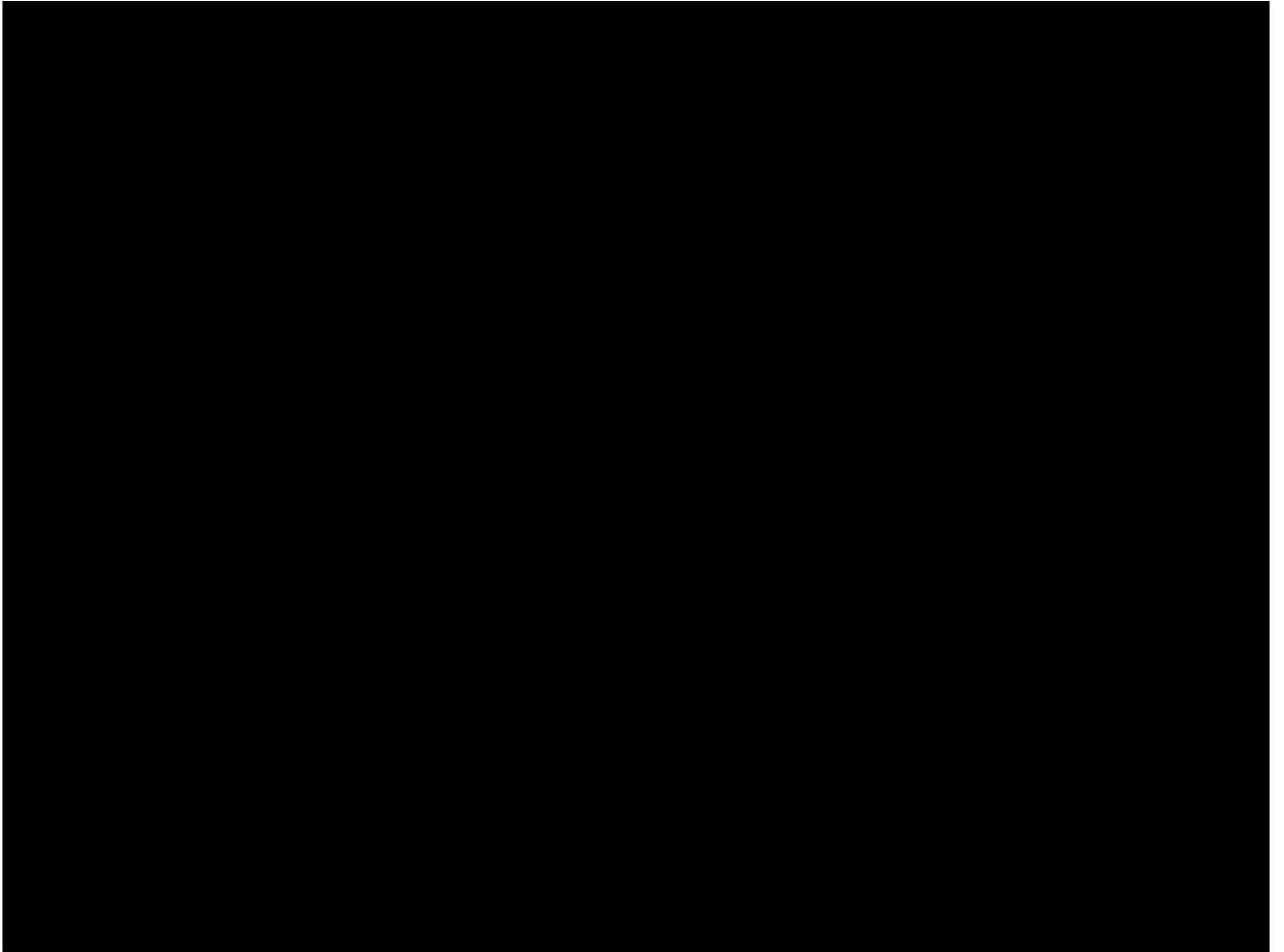


The Climate Change Crisis and the Role of Renewable Energy

NREL Power Lunch
May 19, 2009

Chuck Kutscher
National Renewable Energy Laboratory

50 Years Ago



DOUBLE TAKE

Some things never change. Mike Keefe can attest to that: He's been drawing political cartoons for 32 years. Here's one from his archives, on climate change.

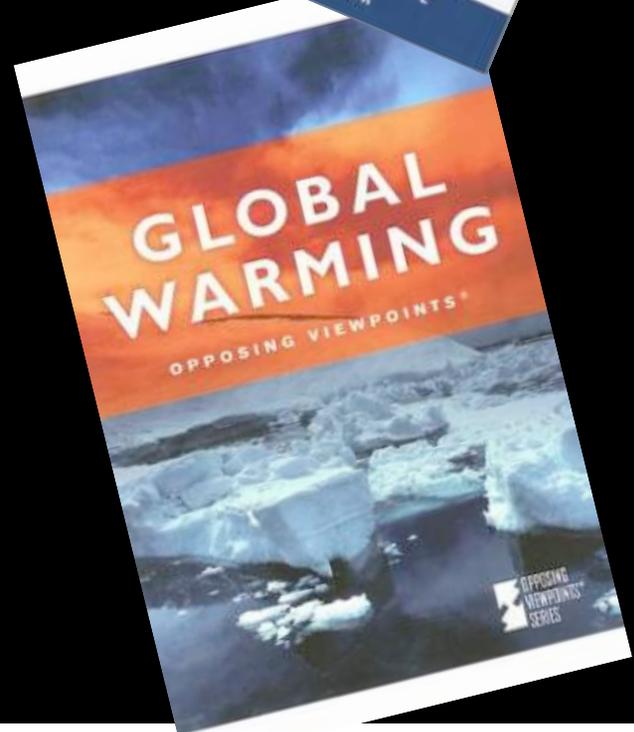
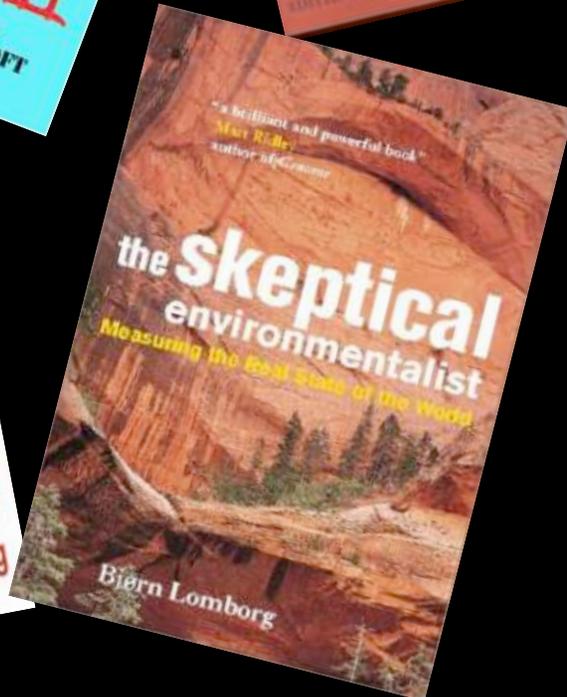
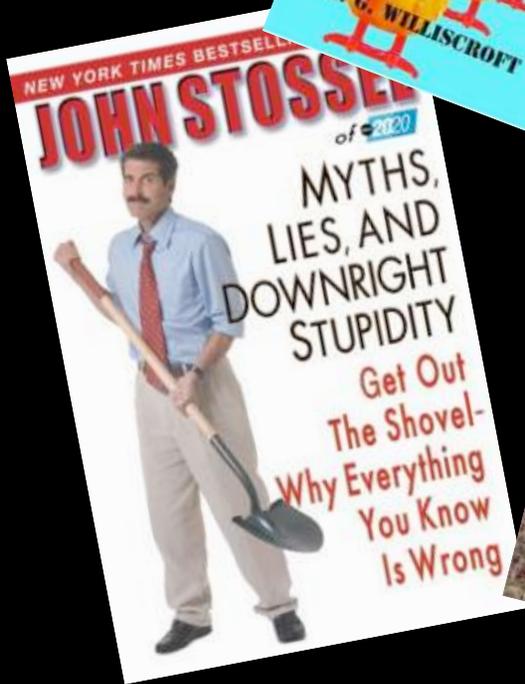
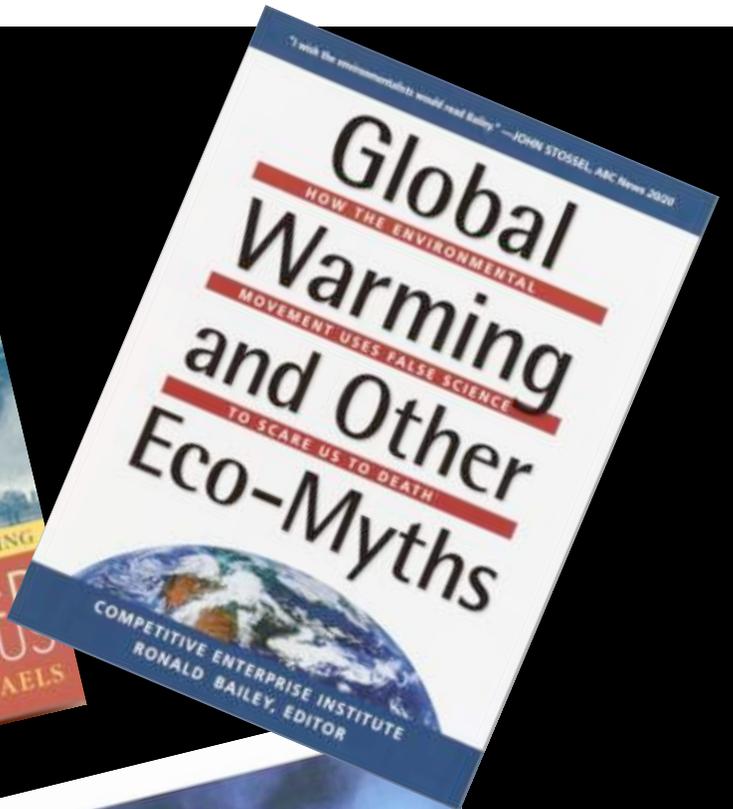
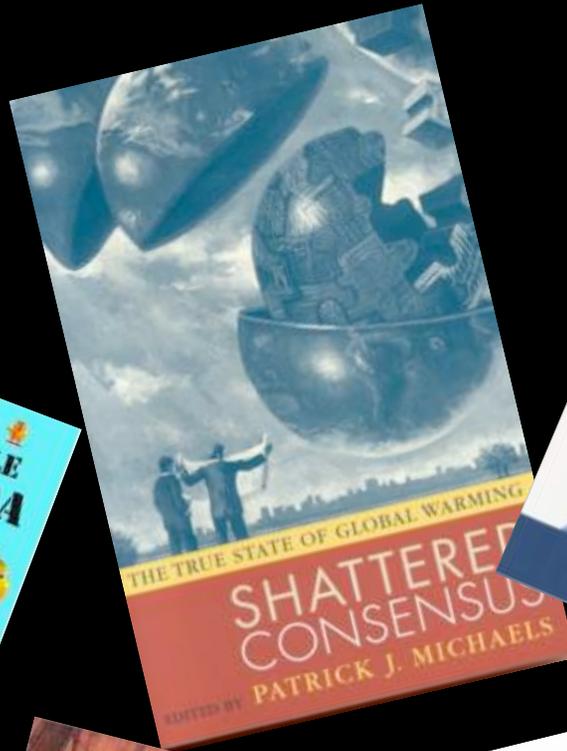
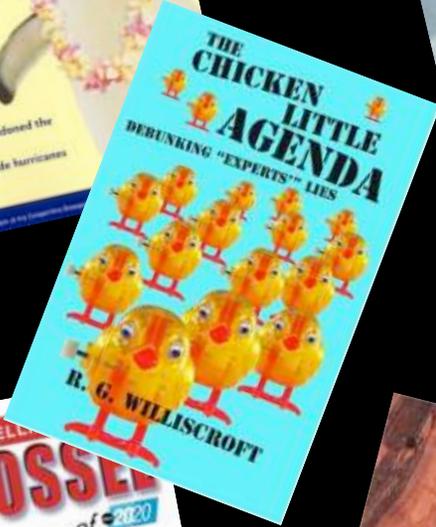
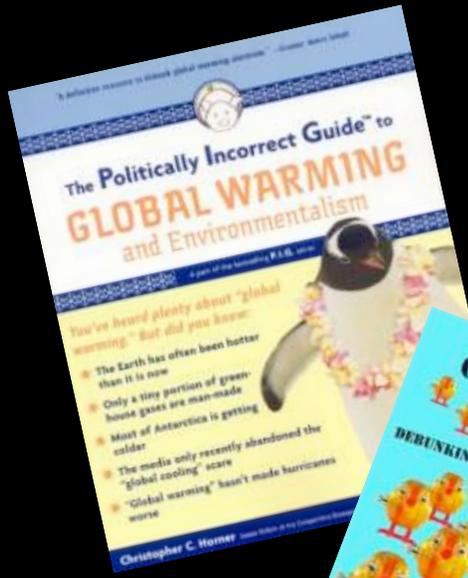
Mike Keefe THE DENVER POST 8.3



Climate Change:

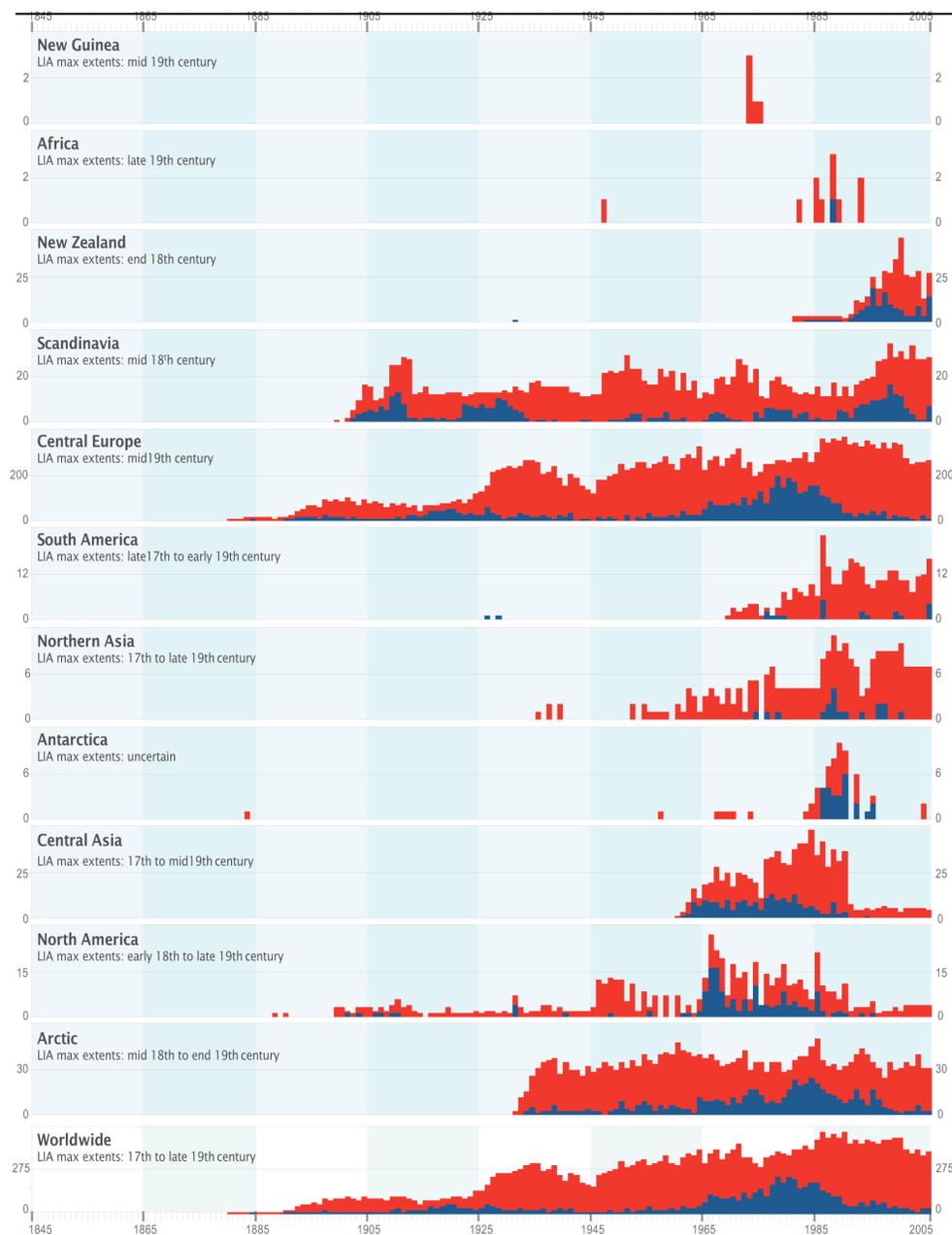
*“The greatest hoax ever
perpetrated
on the American people”?*





"For every shrinking glacier there is a growing one--but the growing ones get much less attention."

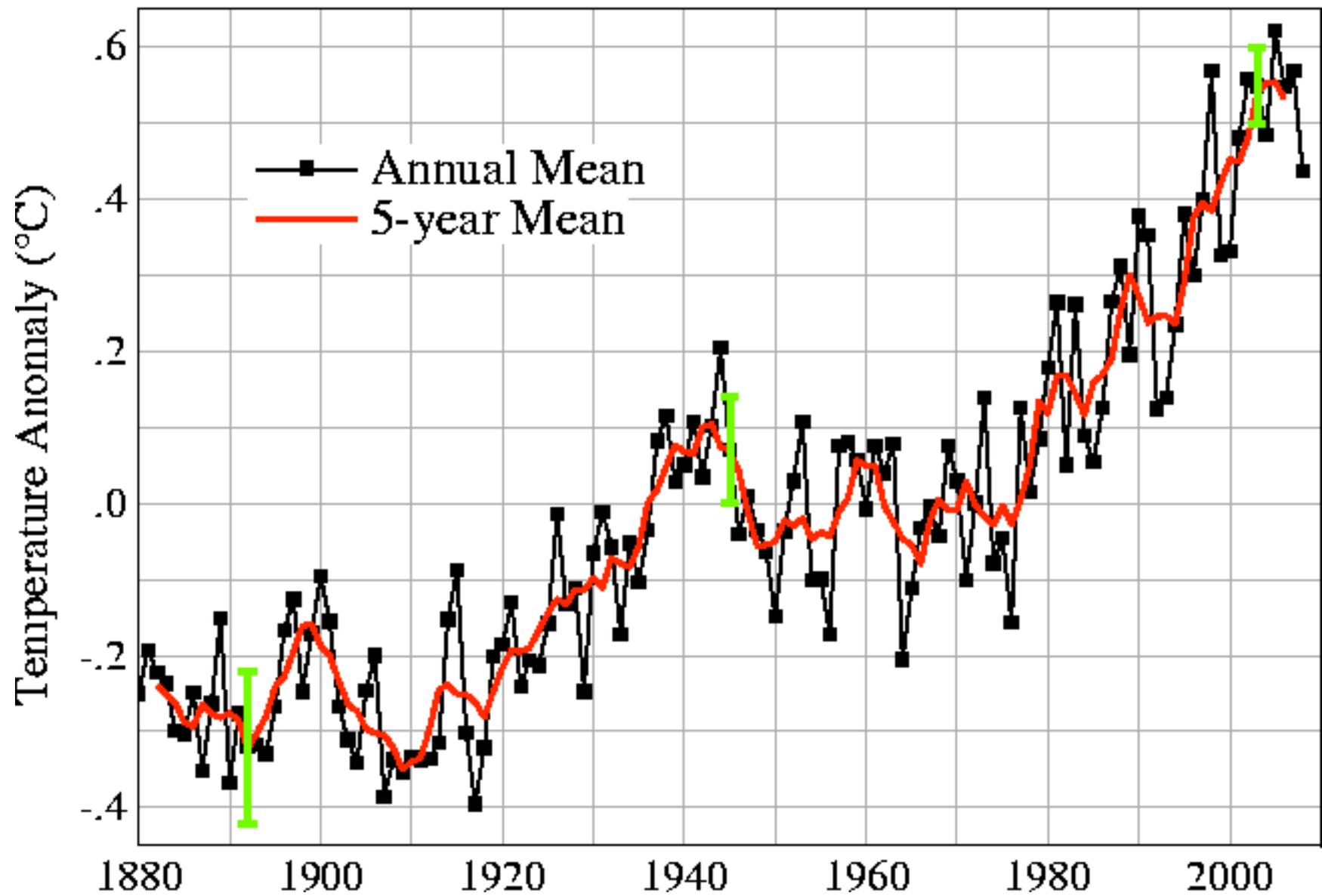
- Christopher Horner, *The Politically Incorrect Guide to Global Warming*, pg. 66

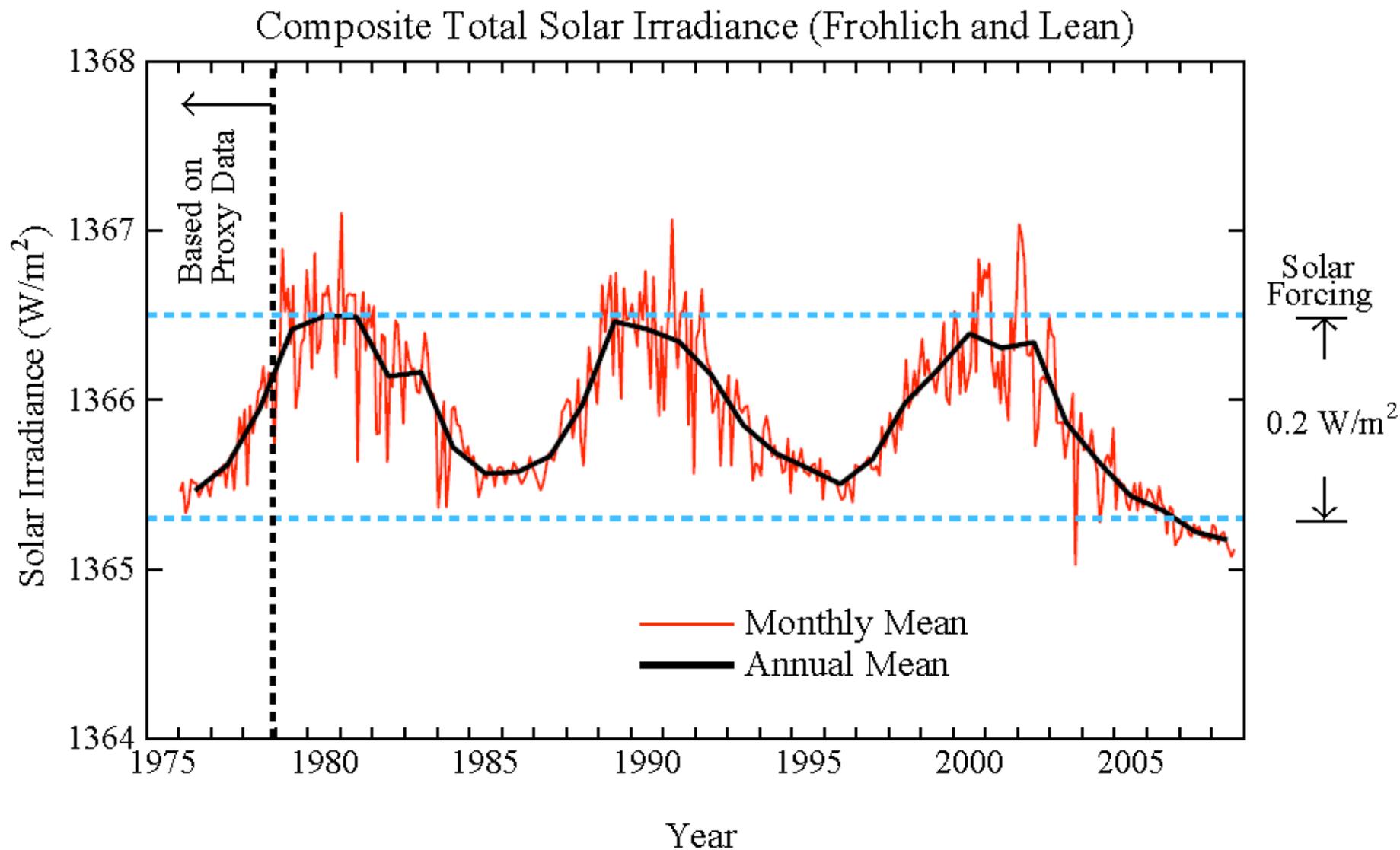


Advancing Retreating

- In 2005 442 glaciers studied:
 - 26 advancing
 - 18 stationary
 - 398 retreating

Global Land-Ocean Temperature Index

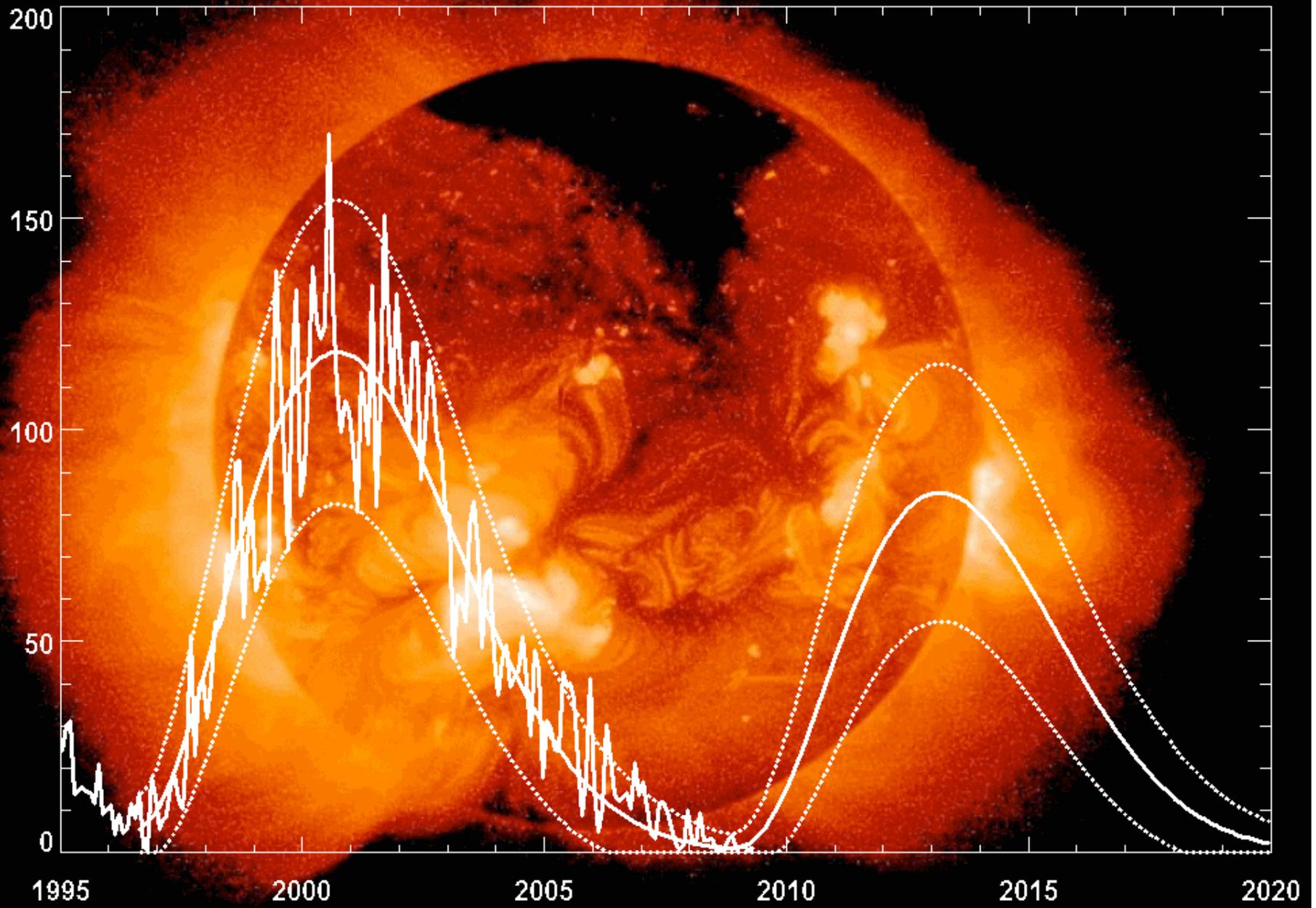




Soar irradiance through September 2008. Reference:

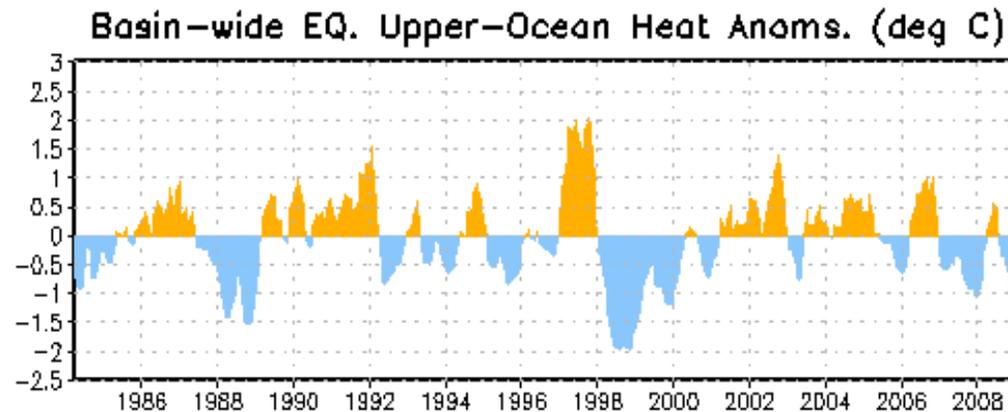
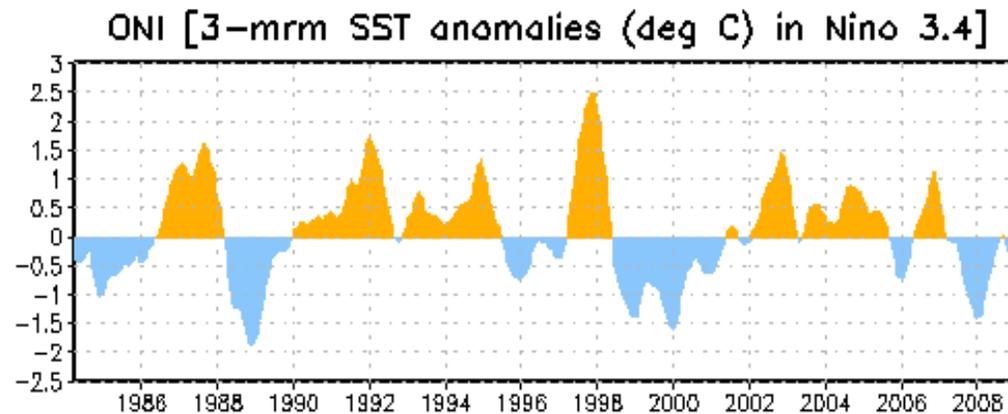
Fröhlich, C. and J. Lean, *Astron. Astrophys. Rev.*, **12**, pp. 273--320, 2004. <http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant>

Cycle 23-24 Sunspot Number Prediction (May 2009)



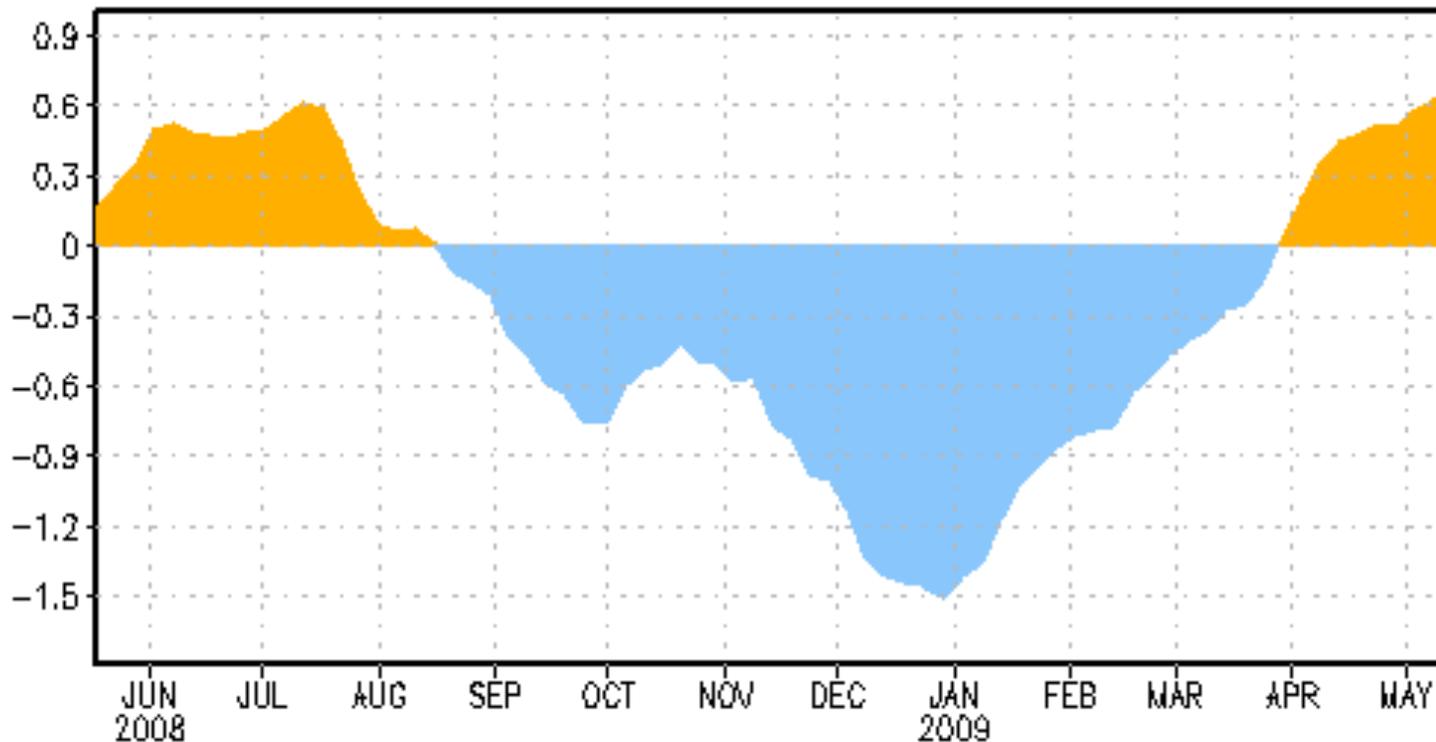
Hathaway/NASA/MSFC

El Niño-La Niña Cycles



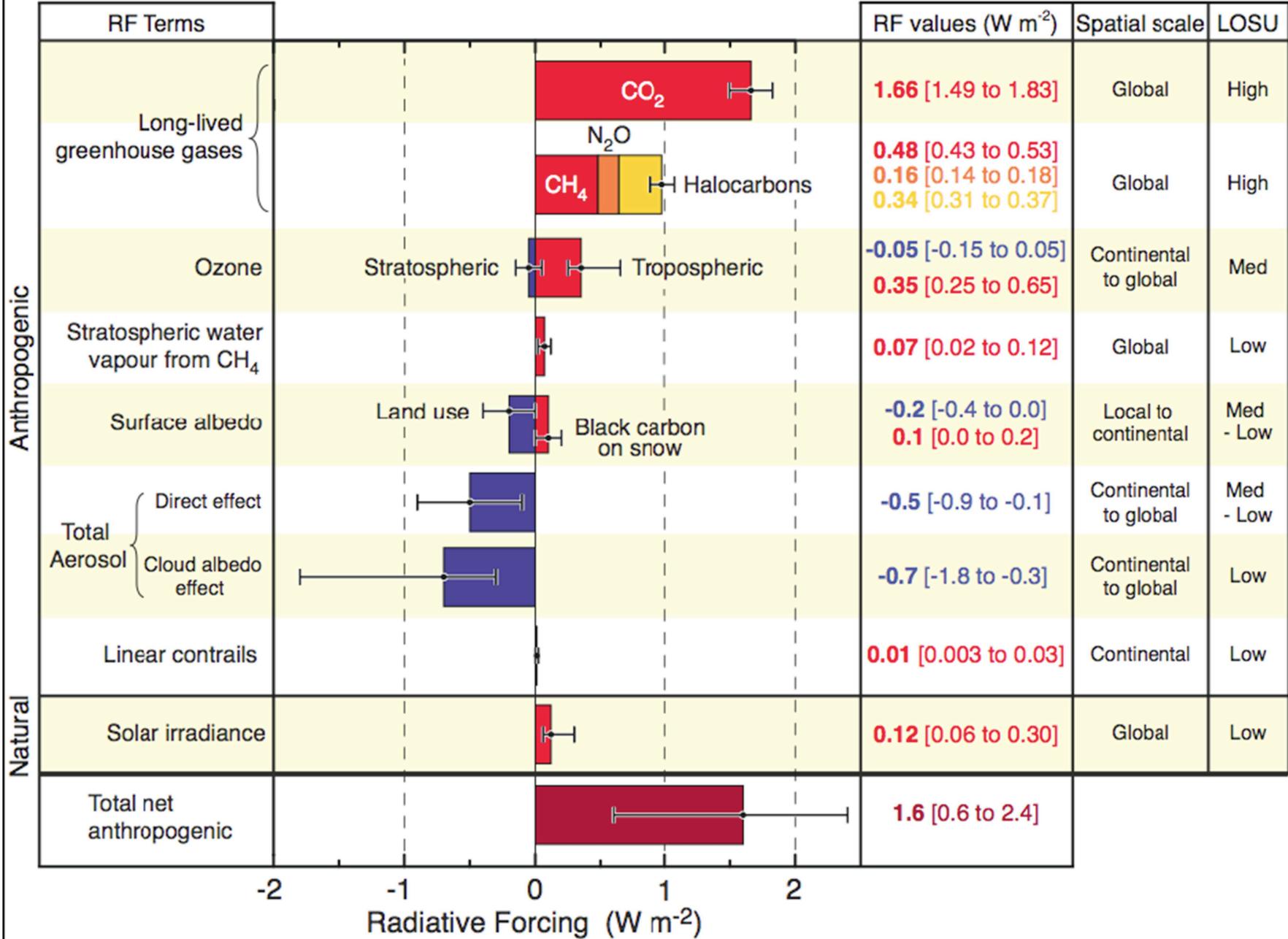
Central & Eastern Pacific Upper-Ocean (0-300 m) Weekly Heat Content Anomalies

EQ. Upper-Ocean Heat Anoms. (deg C) for 180-100W

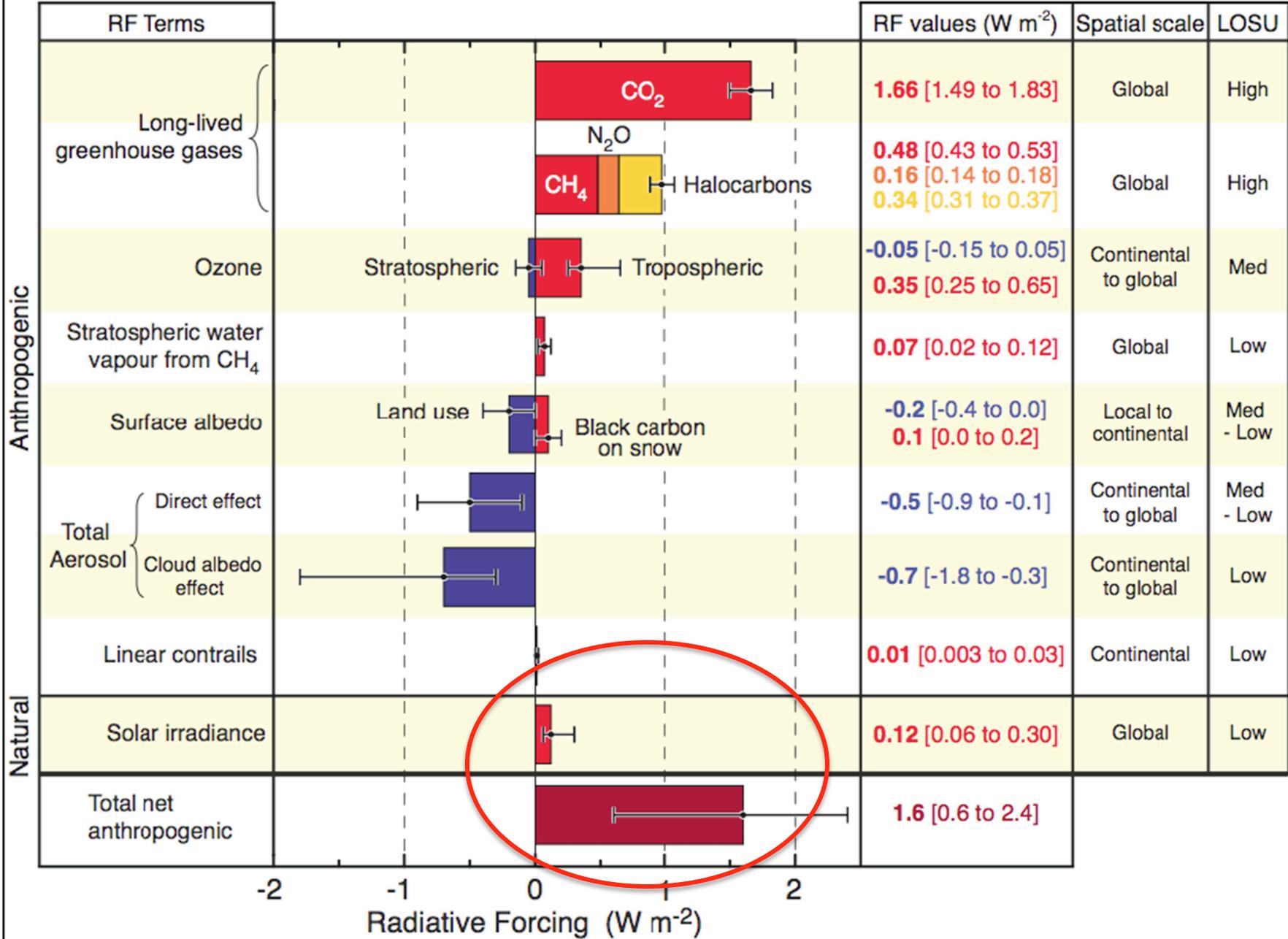


The upper ocean heat content was below-average across the eastern half of the equatorial Pacific Ocean between mid-August 2008 and March 2009. The heat content anomaly reached a minimum in late December 2008, and has since trended upward, becoming positive in late March 2009.

Radiative Forcing Components

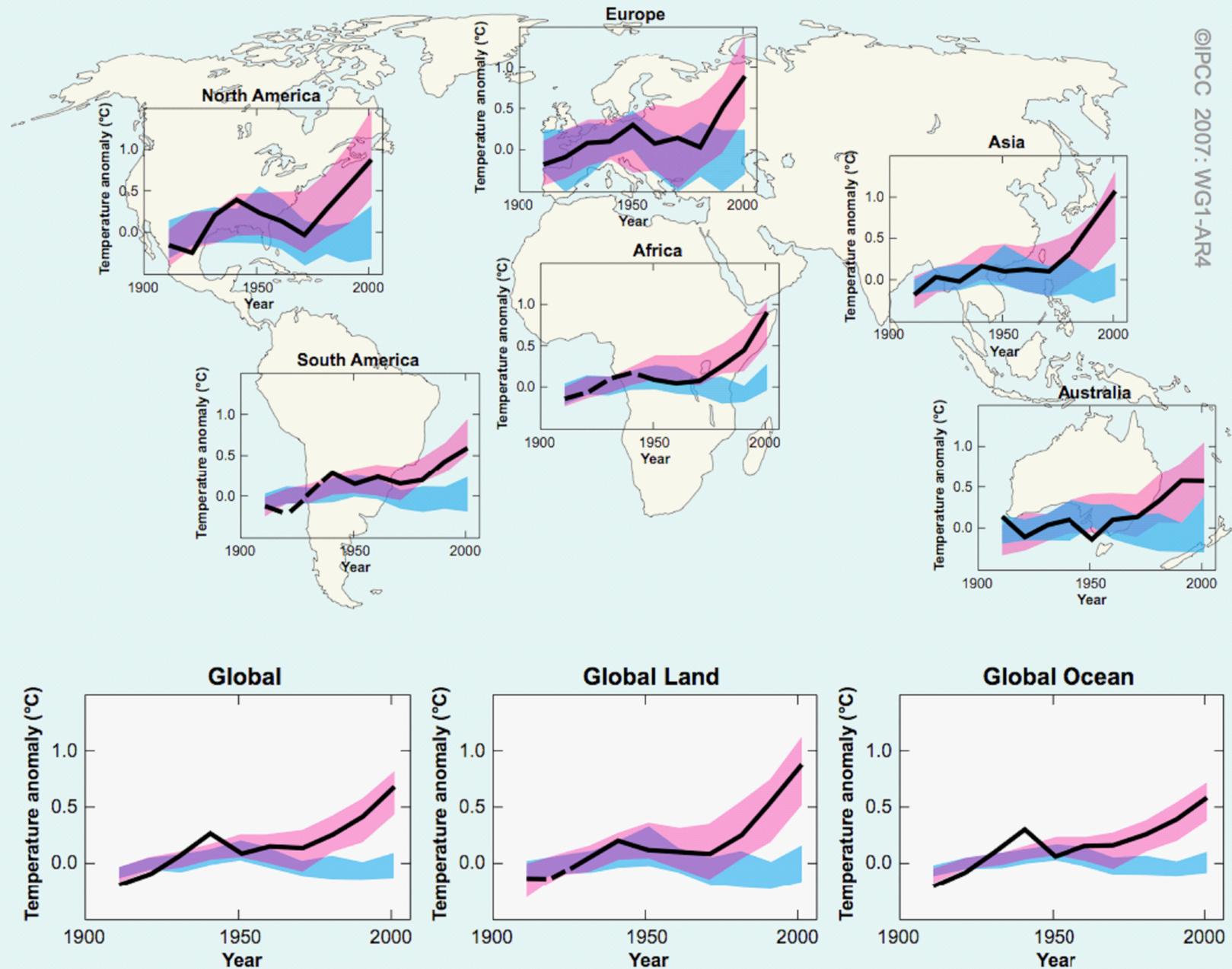


Radiative Forcing Components

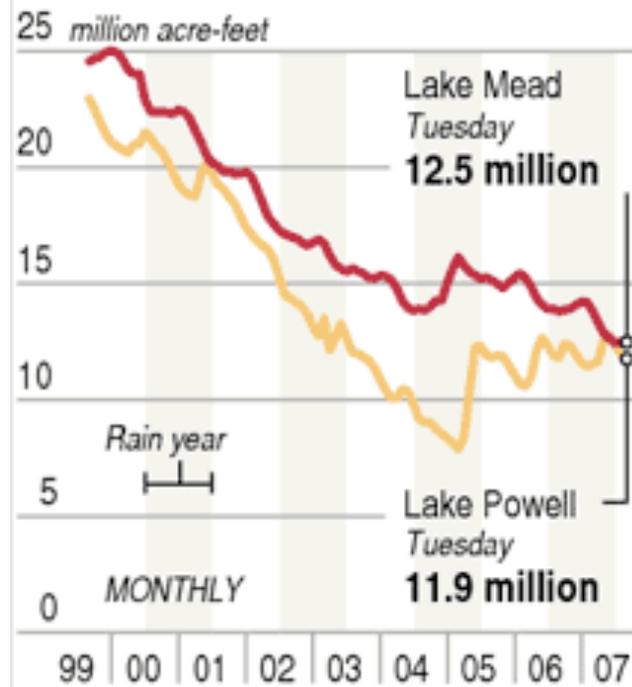


Global and Continental Temperature Change

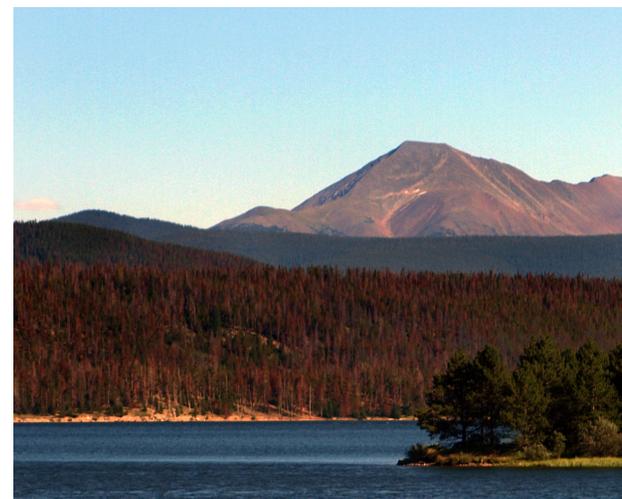
©IPCC 2007: WG1-AR4



A Warmer and Drier West



An acre-foot equals one acre of water one foot deep. A family of four uses roughly one acre-foot of water annually.

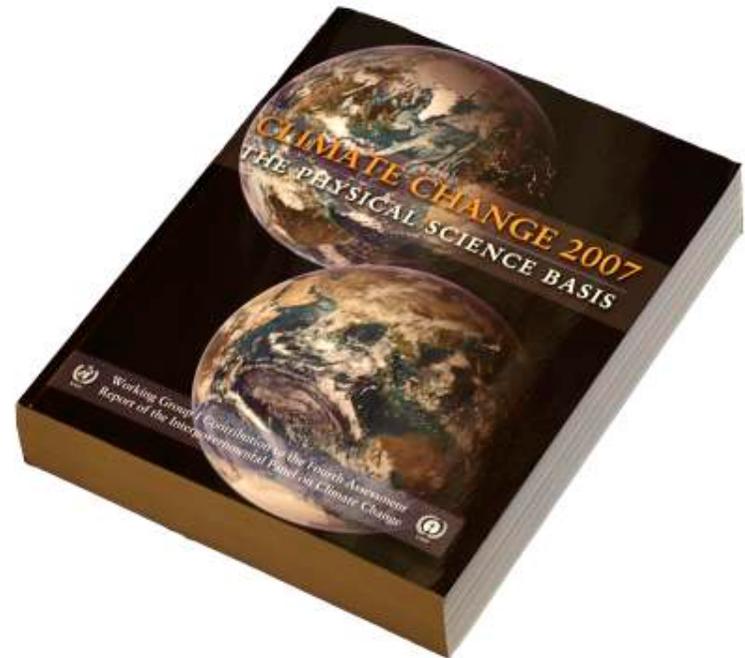




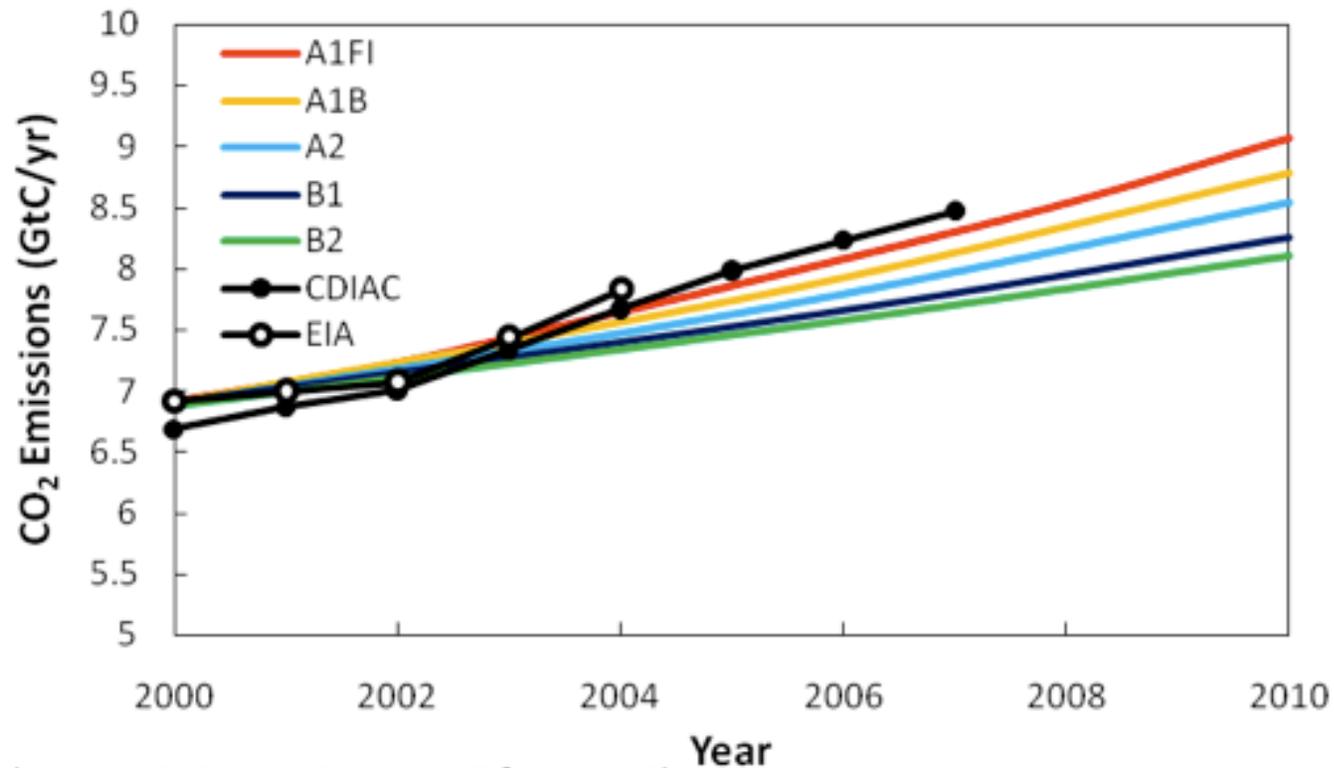


2007 IPCC Report

- *“Warming of the climate is unequivocal.”*
- *“..very likely due to anthropogenic greenhouse gas concentrations.”*



IPCC Scenarios vs. Actual Emissions



(Sources: IPCC, 2001; CDIAC, 2007 & EIA 2005)



What the latest
IPCC study
does not include:

*“future rapid dynamical
changes in ice flow”*

THE
NATION'S
CEMETERY
ARLINGTON

NATIONALGEOGRAPHIC.COM/MAGAZINE

JUNE 2007

NATIONAL GEOGRAPHIC

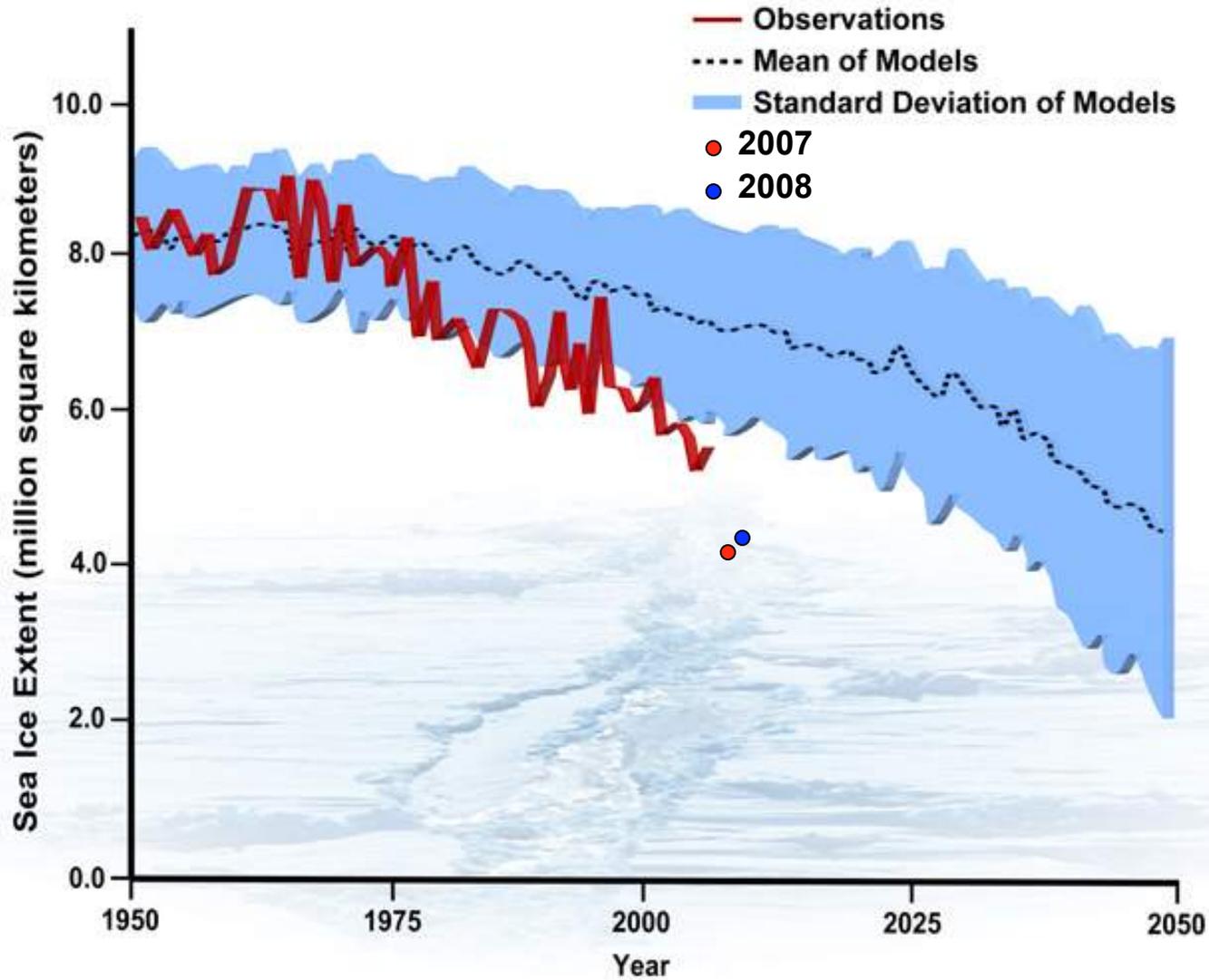
THE BIG THAW

Ice on the Run,
Seas on the Rise

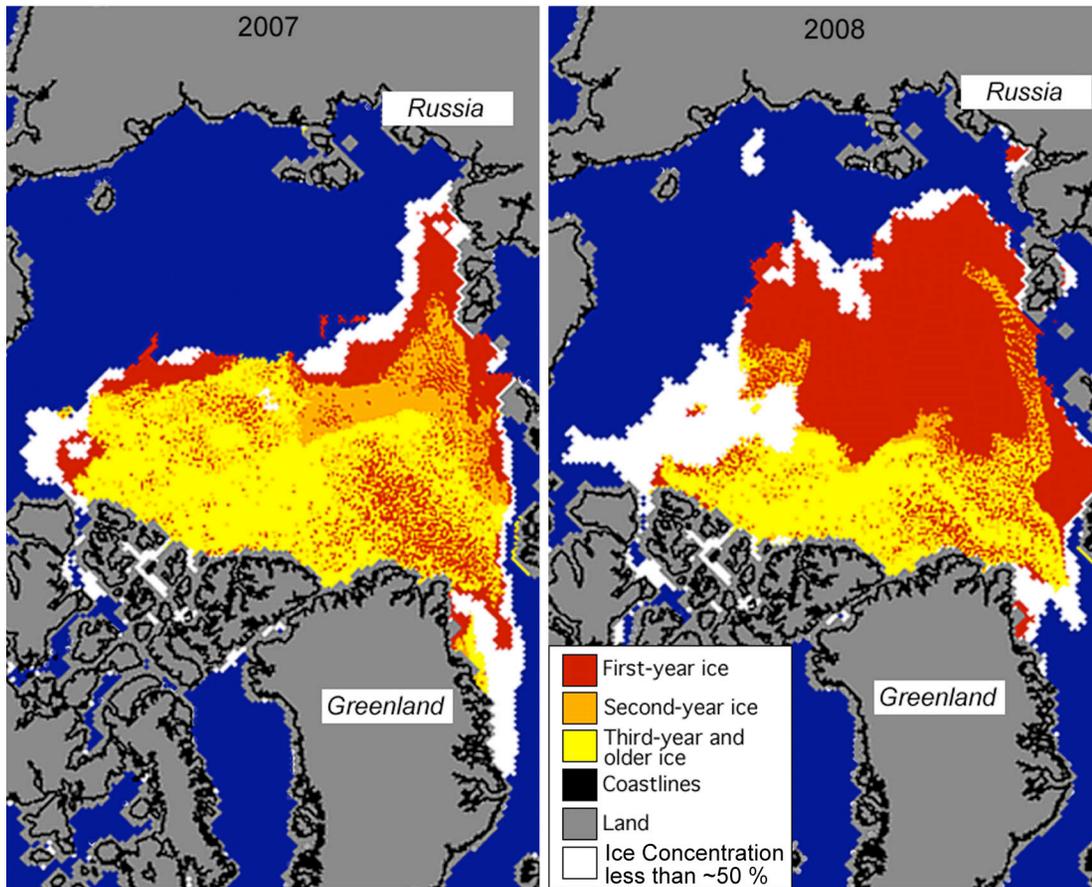
THE MAN WHO NAMED PLANTS CHINA'S BOOMTOWNS



Arctic September Sea Ice Extent: Observations and Model Runs



Arctic Sea Ice Is Getting Thinner



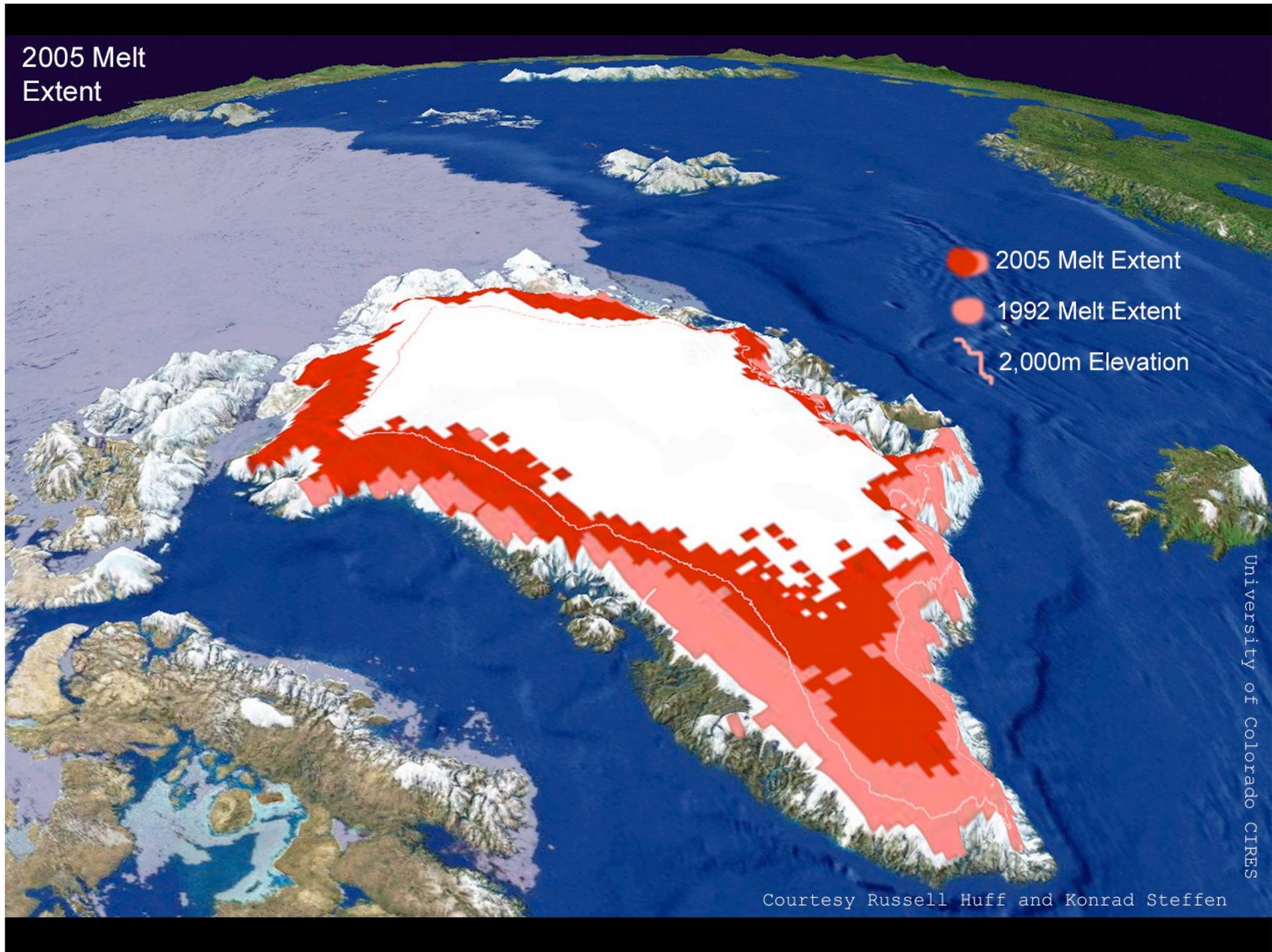
September 2007

September 2008

Qarassup Glacier
Greenland
June 9, 2007
12:12 p.m.



2005 Melt Extent



NATURE INSIGHT RNA SILENCING

22 January 2009 | www.nature.com/nature | \$10

THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

nature

ANTARCTIC WARMING

Climate reconstruction gets
to the heart of the continent

WHO DO YOU THINK YOU ARE?
Personal genomics changes the rules

SOLAR SYSTEM EXPLORATION
The Titan-versus-Europa dilemma

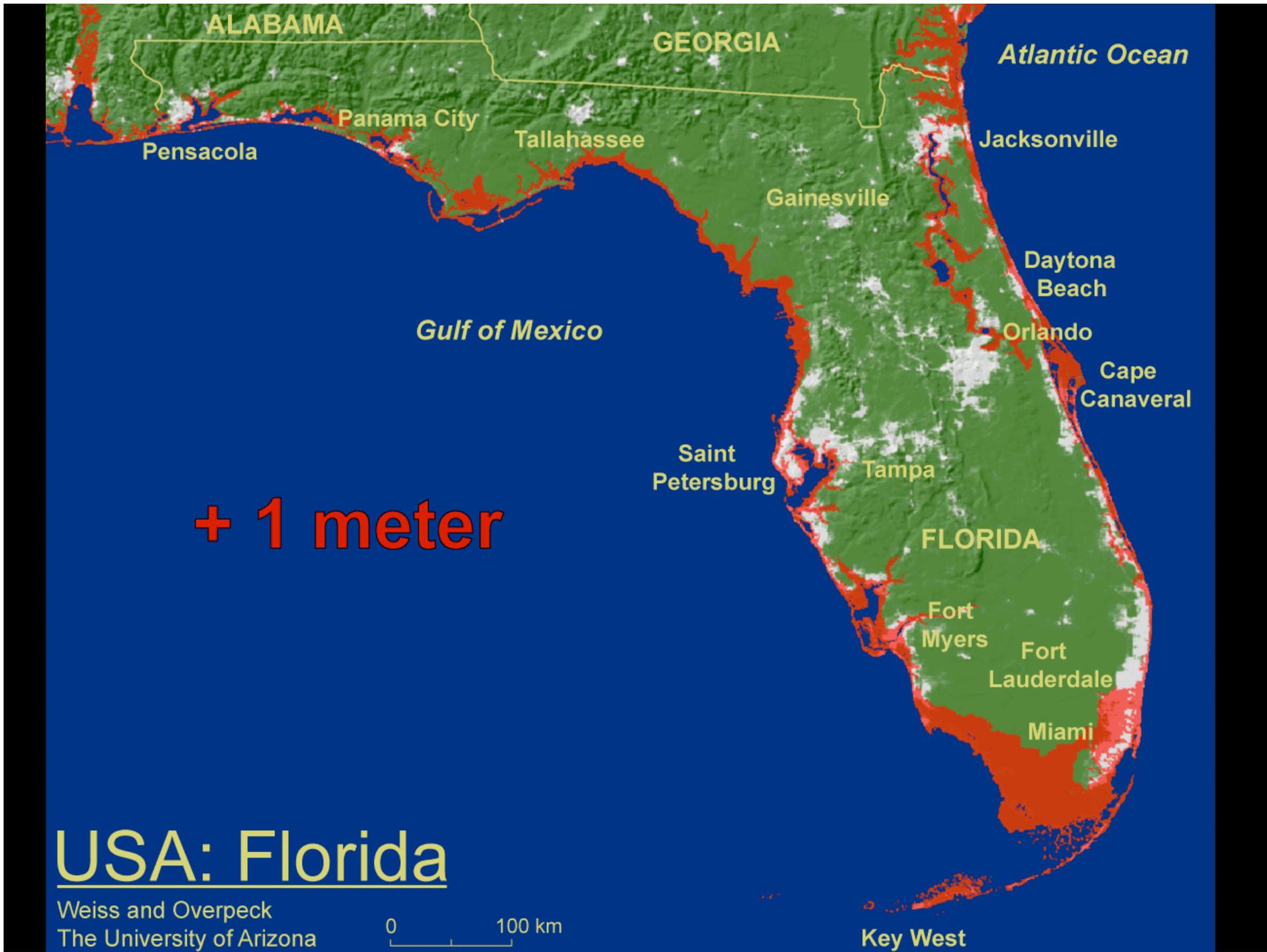
SEXUAL REPRODUCTION
A long wait for *Aspergillus*

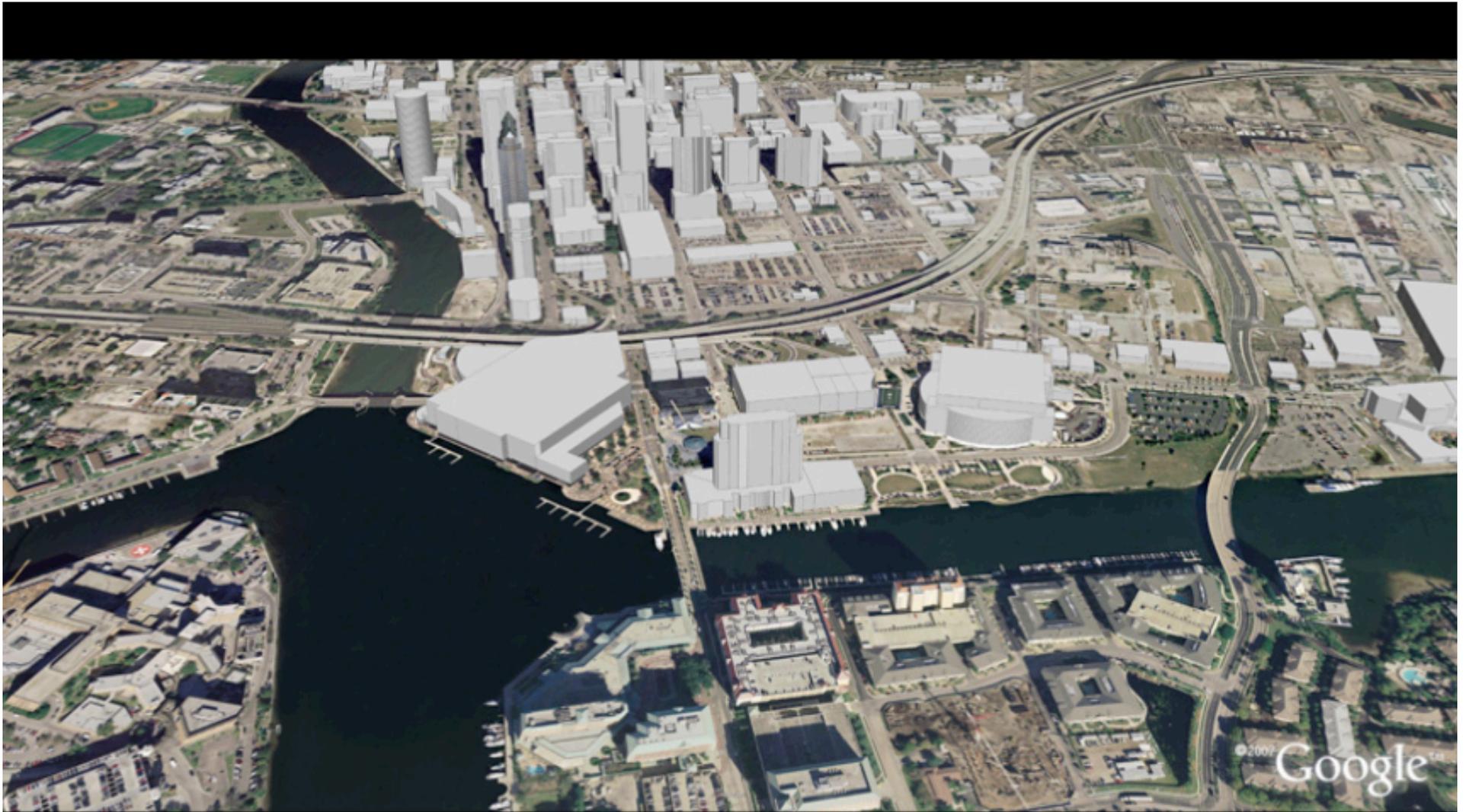
NATUREJOBS
Biotech &
pharmaceuticals

\$10.00US \$12.99CAN









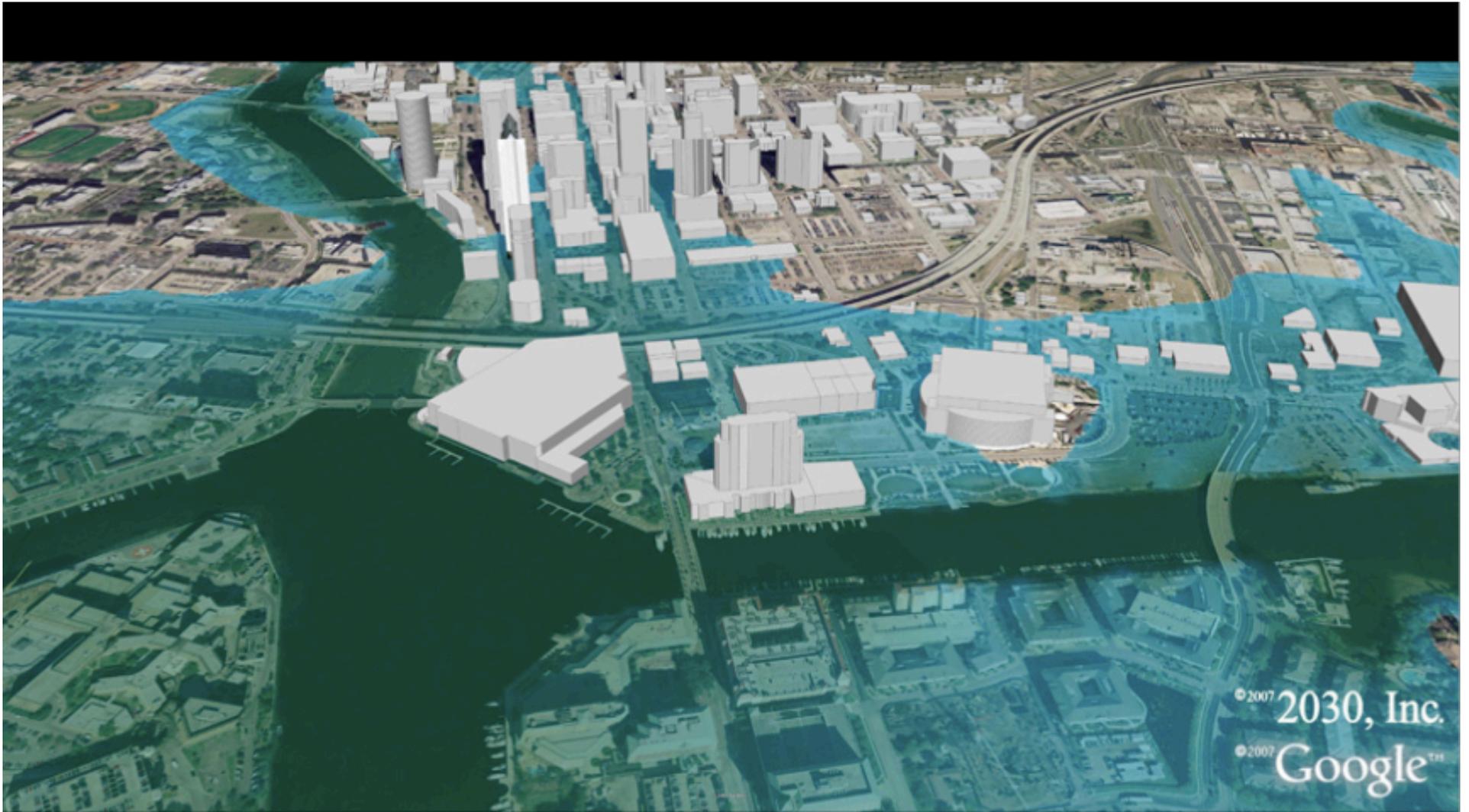
Tampa

Population
382,060

Tampa



Sea level: Google Earth / USGS



© 2007 2030, Inc.
© 2007 Google™

Tampa
1.5 meters



Sea level: Google Earth / USGS

Two Dangerous Feedbacks



Loss of forests



Melting permafrost



*How long can you operate in the **red**?*

...with your car's engine?

...with your planet?



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 beyond 2000
- Reduce U.S. CO₂ emissions 60%–80% (?) by 2050

Total savings needed by 2030: ~1,200 MtC/yr

“Houston, we have a problem.”

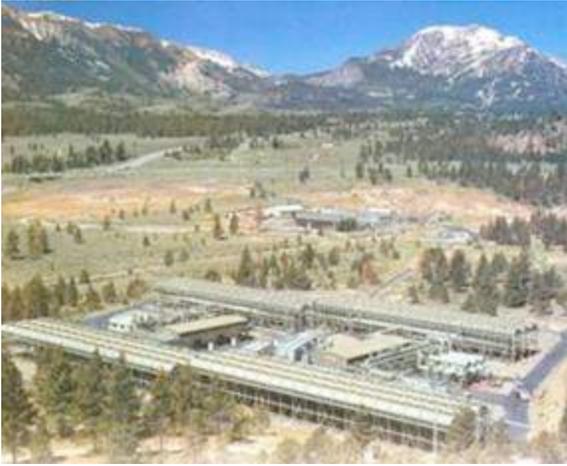


Apollo 13
©Universal Studios



Key Energy Options

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



Geothermal



PV



Biofuels



Efficiency



CSP



Biomass Power



Wind

2007 American Solar Energy
Society 2030 Study:

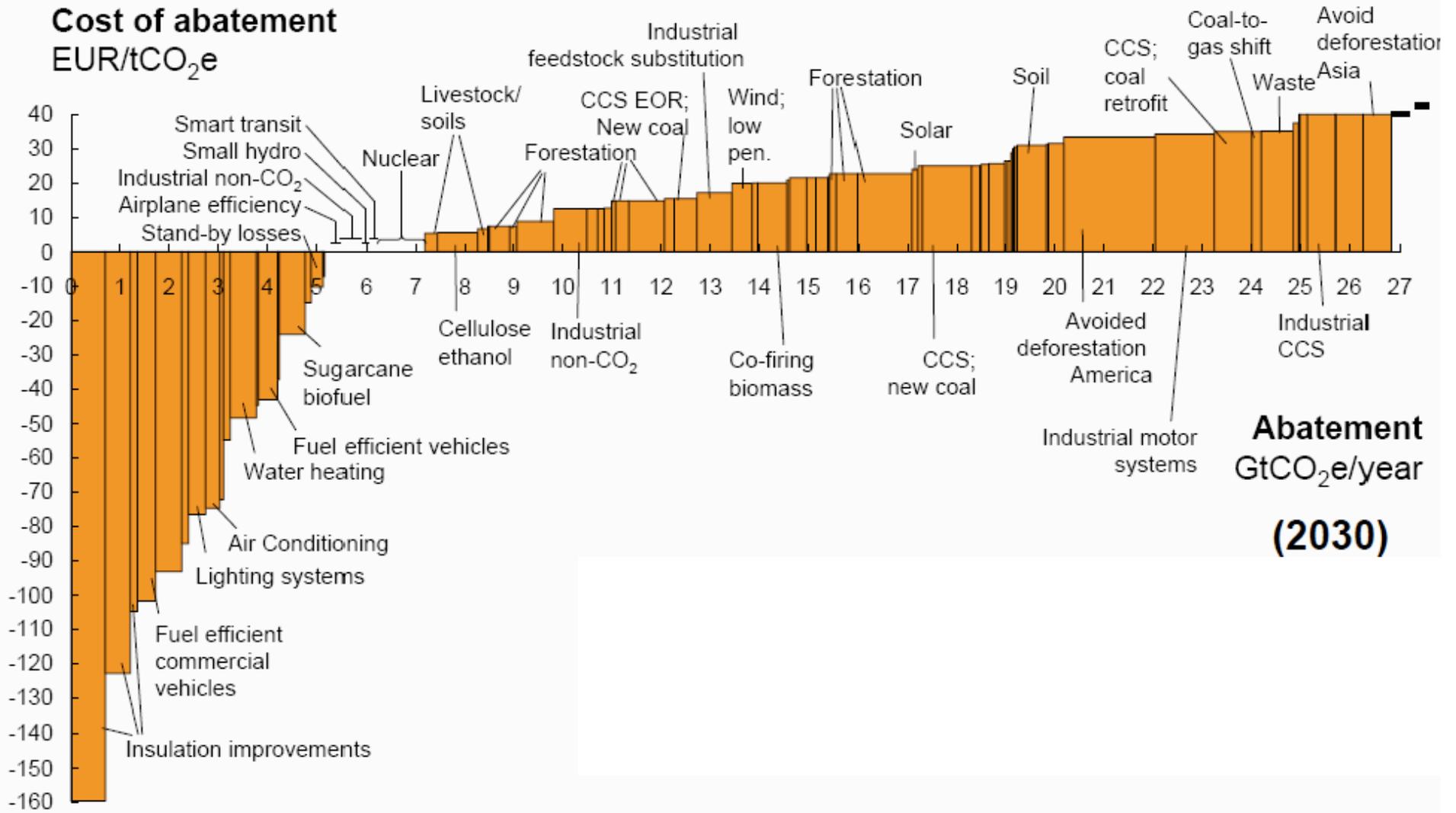
*Tackling Climate Change in
the U.S.*

Energy Efficiency

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



Cost of abatement EUR/tCO₂e



Energy Efficiency Savings

- Electricity: 218 MtC/yr, 0 – 4 ¢/kWh
(20% savings off 2030 projection)
- Oil: 344 MtC/yr, \$5 - \$30/bbl
- Gas: 126 MtC/yr, \$0 - \$3/MBtu



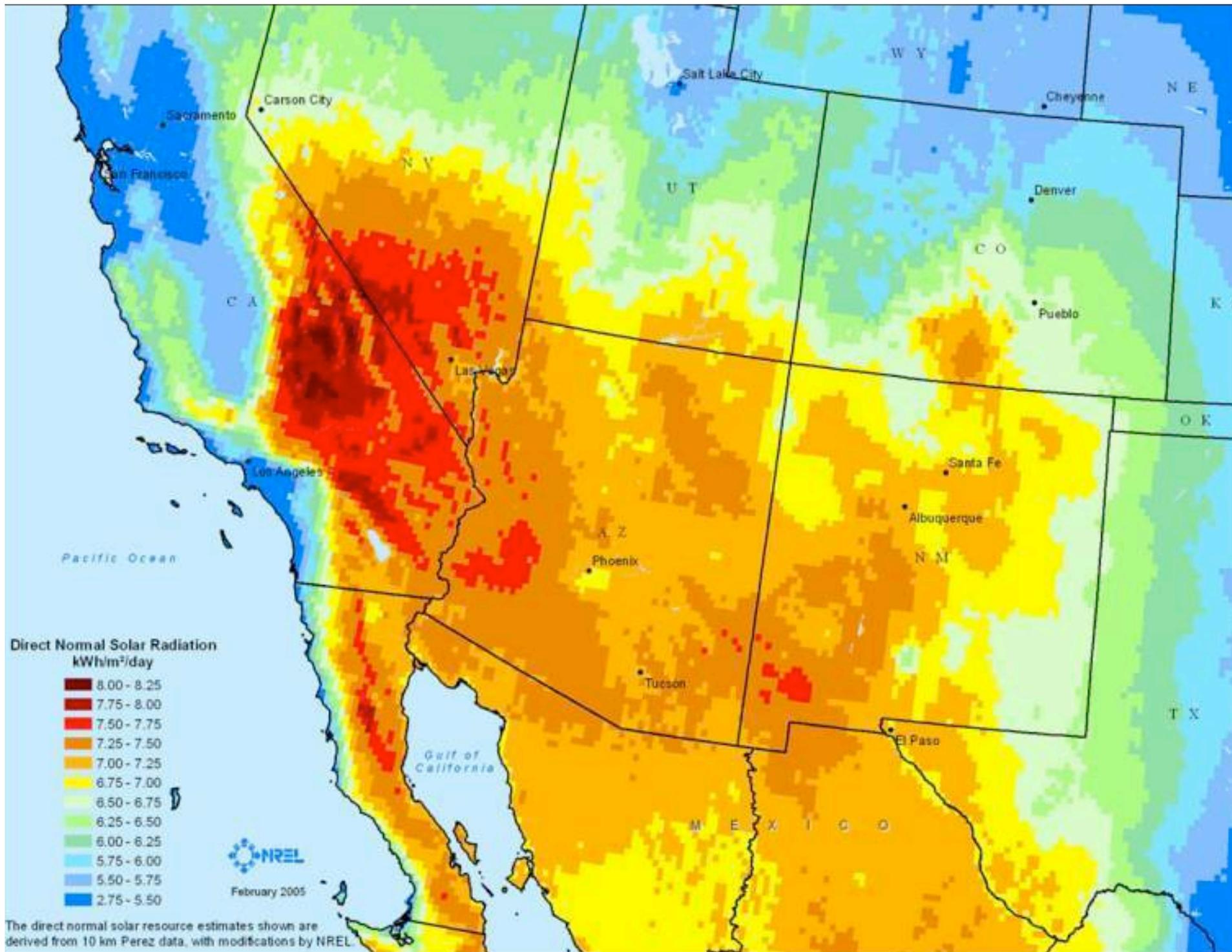
Savings: 688 MtC/yr

Concentrating Solar Power (CSP)



354 MW Solar Electric Generating Systems (SEGS)



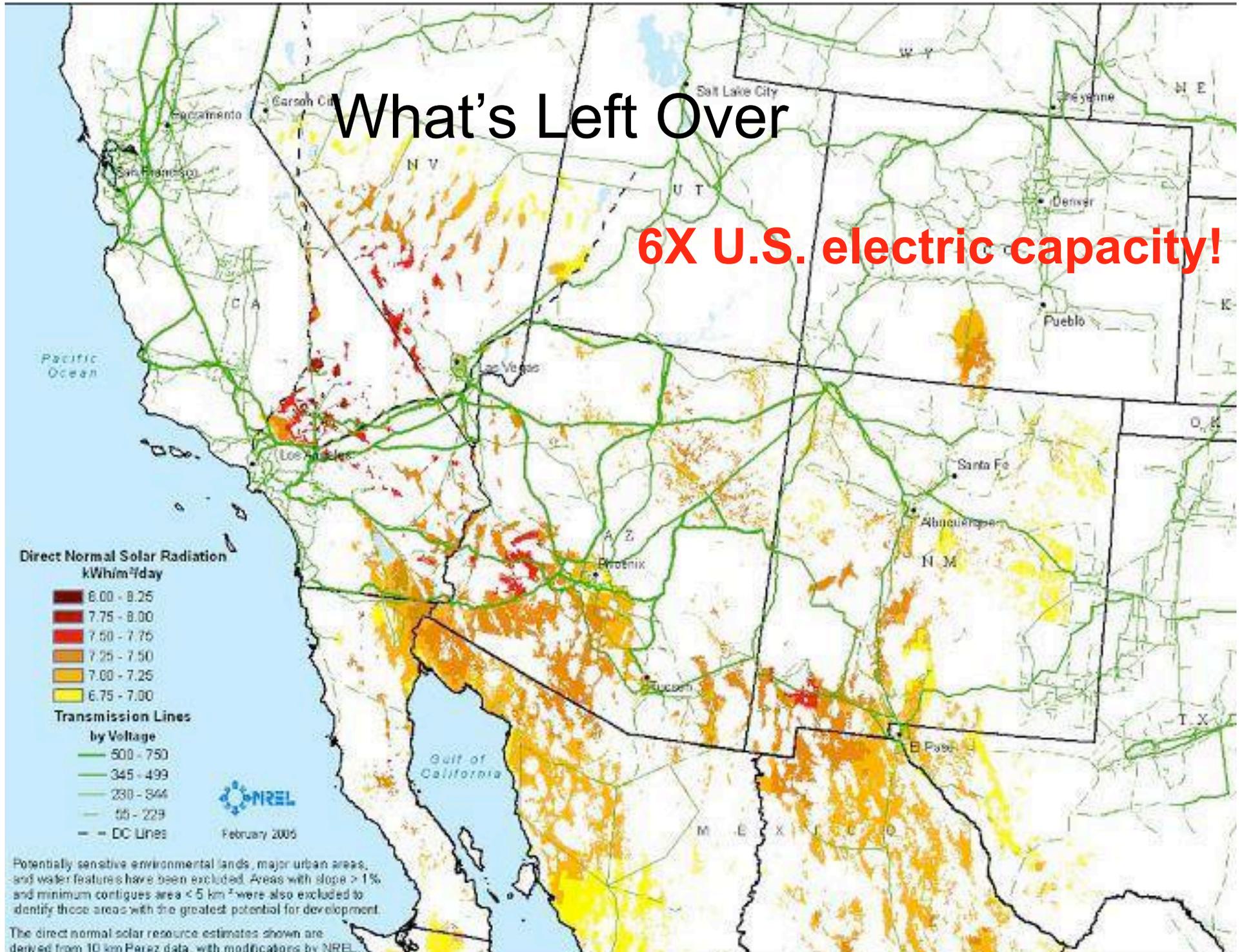


Exclude:

- Used and sensitive land
- Solar < 6.75 kWh/m² per day
- Ground slope > 1%

What's Left Over

6X U.S. electric capacity!



New 64 MWe Acciona Solar Parabolic Trough Plant



Planned 280 MW Solana Plant with 6 hrs Storage



1500 construction jobs
over two years

85 permanent jobs

Artist Rendition



Renewable Energy

Contracts for over 4,000 MW of U.S. Projects



1,365 MW



1,750 MW



1,211 MW



177 MW

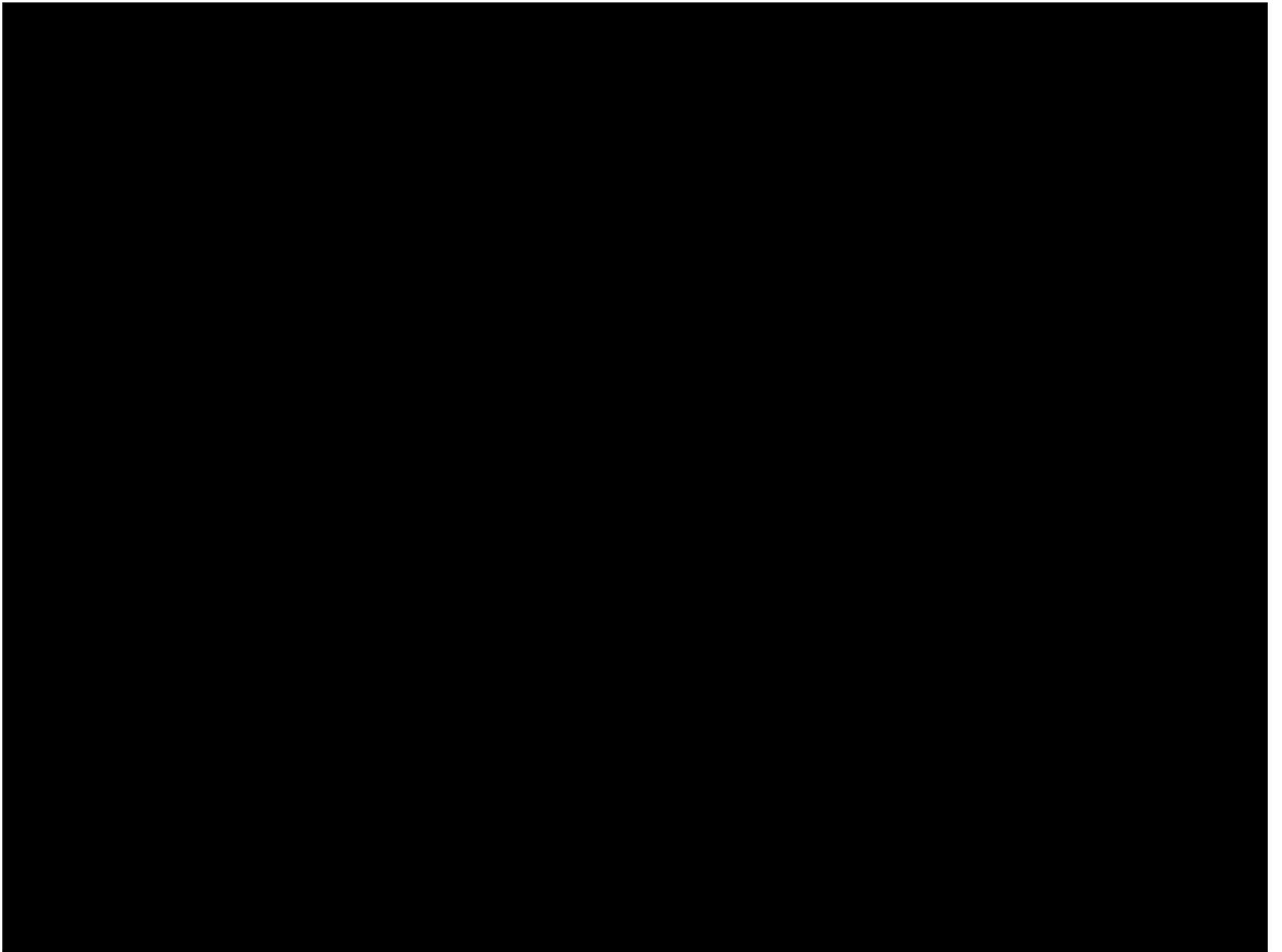
CSP Savings

- Dispatchable power with 6 hr of storage
- 80,000 MW, 6 to 14¢/kWh

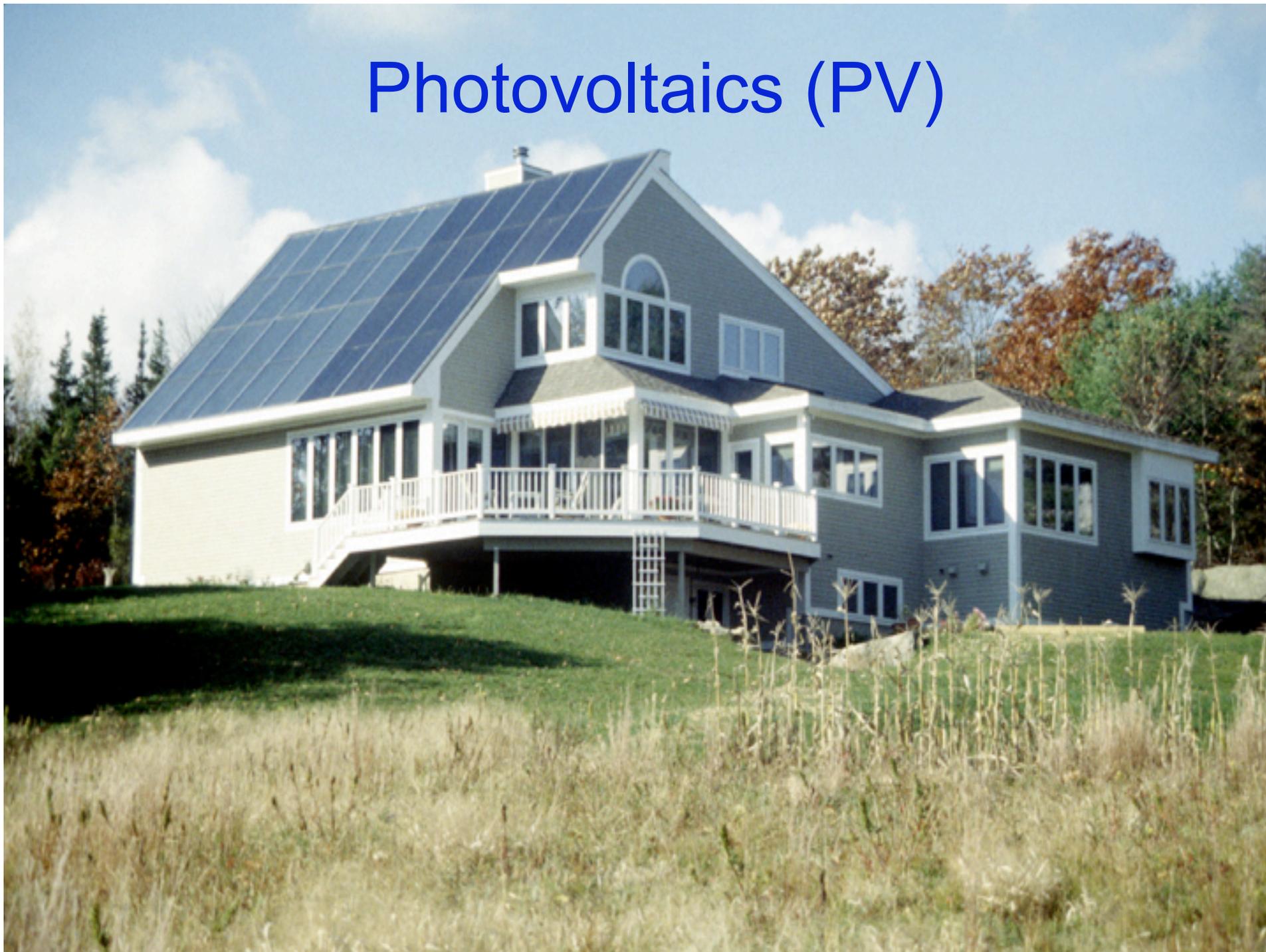


Savings: 63 MtC/yr

the **POWER** of csp



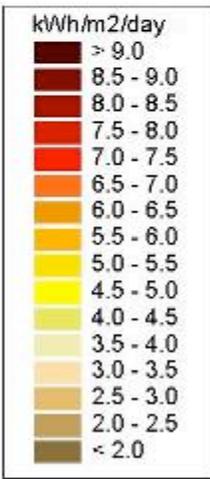
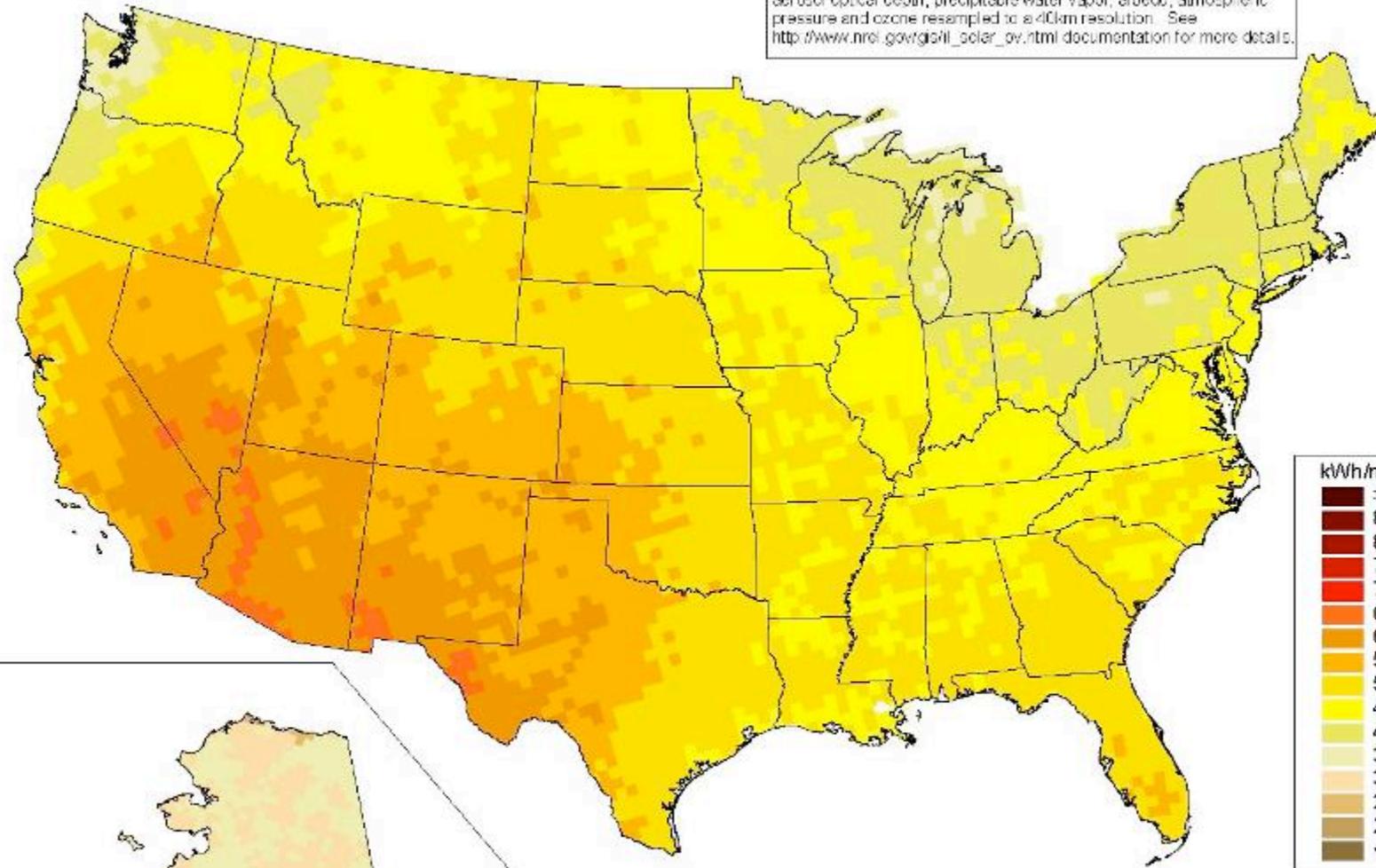
Photovoltaics (PV)



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

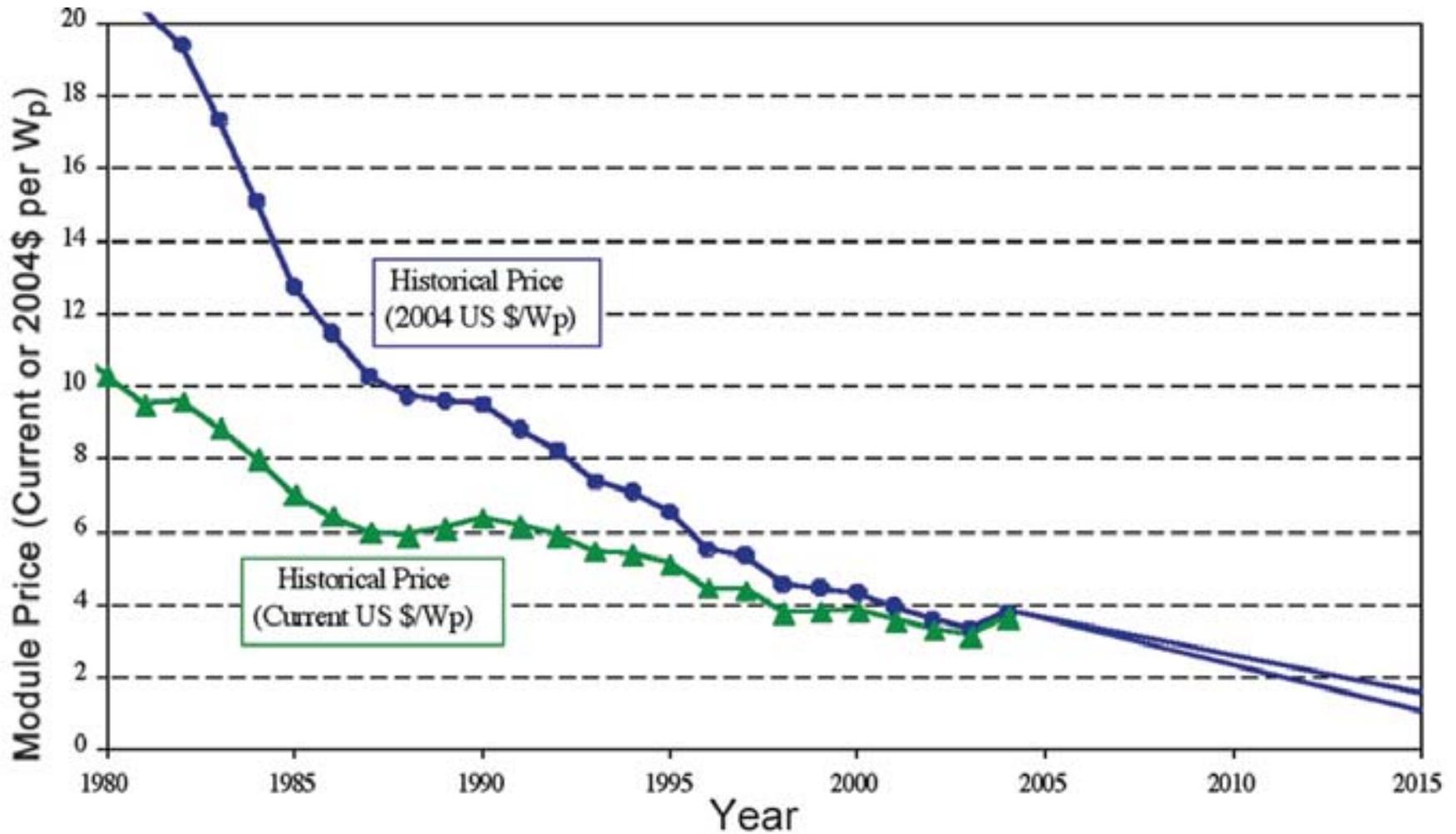
Annual

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/til_solar_pv.html documentation for more details.

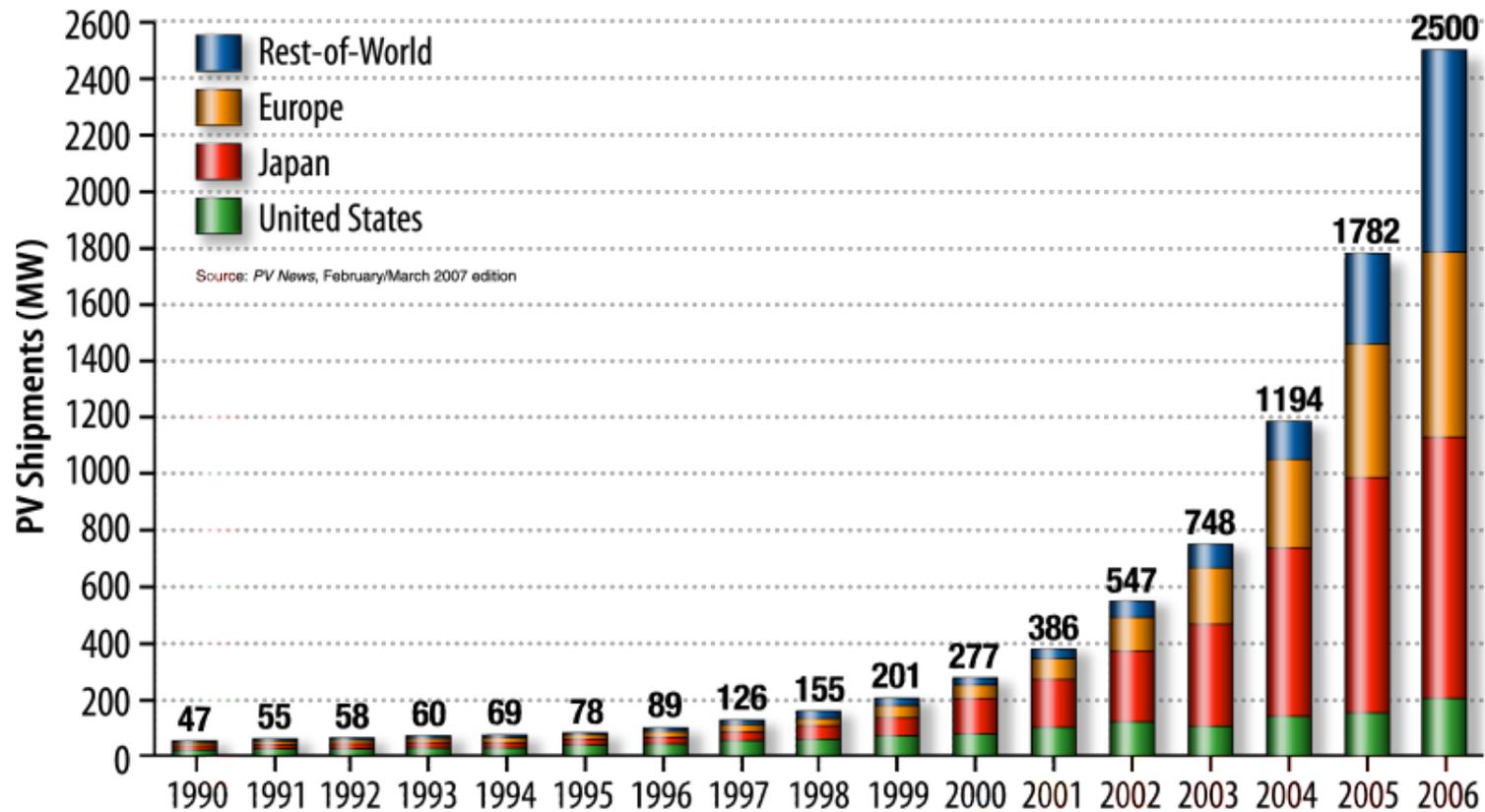


Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004

PV Module Prices



Worldwide PV Shipments



PV Savings

- 200,000 MW_p
- 6 to 28 ¢/kWh (retail)

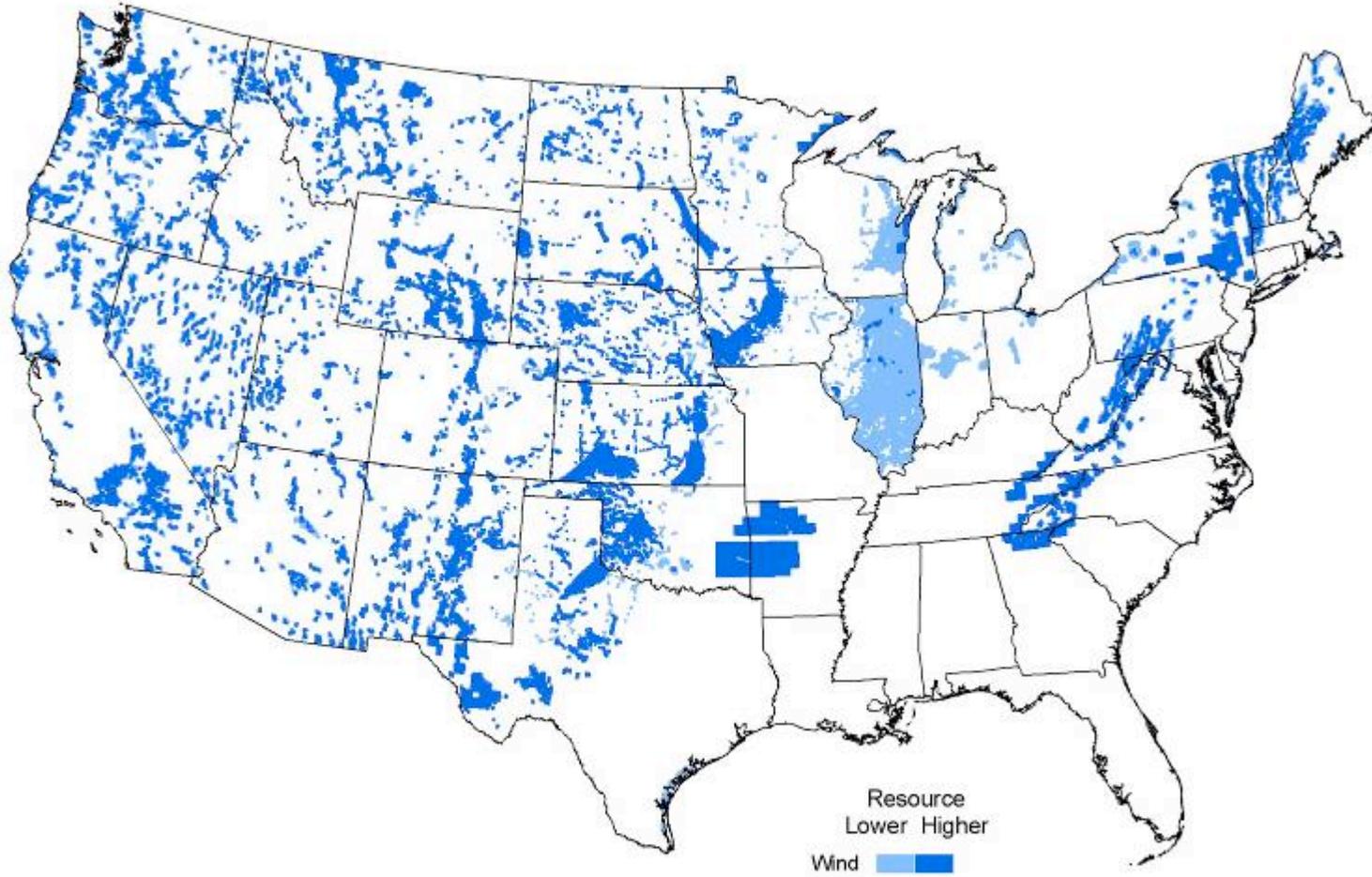


Savings: 63 MtC/yr

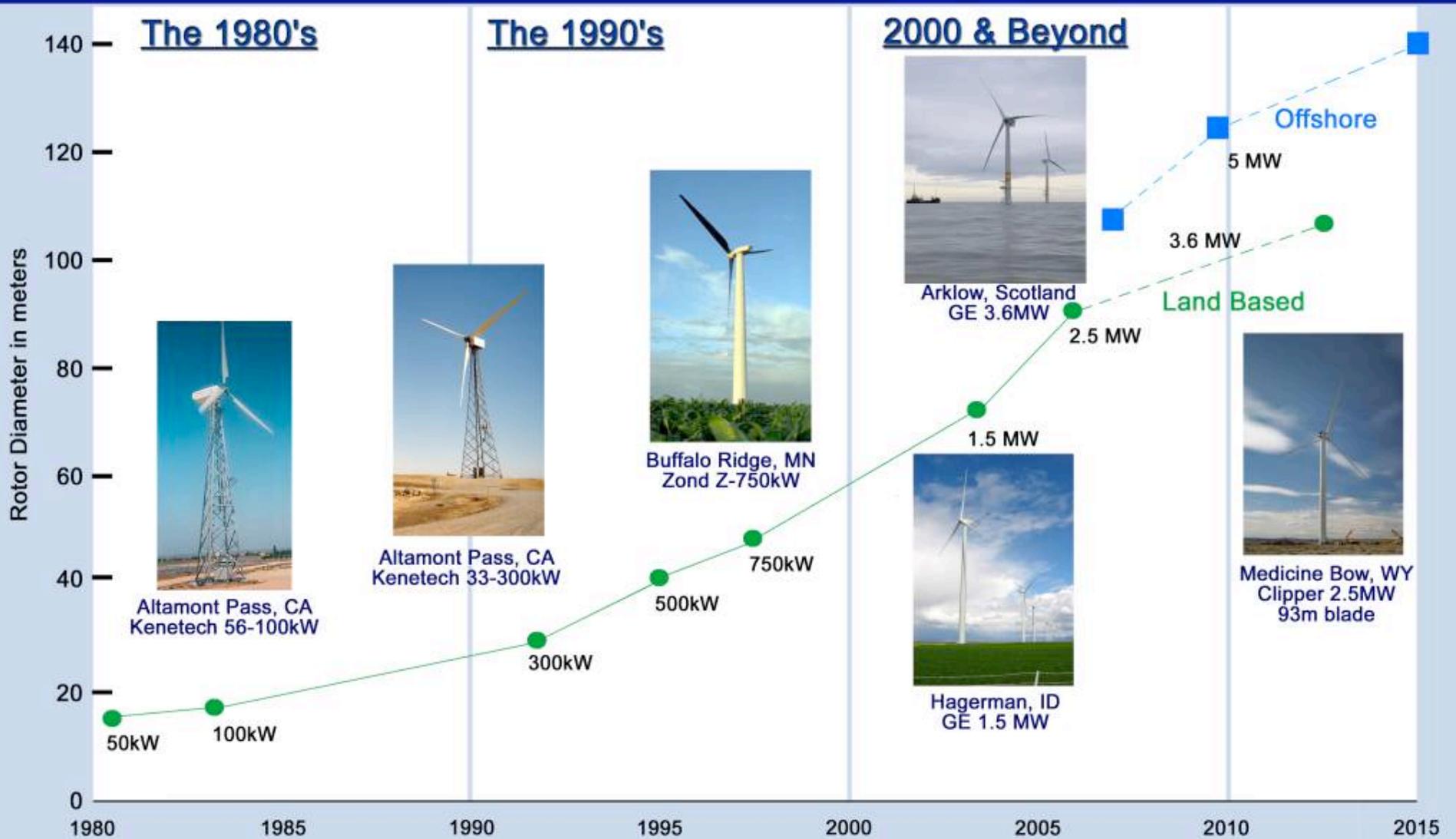
Wind



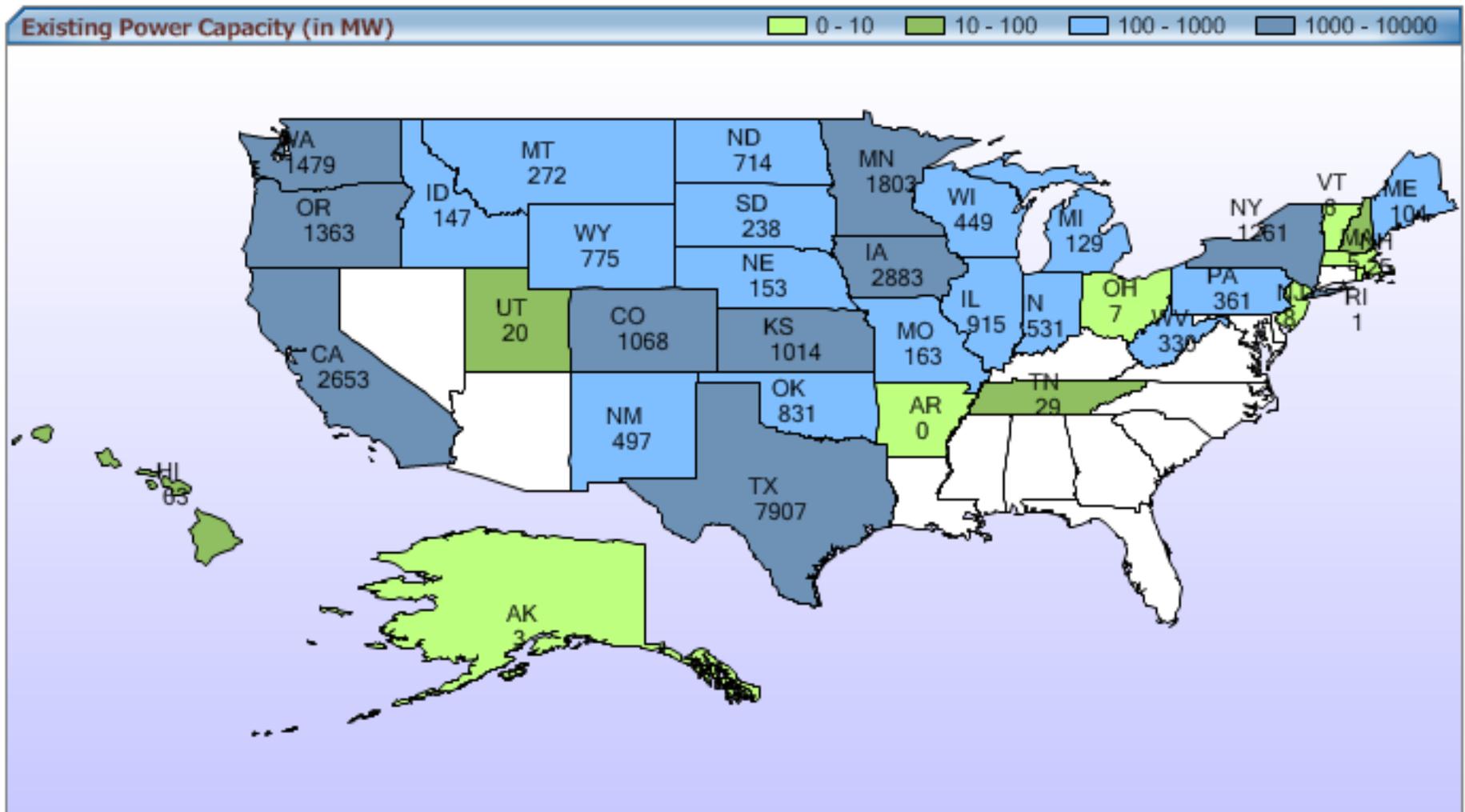
U.S. Wind Resource



Evolution of U.S. Commercial Wind Technology



Wind Power Capacity April 2009



Wind Savings

- 20% grid energy, 245,000 MW
- 3 to 7¢/kWh

Savings: 181 MtC/yr



Biomass and Biofuels

Wood chips



Switch grass



Poplars



Fats and Oils

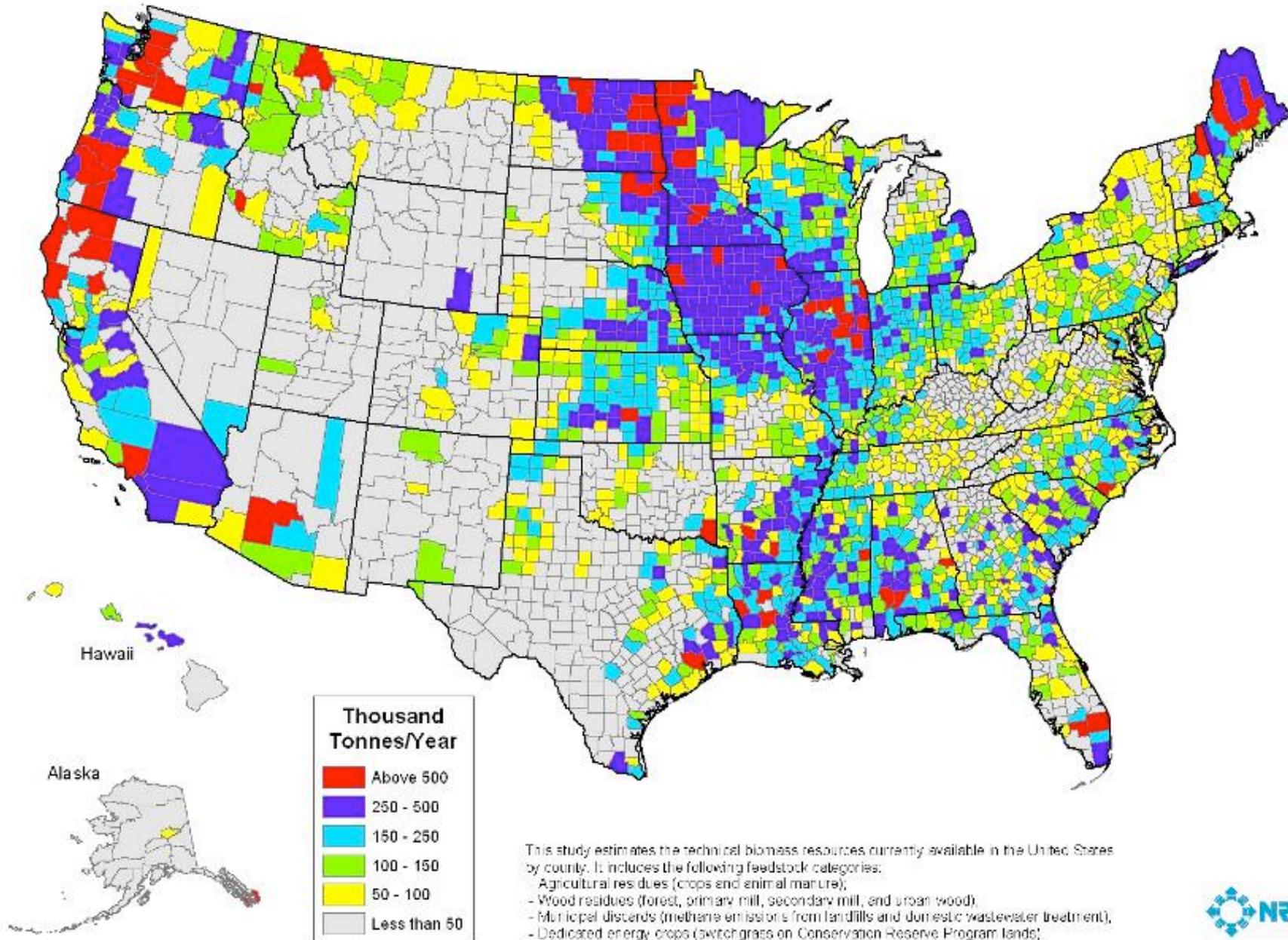


Municipal solid waste



Corn Stover

Biomass Resources Available in the United States



Biomass Power Savings

- Wood residues and municipal discards
- 45,000 MW
- 5 to 8¢/kWh



Savings: 75 MtC/yr

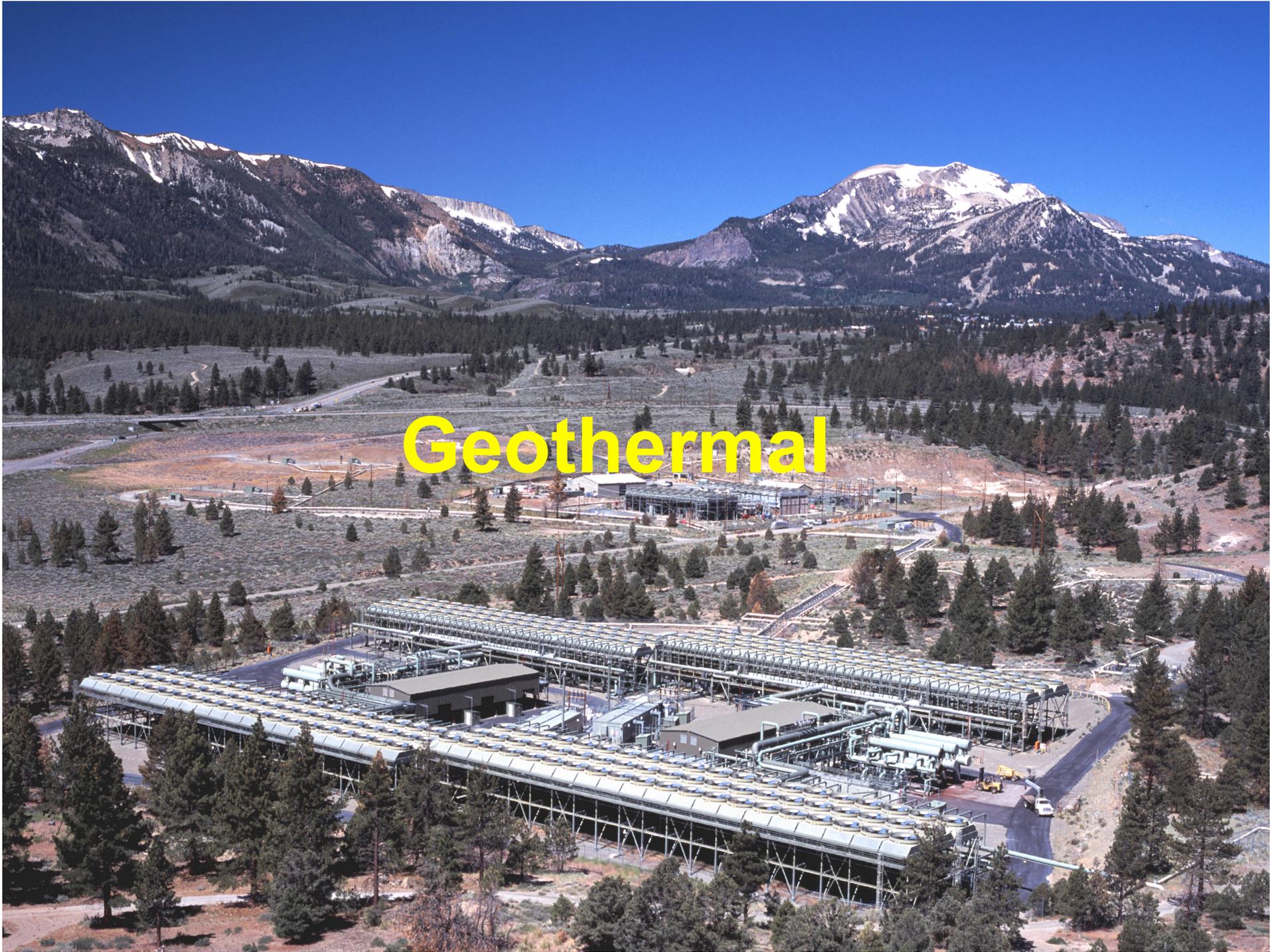
Biofuels Savings

- Ethanol from crop residues & energy crops
- Saves 28 billion gallons of gas in 2030
- \$0.90 to \$3.75/gal gas equiv.

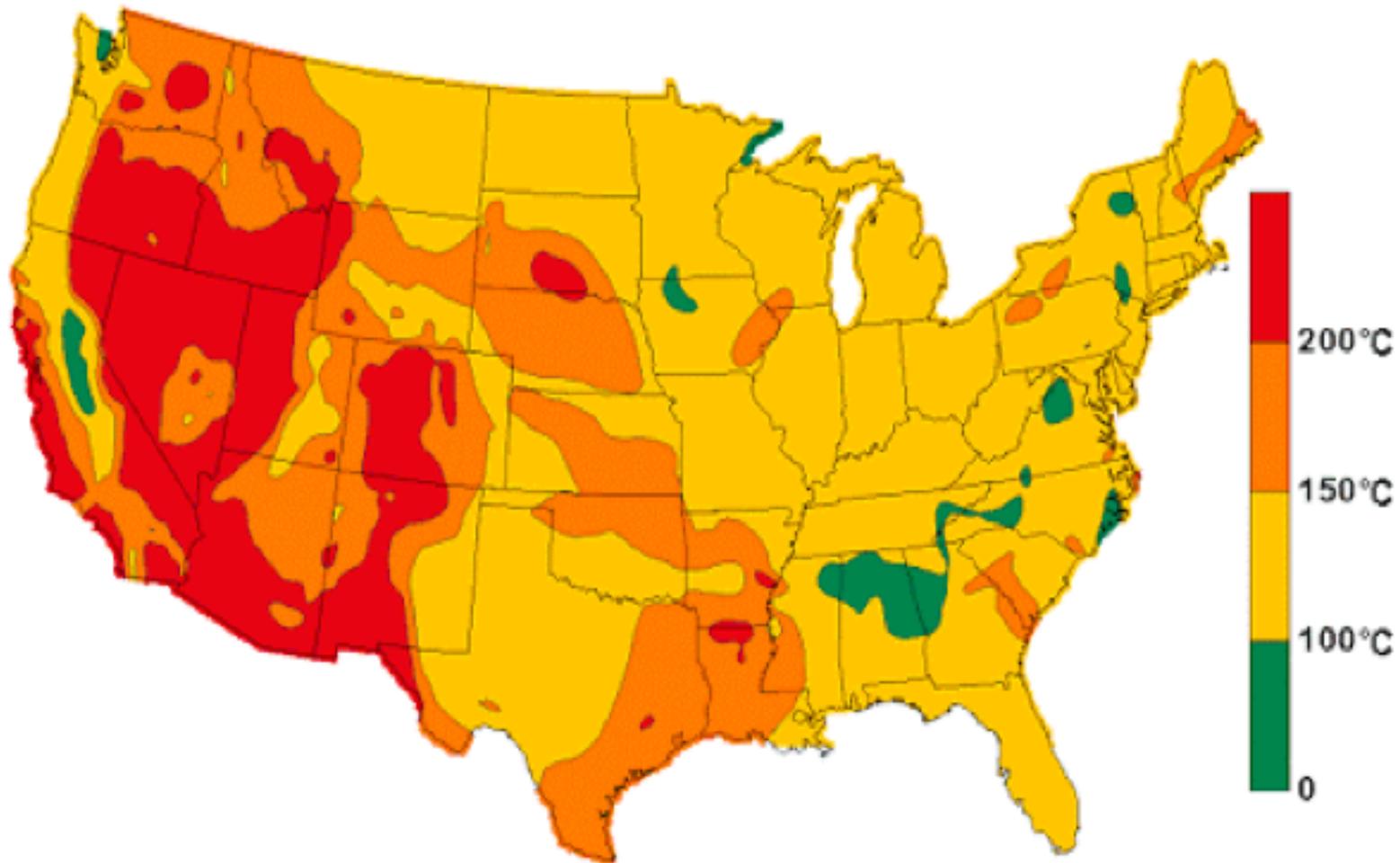


Savings: 58 MtC/yr

Geothermal



Temperatures at 6 km Depth



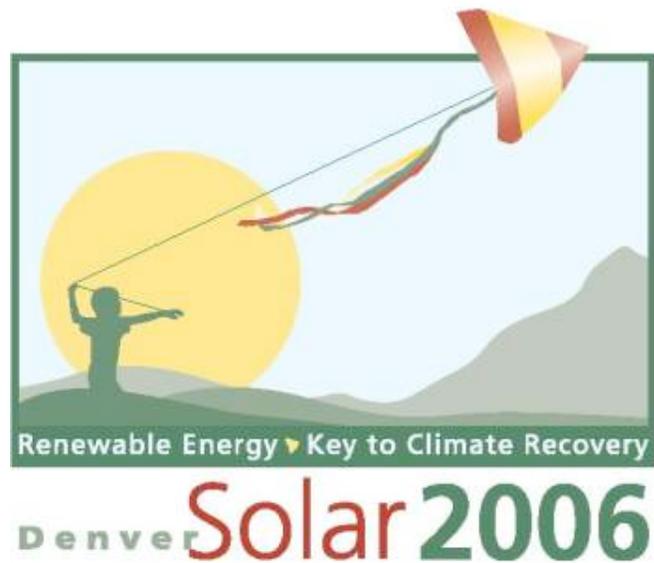
Geothermal Power Savings

- 50,000 MW
- 25% existing resources, 25% expanded, 50% from oil & gas wells
- 5 to 10 ¢/kWh



Savings: 83 MtC/yr

Putting It All Together



Potential Reduction in U.S. Carbon Emissions



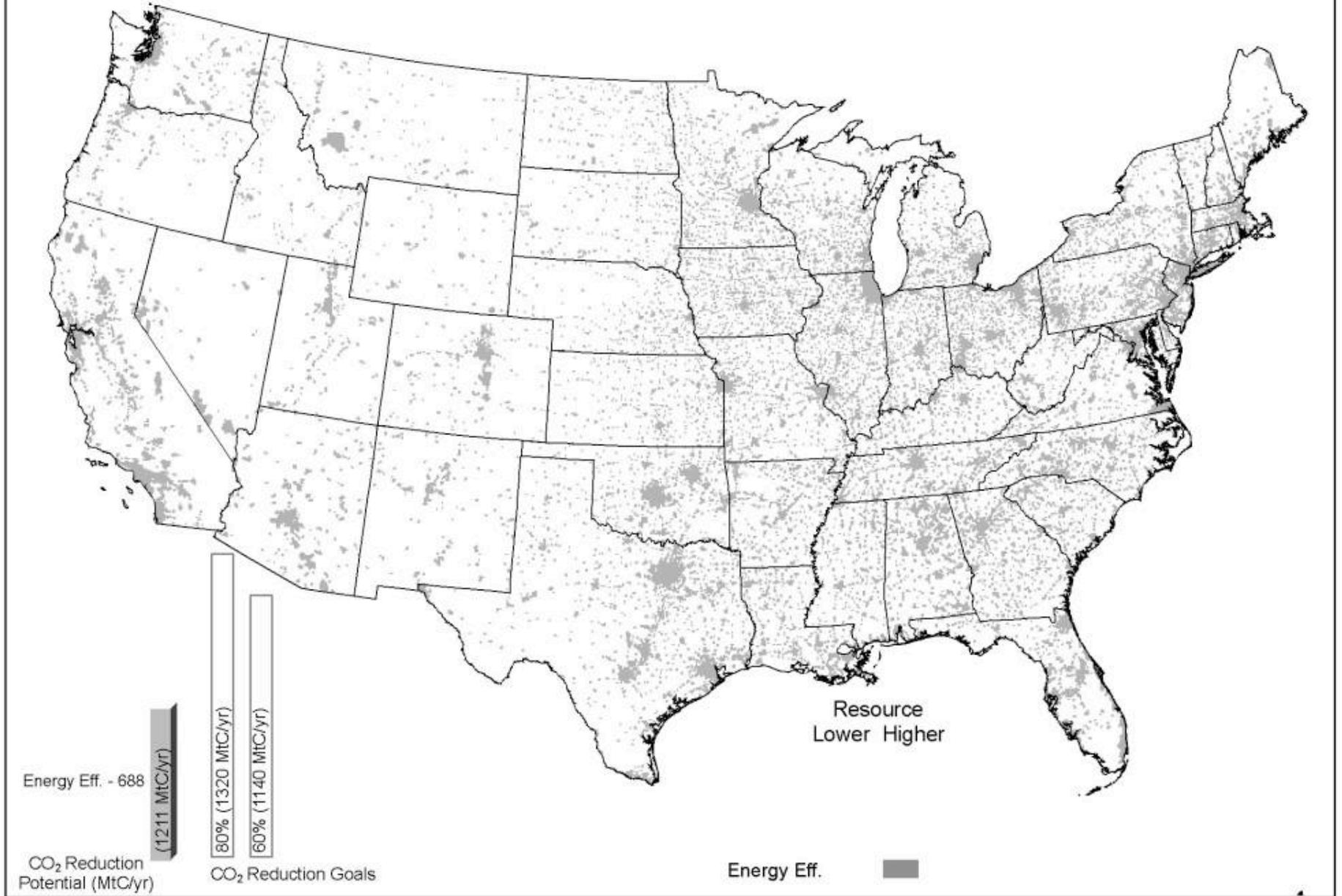
CO₂ Reduction Potential (MtC/yr)

80% (1320 MtC/yr)
60% (1140 MtC/yr)

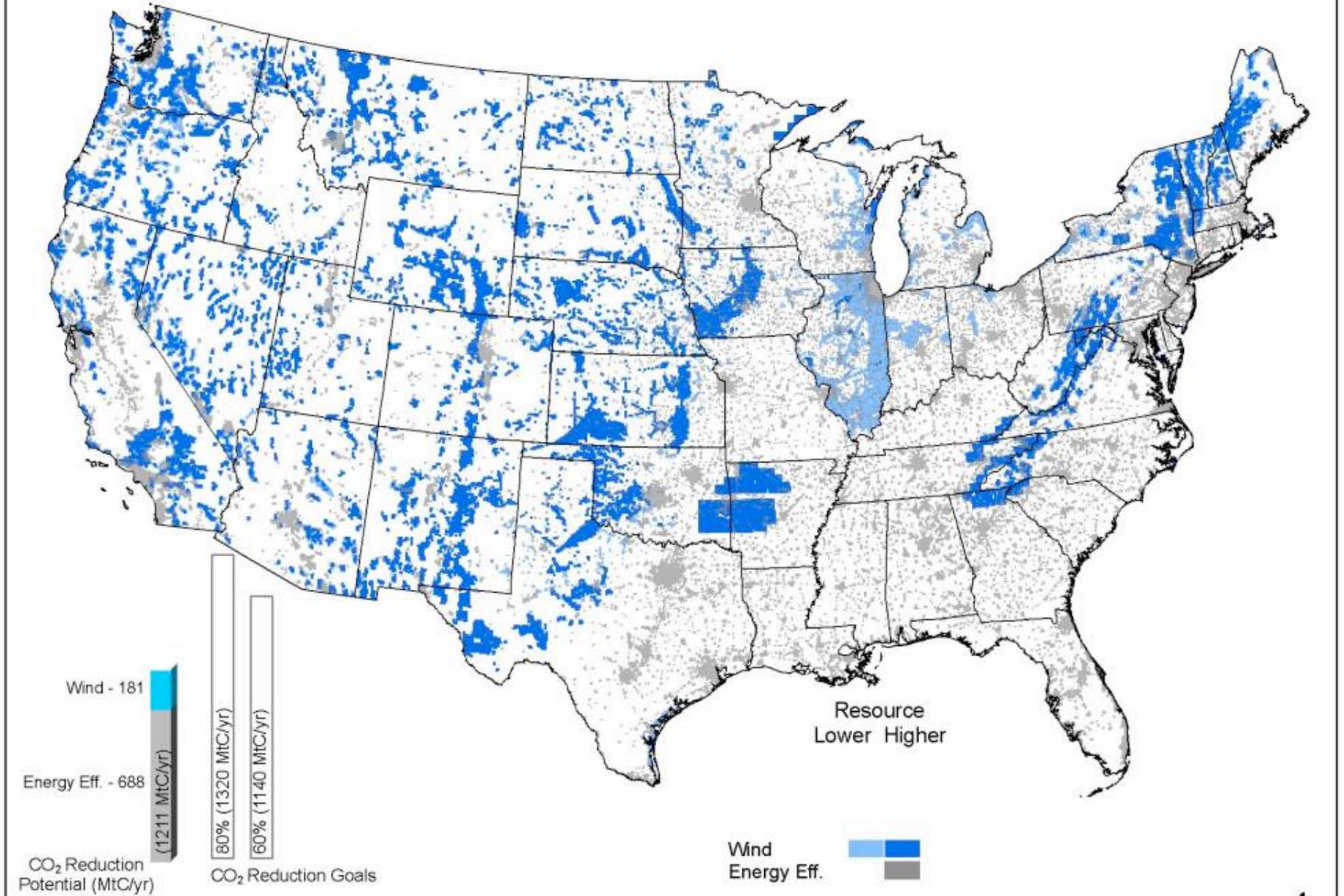
CO₂ Reduction Goals

Resource
Lower Higher

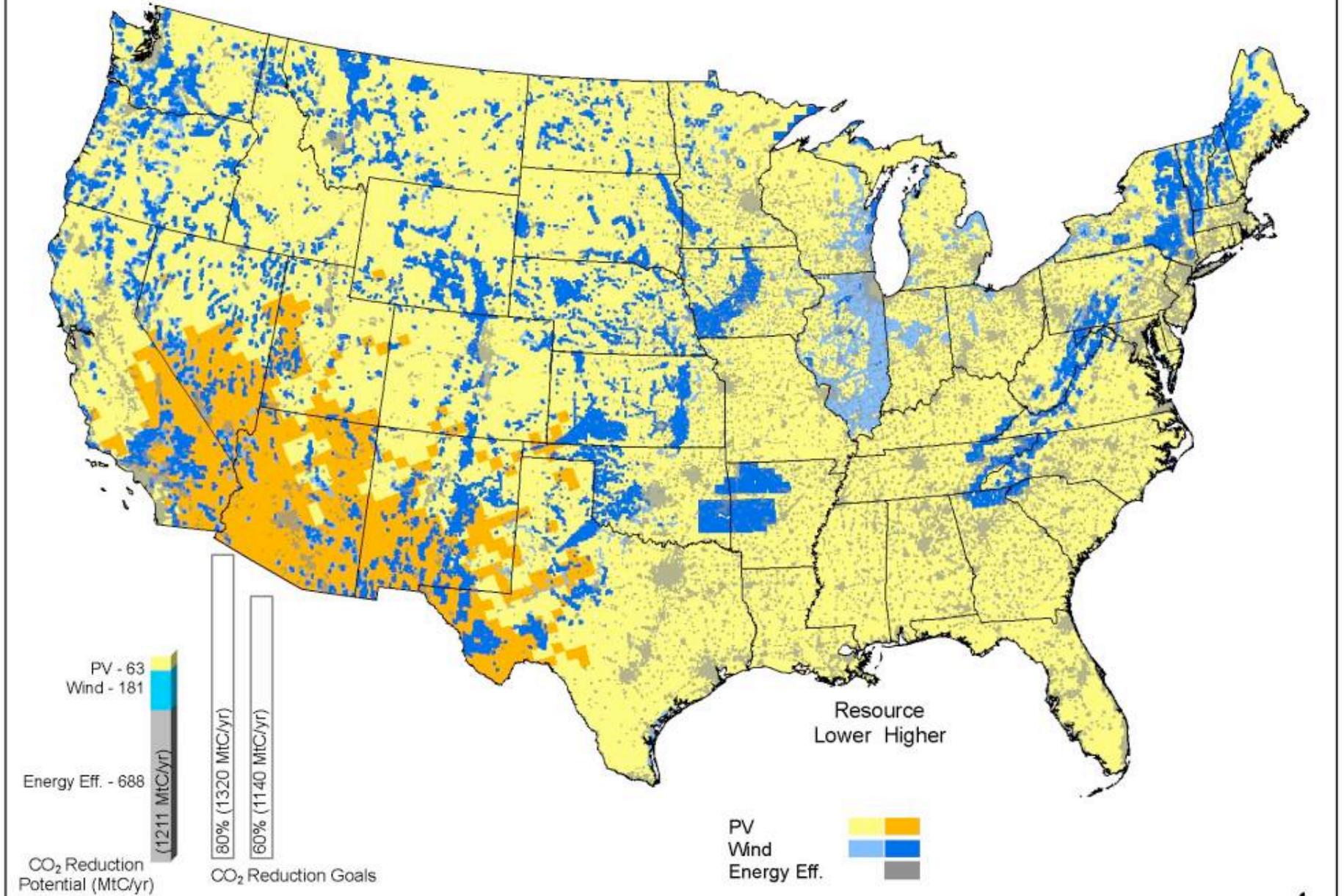
Potential Reduction in U.S. Carbon Emissions



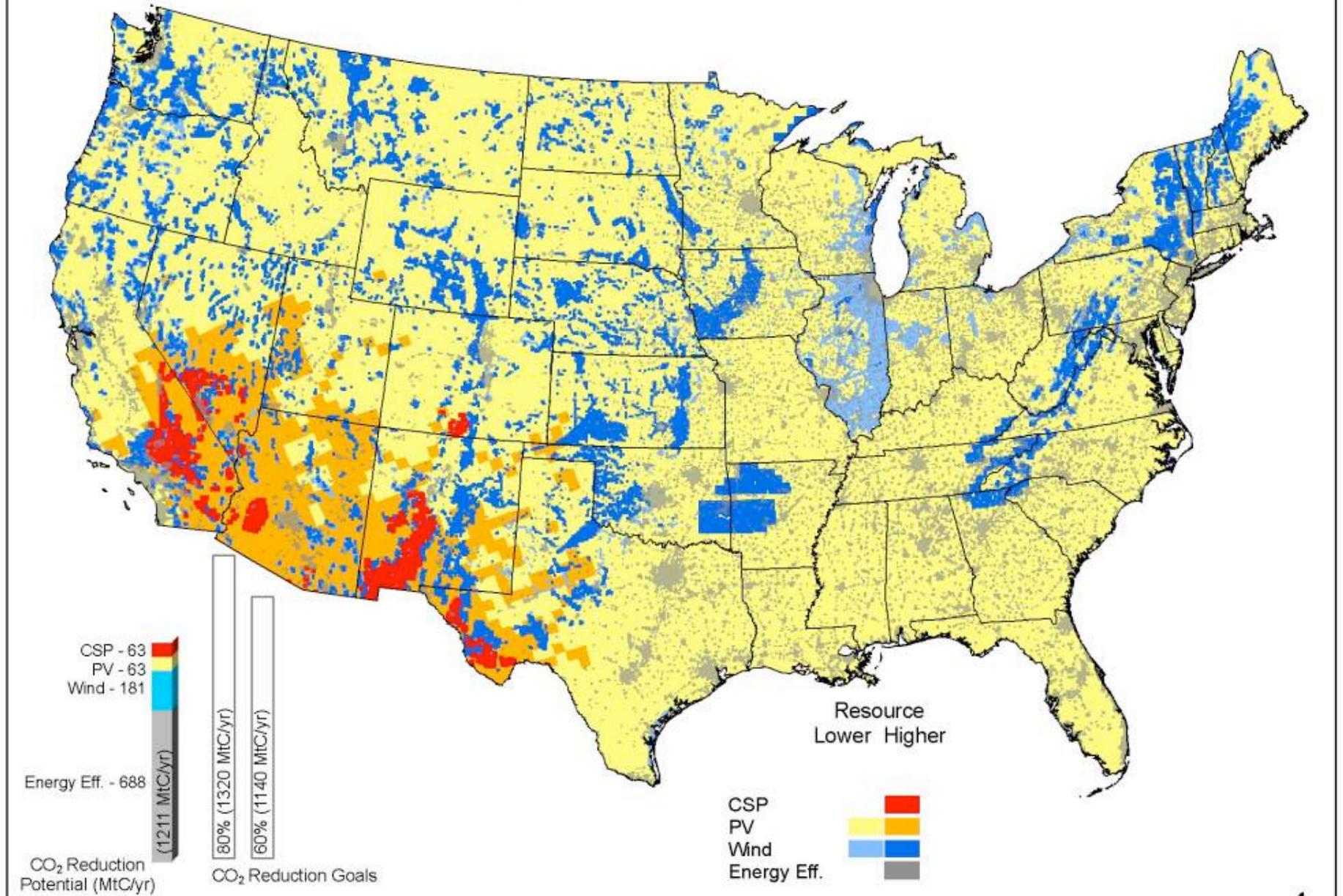
Potential Reduction in U.S. Carbon Emissions



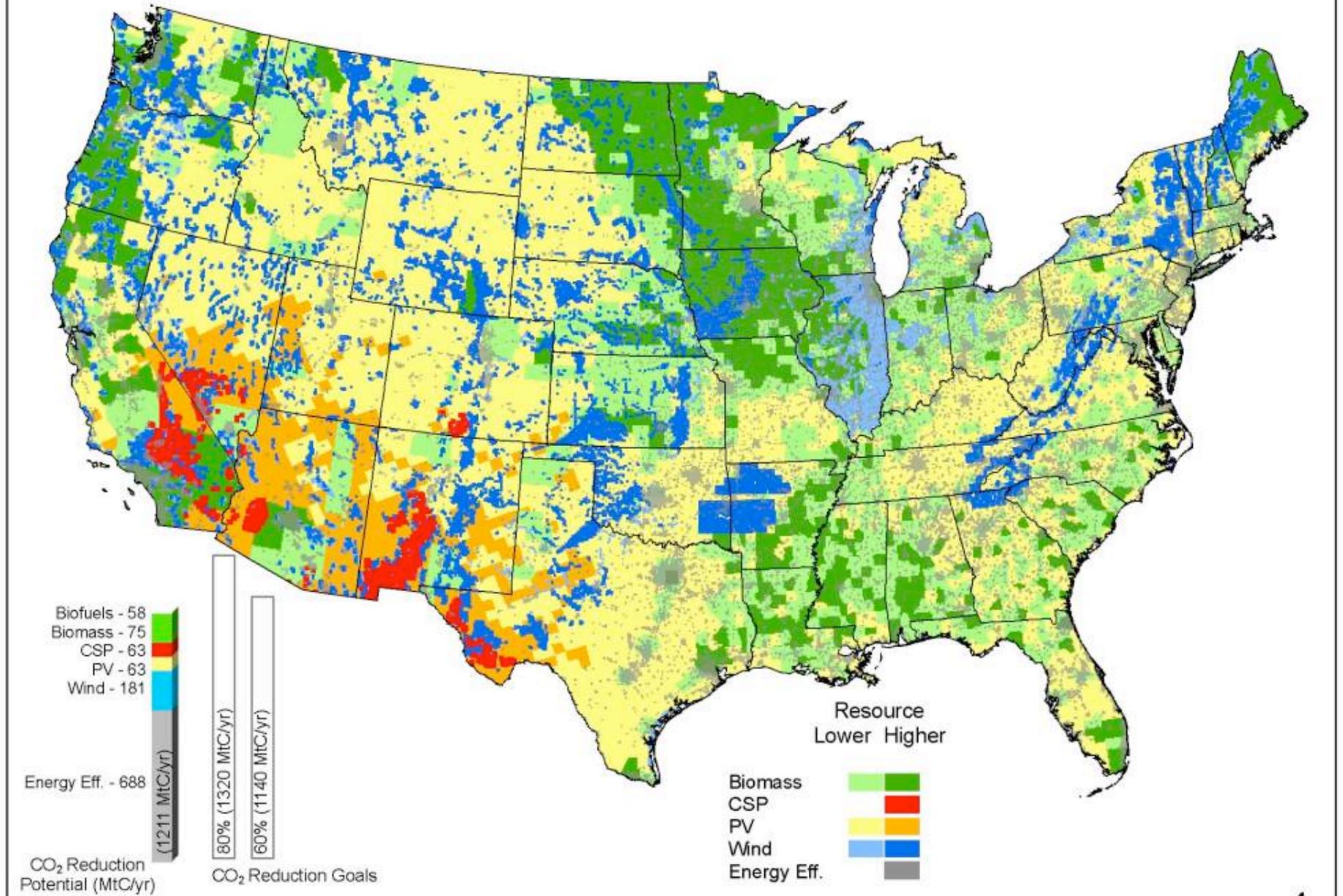
Potential Reduction in U.S. Carbon Emissions



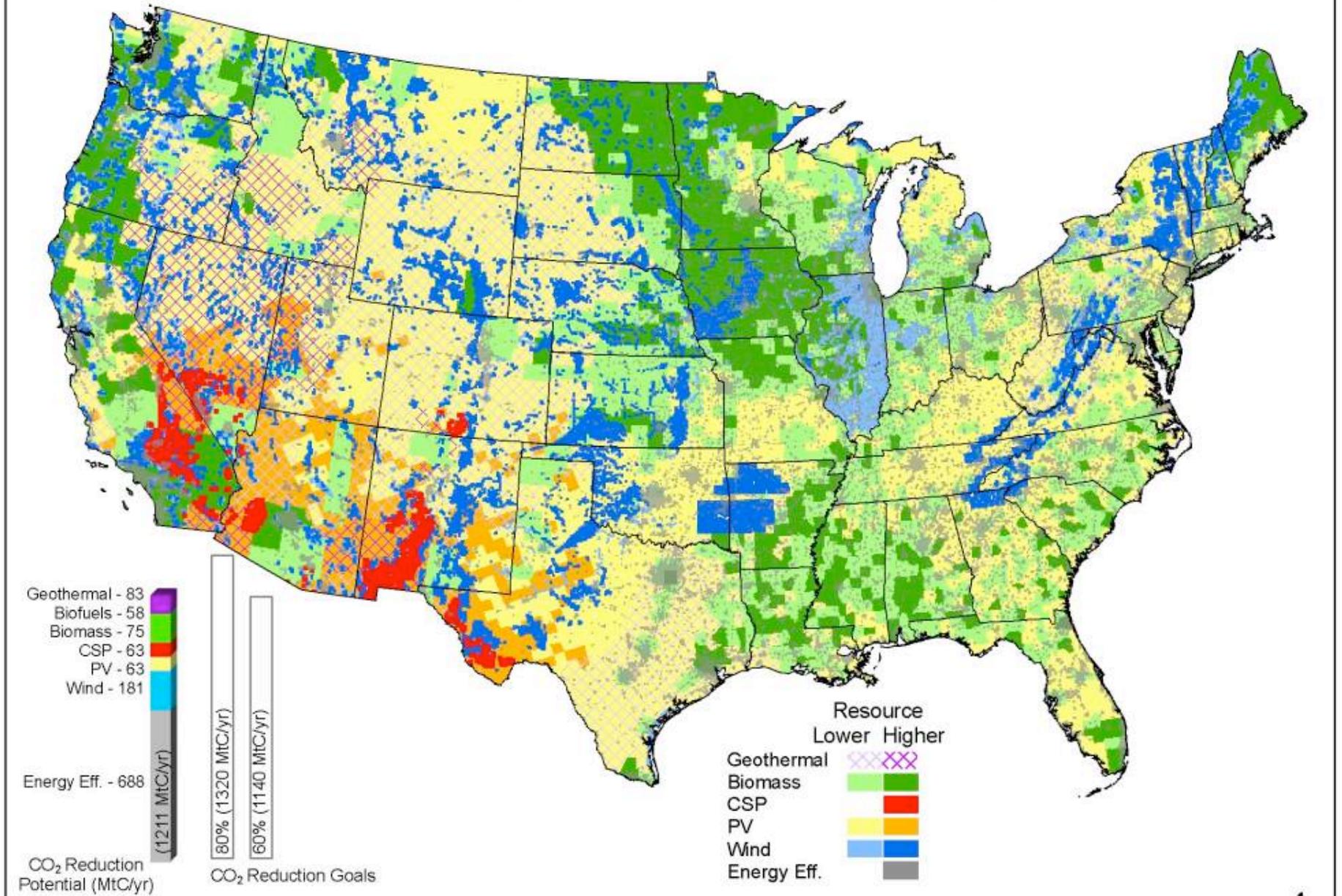
Potential Reduction in U.S. Carbon Emissions



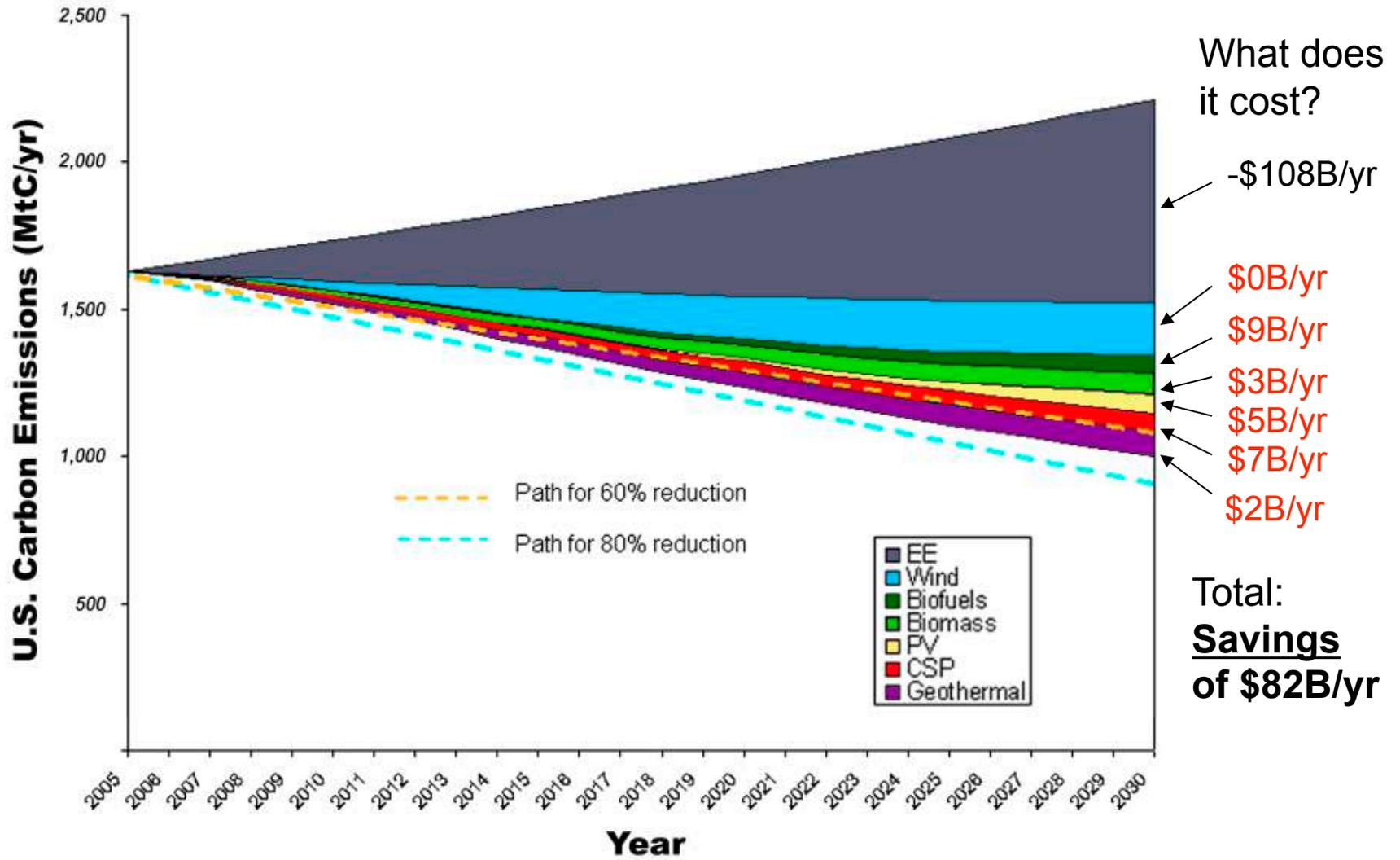
Potential Reduction in U.S. Carbon Emissions



Potential Reduction in U.S. Carbon Emissions

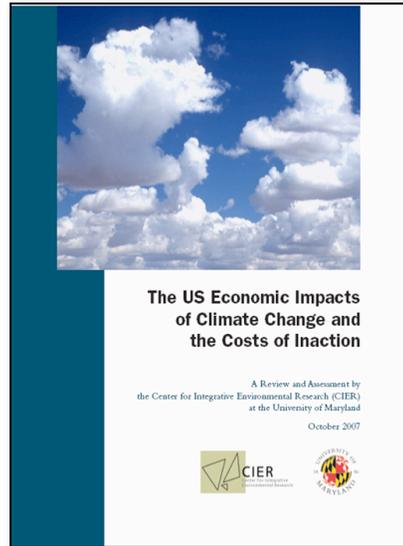


Potential U.S. Carbon Reductions



57% Energy Efficiency, 43% Renewables

Cost of Inaction



“Delayed action (or inaction) will most likely be the most expensive policy option”

The Global Warming Price Tag in Four Impact Areas, 2025 through 2100

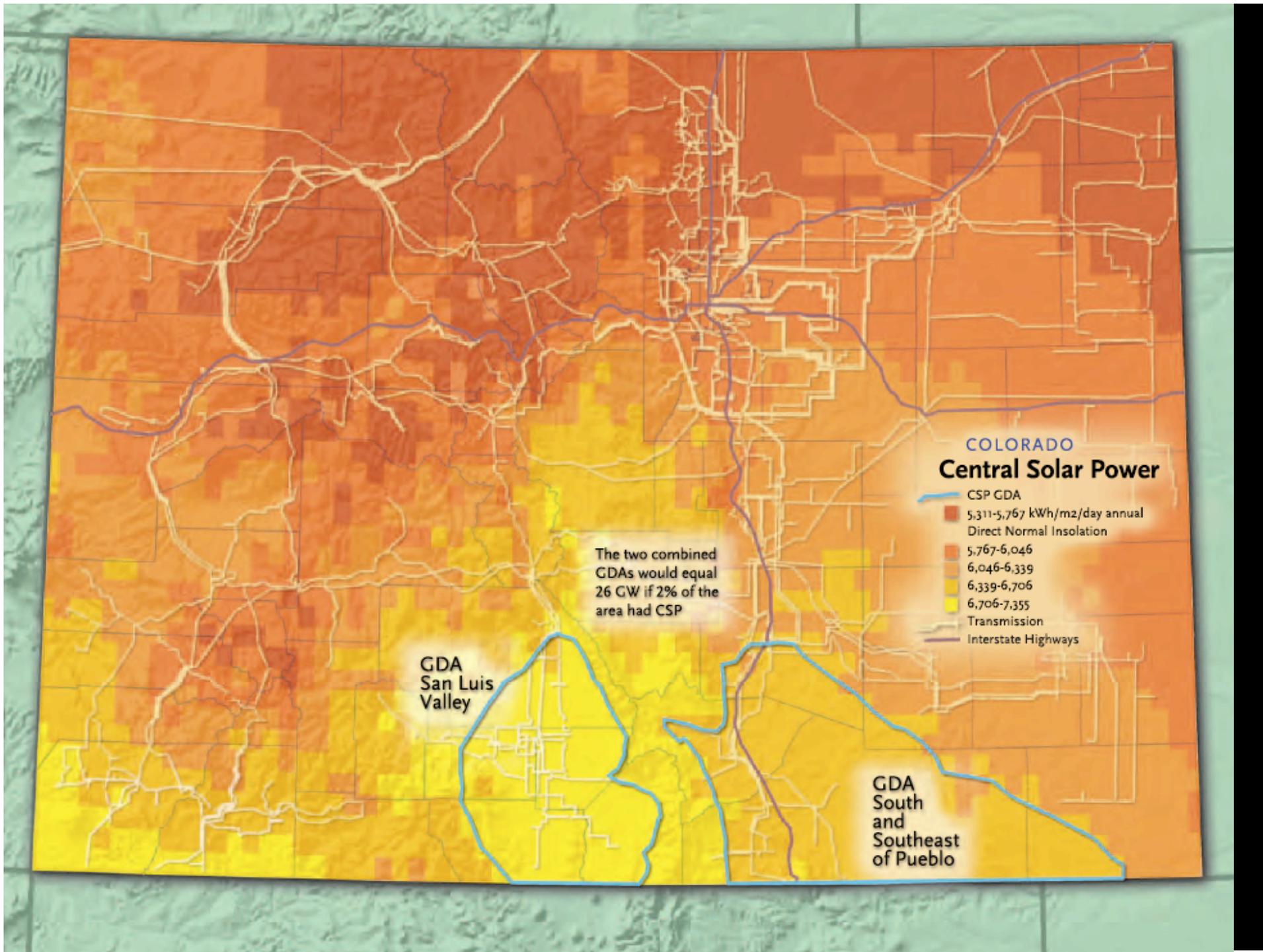
	Cost in billions of 2006 dollars				U.S. Regions Most at Risk
	2025	2050	2075	2100	
 Hurricane Damages	\$10	\$43	\$142	\$422	Atlantic & Gulf Coast states
 Real Estate Losses	\$34	\$80	\$173	\$360	Atlantic & Gulf Coast states
 Energy-Sector Costs	\$28	\$47	\$82	\$141	Southeast & Southwest
 Water Costs	\$200	\$336	\$565	\$950	Western states
	\$271	\$506	\$961	\$1,873	

Ackerman & Stanton, 2008

Stern Review: Cost of action \cong 1% of world GDP

Cost of inaction = 5% to 20% of world GDP

What About Colorado?



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/m ²	Wind Speed ^a at 50 m, m/s	Wind Speed ^a at 50 m, mph
1	Poor	0 - 200	5.0 - 6.9	11.2 - 15.2
2	Marginal	200 - 300	6.9 - 8.7	15.2 - 19.2
3	Fair	300 - 400	8.7 - 7.4	19.2 - 16.5
4	Good	400 - 600	7.4 - 7.9	16.5 - 17.7
5	Excellent	600 - 800	7.9 - 8.4	17.7 - 18.5
6	Outstanding	800 - 900	8.4 - 9.5	18.5 - 20.9
7	Superb	> 900	> 9.5	> 20.9

^a Wind speeds are based on a Weibull k of 2.0 at 1600 m elevation.

Indian Reservation

- 1. Ute Mountain
- 2. Southern Ute

Transmission Line^a

Voltage (kV)

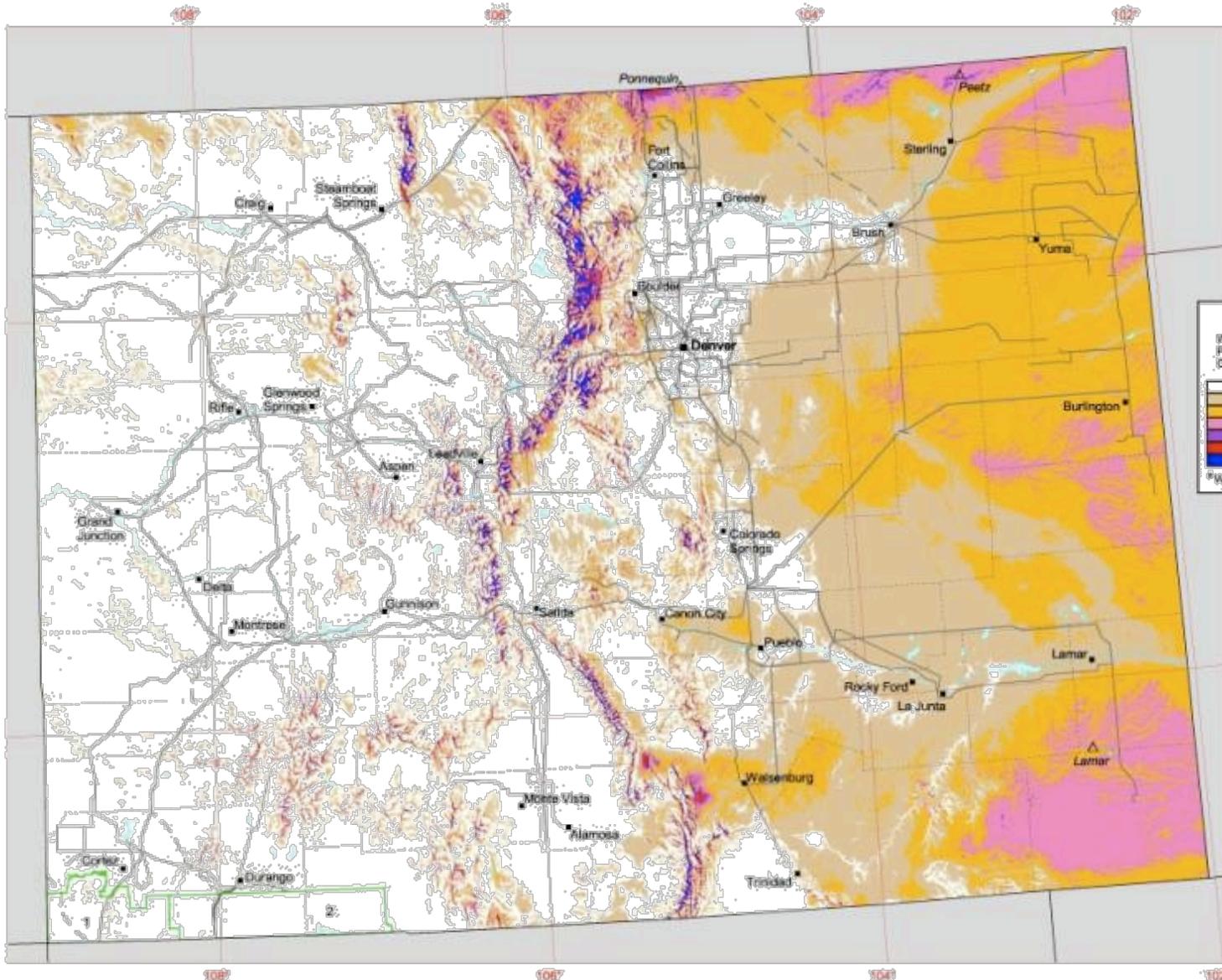
- 115 - 161
- 230
- - - 345

▲ Wind Farm^b

^a Source: POWERPLAN ©2004
 Maps a Division of the
 Hydro-Electric Company



U.S. Department of Energy
 National Renewable Energy Laboratory



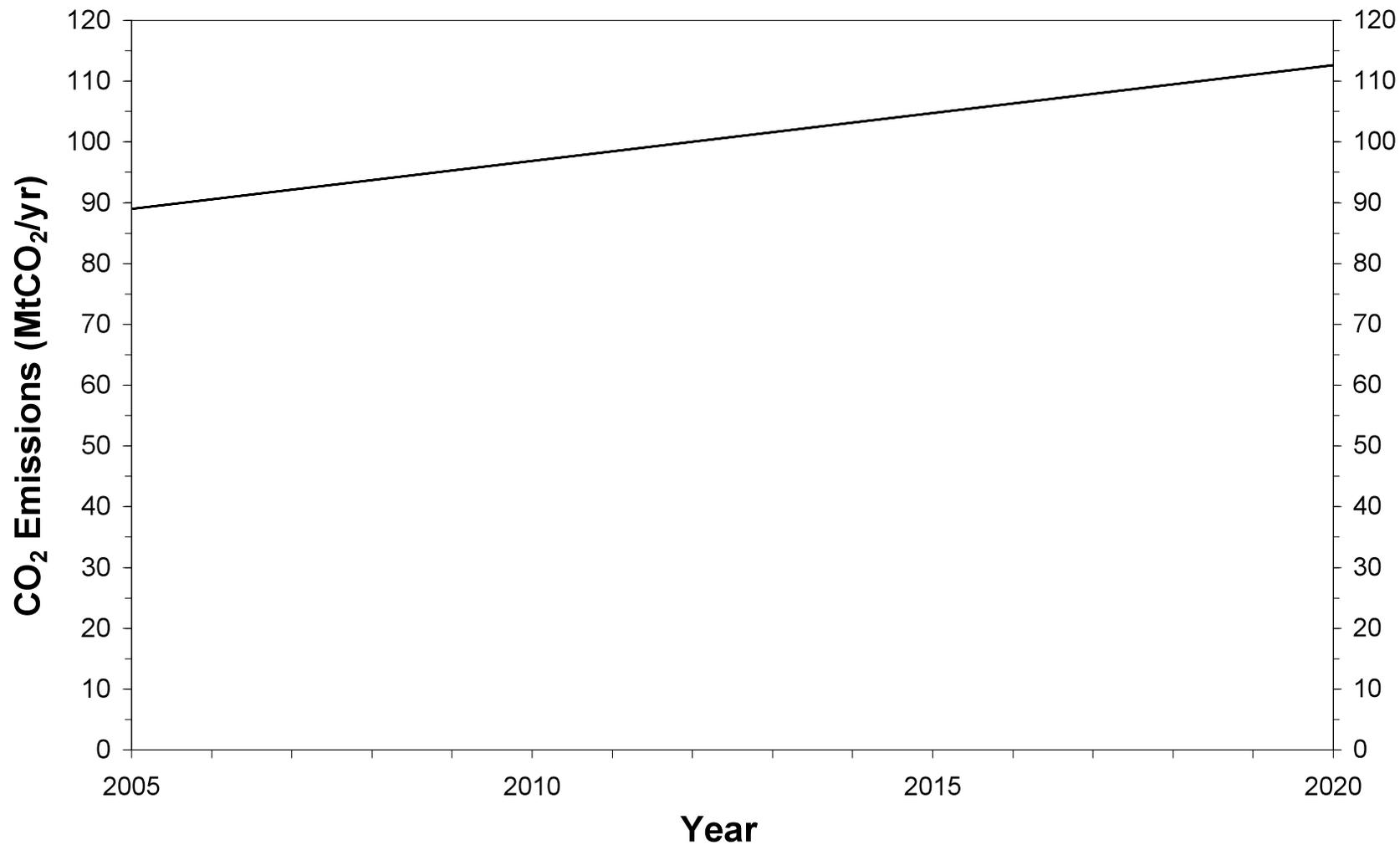
Example Colorado Scenario

30% True RES - 2020

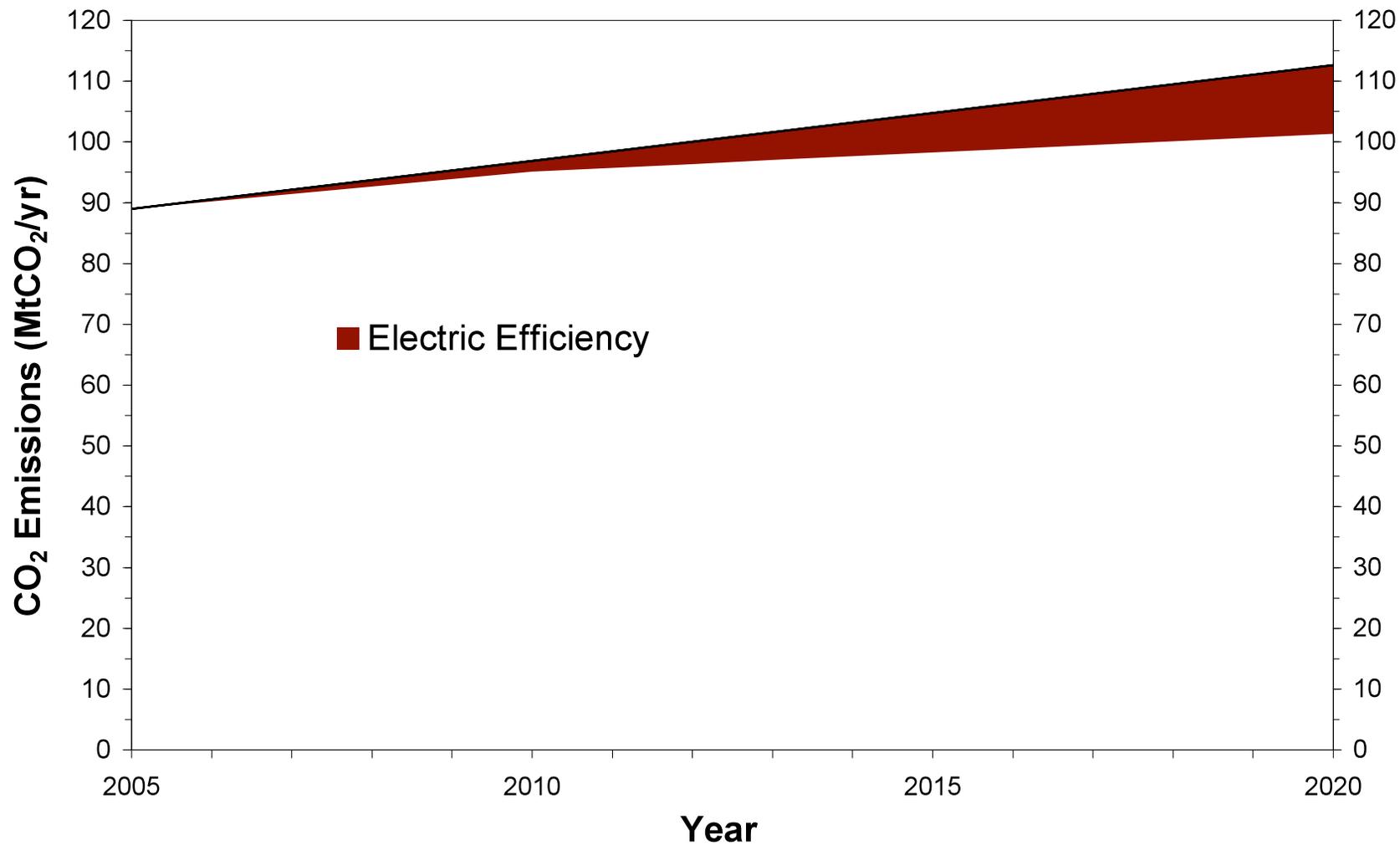
Renewable Electric Source	2020 Capacity (MW)
Wind	4,500
Photovoltaics	600
Concentrating Solar Power*	800
Biomass*	300
Geothermal*	50

*Base load or near-base load power

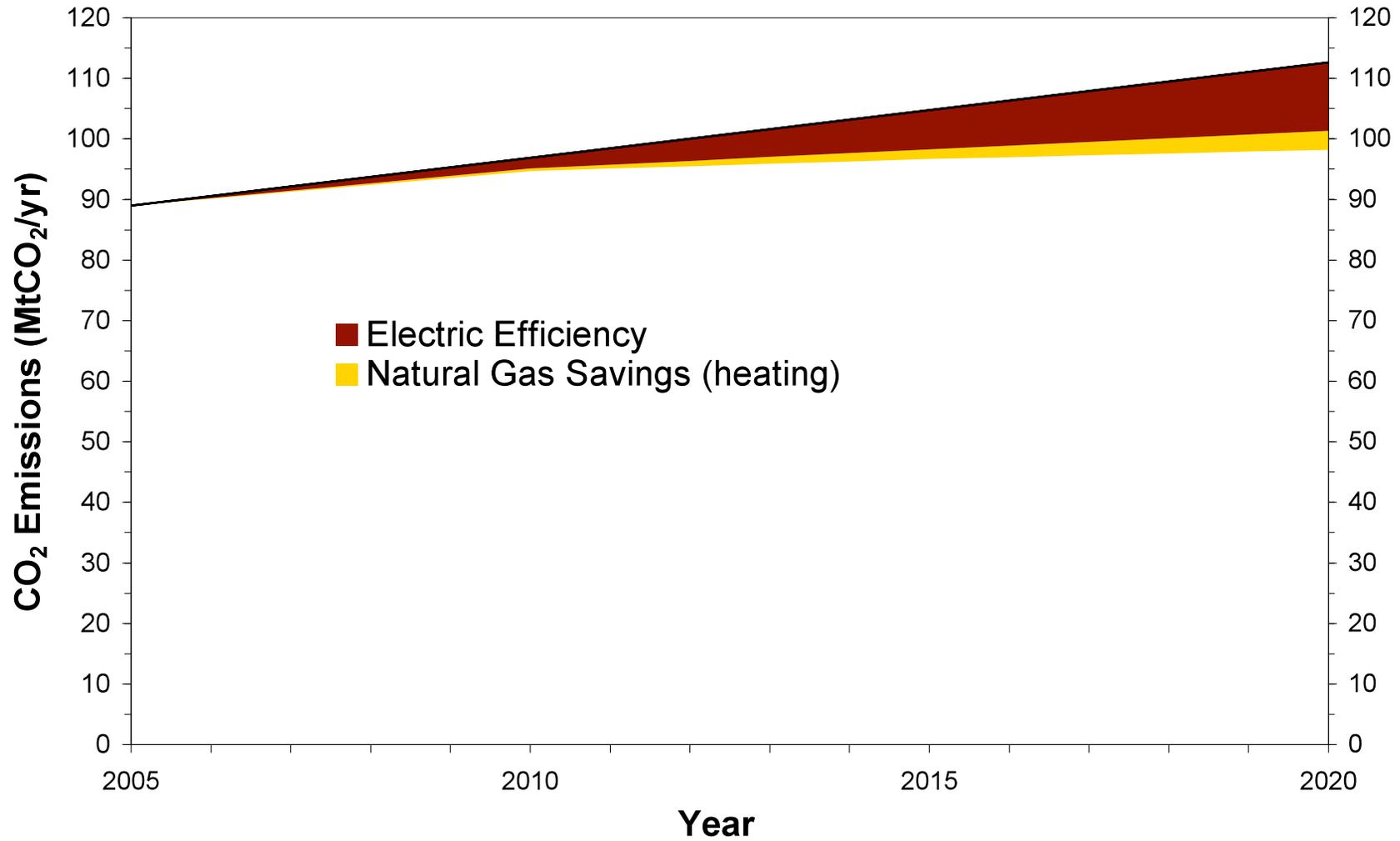
CO₂ Displacement from Efficiency and Renewable Energy Colorado 30% RES Scenario 2005 - 2020



CO₂ Displacement from Efficiency and Renewable Energy Colorado 30% RES Scenario 2005 - 2020

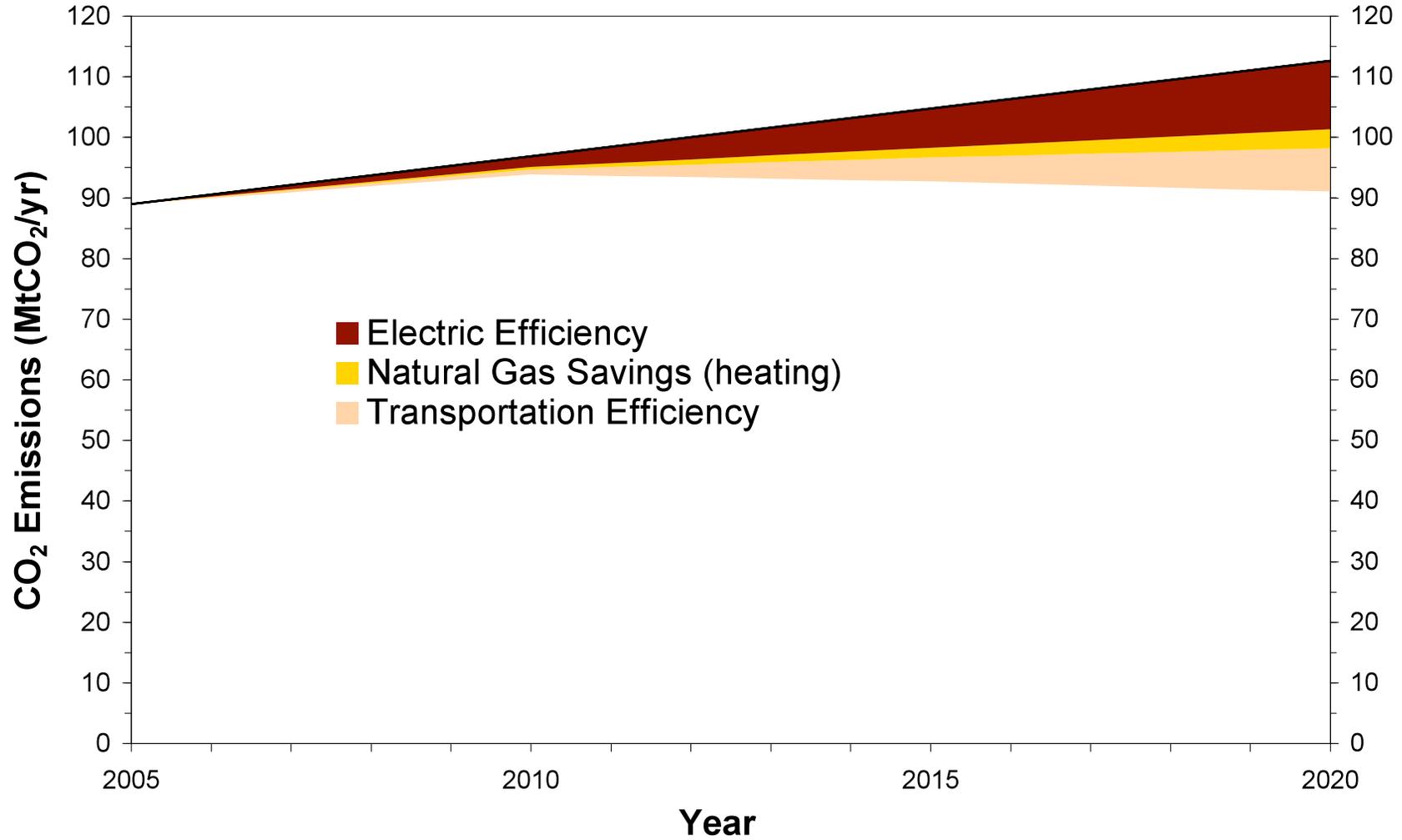


CO₂ Displacement from Efficiency and Renewable Energy Colorado 30% RES Scenario 2005 - 2020

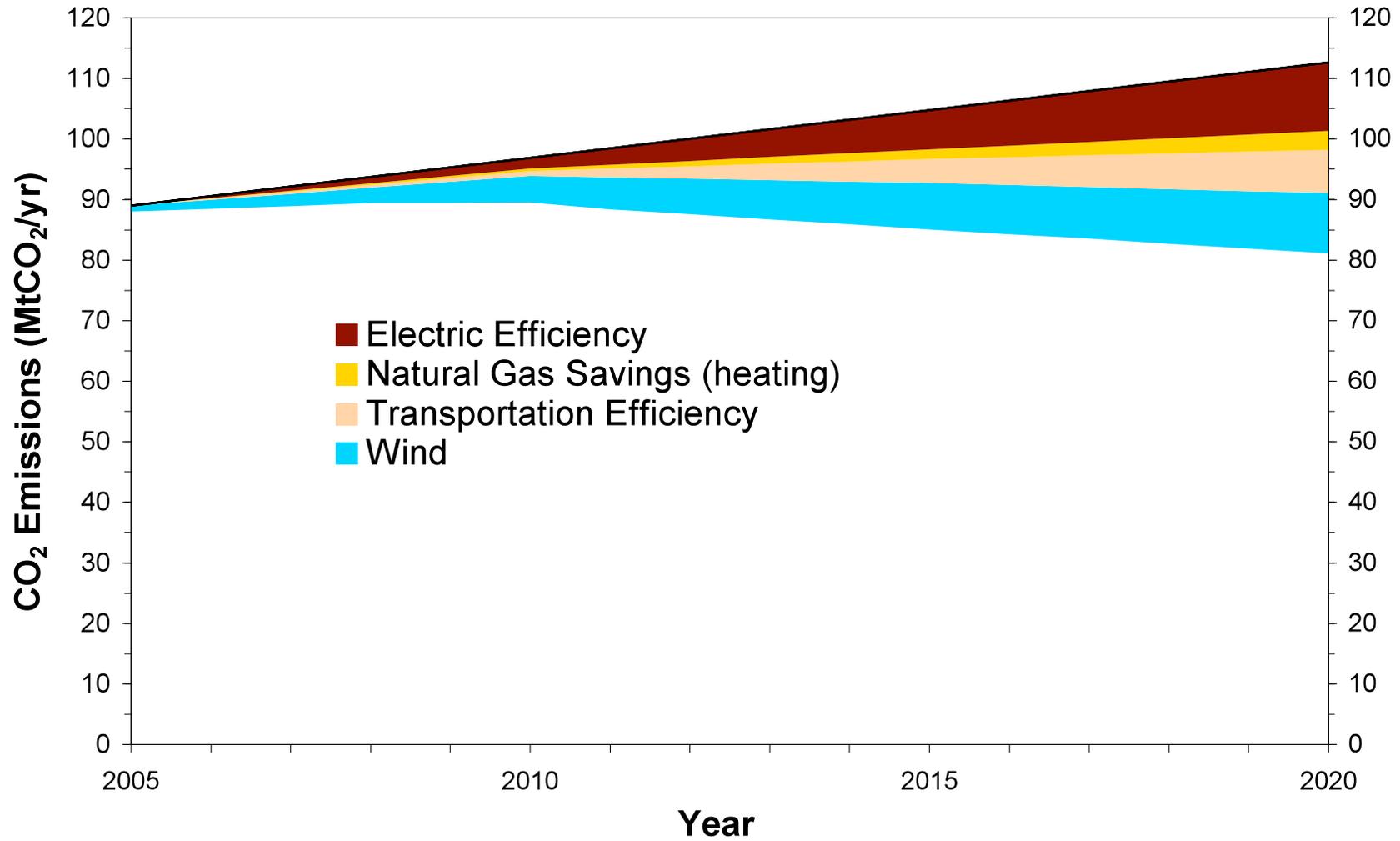


CO₂ Displacement from Efficiency and Renewable Energy

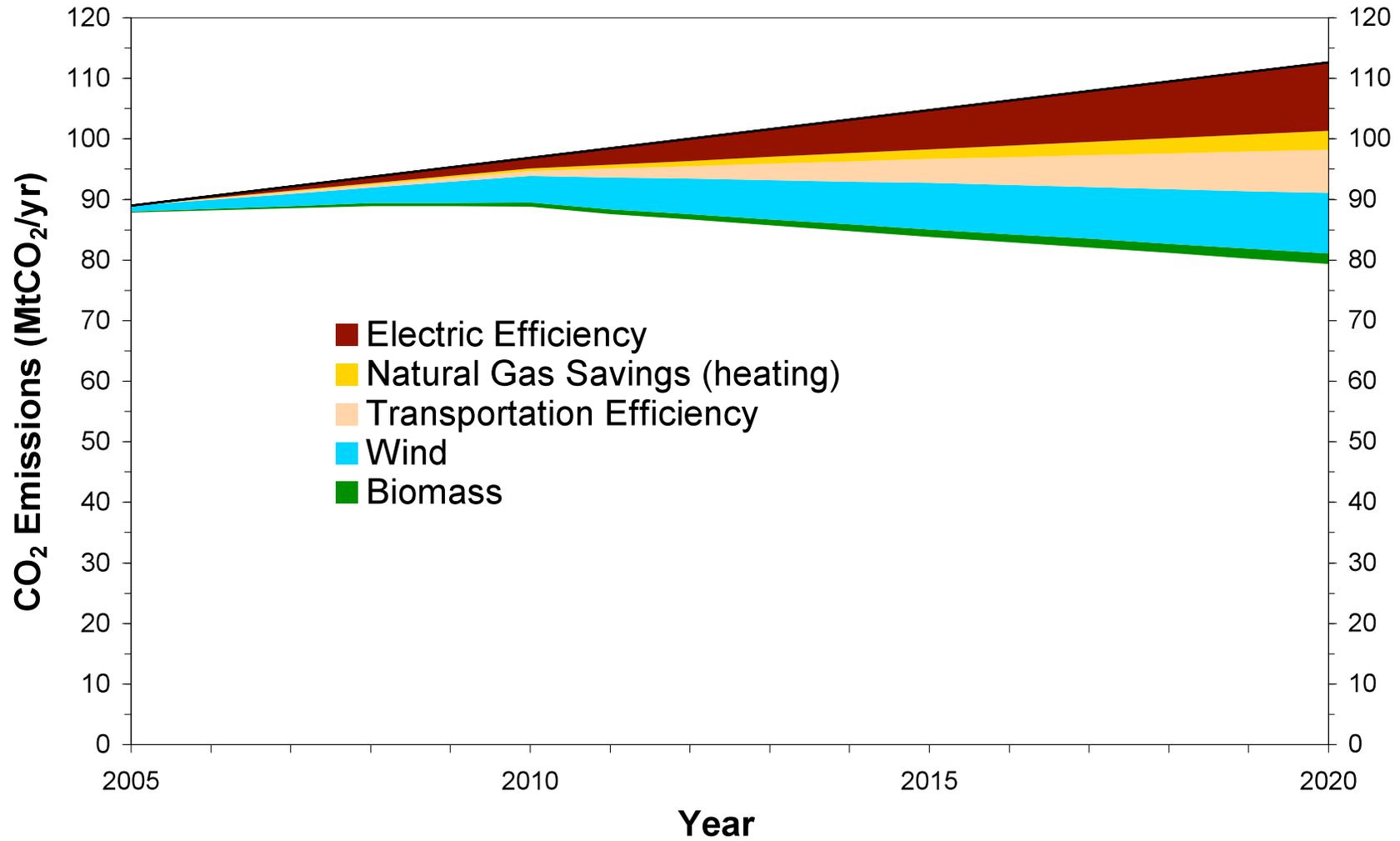
Colorado 30% RES Scenario 2005 - 2020



CO₂ Displacement from Efficiency and Renewable Energy Colorado 30% RES Scenario 2005 - 2020

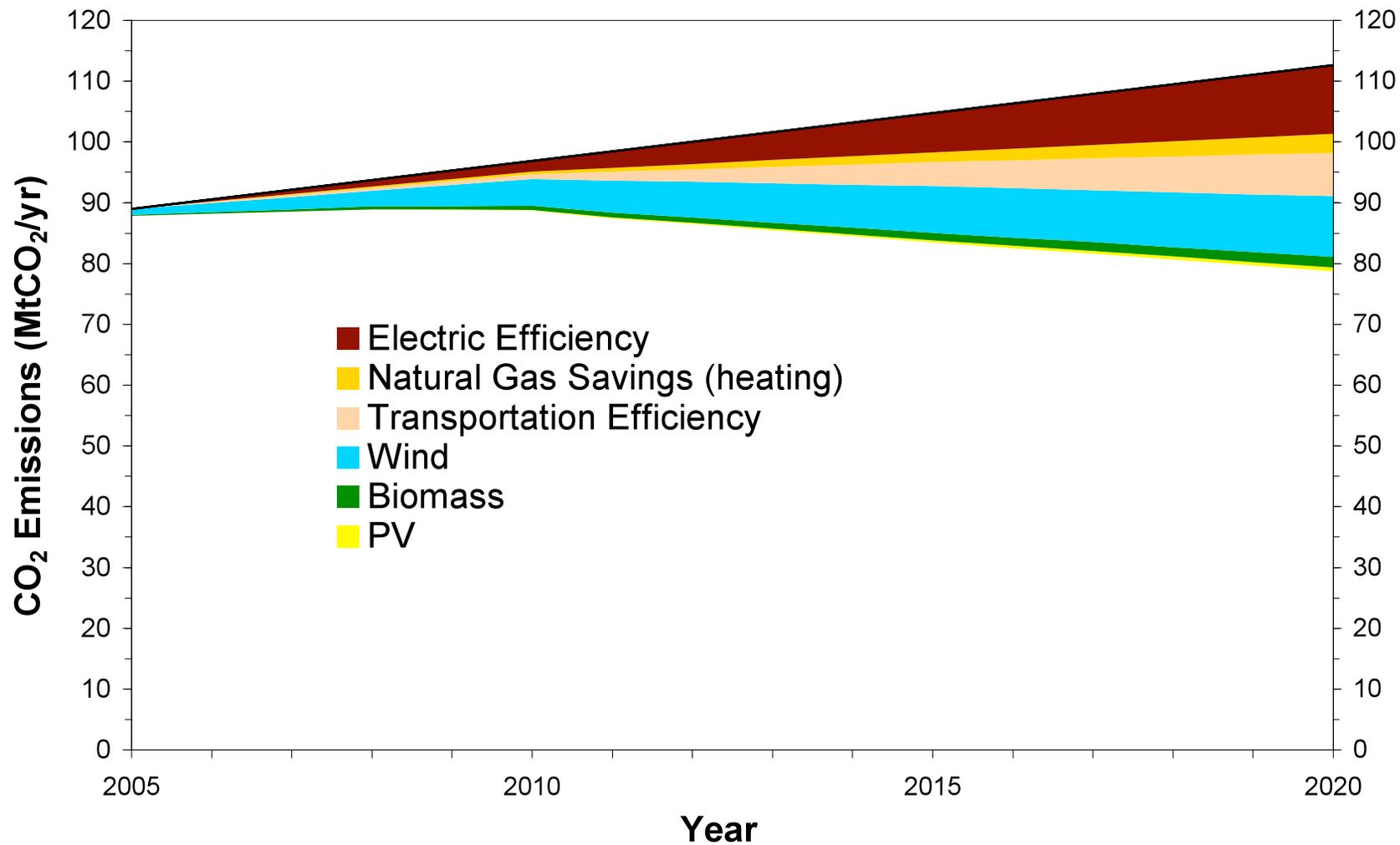


CO₂ Displacement from Efficiency and Renewable Energy Colorado 30% RES Scenario 2005 - 2020

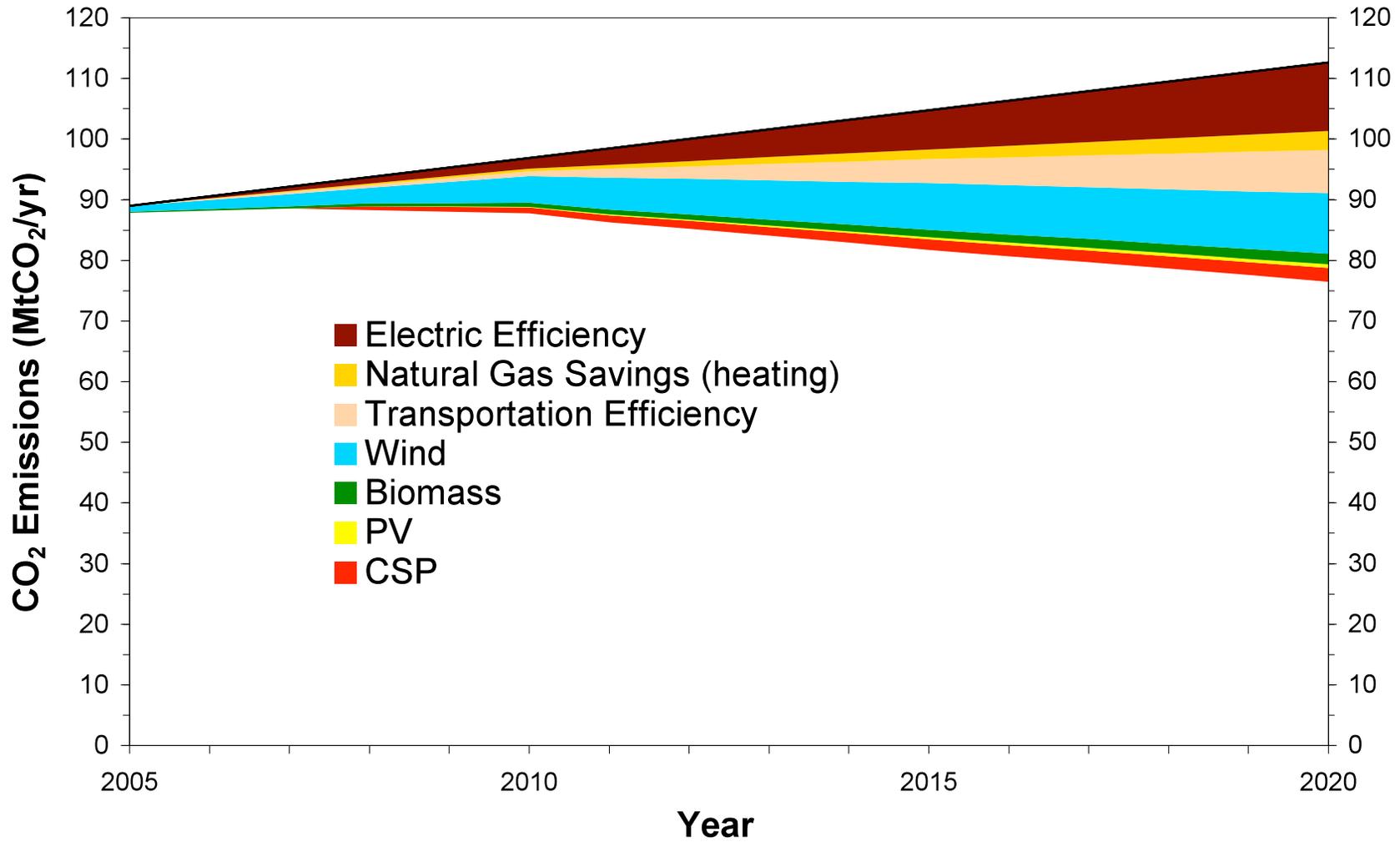


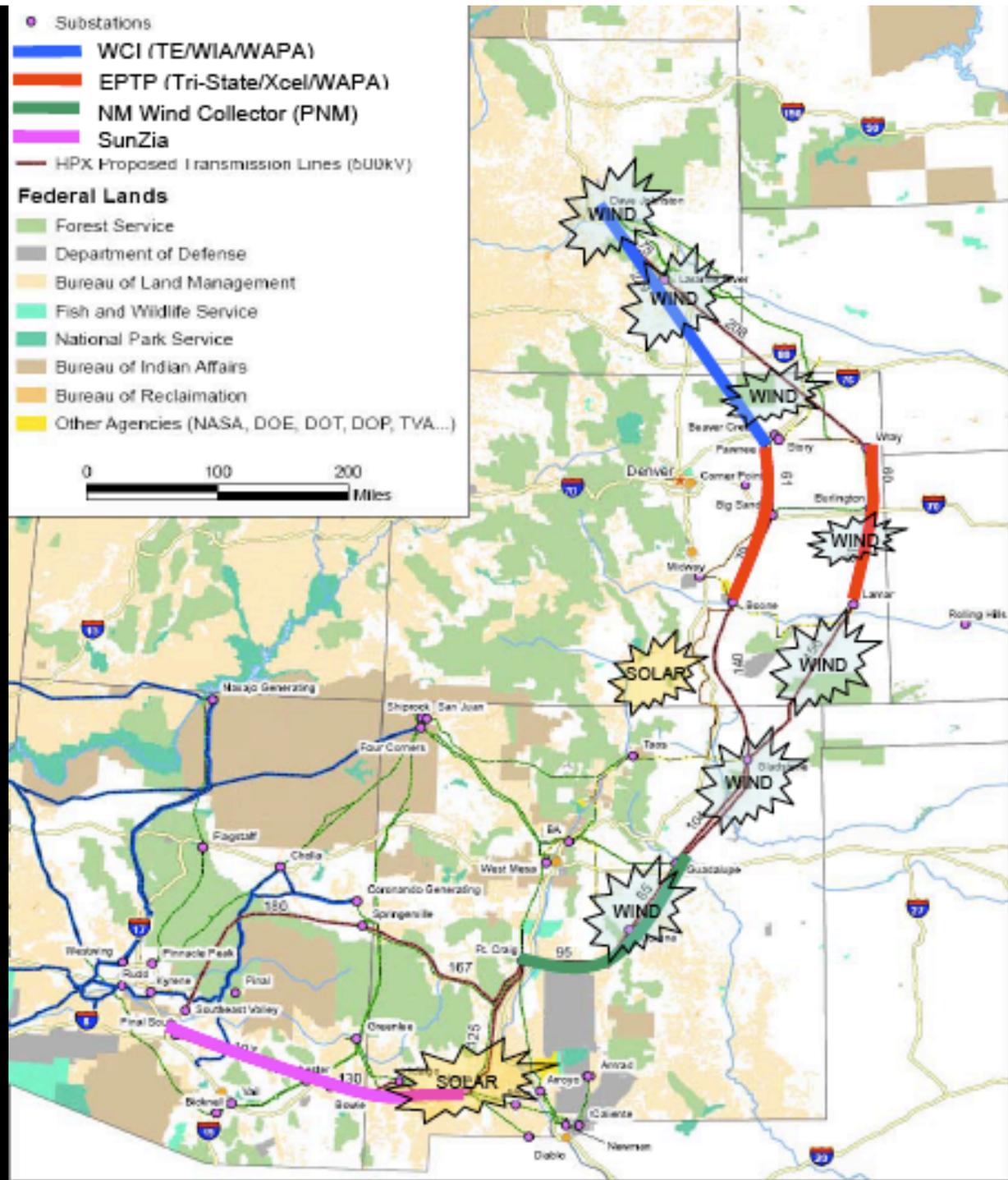
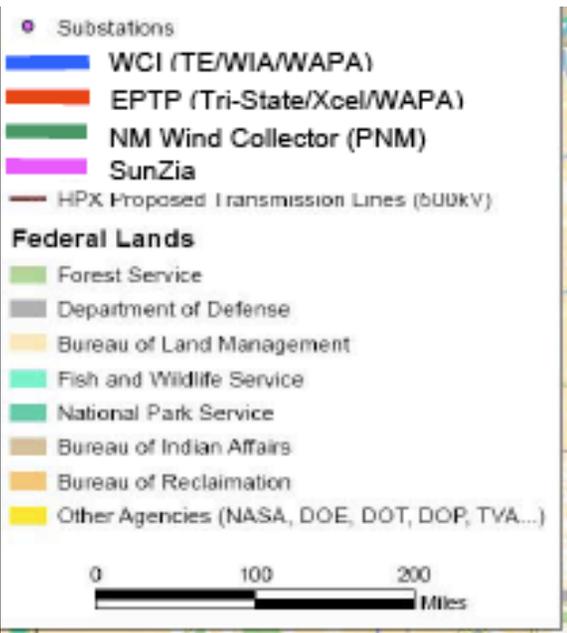
CO₂ Displacement from Efficiency and Renewable Energy

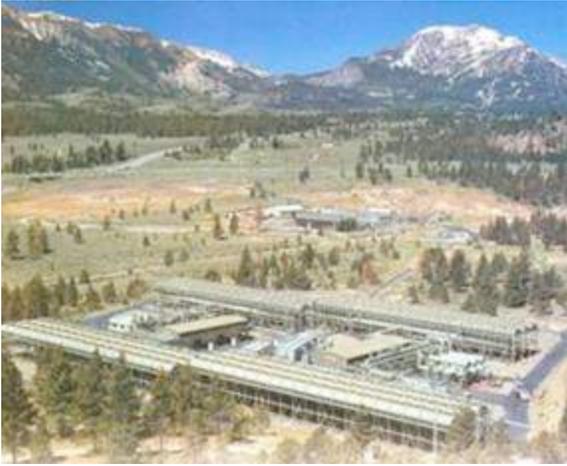
Colorado 30% RES Scenario 2005 - 2020



CO₂ Displacement from Efficiency and Renewable Energy Colorado 30% RES Scenario 2005 - 2020

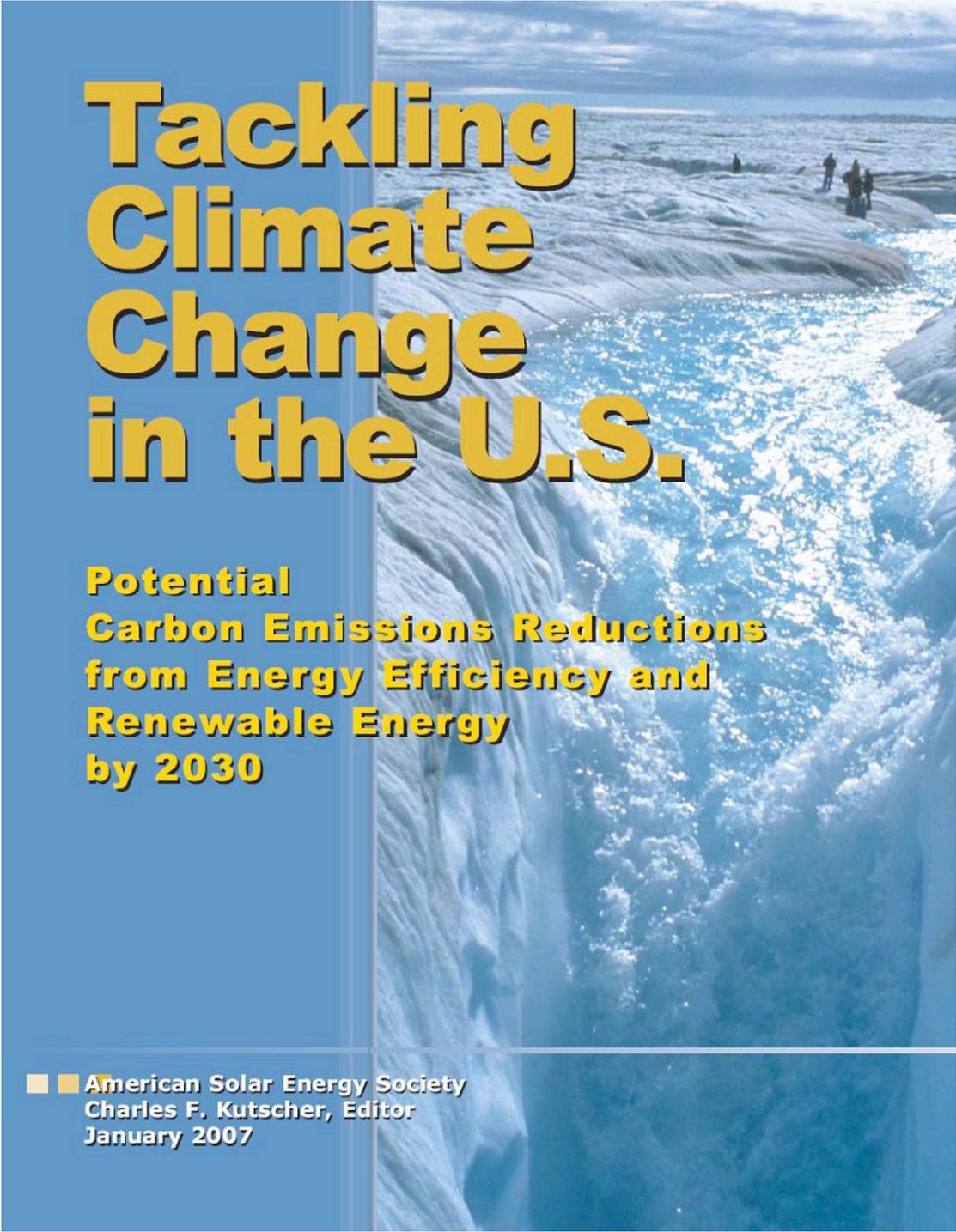






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