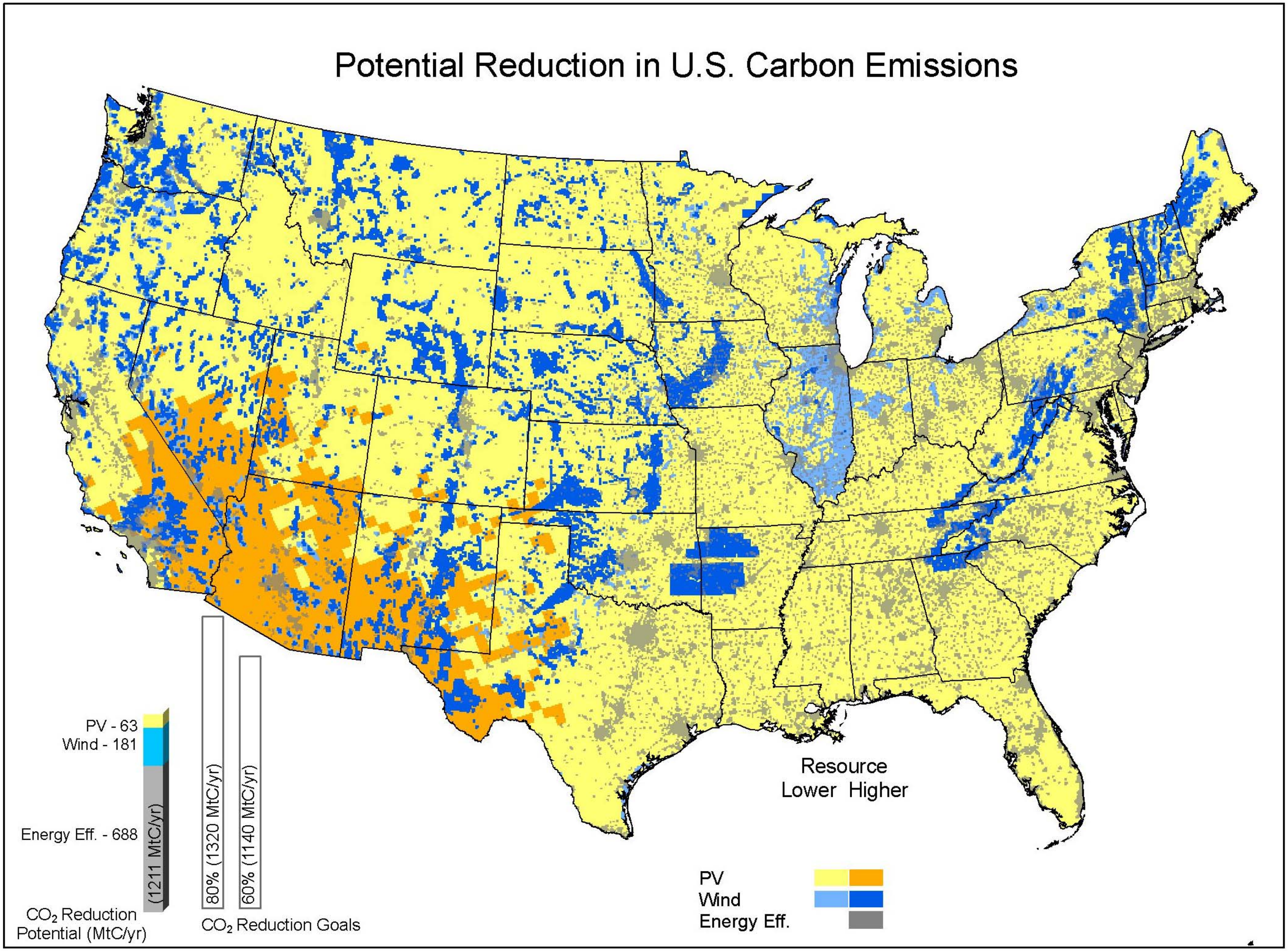
Potential Reduction in U.S. Carbon Emissions
80% (1320 MtC/yr)
60% (1140 MtC/yr)
Resource
Lower Higher
CO_2 Reduction Potential (MtC/yr)
CO_2 Reduction Goals



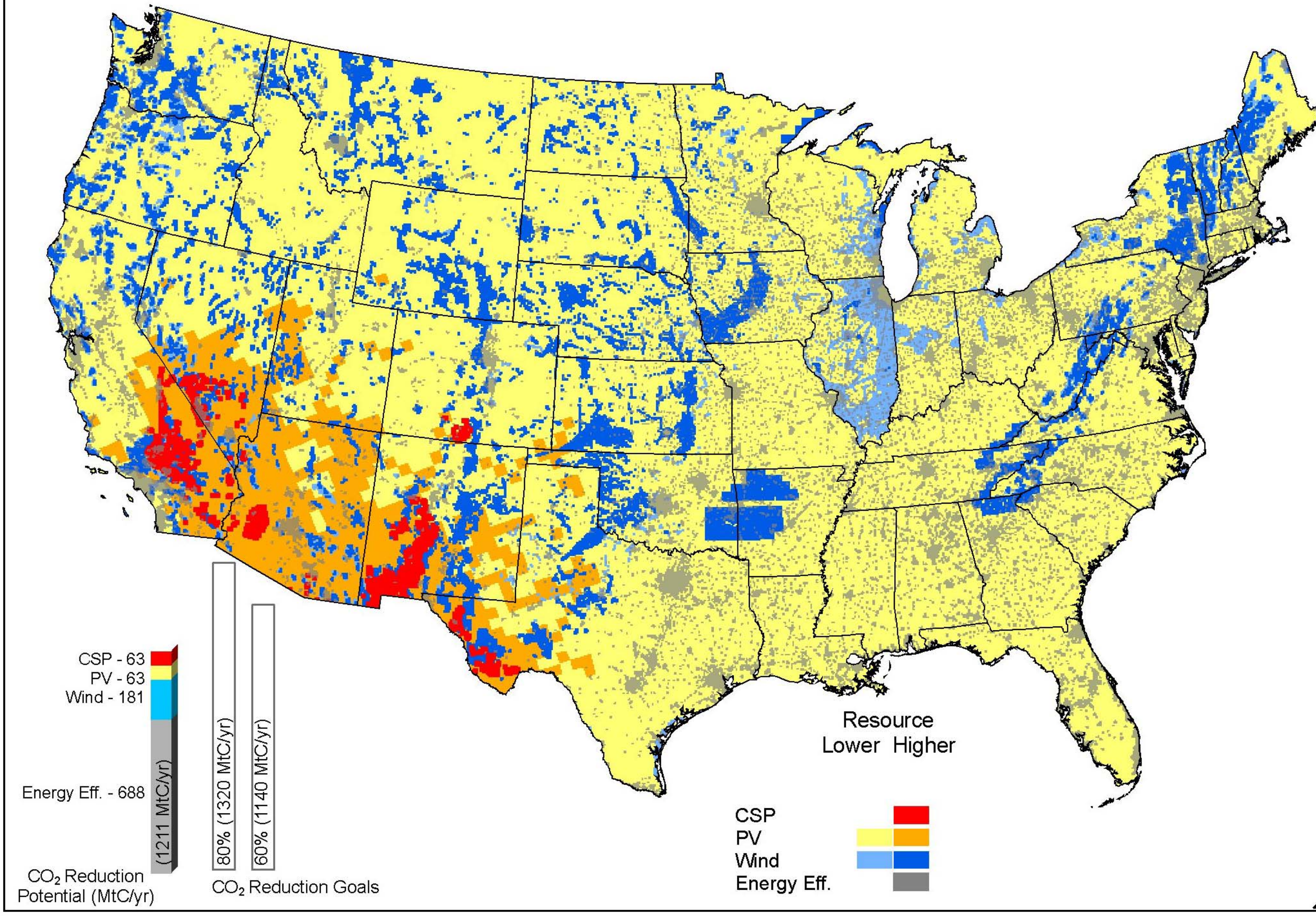
Potential Reduction in U.S. Carbon Emissions
Resource
Lower Higher
Energy Eff. - 688
(1211 MtC/yr)
80% (1320 MtC/yr)
60% (1140 MtC/yr)
CO2 Reduction
Potential (MtC/yr)
CO2 Reduction Goals
Energy Eff.

Potential Reduction in U.S. Carbon Emissions

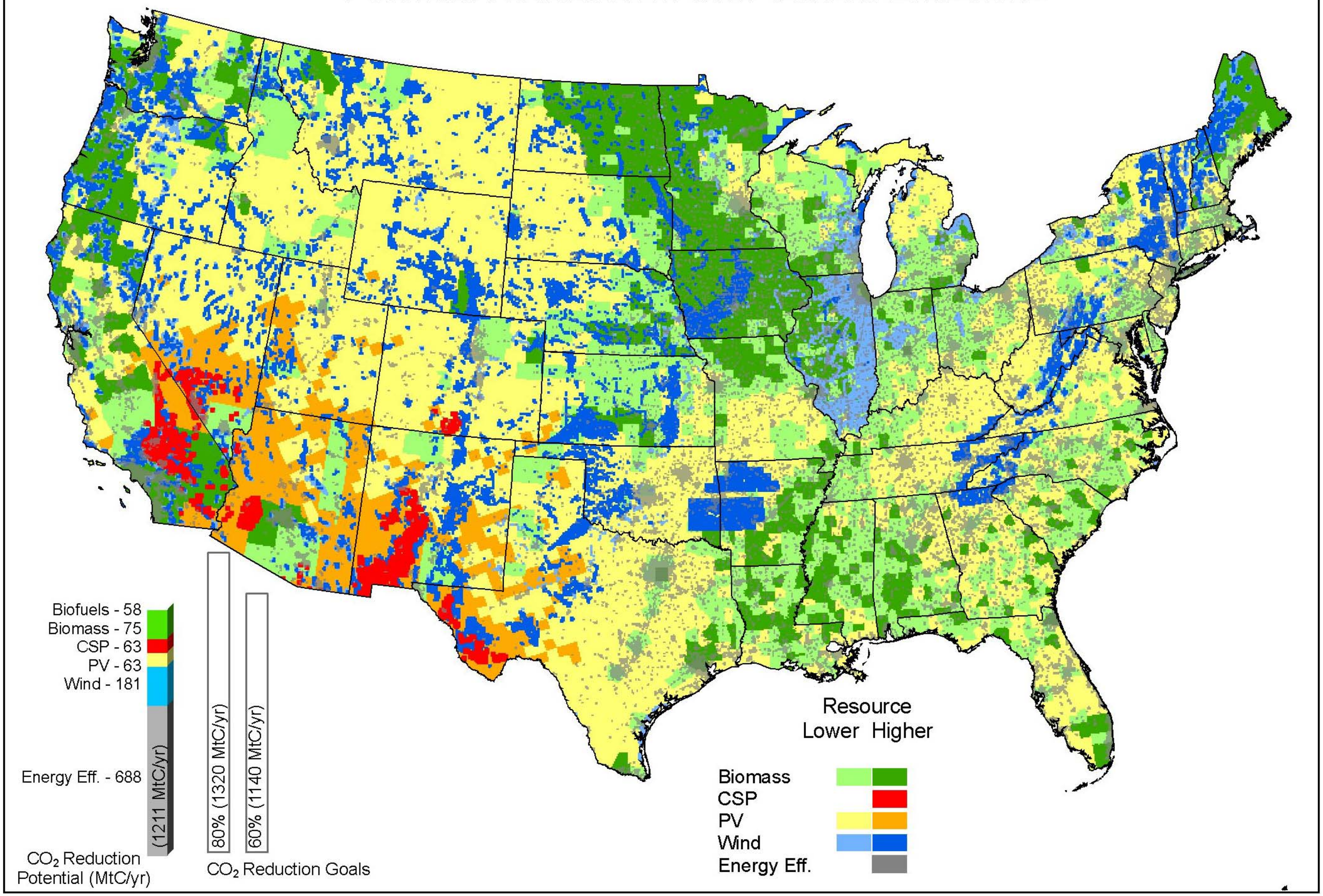



Potential Reduction in U.S. Carbon Emissions
PV - 63
Wind - 181
Energy Eff. - 688
(1211 MtC/yr)
CO2 Reduction
Potential (MtC/yr)
80% (1320 MtC/yr)
60% (1140 MtC/yr)
CO2 Reduction Goals
Resource
Lower Higher
PV
Wind
Energy Eff.

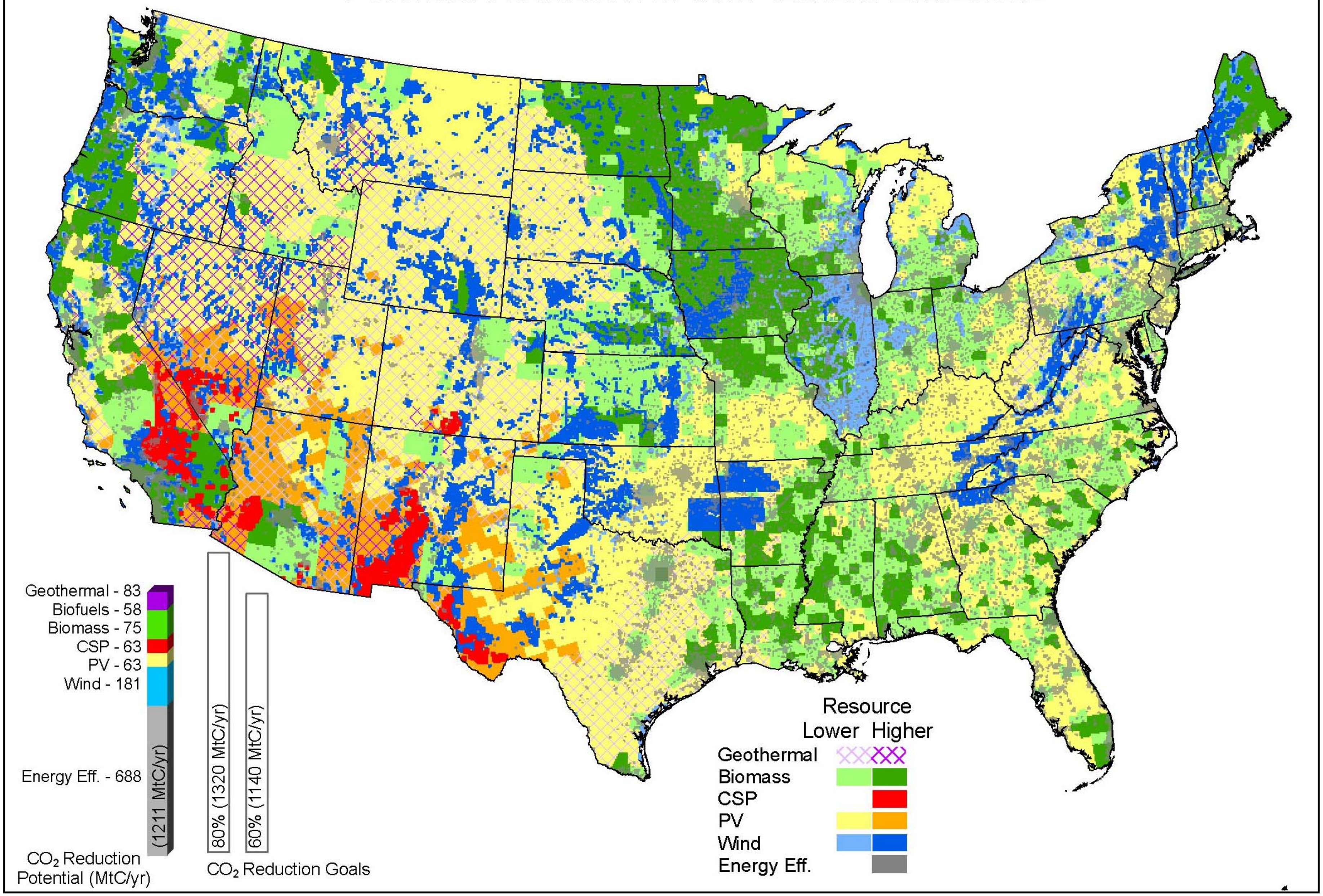
Potential Reduction in U.S. Carbon Emissions



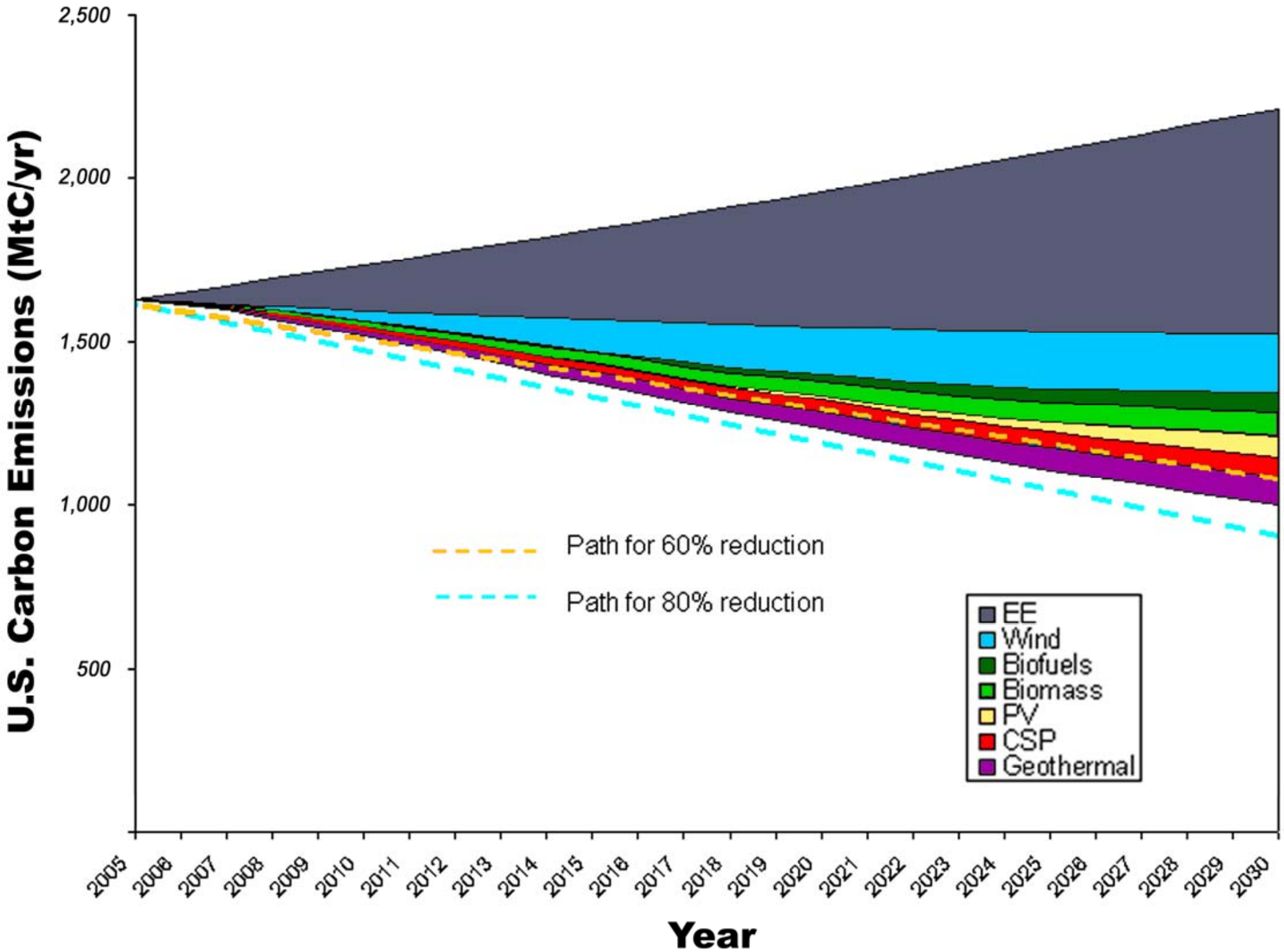
Potential Reduction in U.S. Carbon Emissions



Potential Reduction in U.S. Carbon Emissions

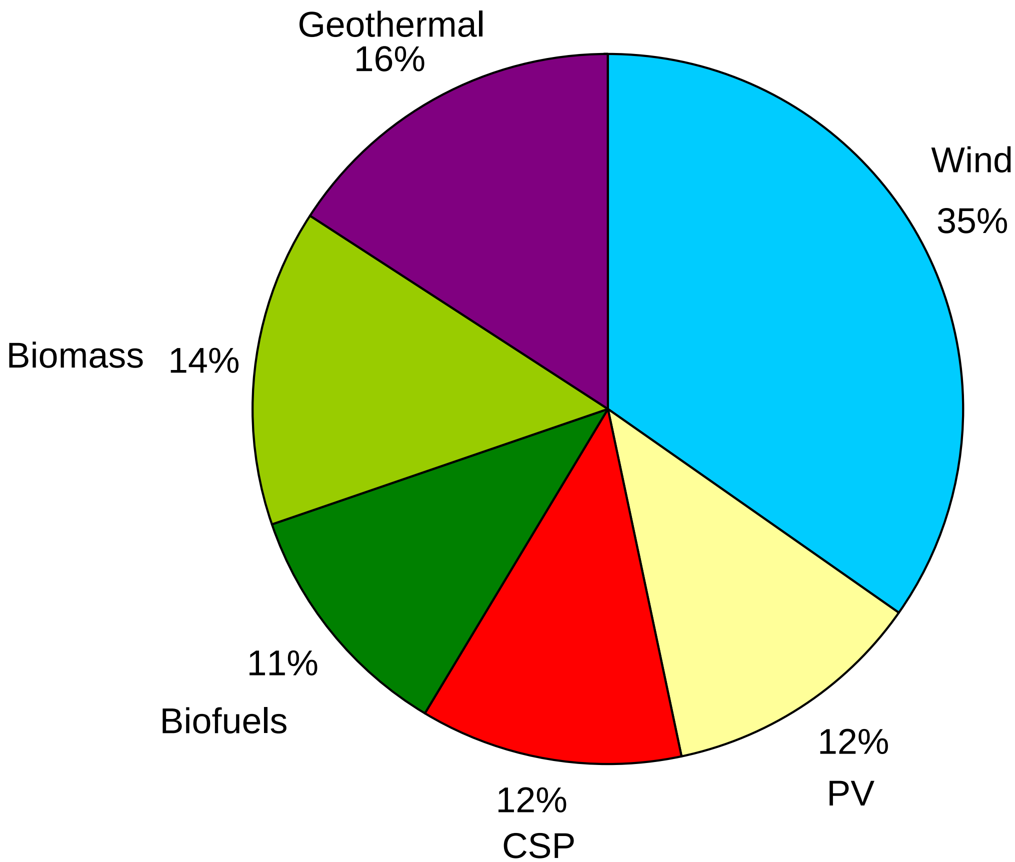


U.S. Carbon Emissions Displacement Potential from Energy Efficiency and Renewable Energy by 2030



57% Energy Efficiency, 43% Renewables

Renewable Contributions to Carbon Reduction



U.S. Renewable Electricity Generation in 2030

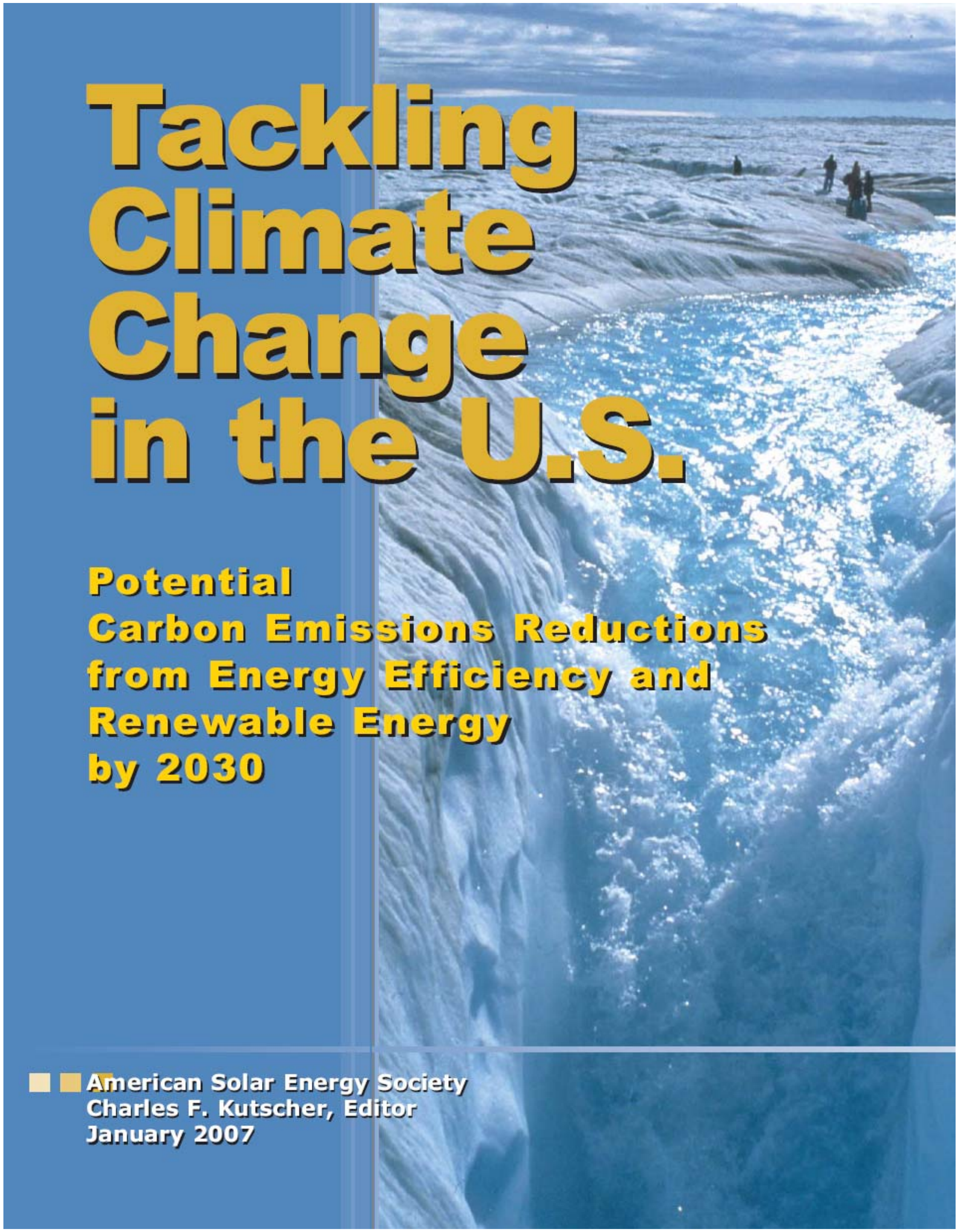
Technology	**Percent of Grid Energy in 2030**
Concentrating Solar Power*	7
Photovoltaics	7
Wind	20
Biomass*	8
Geothermal*	9
Total	**51**

*Can provide baseload or near-baseload power

Conclusions

- Energy efficiency can negate U.S. emissions growth
- Renewables can provide deep cuts in emissions
- The U.S. is blessed with abundant renewable resources spread throughout the country
- Wind can provide ~1/3 of renewable energy; remaining split about evenly among other resources
- EE and RE can begin **today** to tackle global warming
- Continued R&D and policy support will help these technologies achieve their large future potential

"Houston, we have a solution!"



ASES report released Jan. 31, 2007

Available at: www.ases.org

Adopted by Sierra Club as their "energy roadmap"