The Urgency of Climate Change

and the Role of Renewable Energy

Santa Fe Institute
Summer School on Global Sustainability

Chuck Kutscher
National Renewable Energy Laboratory

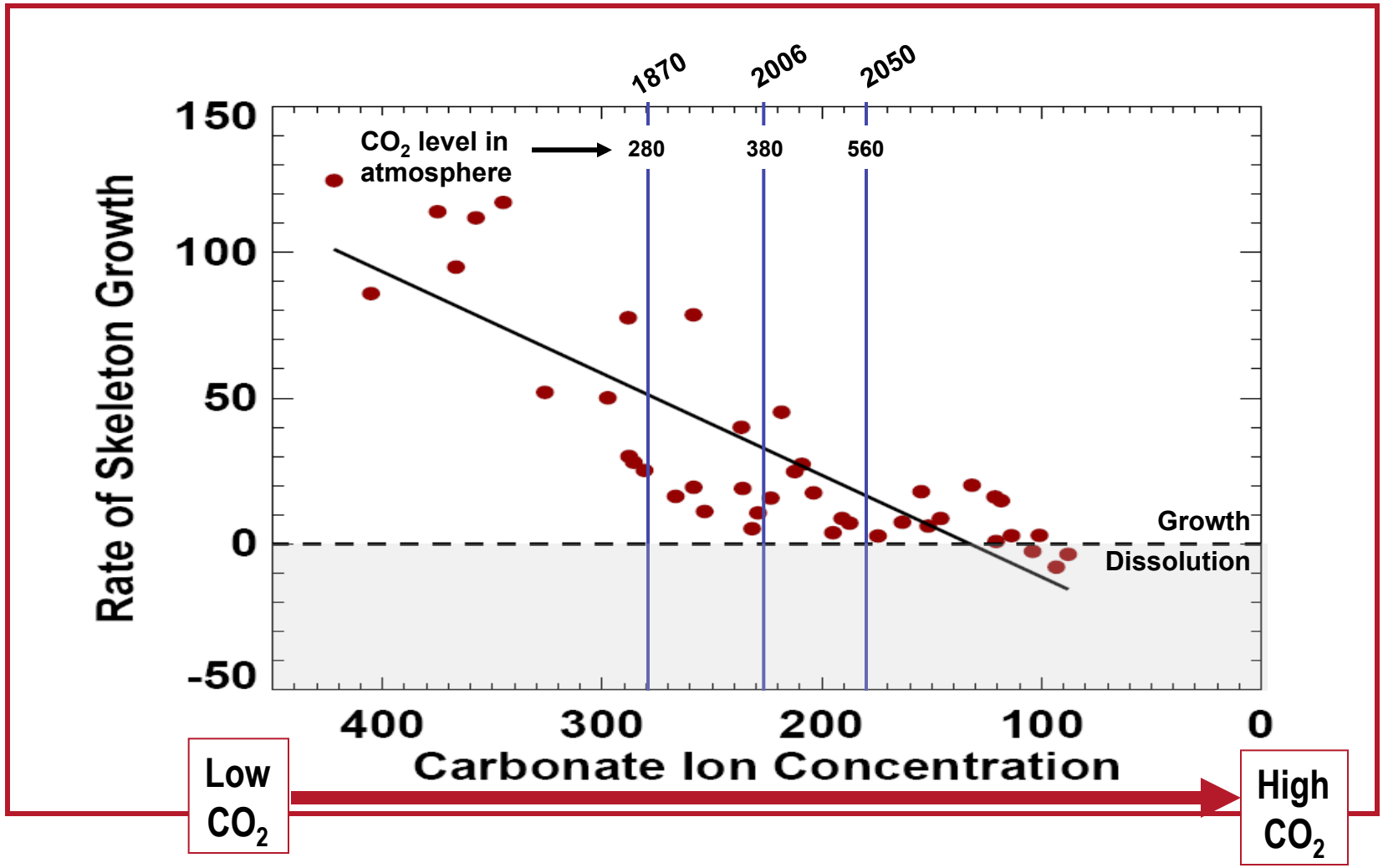
Global Warming:
A Personal Perspective

March 31, 2006 Headline:

Caribbean coral suffers record die-off

World's coral reef loss 'an underwater holocaust'

Impact of CO_2 on Coral



Data from Chris Langdon

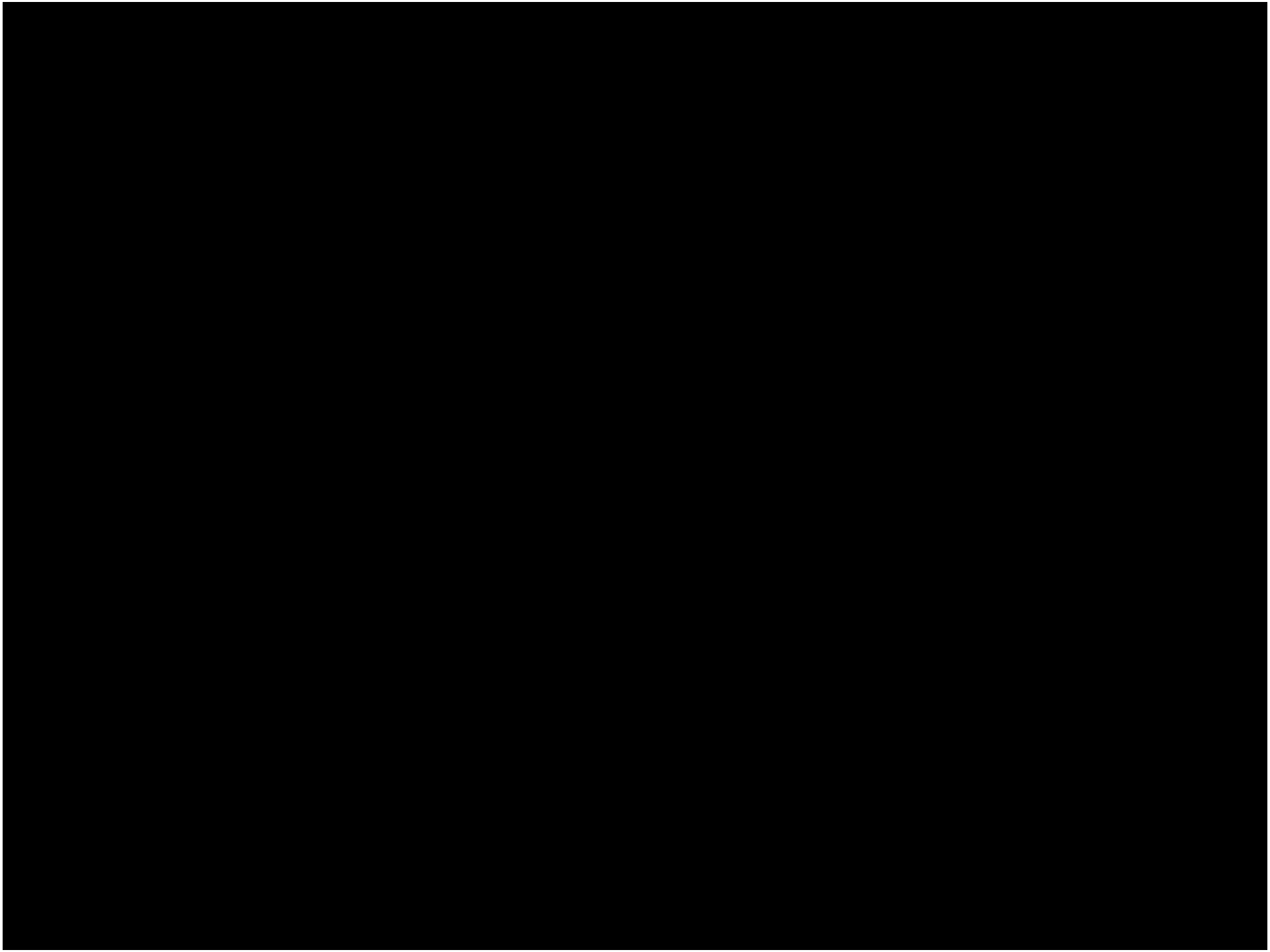
OPINION

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.

Reprinted from the Denver Post of Oct. 23, 1983

50 Years Ago



Climate Change:

"The greatest hoax ever perpetrated on the American people"?

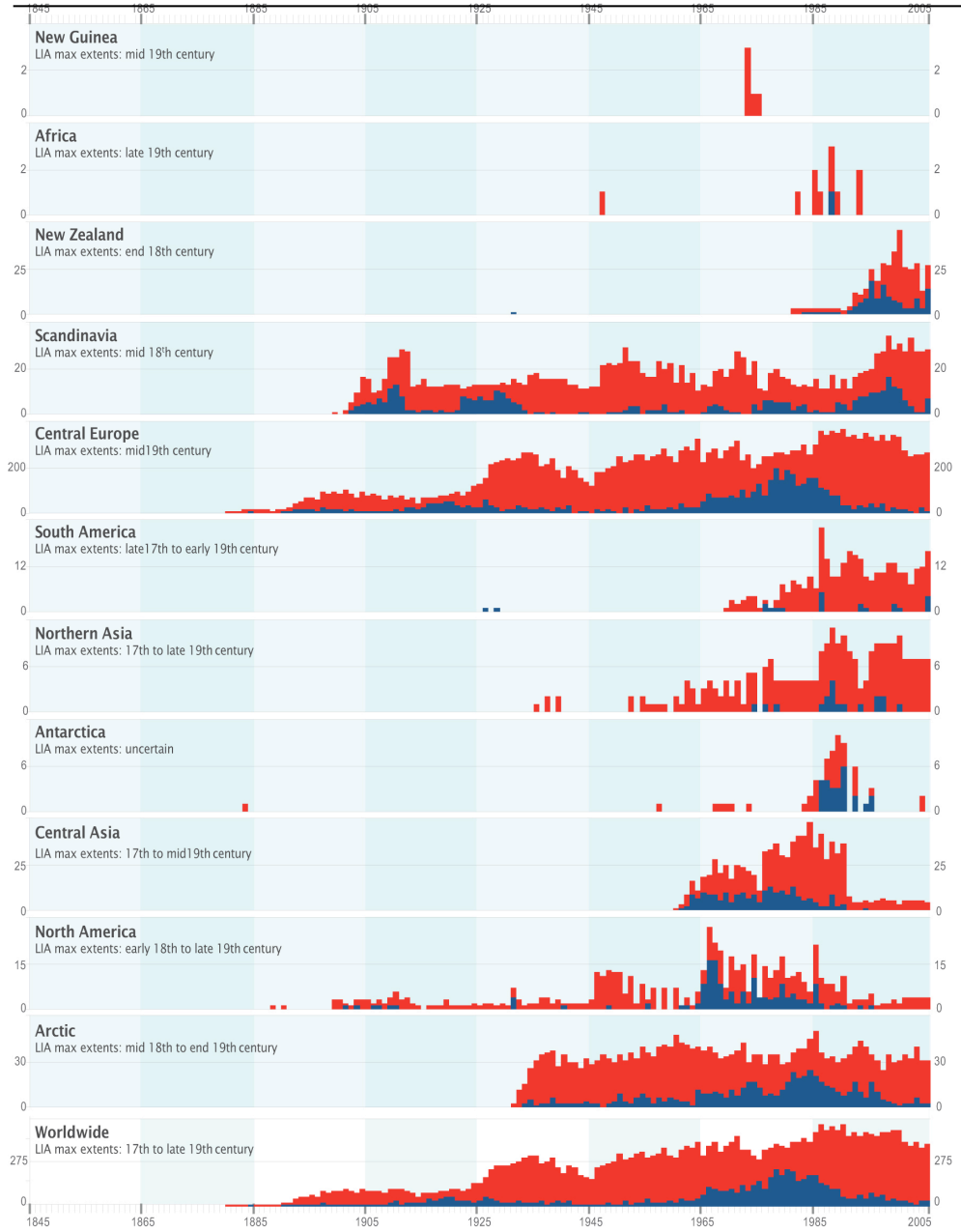

FOX
FOX NEWS channel
IN FOCUS
AL GORE'S GLOBAL WARMING MOVIE:
COULD IT DESTROY OUR ECONOMY?
GLOBAL WARMING
SNOWJOB
WATCH THE VIDEO!
LIVE
CNN
HEATED DEBATE
OTHER SIDE OF GLOBAL WARMING
7:14 A CT
LIVE
IS GLOBAL WARMING FOR REAL?
NBC


The Politically Incorrect Guide™ to
GLOBAL WARMING
and Environmentalism
Christopher C. Horner
THE CHICKEN LITTLE AGENDA
DEBUNKING "EXPERTS'" LIES
R. G. WILLISCROFT
THE TRUE STATE OF GLOBAL WARMING
SHATTERED CONSENSUS
EDITED BY PATRICK J. MICHAELS
Global Warming and Other Eco-Myths
HOW THE ENVIRONMENTAL MOVEMENT USES FALSE SCIENCE TO SCARE US TO DEATH
COMPETITIVE ENTERPRISE INSTITUTE
RONALD BAILEY, EDITOR
NEW YORK TIMES BESTSELLER
JOHN STOSSEL
of 20/20
MYTHS, LIES, AND DOWNRIGHT STUPIDITY
Get Out The Shovel- Why Everything You Know Is Wrong
the skeptical environmentalist
Measuring the Real State of the World
Bjørn Lomborg
GLOBAL WARMING
OPPOSING VIEWPOINTS

"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

World Glacier Monitoring Service



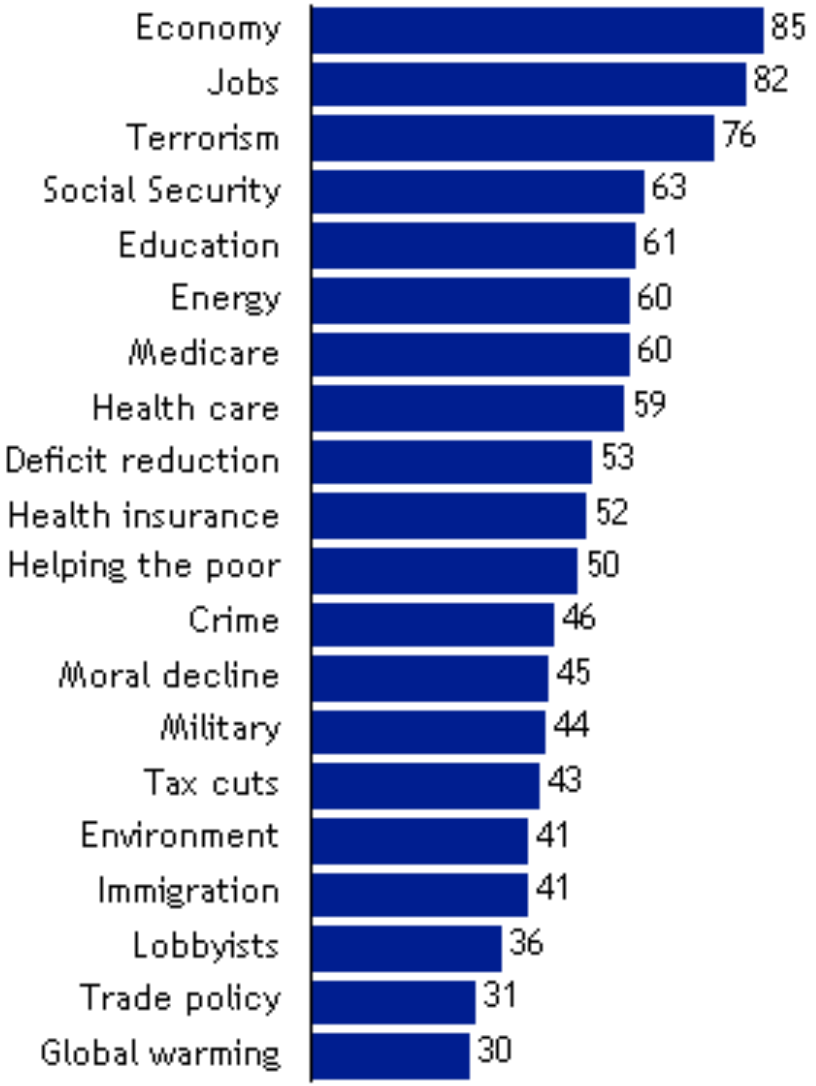
Advancing

Retreating

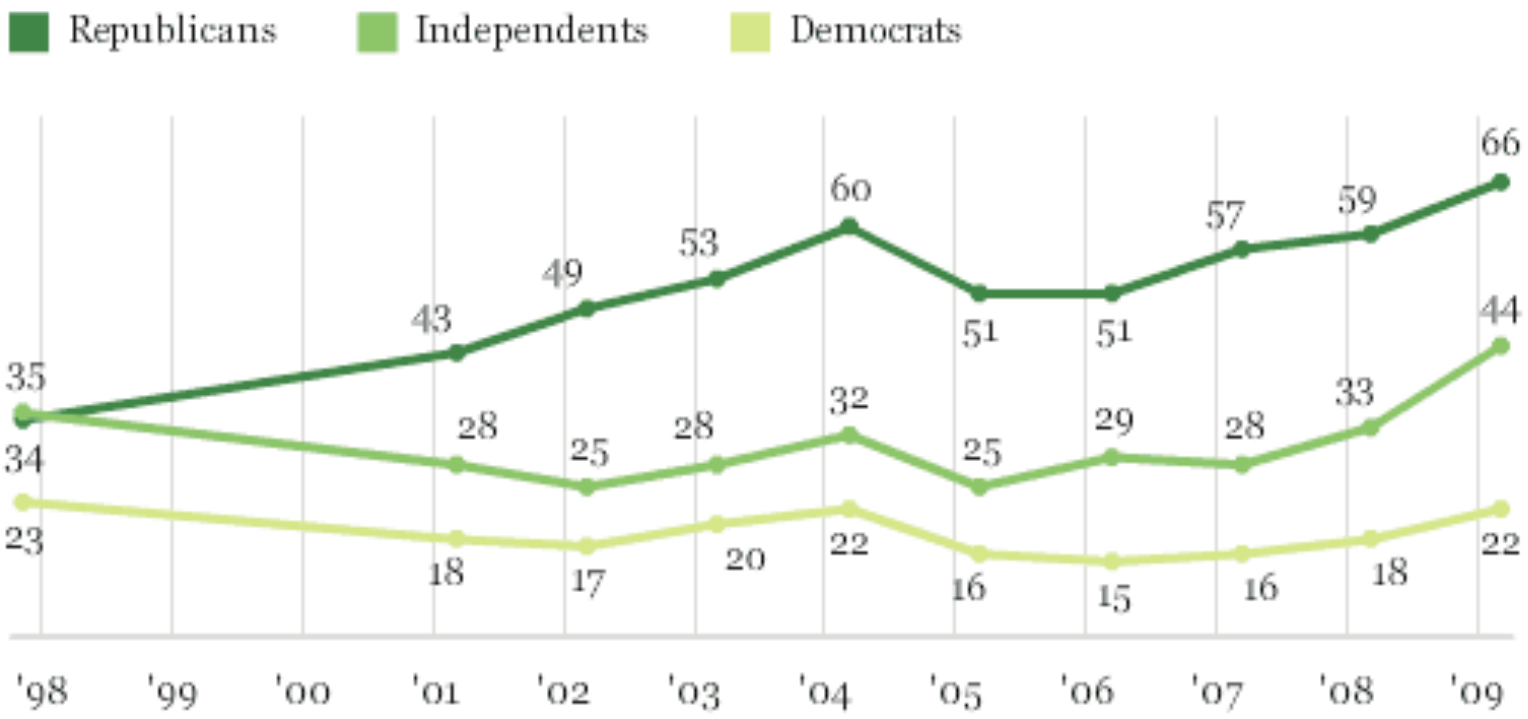
- In 2005 442 glaciers studied:
  - 26 advancing
  - 18 stationary
  - 398 retreating

Top Priorities for 2009

Percent rating each a "top priority"



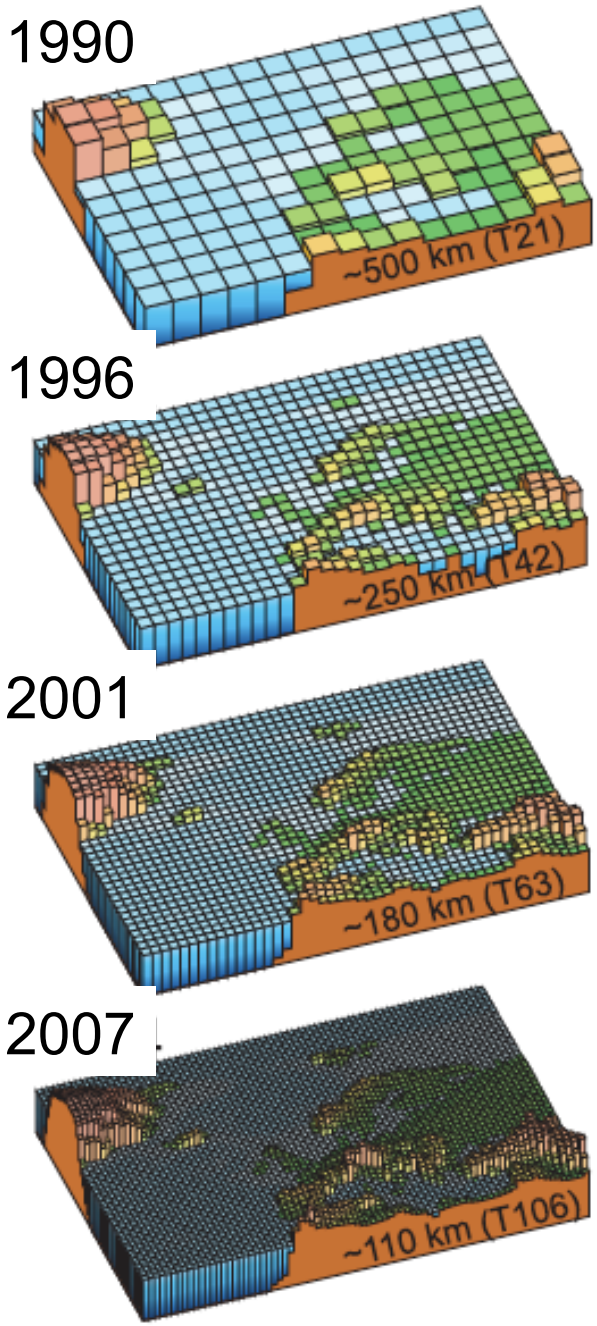
Percentage Saying News of Global Warming Is Exaggerated, by Party ID



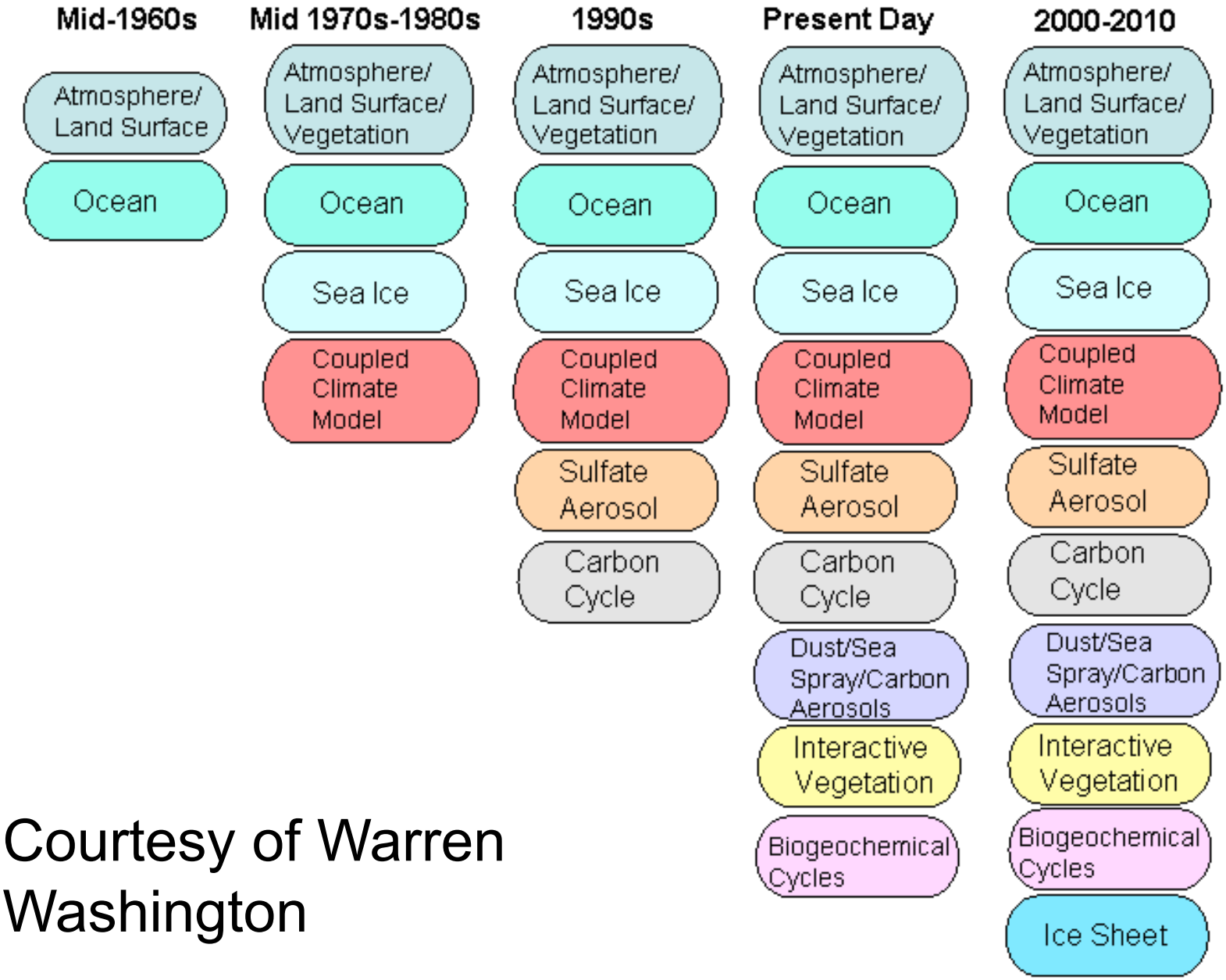
GALLUP POLL

Proof of Human-Induced Climate Change

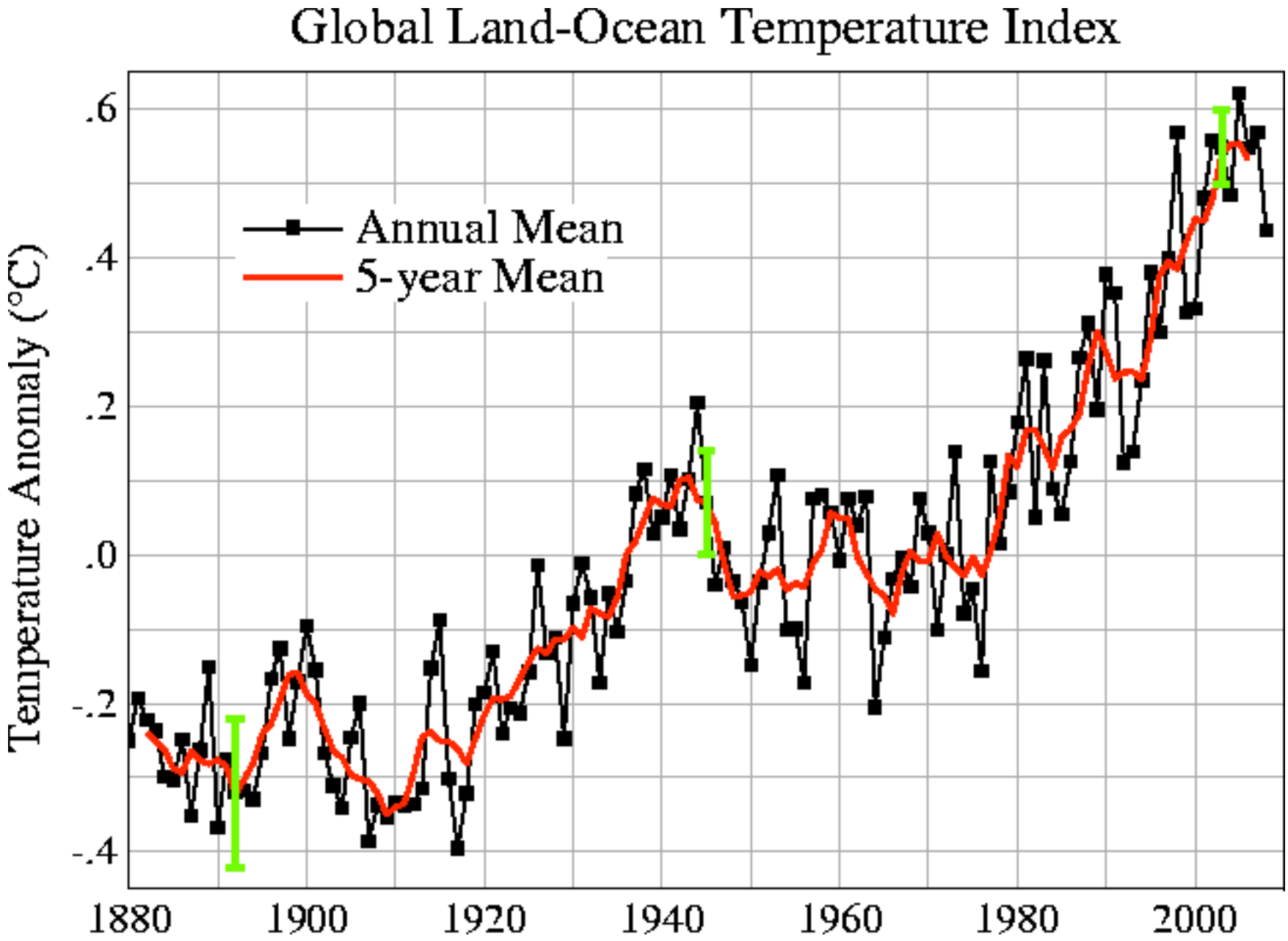
- Paleoclimatic data (ice cores and other evidence)
- Agreement between rapidly improved climate models from around the world
- Today's field measurements

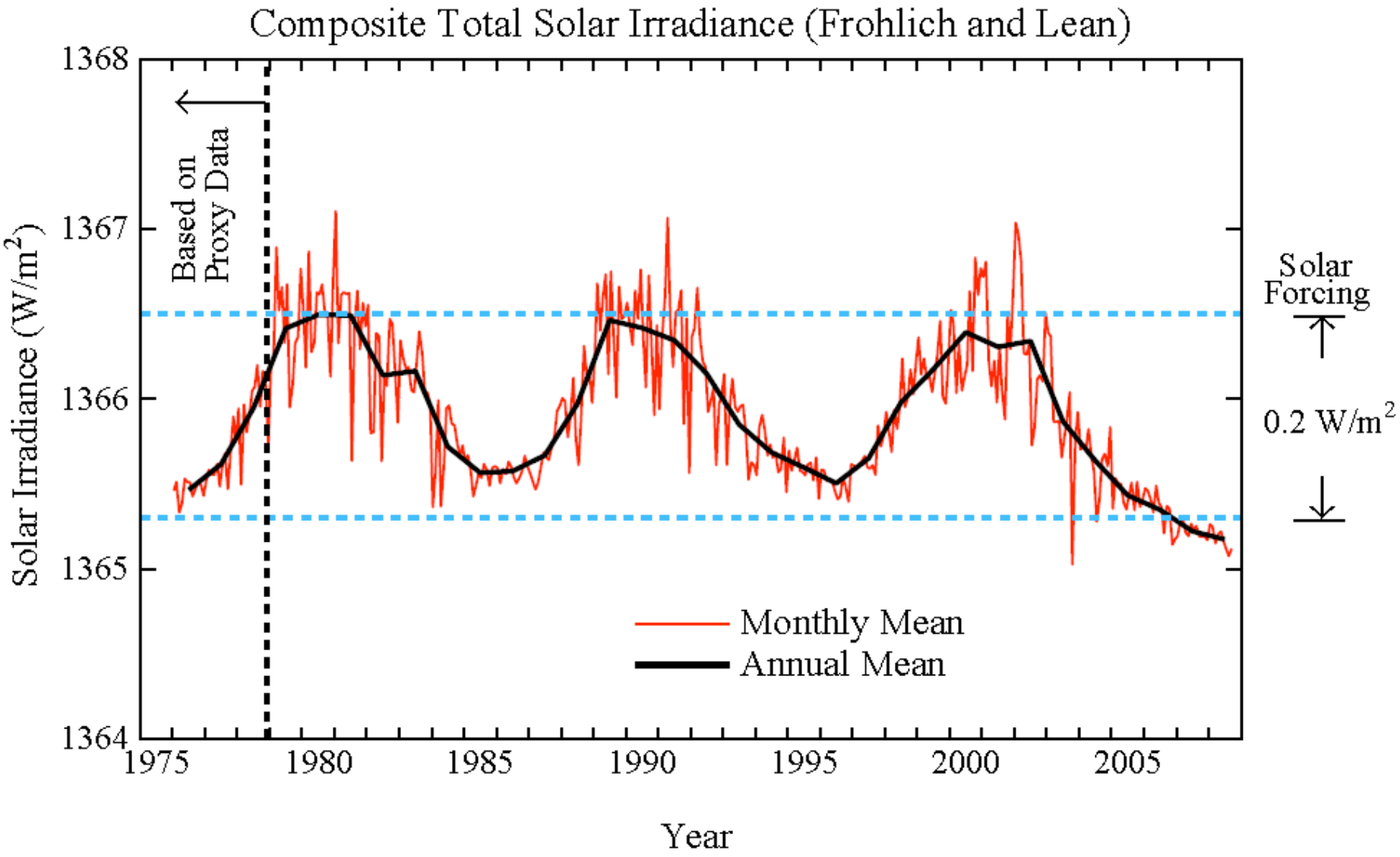

1990
~500 km (T21)
1996
~250 km (T42)
2001
~180 km (T63)
2007
~110 km (T106)

Timeline of Climate Model Development



Courtesy of Warren Washington

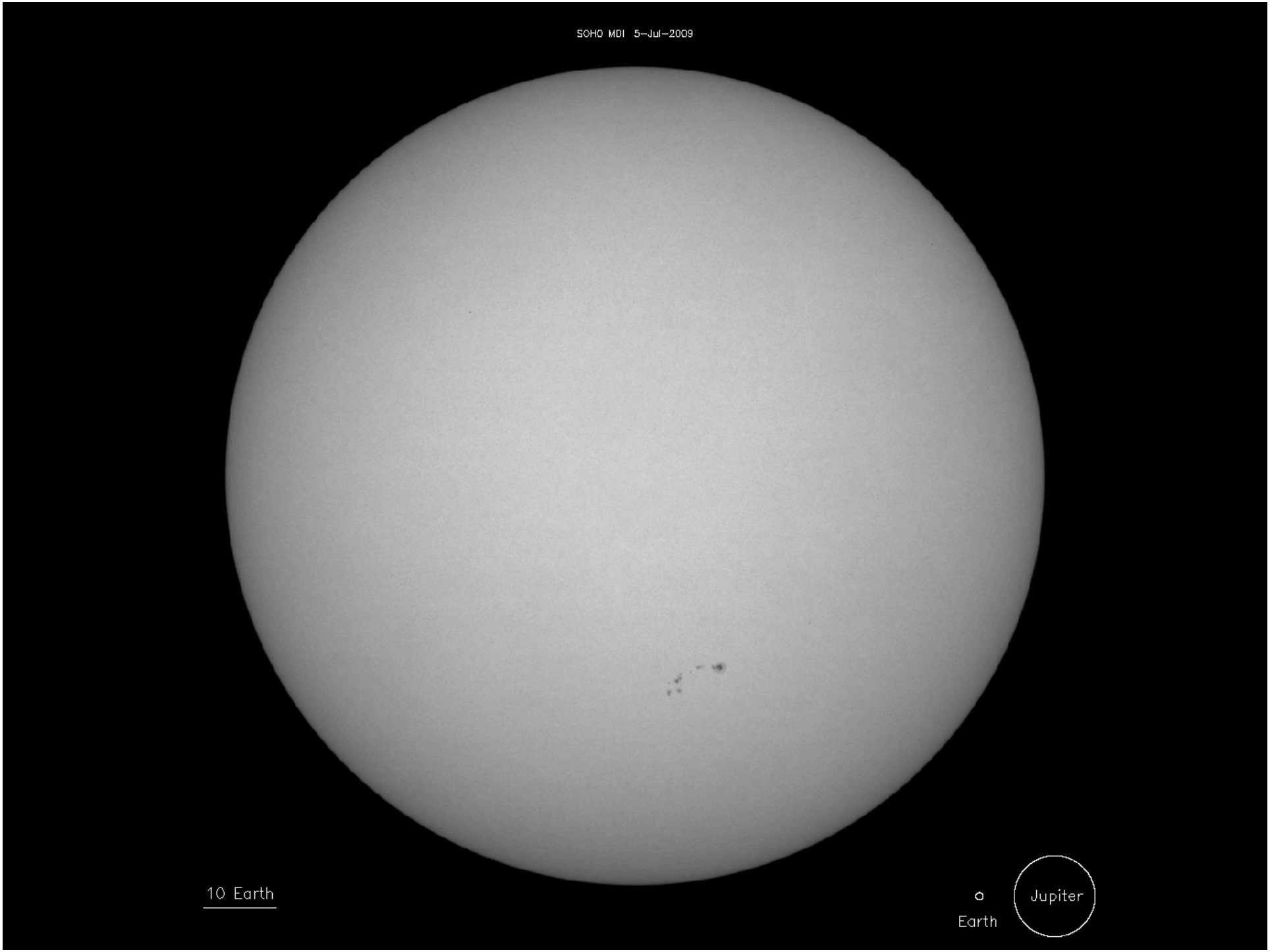

Global Land-Ocean Temperature Index
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
Annual Mean
5-year Mean
1880
1900
1920
1940
1960
1980
2000

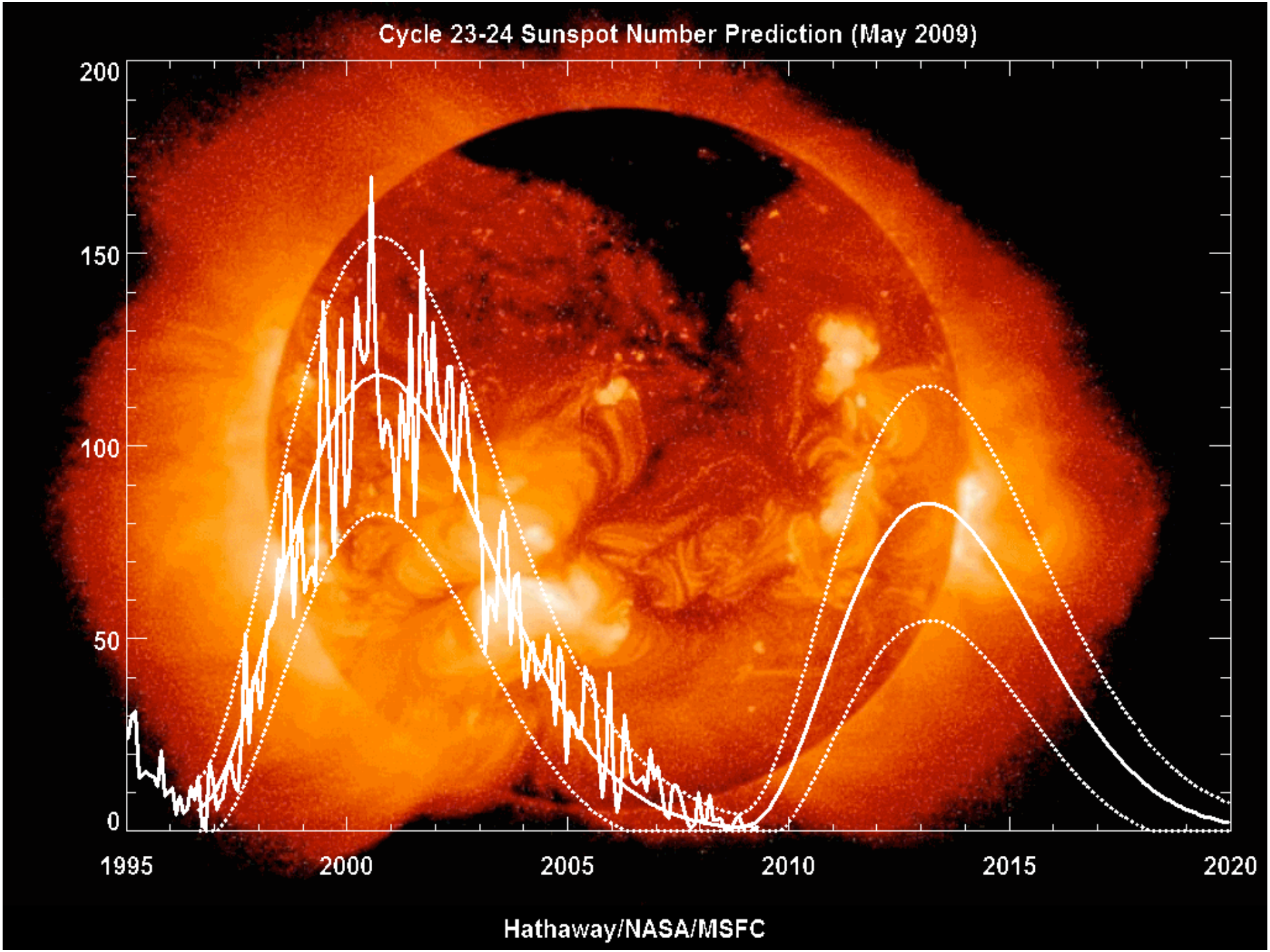


Soar irradiance through September 2008. Reference:

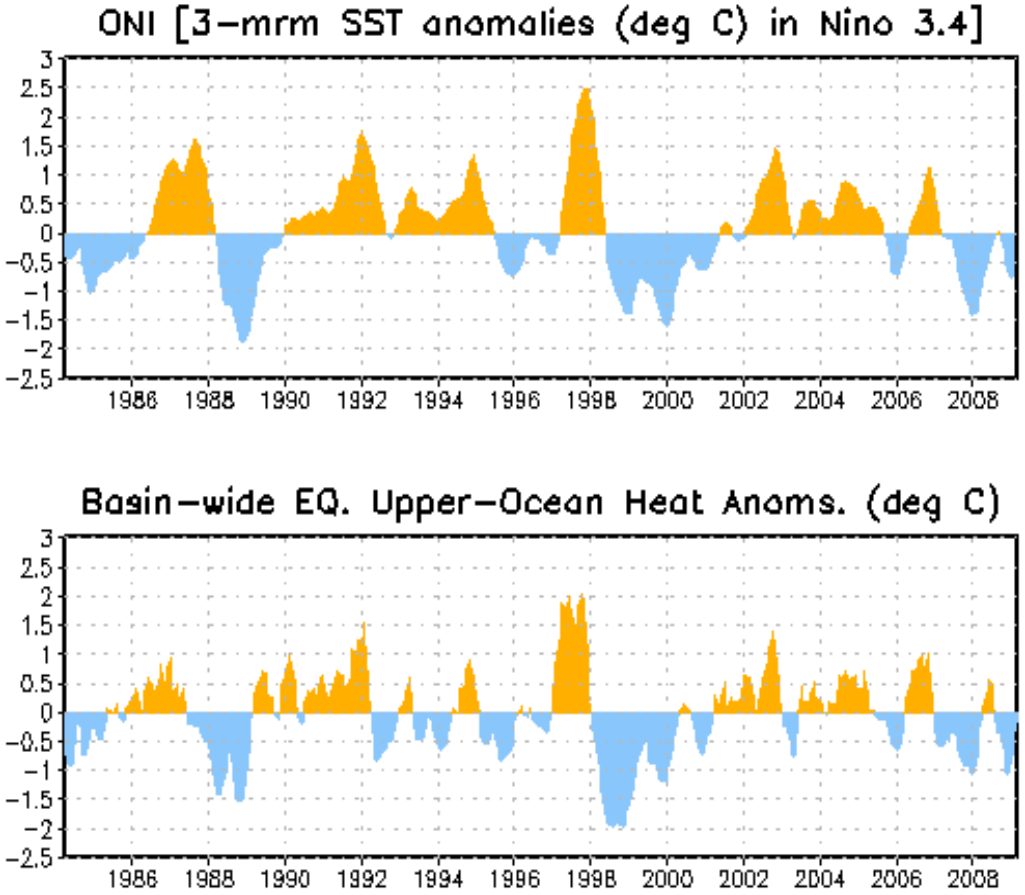
Fröhlich, C. and J. Lean, *Astron. Astrophys. Rev.*, **12**, pp. 273--320, 2004. http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant


SOHO MDI 3-Jul-2009
10 Earth
Earth
Jupiter

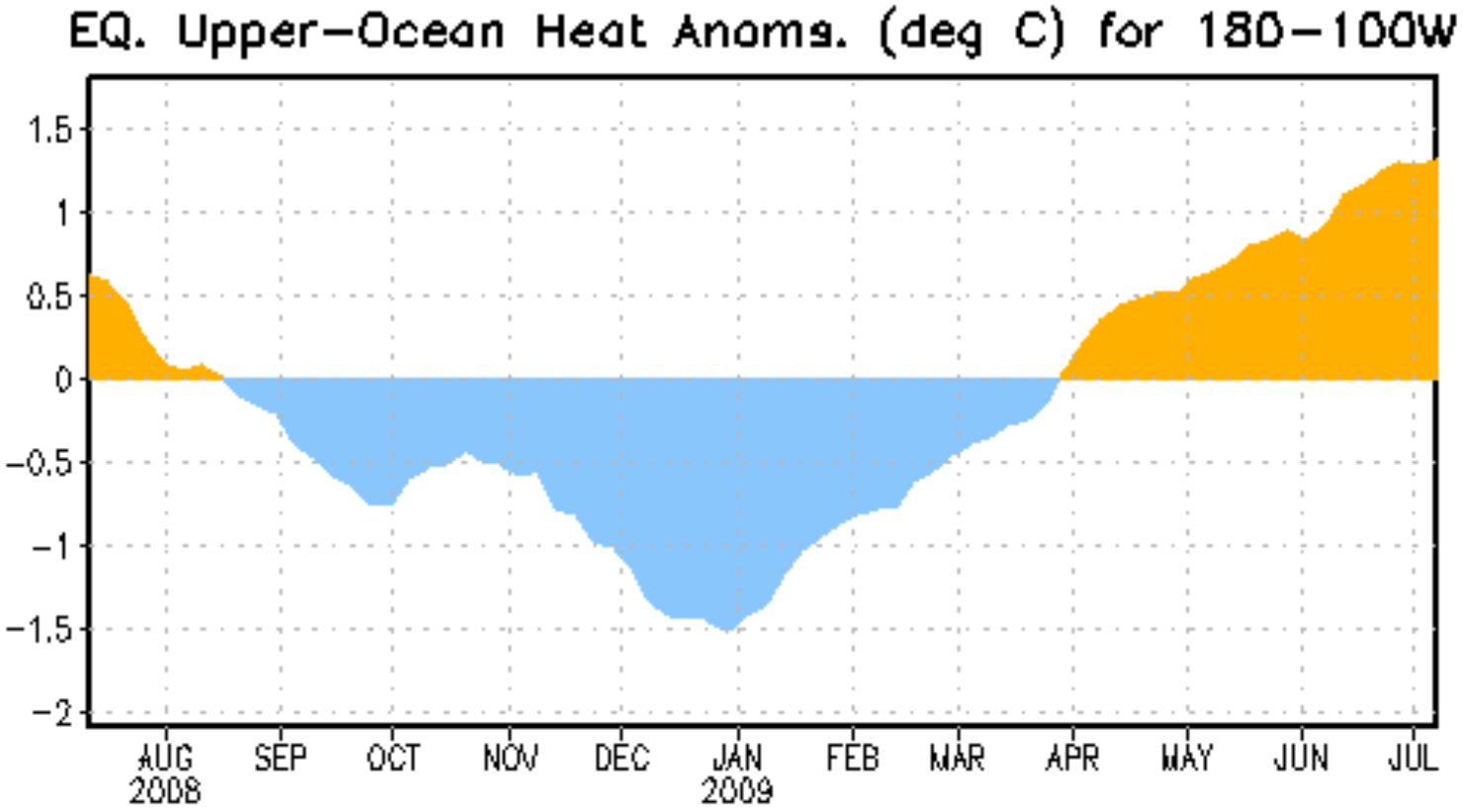

SOHO MDI 5-Jul-2009
10 Earth
Earth
Jupiter


Cycle 23-24 Sunspot Number Prediction (May 2009)
200
150
100
50
0
1995
2000
2005
2010
2015
2020
Hathaway/NASA/MSFC

El Niño-La Niña Cycles

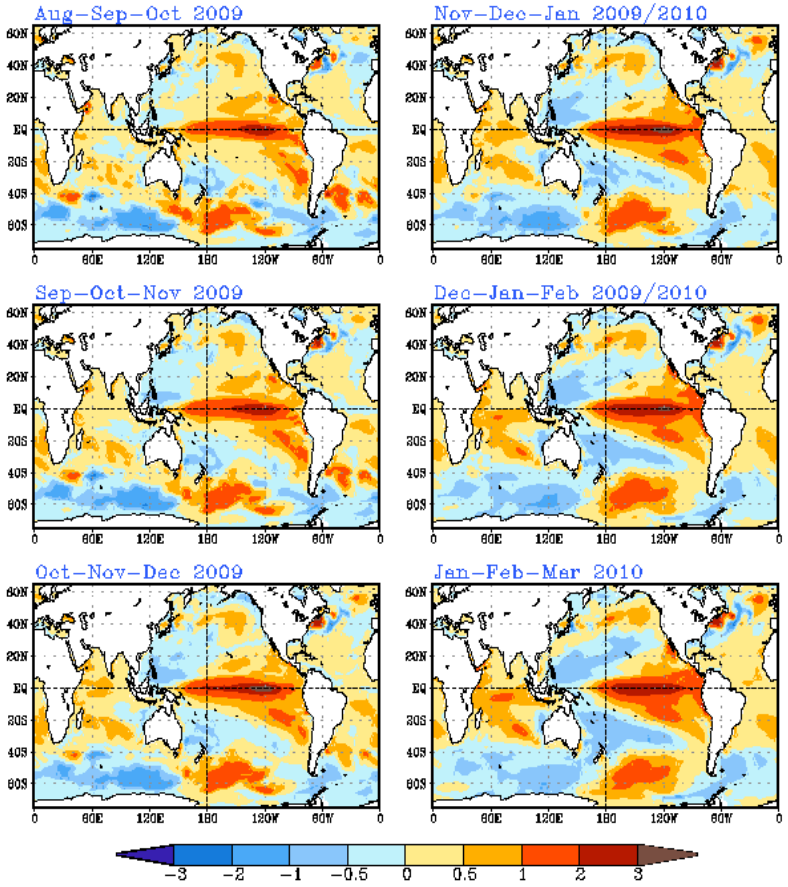


Central & Eastern Pacific Upper-Ocean (0-300 m) Weekly Heat Content Anomalies

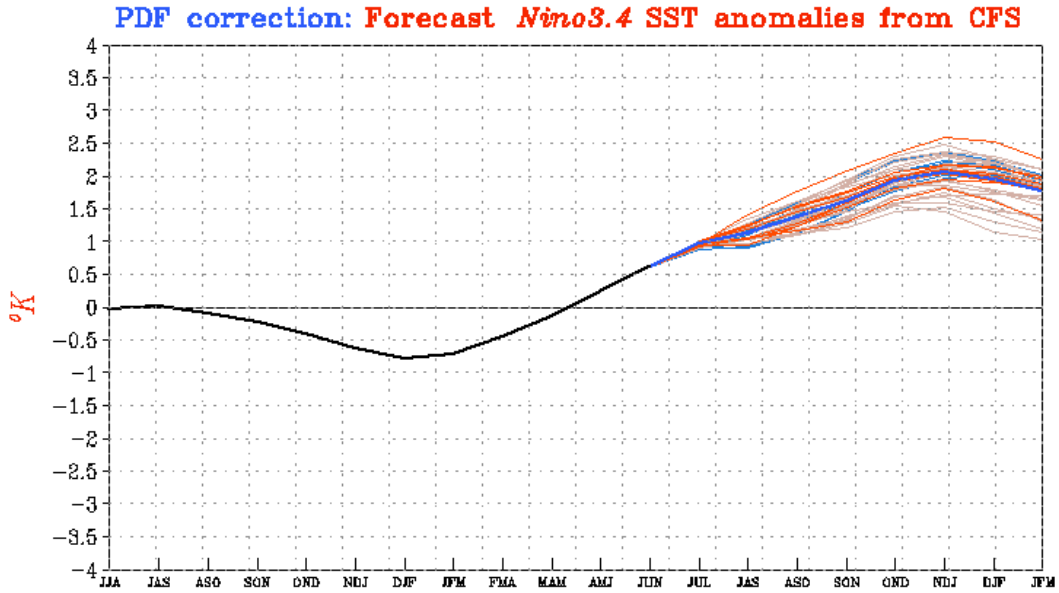


The upper ocean heat content was below-average across the eastern half of the equatorial Pacific Ocean between mid-August 2008 and March 2009, with a minimum reached in late December 2008. The heat content anomalies have been positive since April, and have steadily increased since that time.

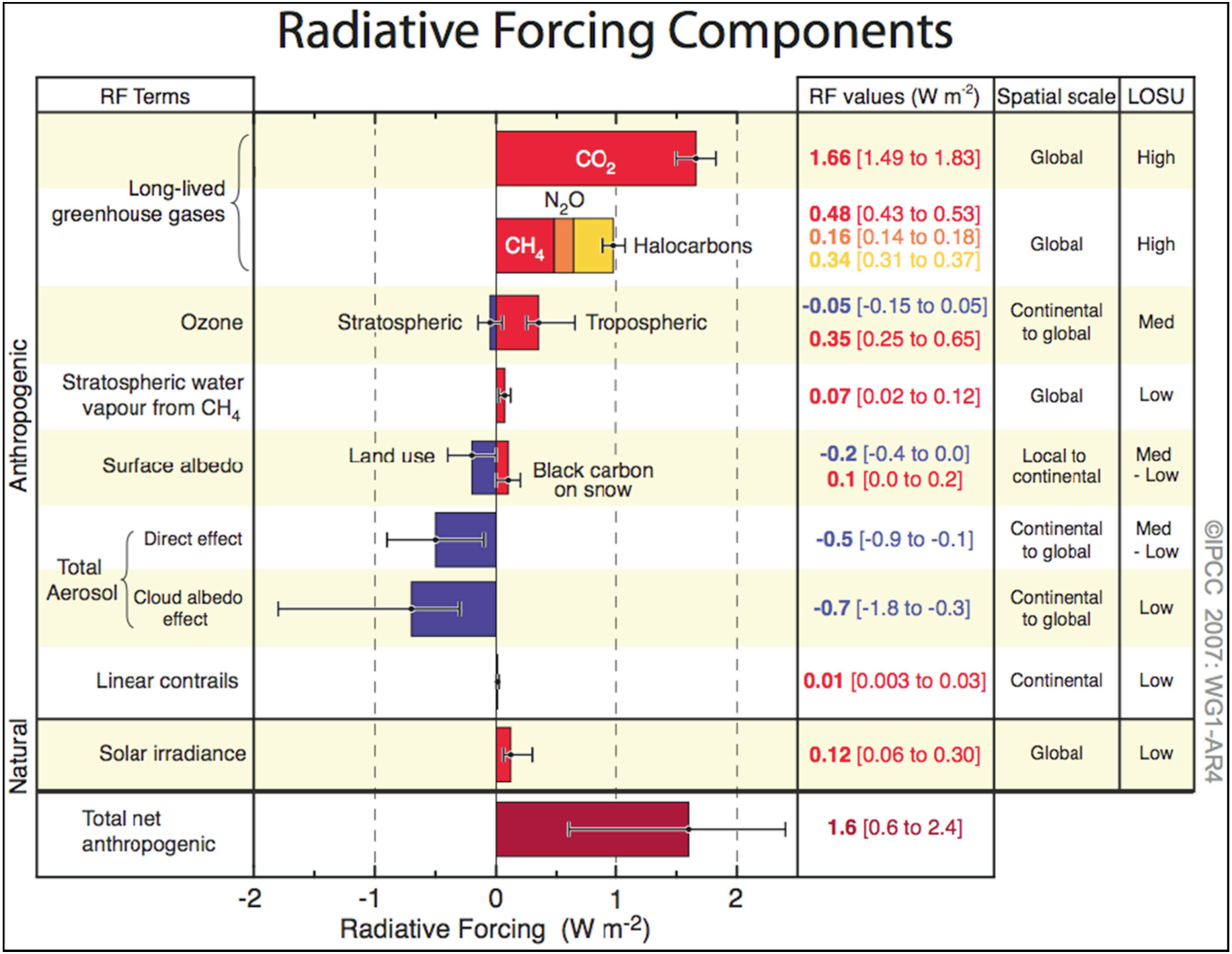
SST Outlook: NCEP CFS Forecast Issued 12 July 2009



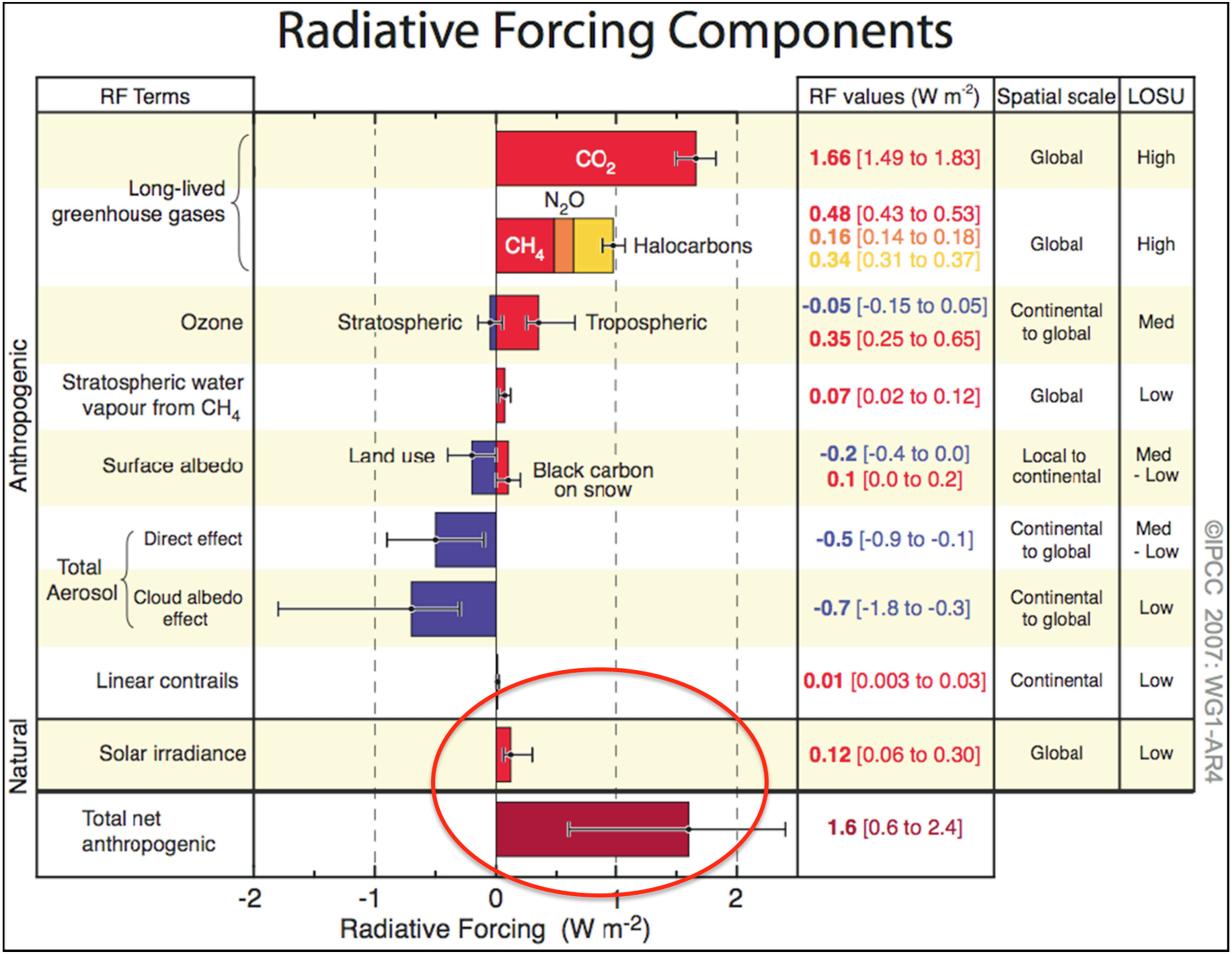
The CFS ensemble mean (heavy blue line) predicts El Niño to last through Northern Hemisphere Winter 2009-10.



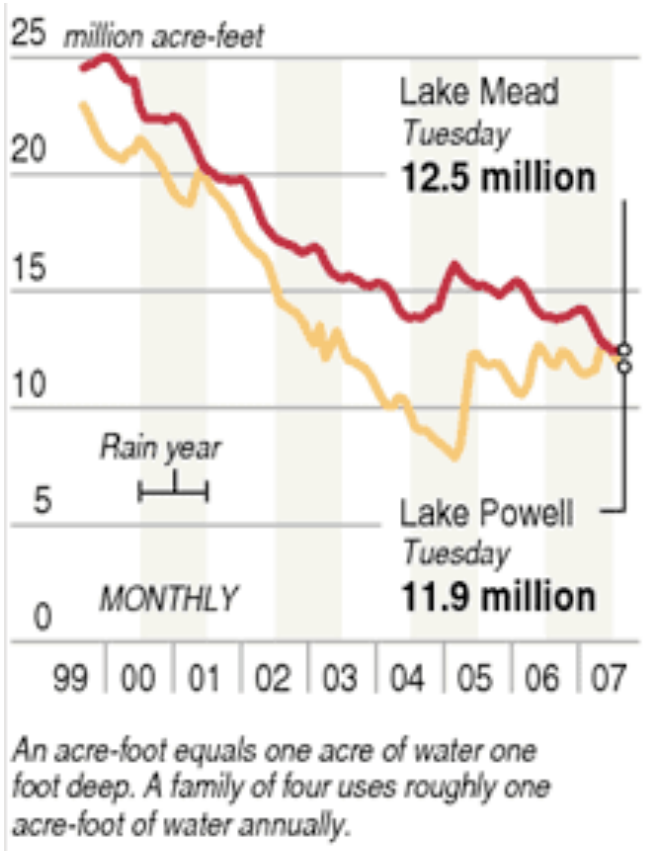
Radiative Forcing Components



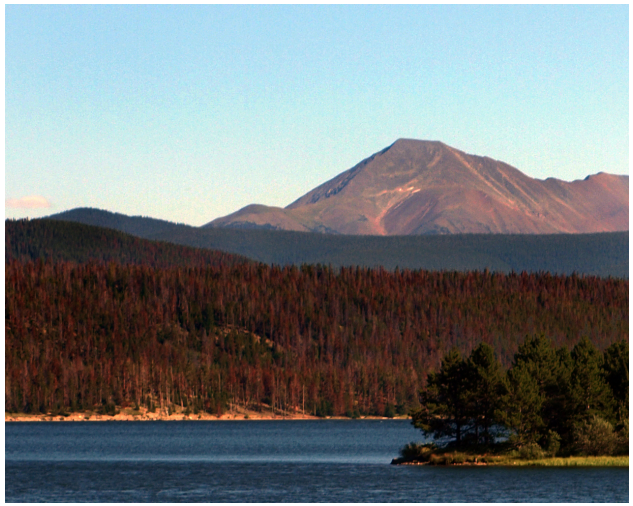
Radiative Forcing Components



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.

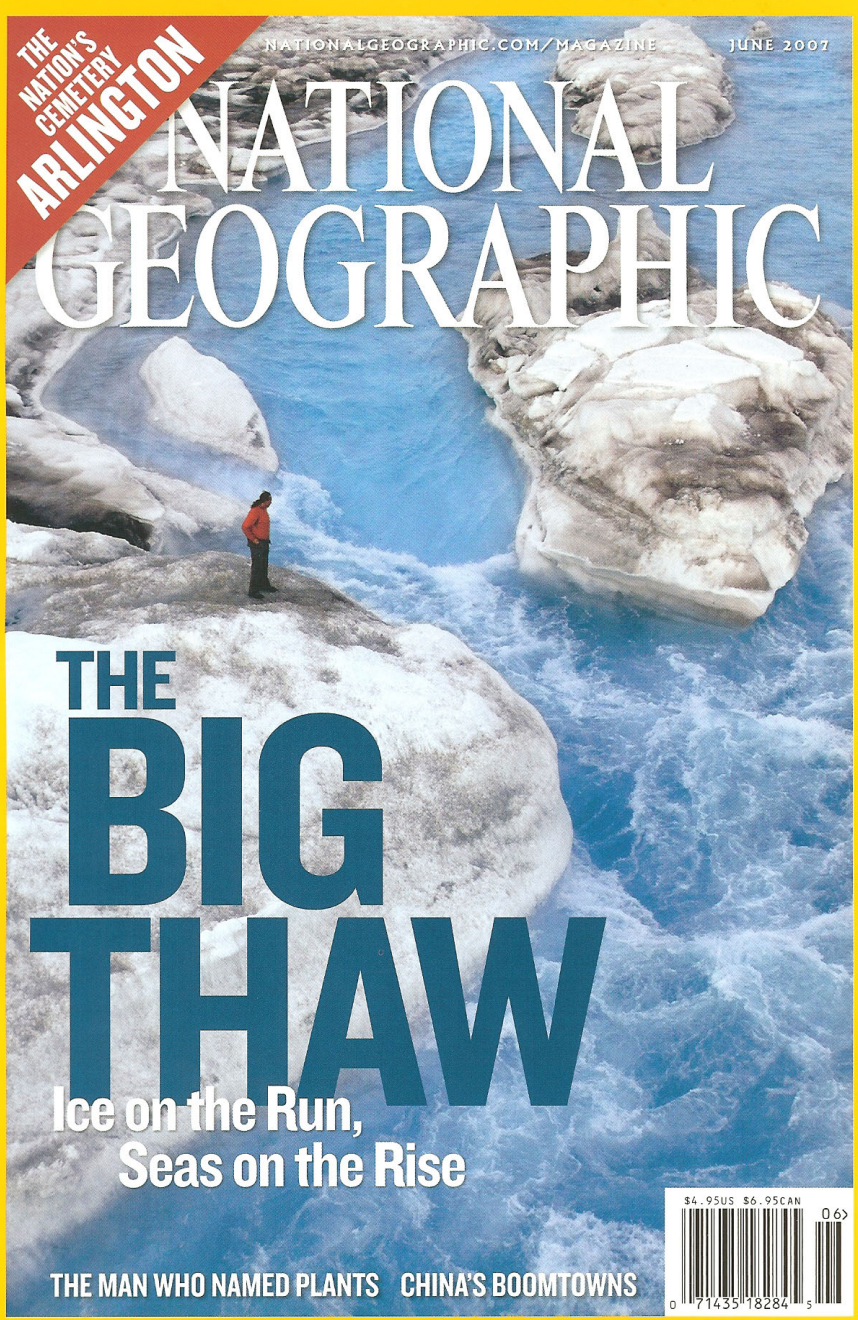


2007 IPCC Report

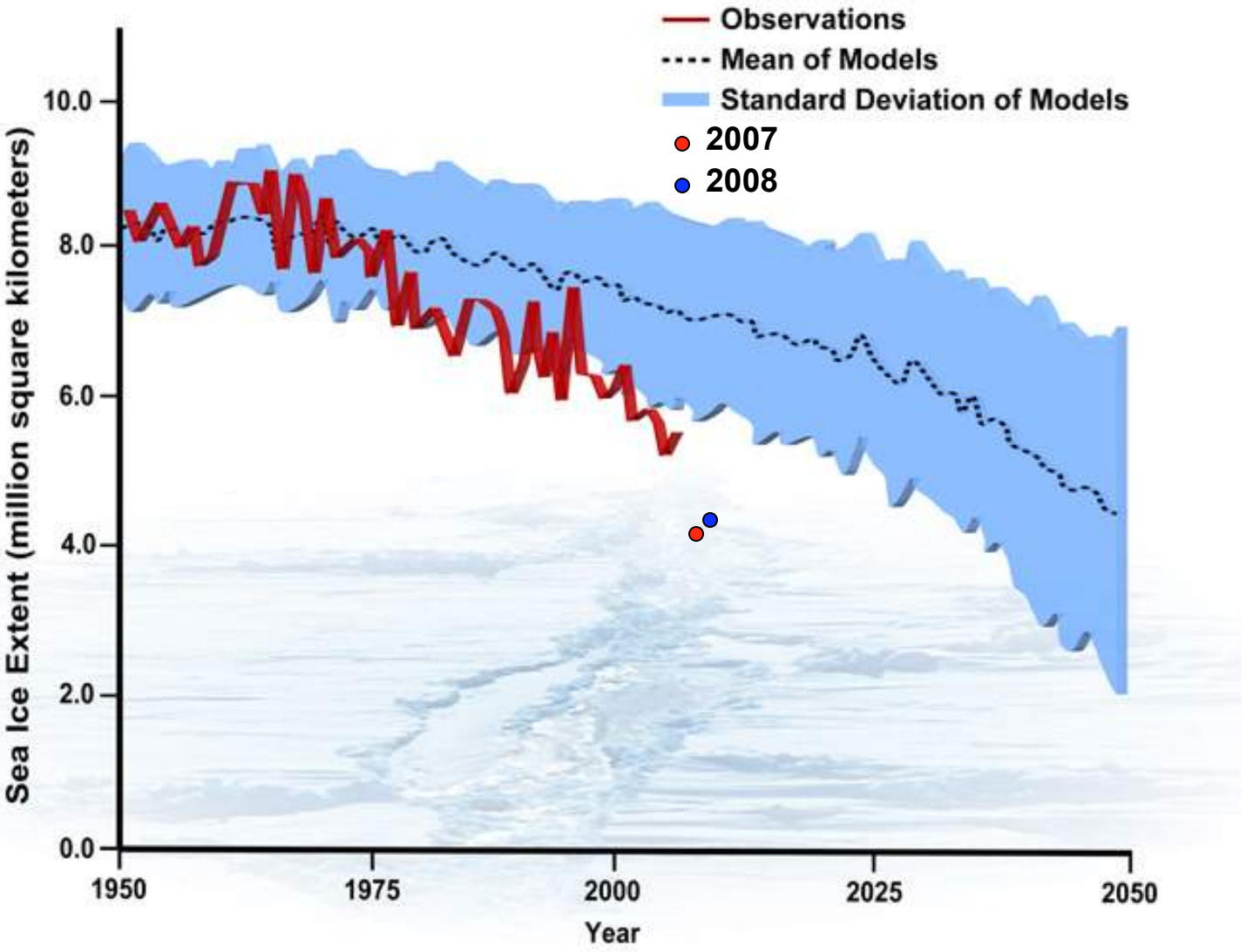
- *"Warming of the climate is unequivocal."*
- *"..very likely due to anthropogenic greenhouse gas concentrations."*

What the latest IPCC study does not include:

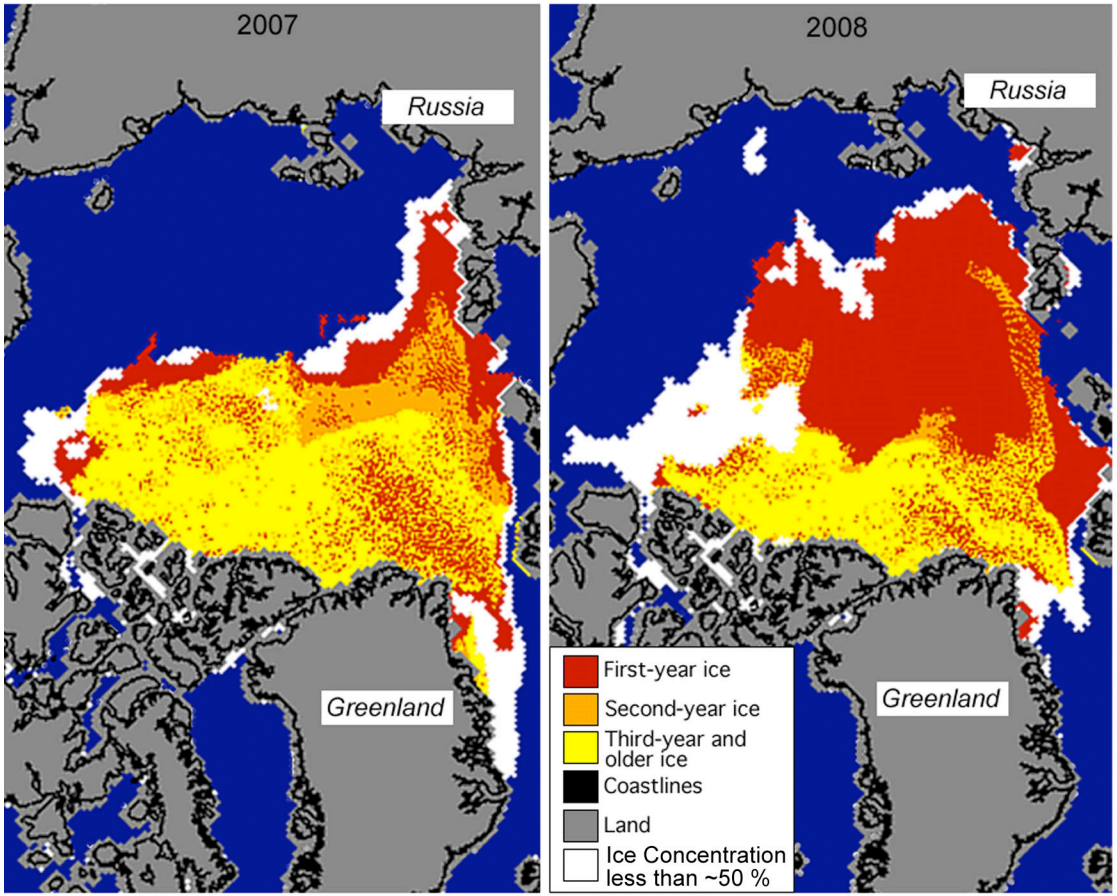
"future rapid dynamical changes in ice flow"


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
$4.95US $6.95CAN
06

Arctic September Sea Ice Extent: Observations and Model Runs



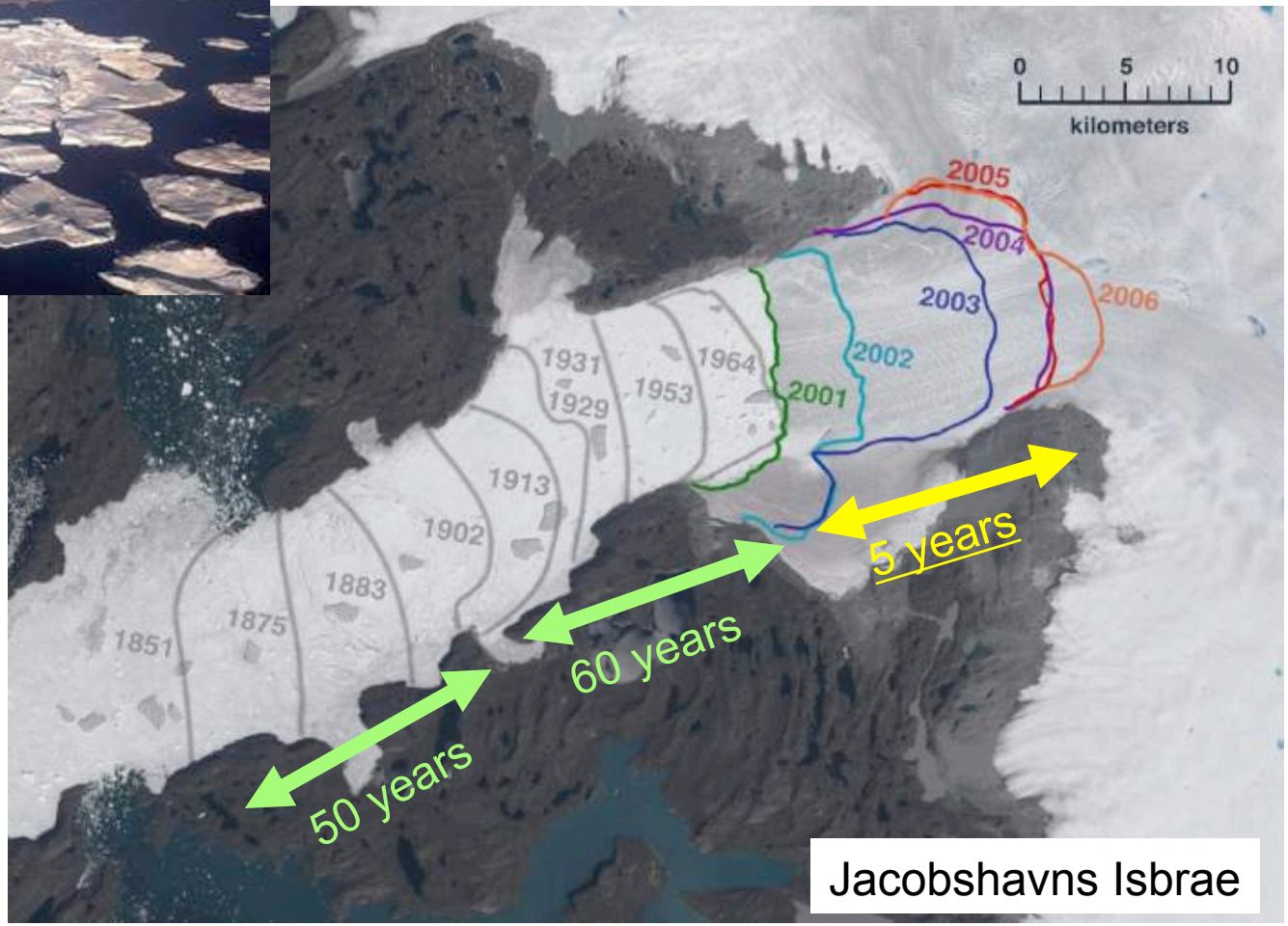
Arctic Sea Ice Is Getting Thinner



September 2007 September 2008

Rapid Retreat

Average speed
5 ft per hour!

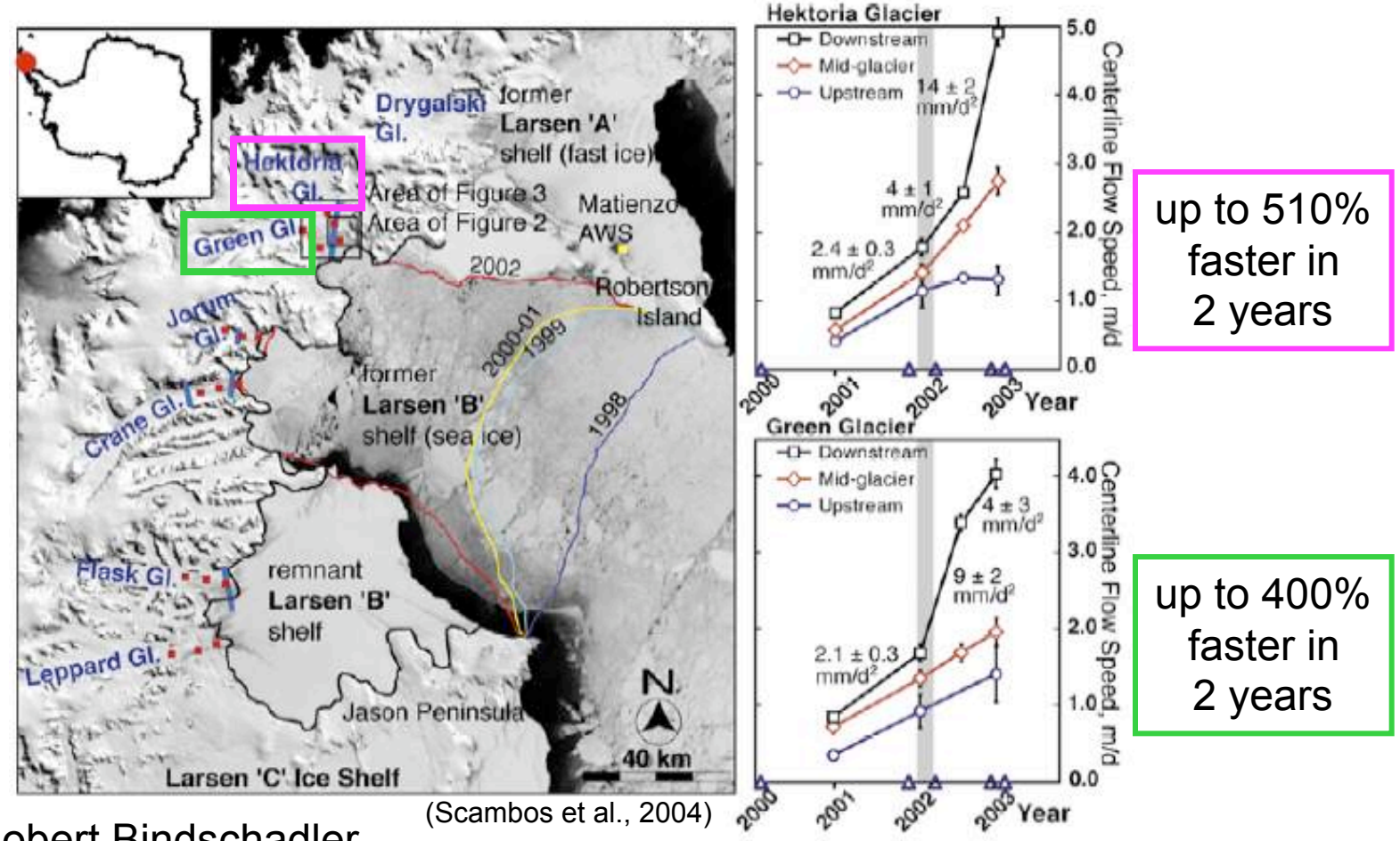


Iceberg-choked fjord created by rapid retreat

Courtesy of Robert Bindschadler

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

Ice Shelf Buttressing



(Scambos et al., 2004)

up to 510% faster in 2 years

up to 400% faster in 2 years

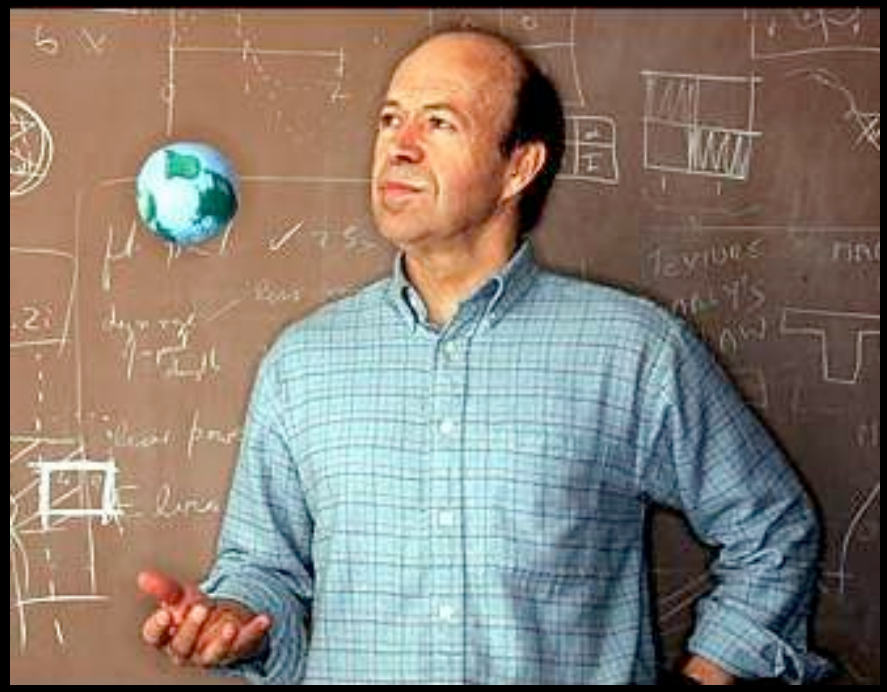
Courtesy of Robert Bindschadler

Formerly buttressed glaciers accelerate

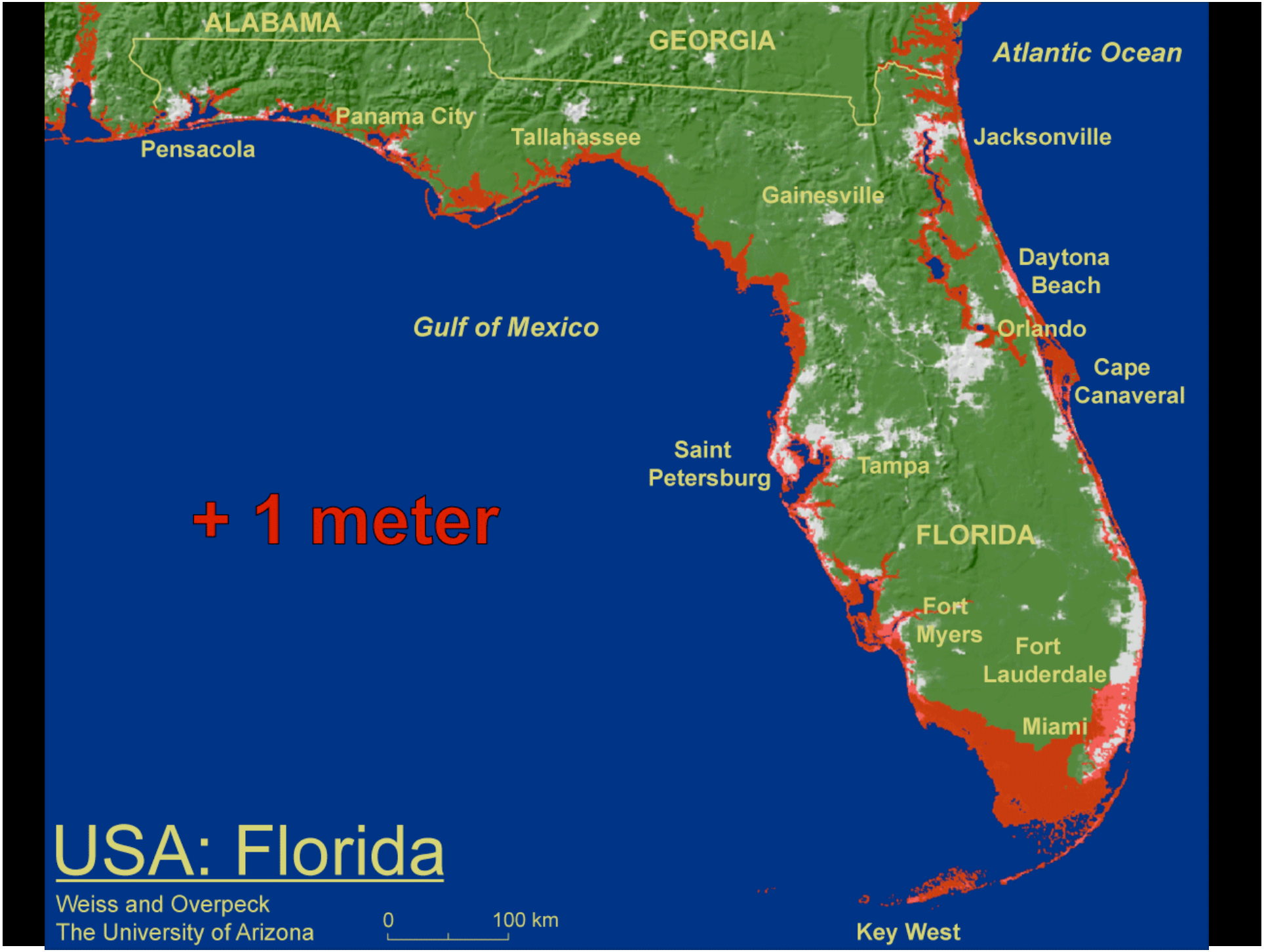

NATURE INSIGHT RNA SILENCING
22 January 2009 | www.nature.com/nature | $10
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
nature
ANTARCTIC WARMING
Climate reconstruction gets to the heart of the continent
WHO DO YOU THINK YOU ARE?
Personal genomics changes the rules
SOLAR SYSTEM EXPLORATION
The Titan-versus-Europa dilemma
SEXUAL REPRODUCTION
A long wait for Aspergillus
NATUREJOBS
Biotech & pharmaceuticals
$10.00US $12.99CAN

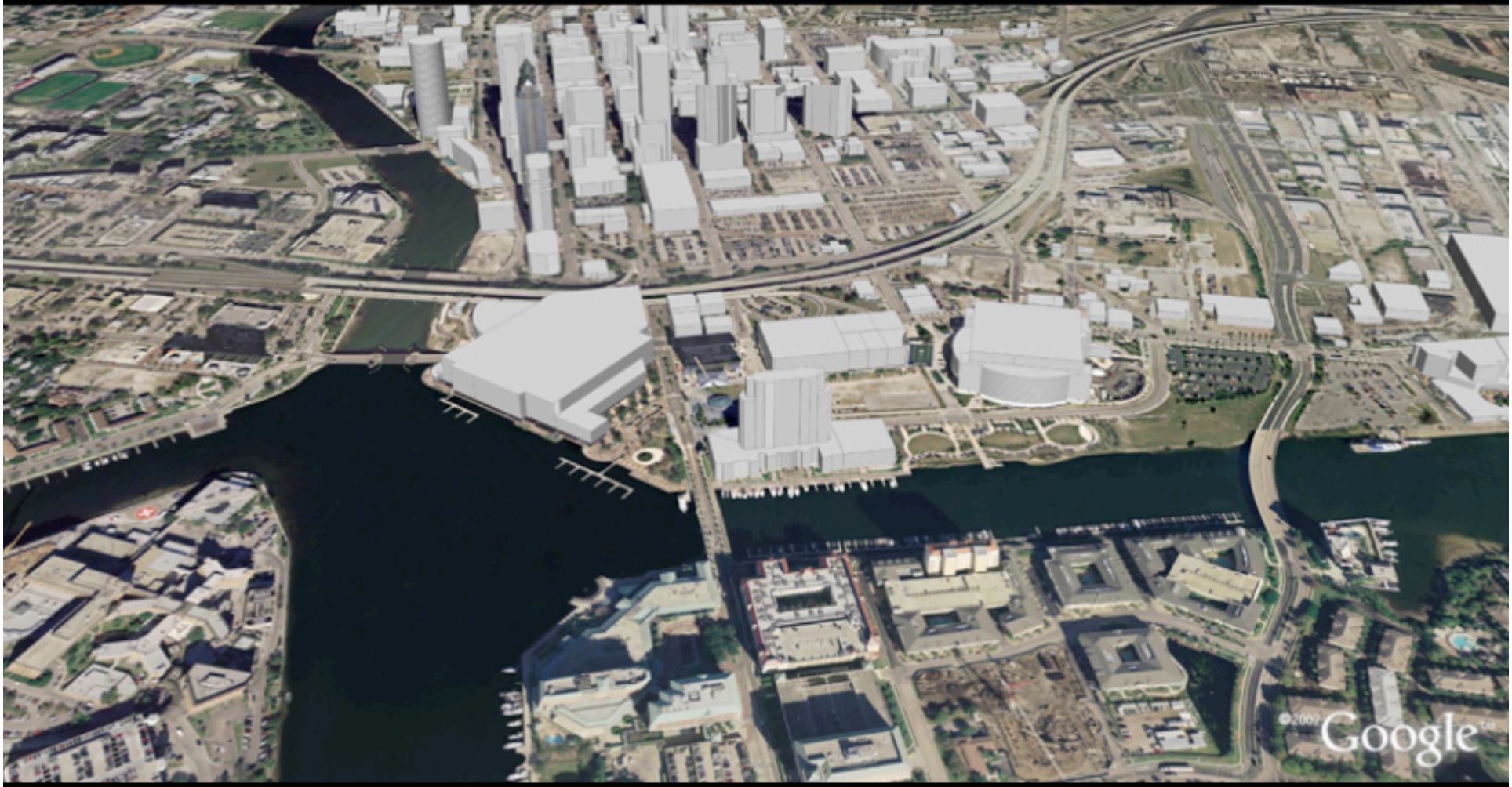
“The last time a large ice sheet melted, sea level went up one meter every 20 years.”

– Dr. James Hansen, Director
Goddard Institute for Space Studies




ALABAMA
GEORGIA
Atlantic Ocean
Panama City
Tallahassee
Pensacola
Jacksonville
Gainesville
Daytona Beach
Gulf of Mexico
Orlando
Cape Canaveral
Saint Petersburg
Tampa
Present
FLORIDA
Fort Myers
Fort Lauderdale
Miami
USA: Florida
Weiss and Overpeck
The University of Arizona
0
100 km
Key West


ALABAMA
GEORGIA
Atlantic Ocean
Panama City
Tallahassee
Pensacola
Jacksonville
Gainesville
Daytona Beach
Gulf of Mexico
Orlando
Cape Canaveral
Saint Petersburg
Tampa
+ 1 meter
FLORIDA
Fort Myers
Fort Lauderdale
Miami
USA: Florida
Weiss and Overpeck
The University of Arizona
0
100 km
Key West

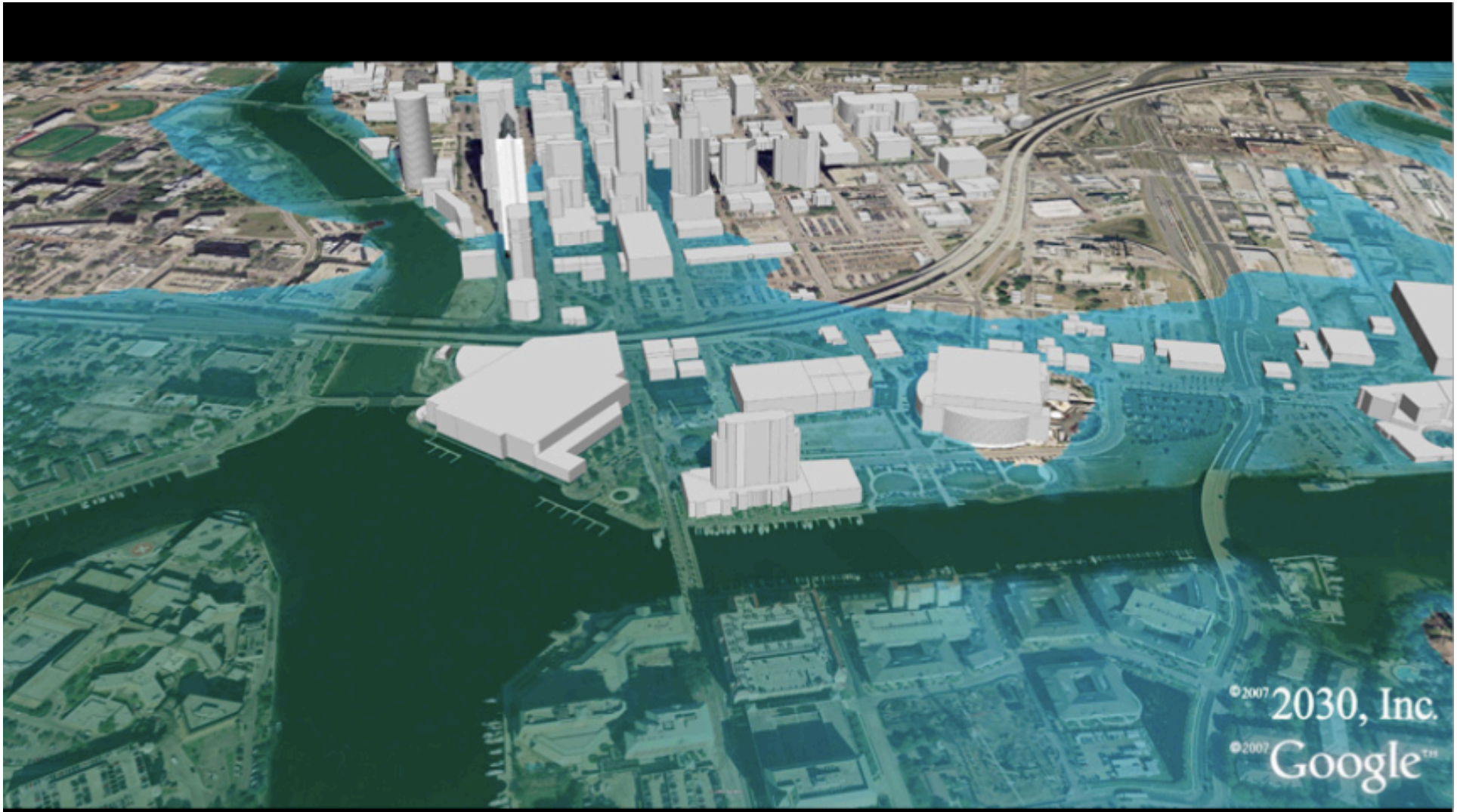


Tampa

Population
382,060

Tampa

Sea level: Google Earth / USGS



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?

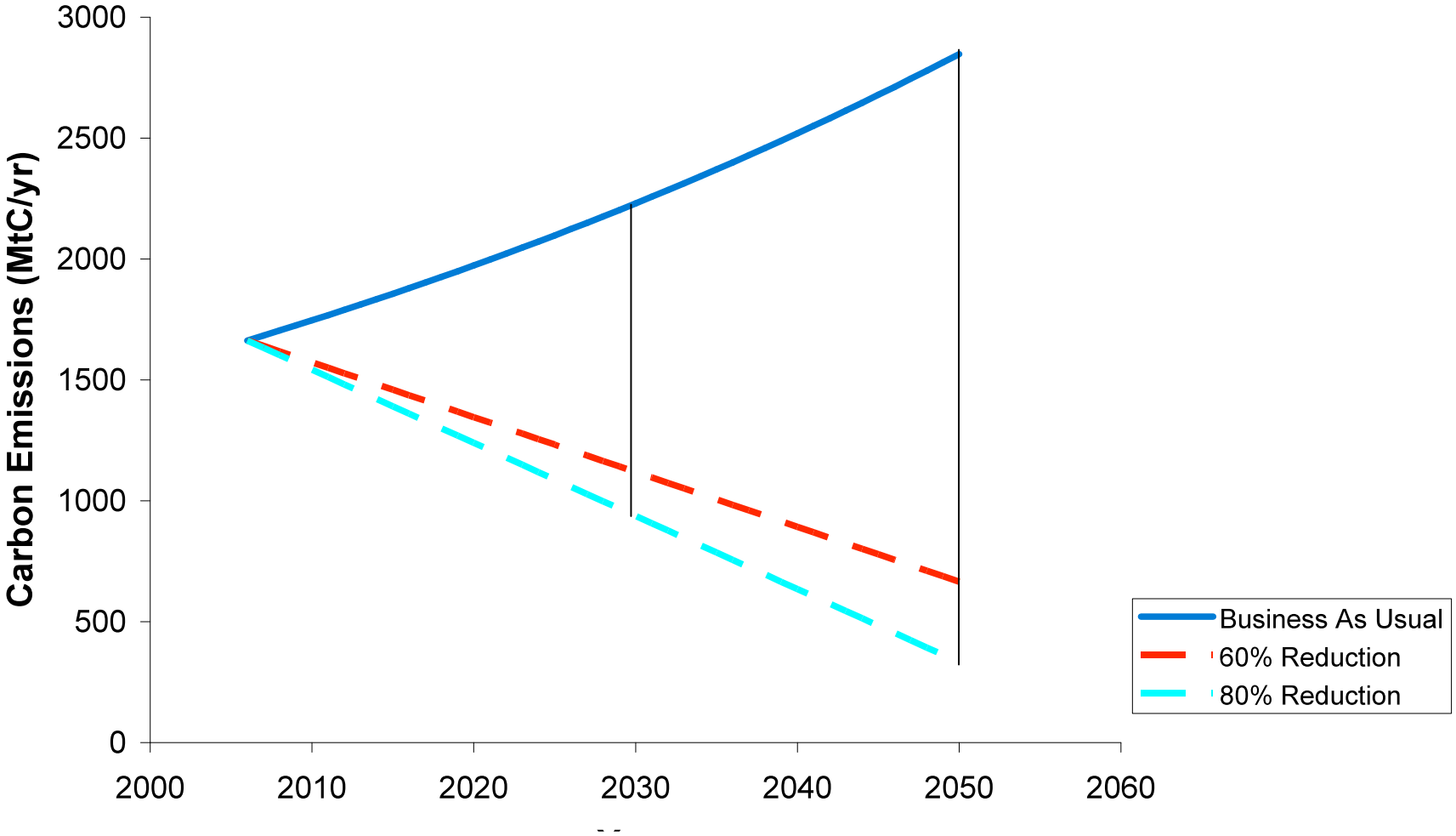
...with your planet?

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. CO_2 emissions 60%–80% (?) by 2050

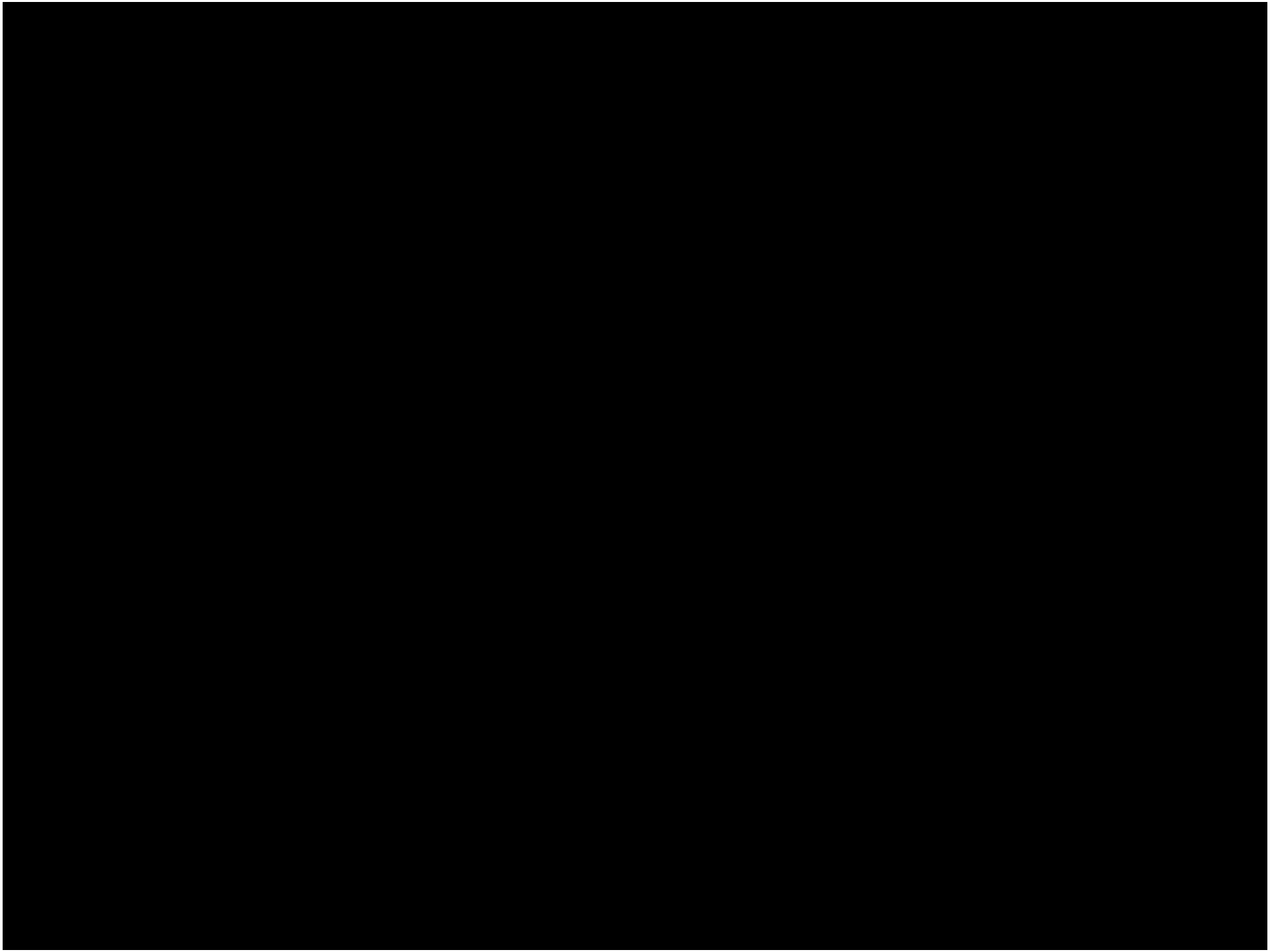
U.S. Carbon Reduction Triangles



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

“Houston, we have a problem.”

Apollo 13

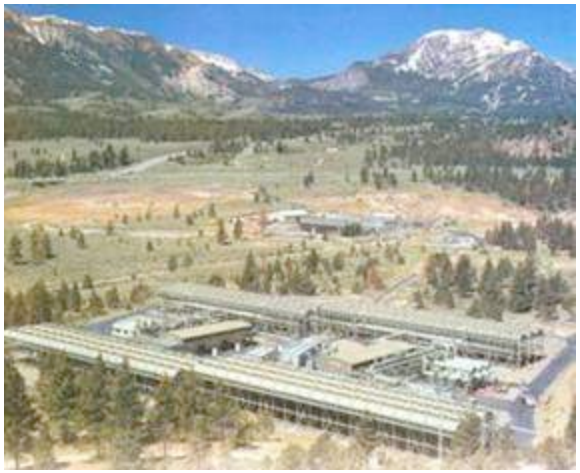


Key Energy Options

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

American Solar Energy Society
WORKING TOWARD A SUSTAINABLE ENERGY FUTURE

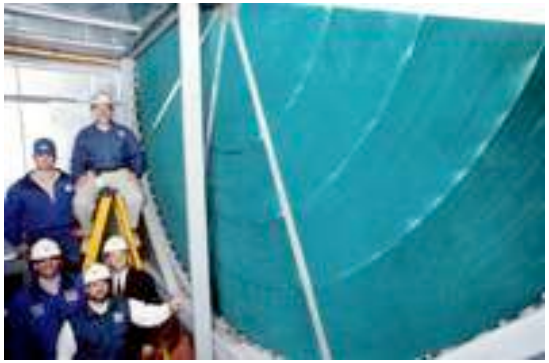
SOLAR 2006, Denver
"Renewable Energy: Key to Climate Recovery"



Geothermal

PV

Biofuels



Efficiency

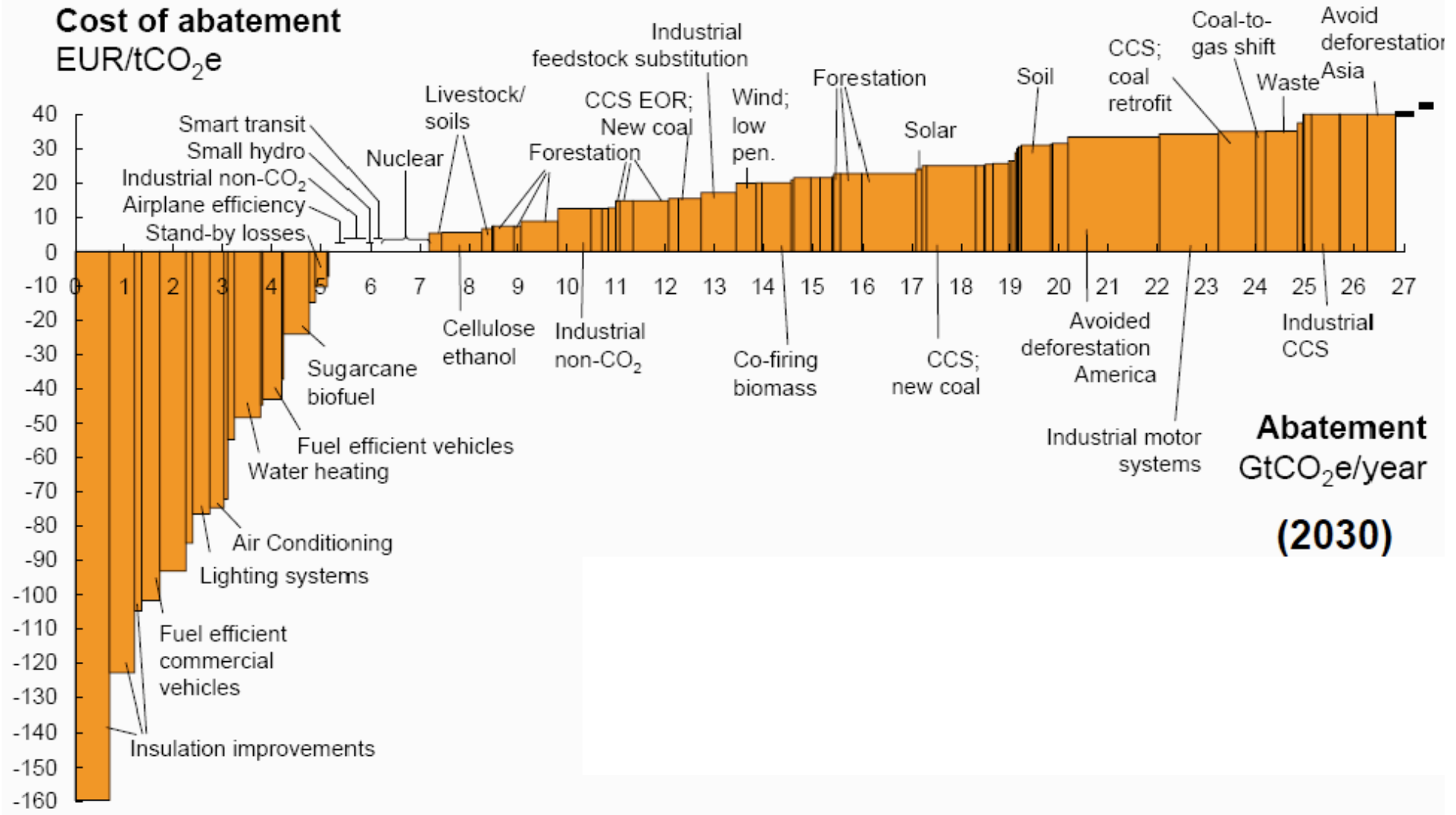
CSP

Biomass Power

Wind

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

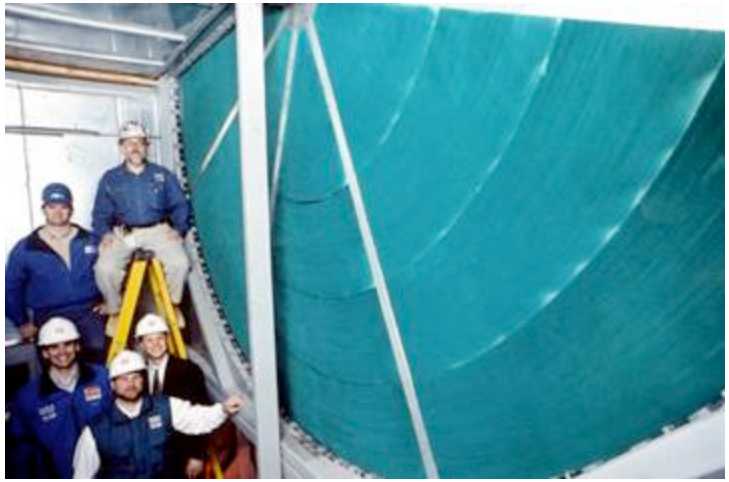

Cost of abatement
EUR/tCO2e
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
Smart transit
Small hydro
Industrial non-CO2
Airplane efficiency
Stand-by losses
Nuclear
Livestock/ soils
Forestation
Industrial feedstock substitution
CCS EOR; New coal
Wind; low pen.
Forestation
Solar
Soil
CCS; coal retrofit
Coal-to-gas shift
Waste
Avoid deforestation Asia
Sugarcane biofuel
Fuel efficient vehicles
Water heating
Air Conditioning
Lighting systems
Fuel efficient commercial vehicles
Insulation improvements
Cellulose ethanol
Industrial non-CO2
Co-firing biomass
CCS; new coal
Avoided deforestation America
Industrial motor systems
Industrial CCS
Abatement
GtCO2e/year
(2030)

Energy Efficiency Savings

- Electricity: 218 MtC/yr, 0 – 4 ¢/kWh
  (20% savings off 2030 projection)

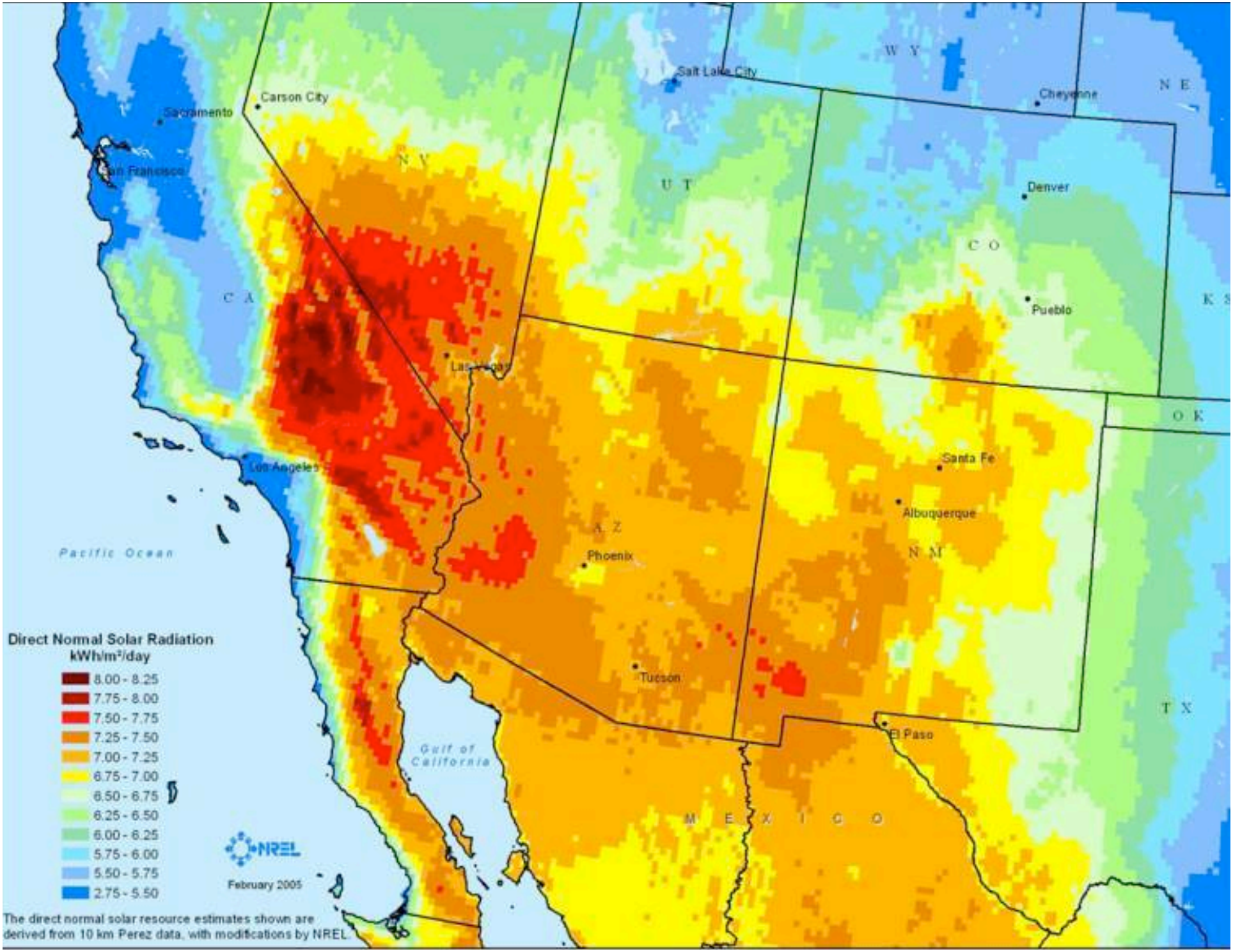
- Oil: 344 MtC/yr, $5 - $30/bbl

- Gas: 126 MtC/yr, $0 - $3/MBtu



Savings: 688 MtC/yr

Concentrating Solar Power (CSP)


Direct Normal Solar Radiation
kWh/m²/day
8.00 - 8.25
7.75 - 8.00
7.50 - 7.75
7.25 - 7.50
7.00 - 7.25
6.75 - 7.00
6.50 - 6.75
6.25 - 6.50
6.00 - 6.25
5.75 - 6.00
5.50 - 5.75
2.75 - 5.50
NREL
February 2005
The direct normal solar resource estimates shown are derived from 10 km Perez data, with modifications by NREL
Pacific Ocean
Gulf of California
M E X I C O
Salt Lake City
Carson City
Sacramento
Denver
Cheyenne
Pueblo
Santa Fe
Albuquerque
Phoenix
Tucson
El Paso
Los Angeles
W Y
N E
N V
U T
C O
K S
C A
O K
A Z
N M
T X

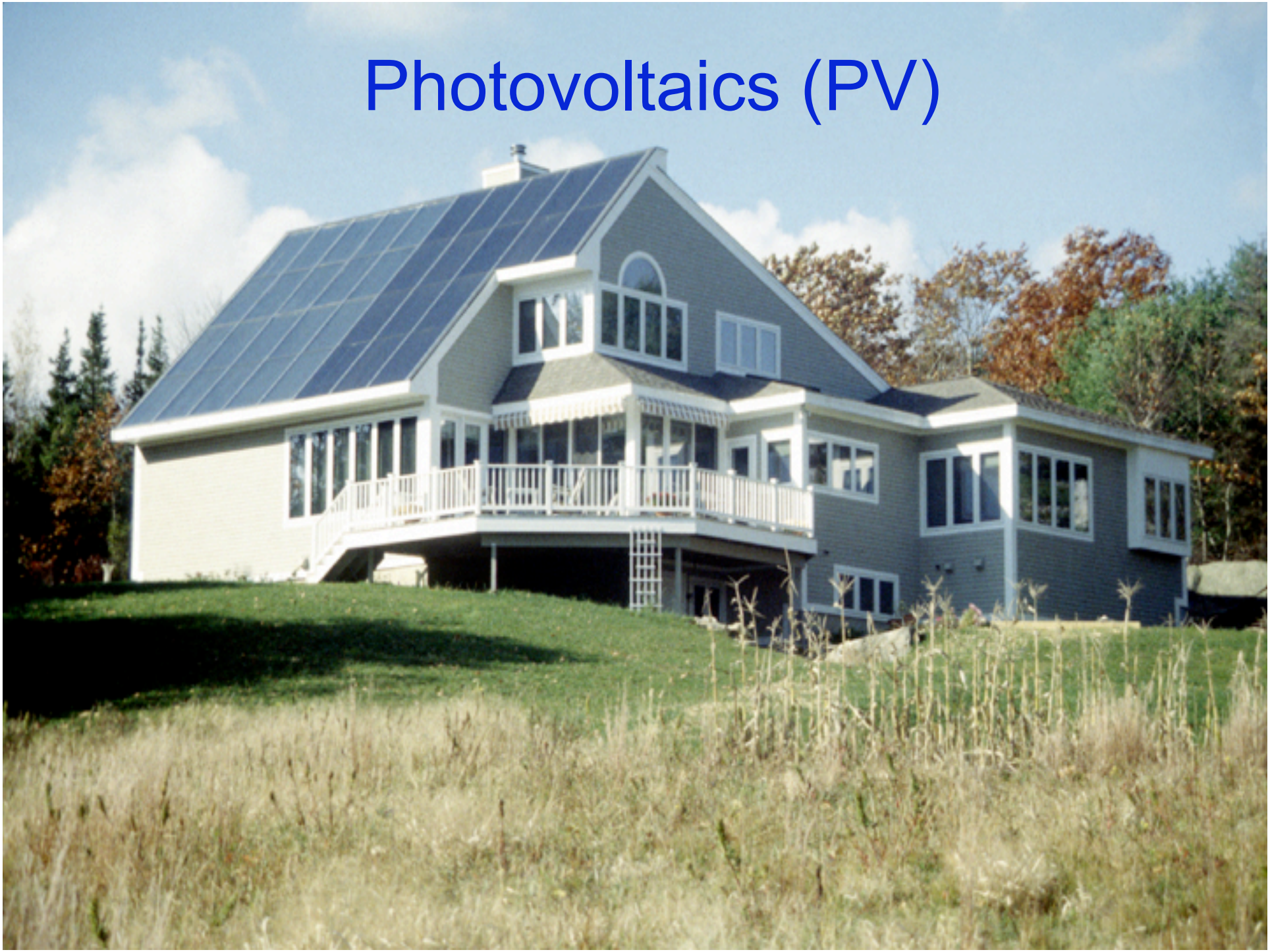
New 64 MWe Acciona Solar Parabolic Trough Plant

CSP Savings

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

Savings: 63 MtC/yr

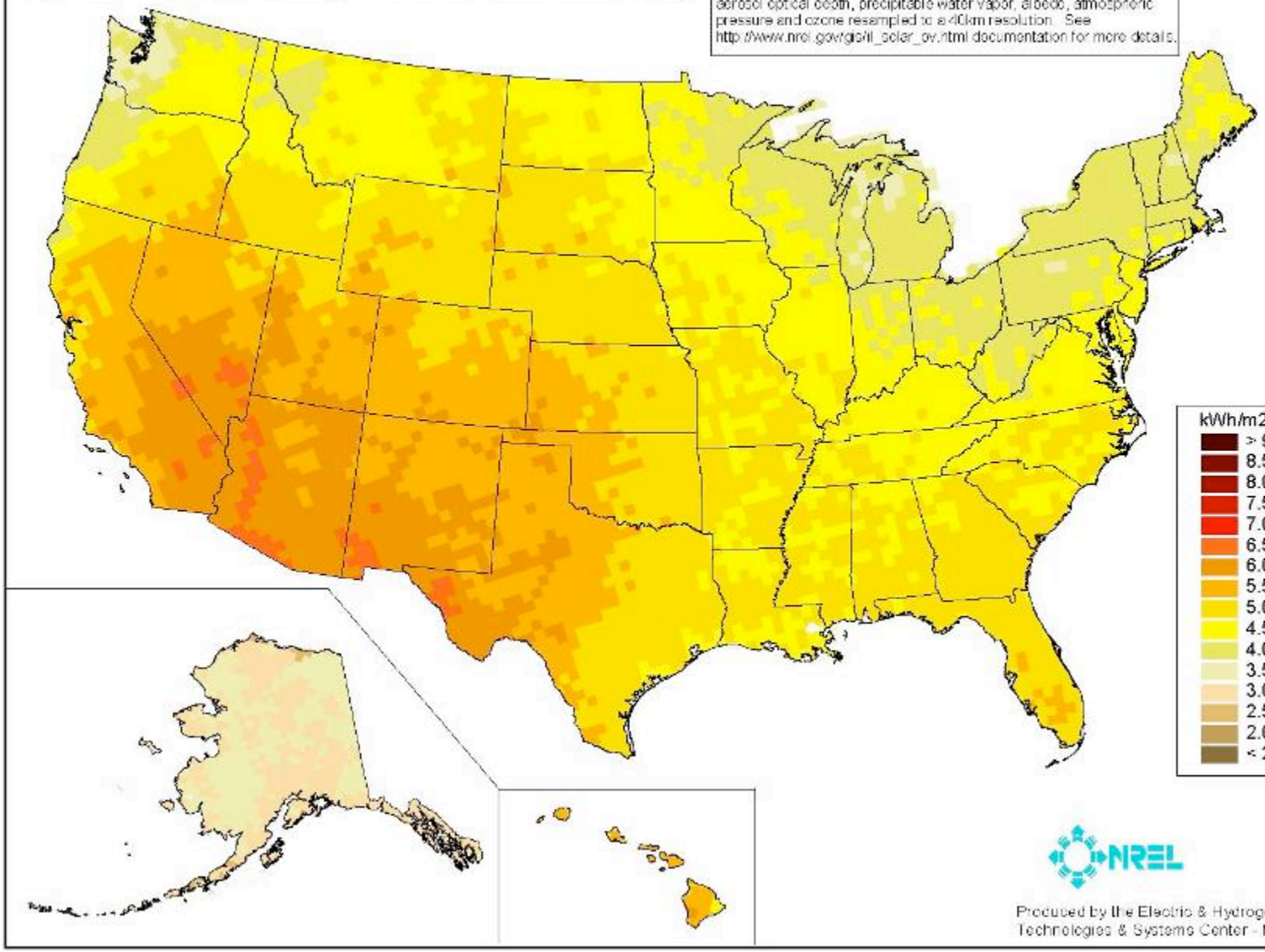
Photovoltaics (PV)



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

Annual

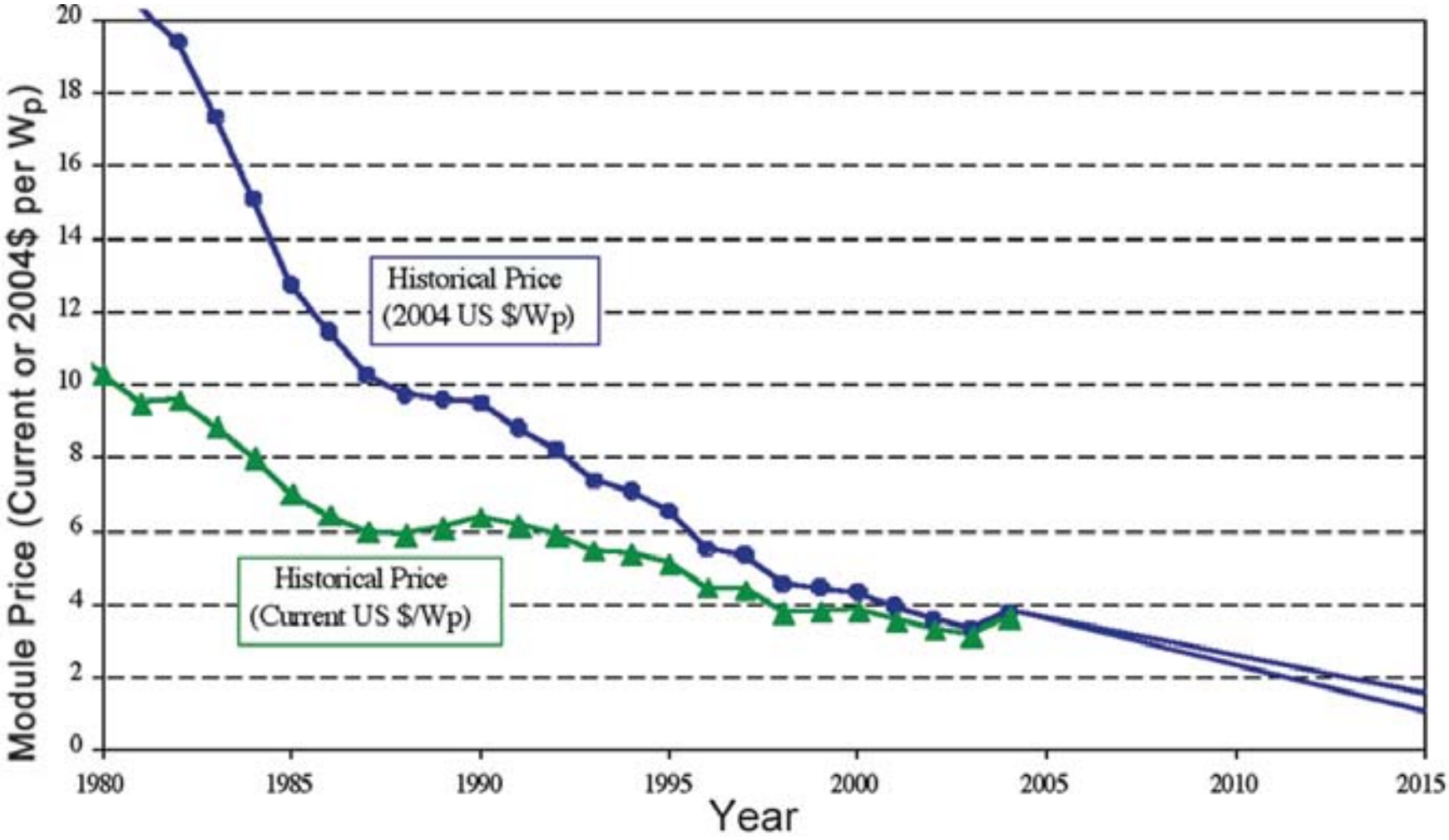
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/rl_solar_pv.html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



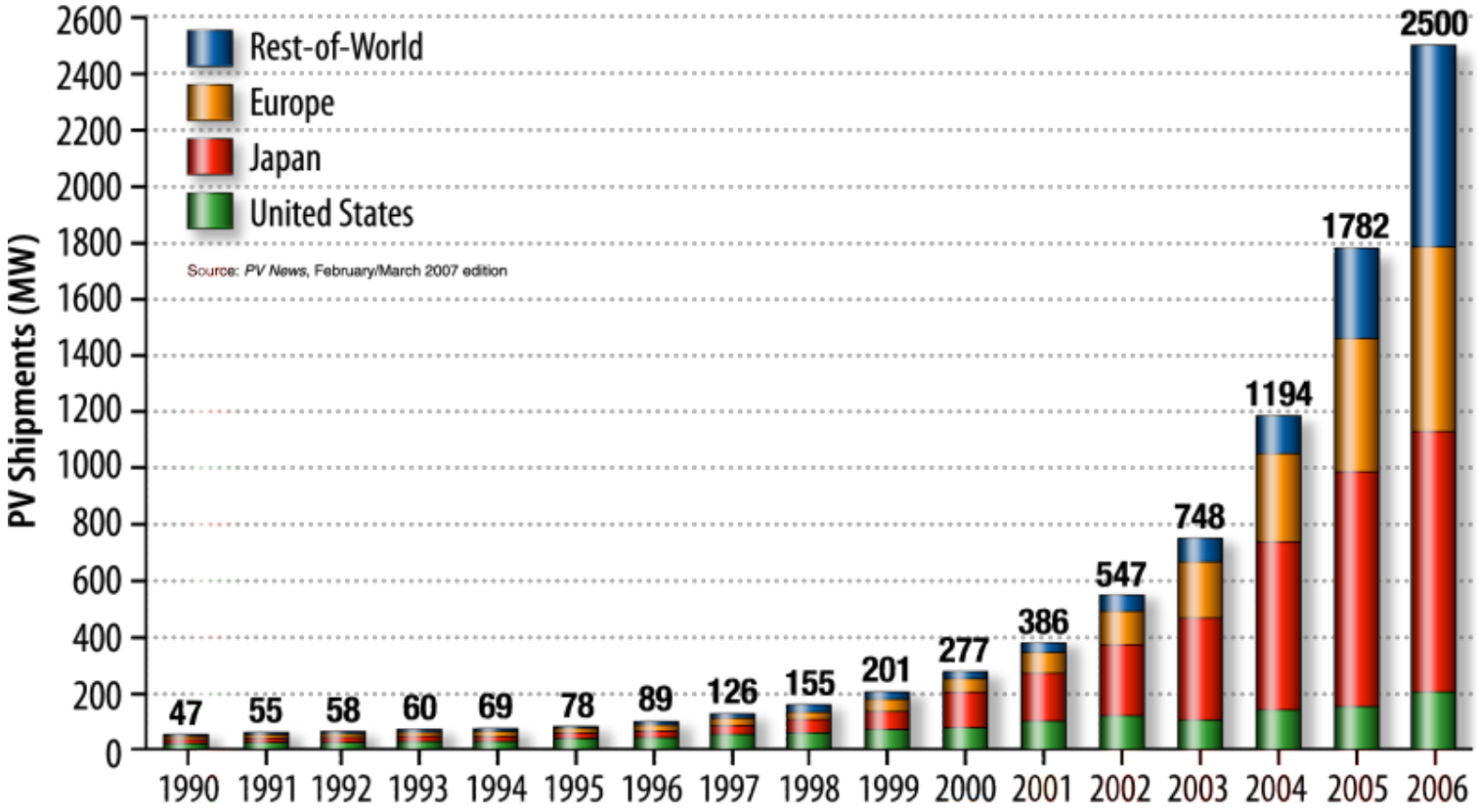
NREL

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

PV Module Prices



Worldwide PV Shipments



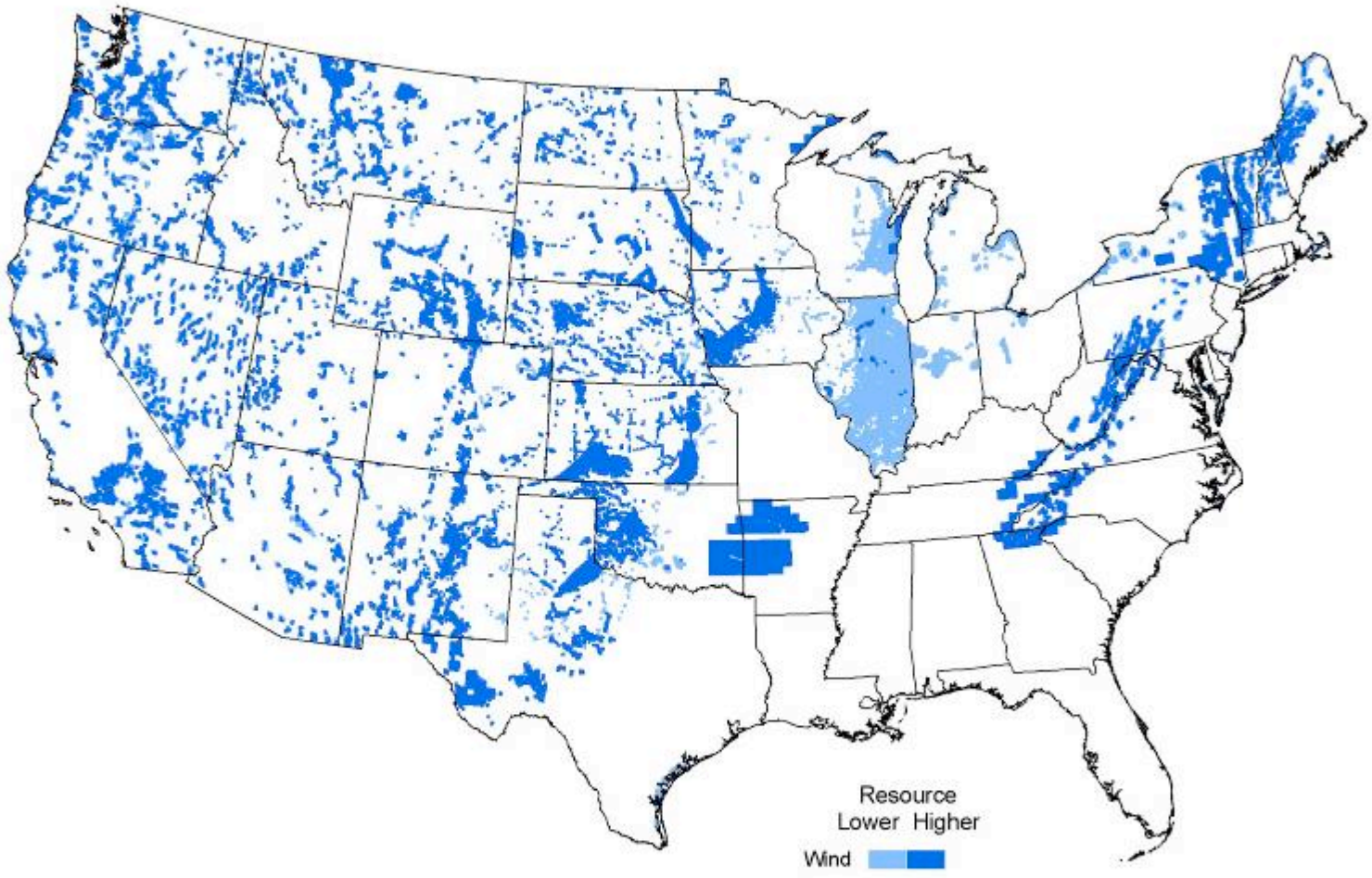
PV Savings

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

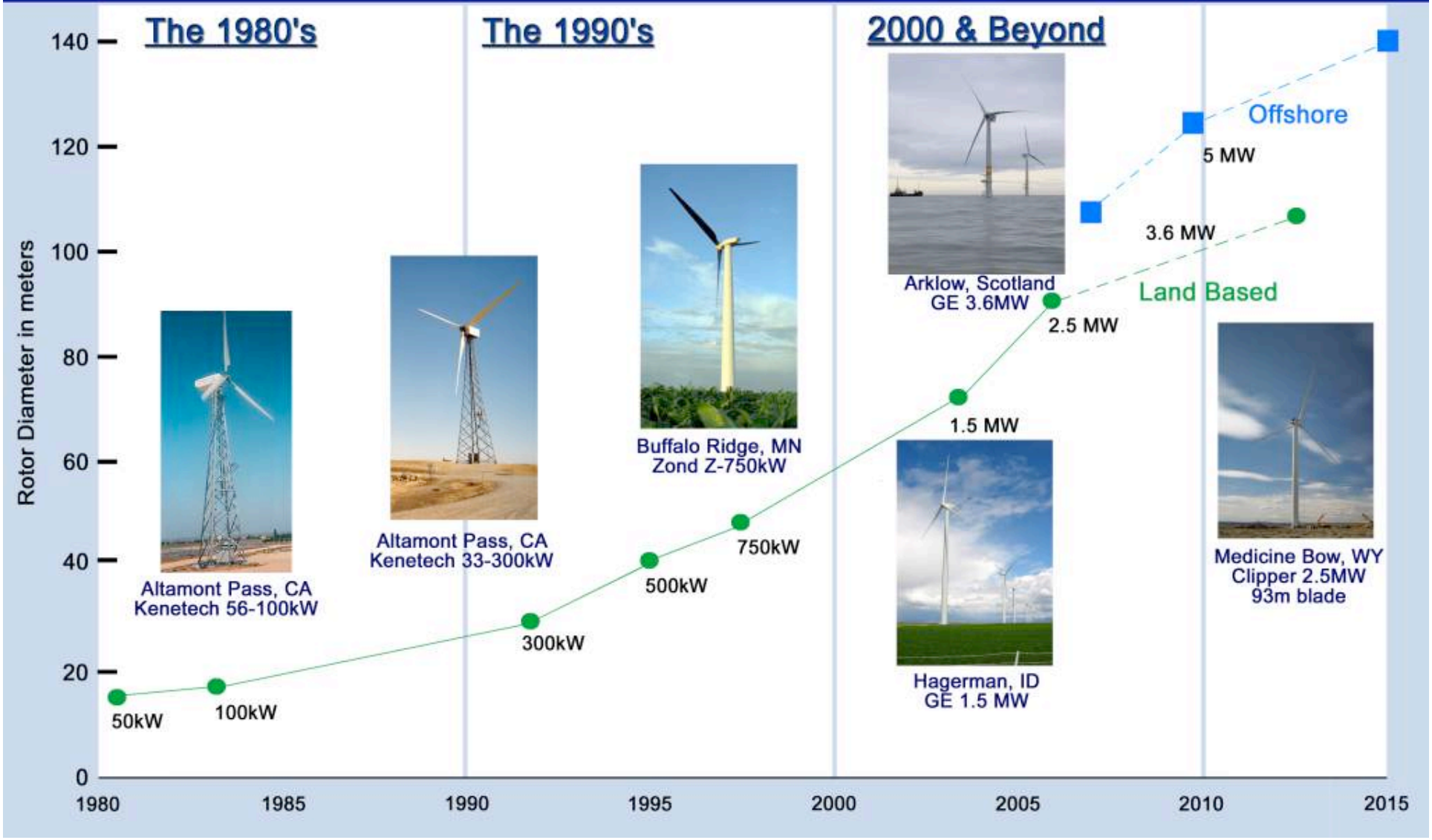
Savings: 63 MtC/yr

Wind

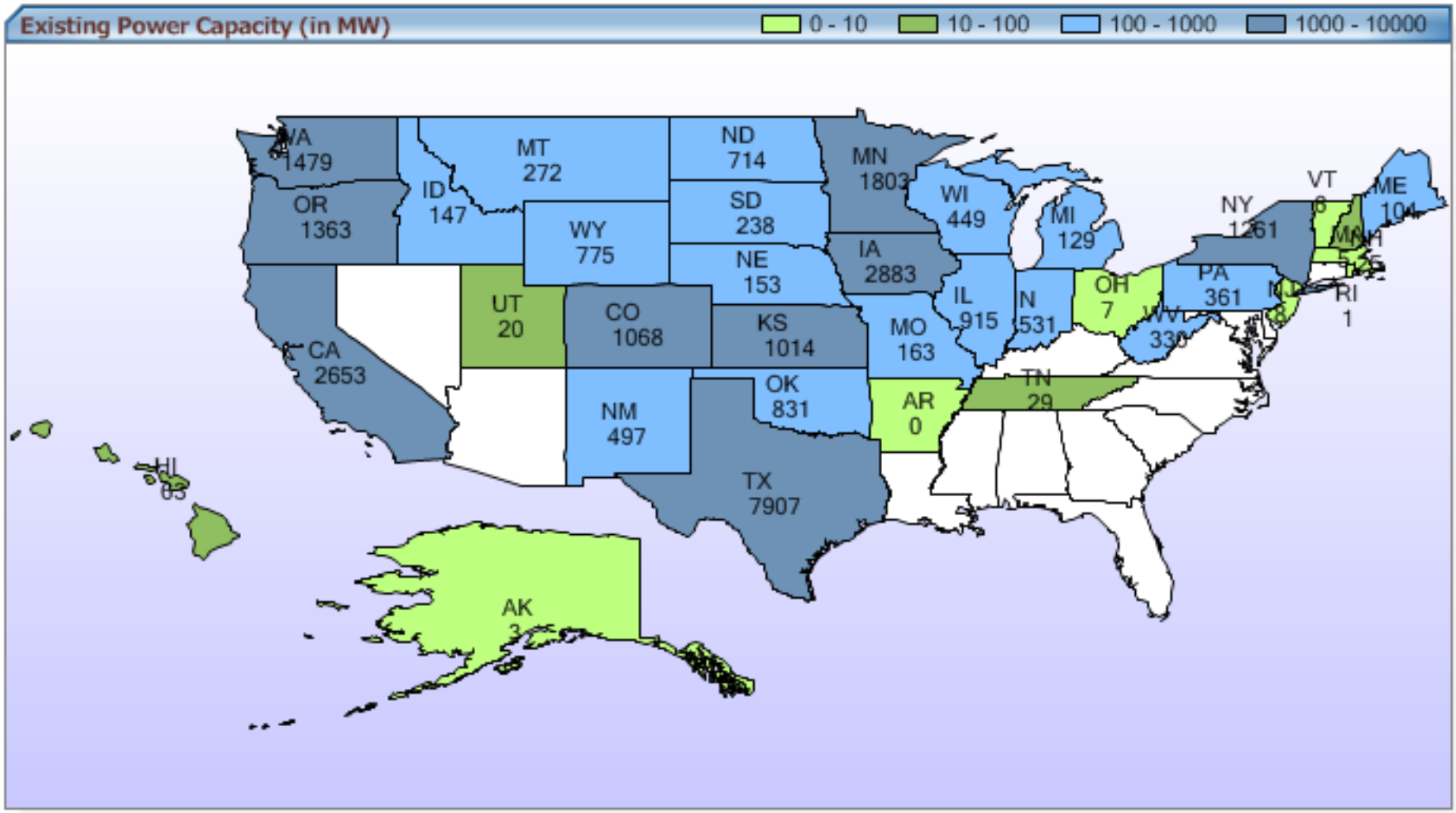
U.S. Wind Resource



Evolution of U.S. Commercial Wind Technology



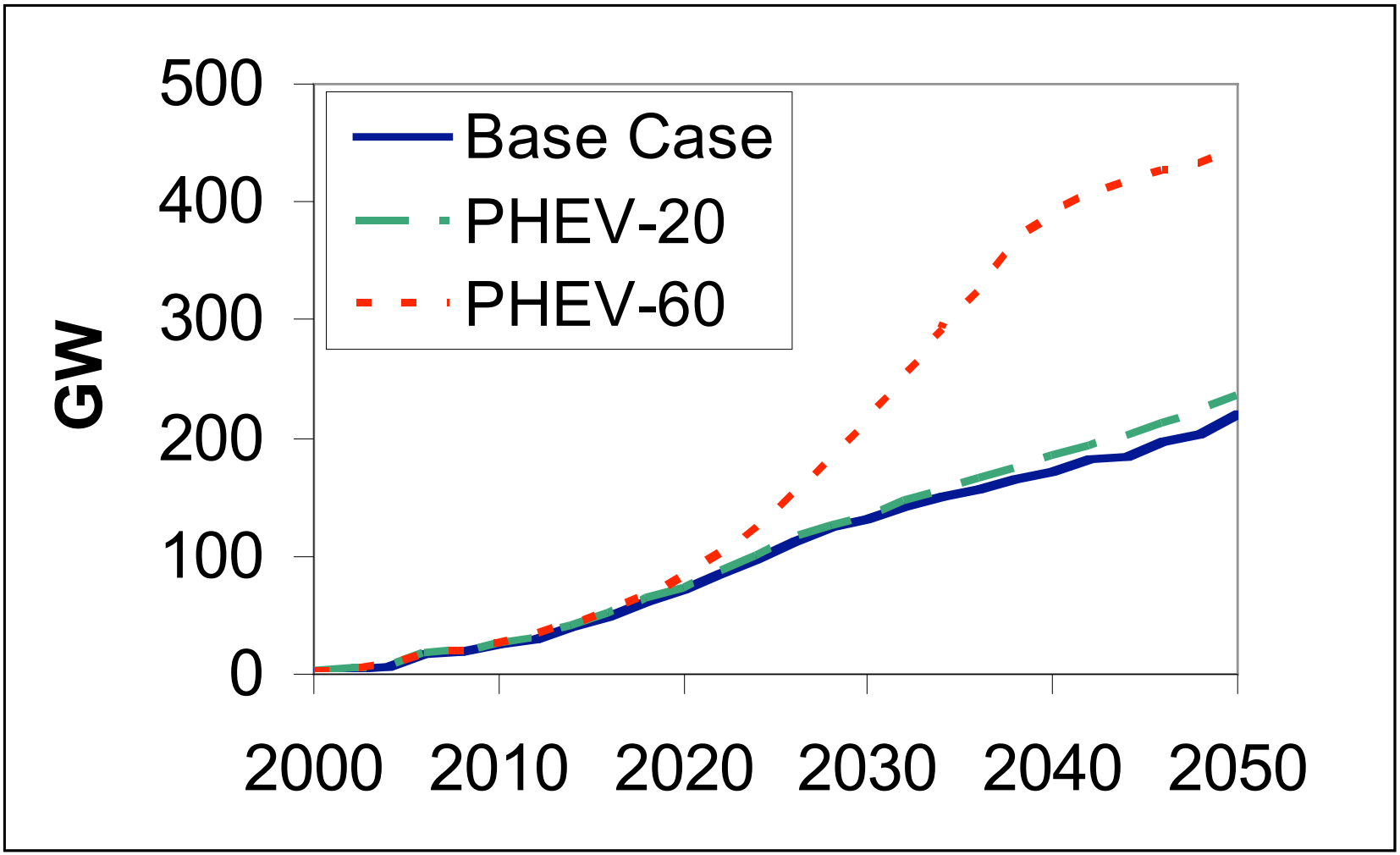
Wind Power Capacity
April 2009



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

PHEVs* Can Increase Wind Penetration



* Assumes 50% PHEV-V2G penetration by 2050

Wind Savings

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

Savings: 181 MtC/yr

Biomass and Biofuels

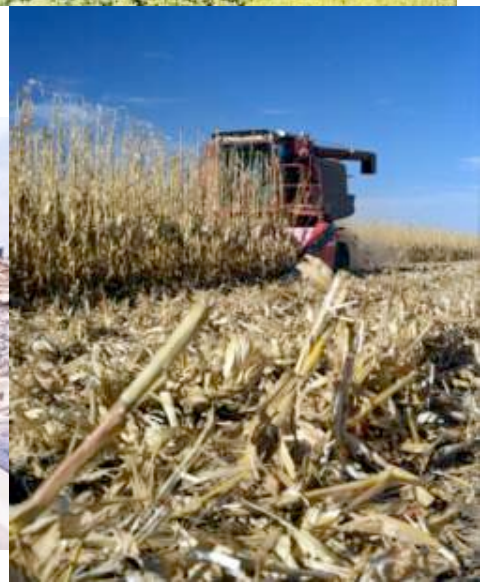
Wood chips

Switch grass

Poplars

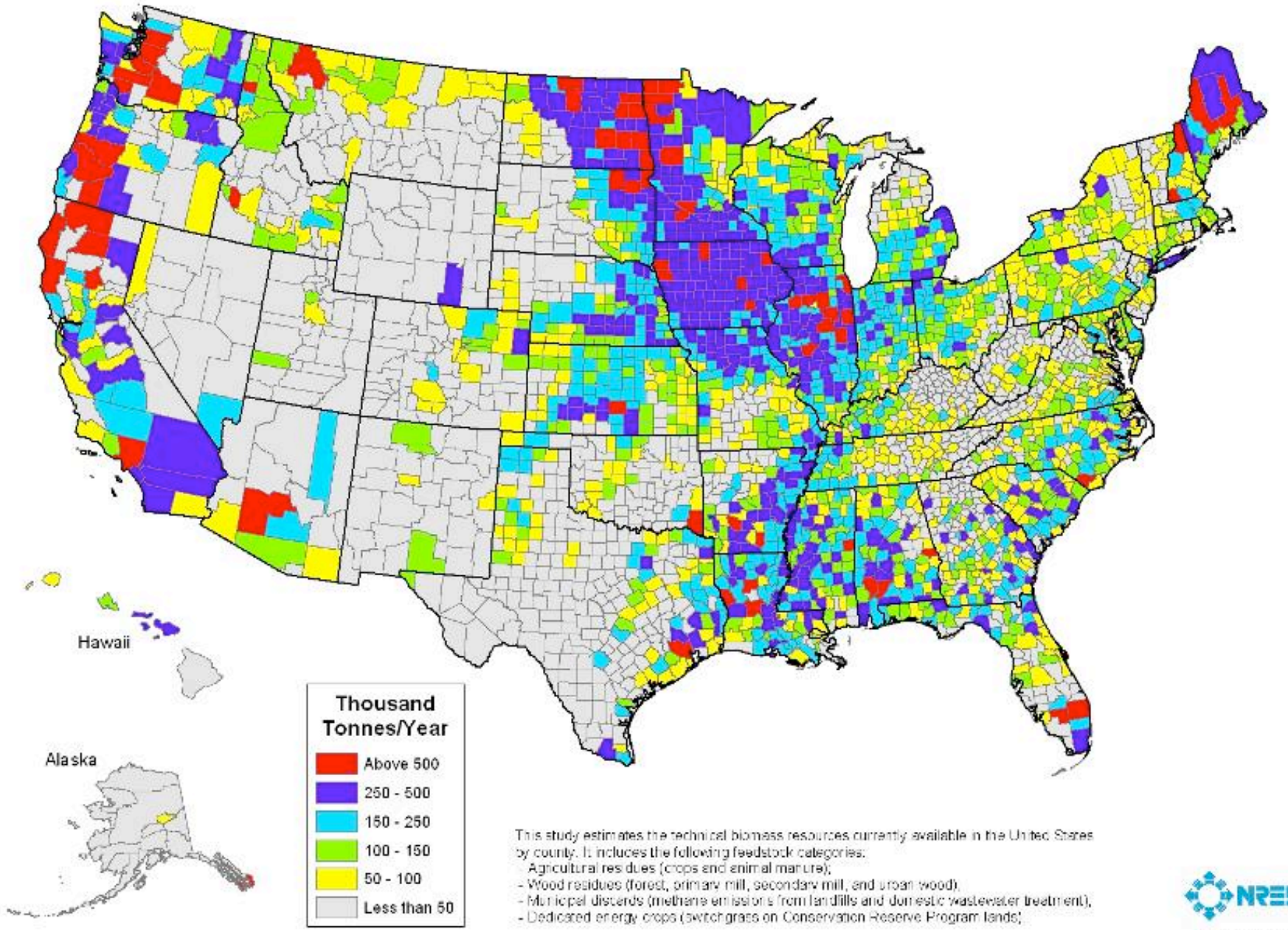
Fats and Oils

Municipal solid waste



Corn Stover

Biomass Resources Available in the United States



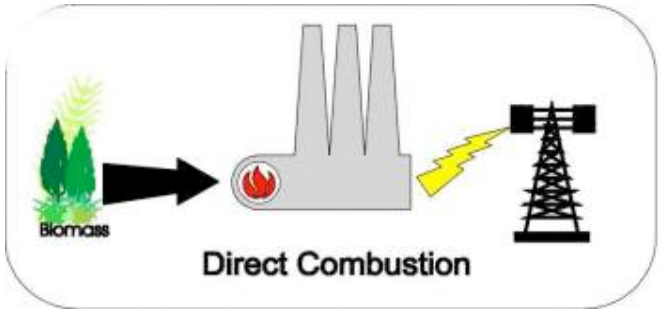
This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:
- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops (switchgrass on Conservation Reserve Program lands).

NREL

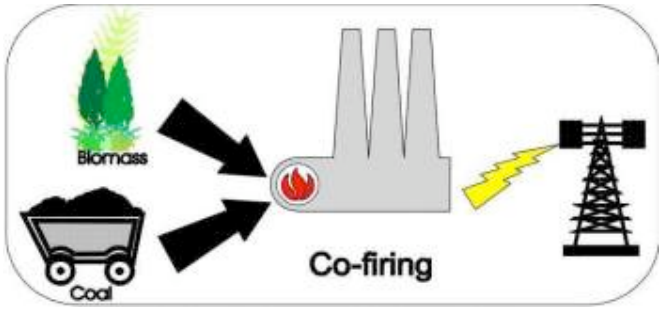
September 2005

Biomass Power

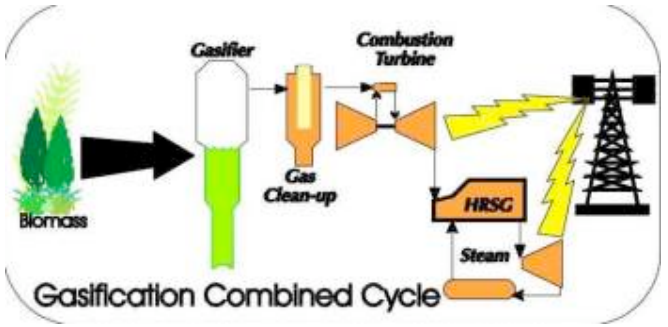
Direct combustion



Co-firing



Gasification



Biomass Power Savings

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

Savings: 75 MtC/yr

Routes to Biofuels

Bio/chemical transformation

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

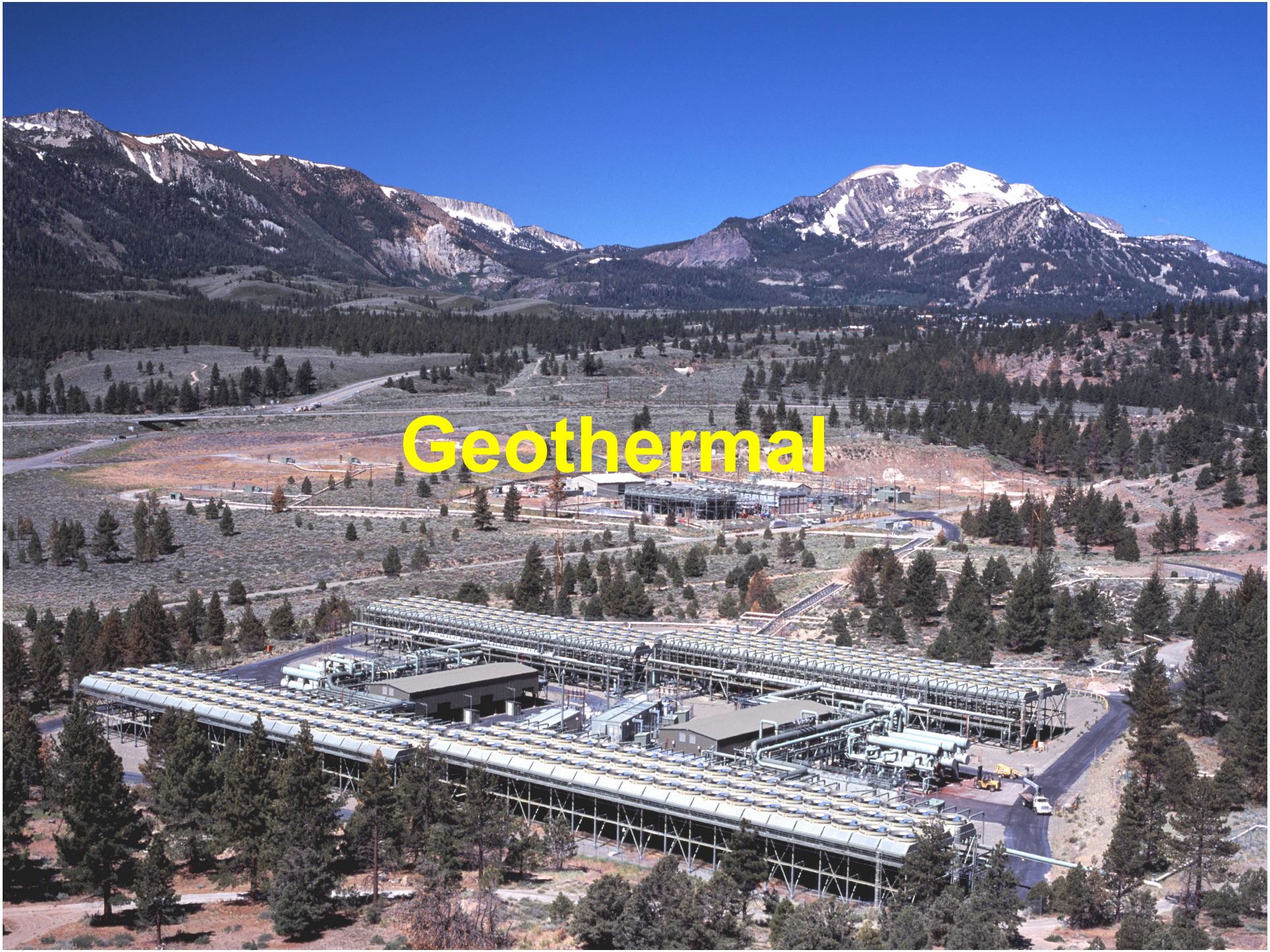
Thermochemical reduction to "syngas" (H_2, CO)

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

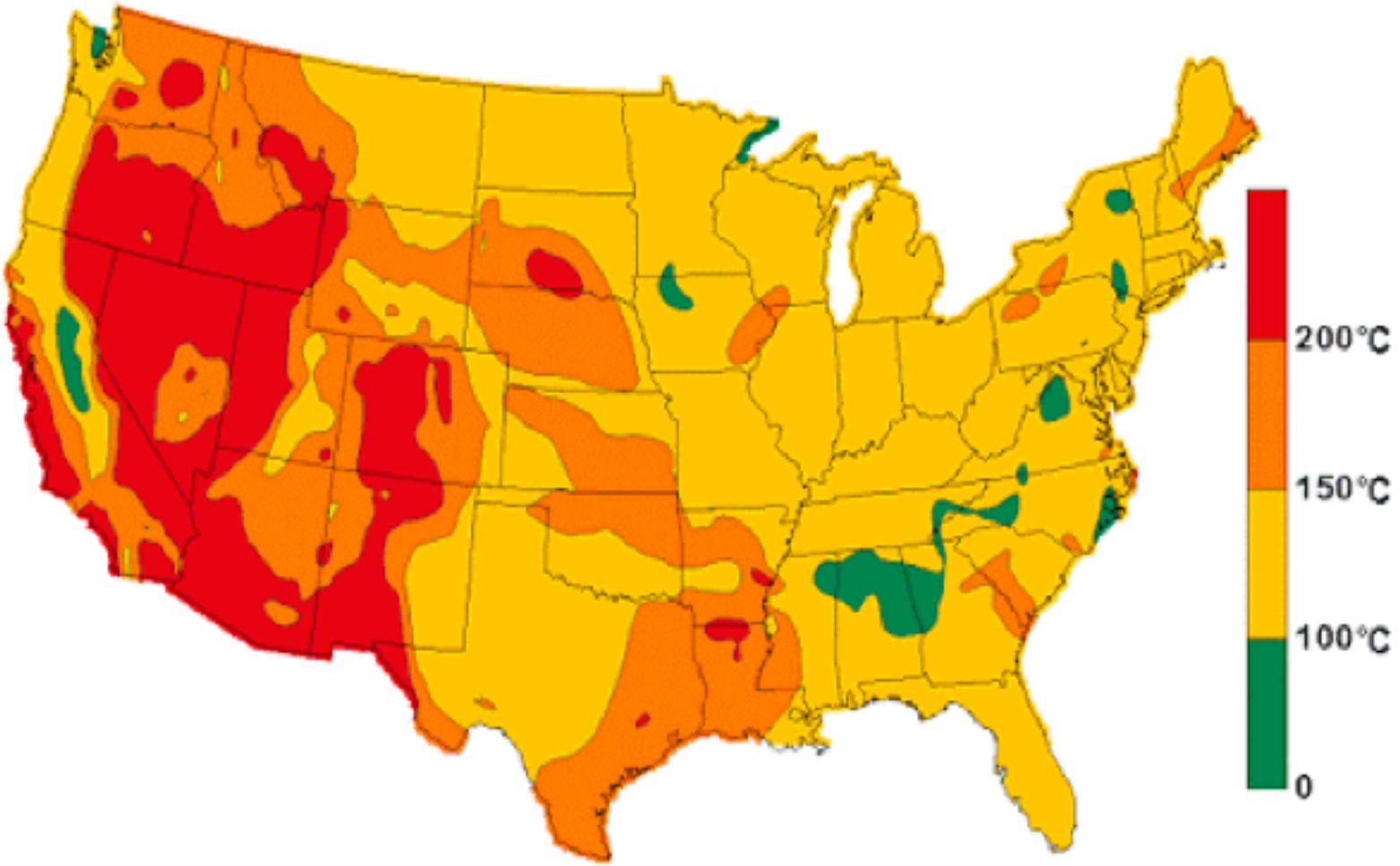
Biofuels Savings

- 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

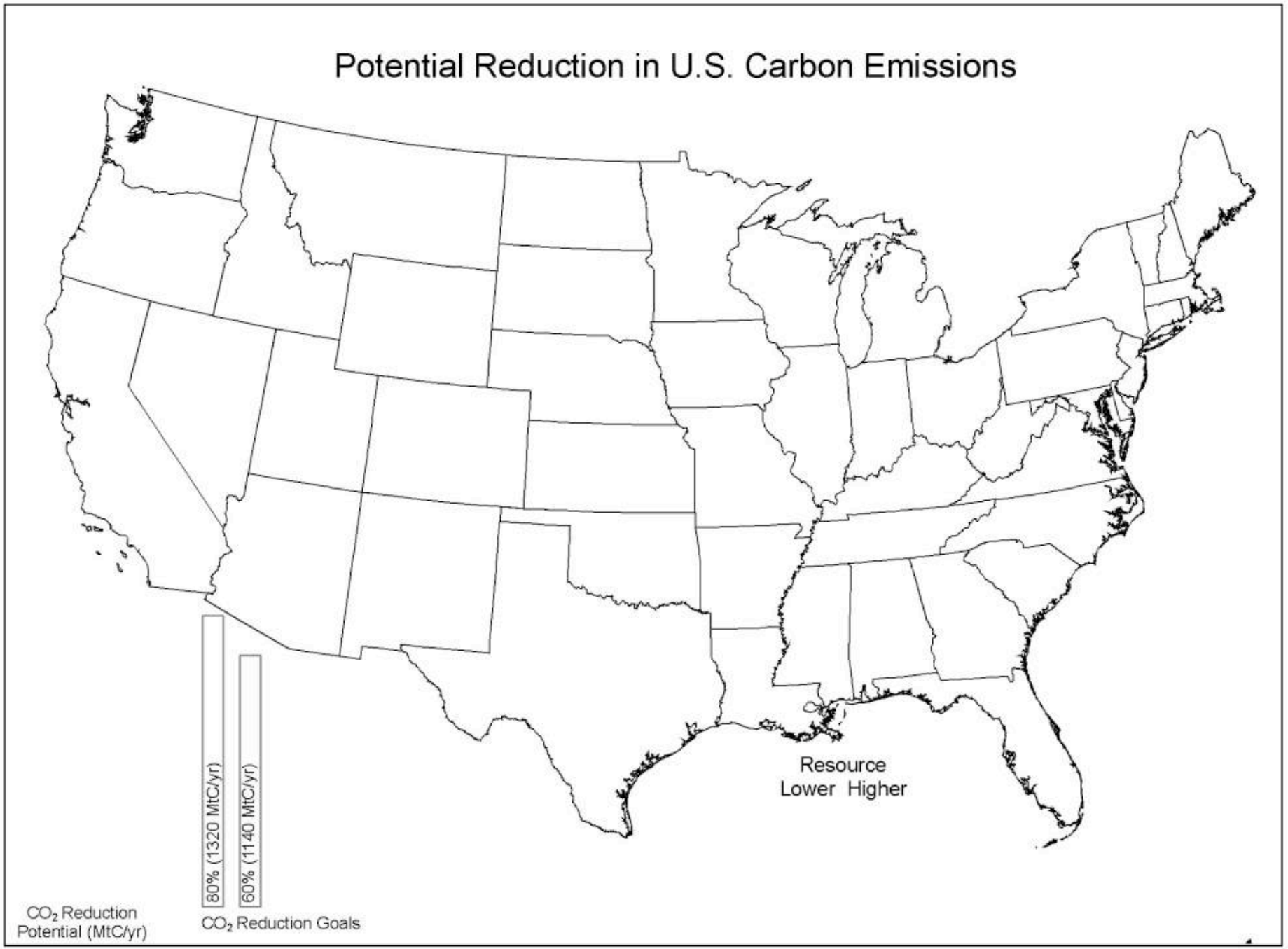


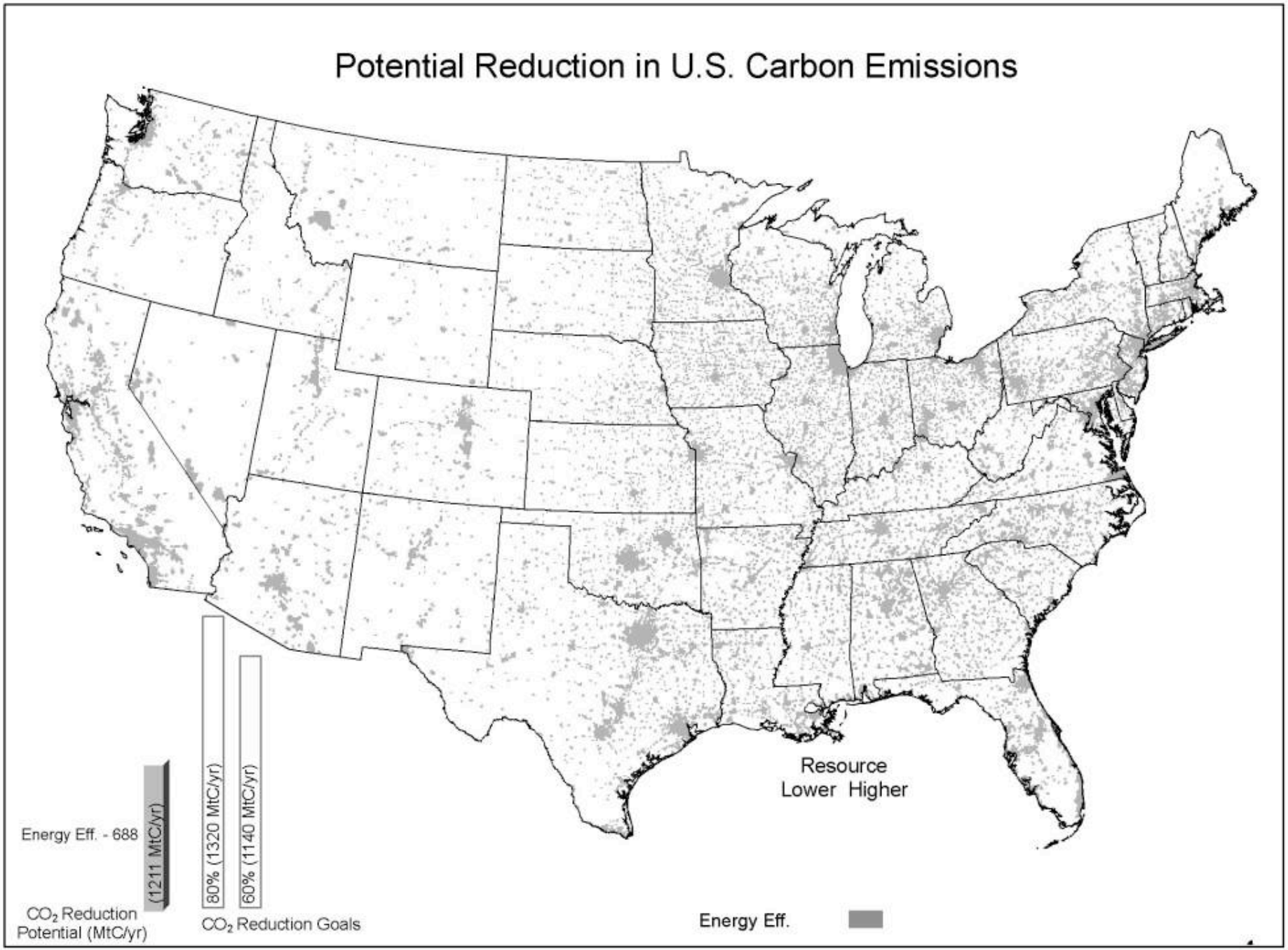
Geothermal Power Savings

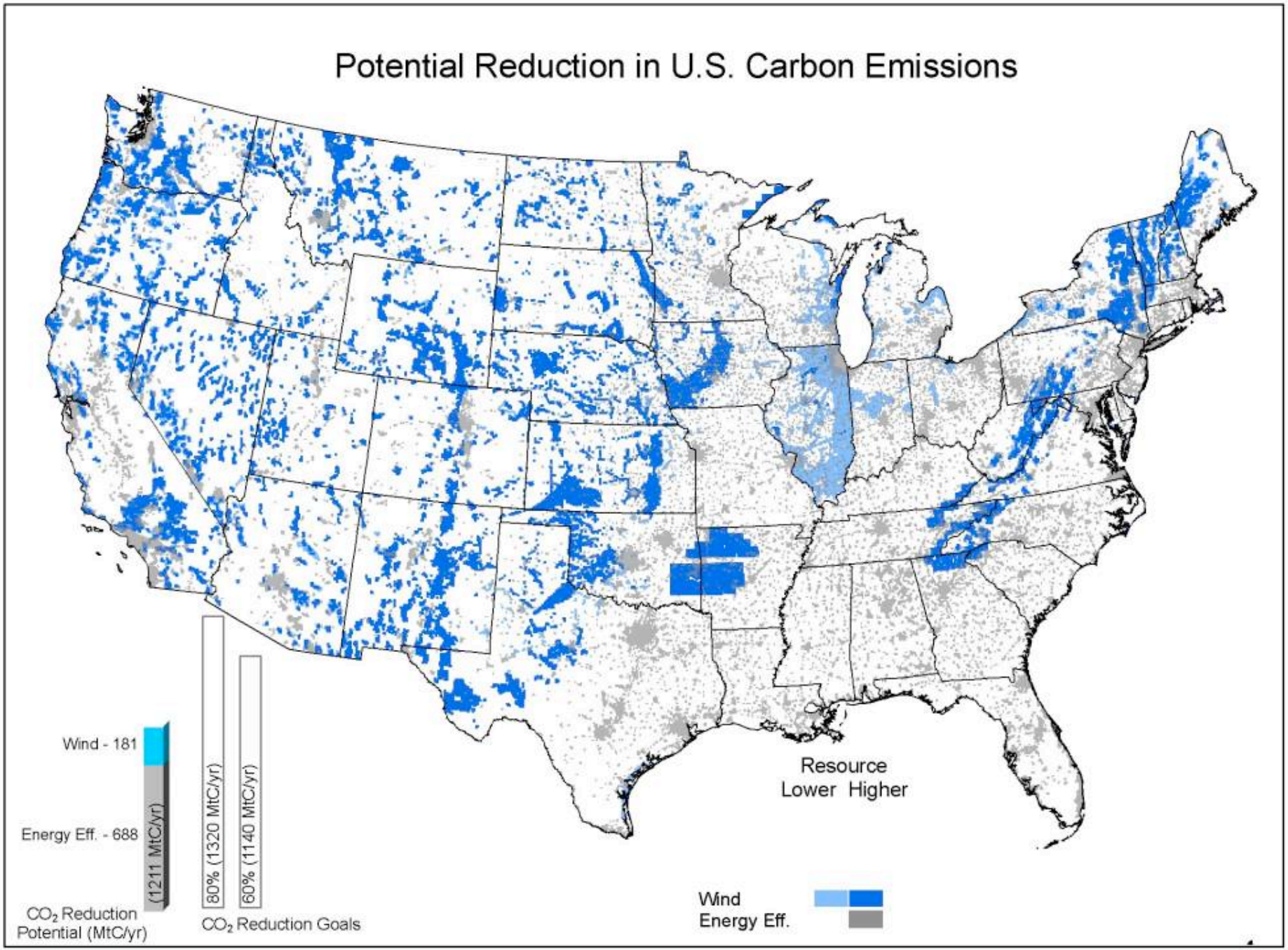
- 50,000 MW
- 25% existing resources, 25% expanded, 50% from oil & gas wells
- 5 to 10 ¢/kWh

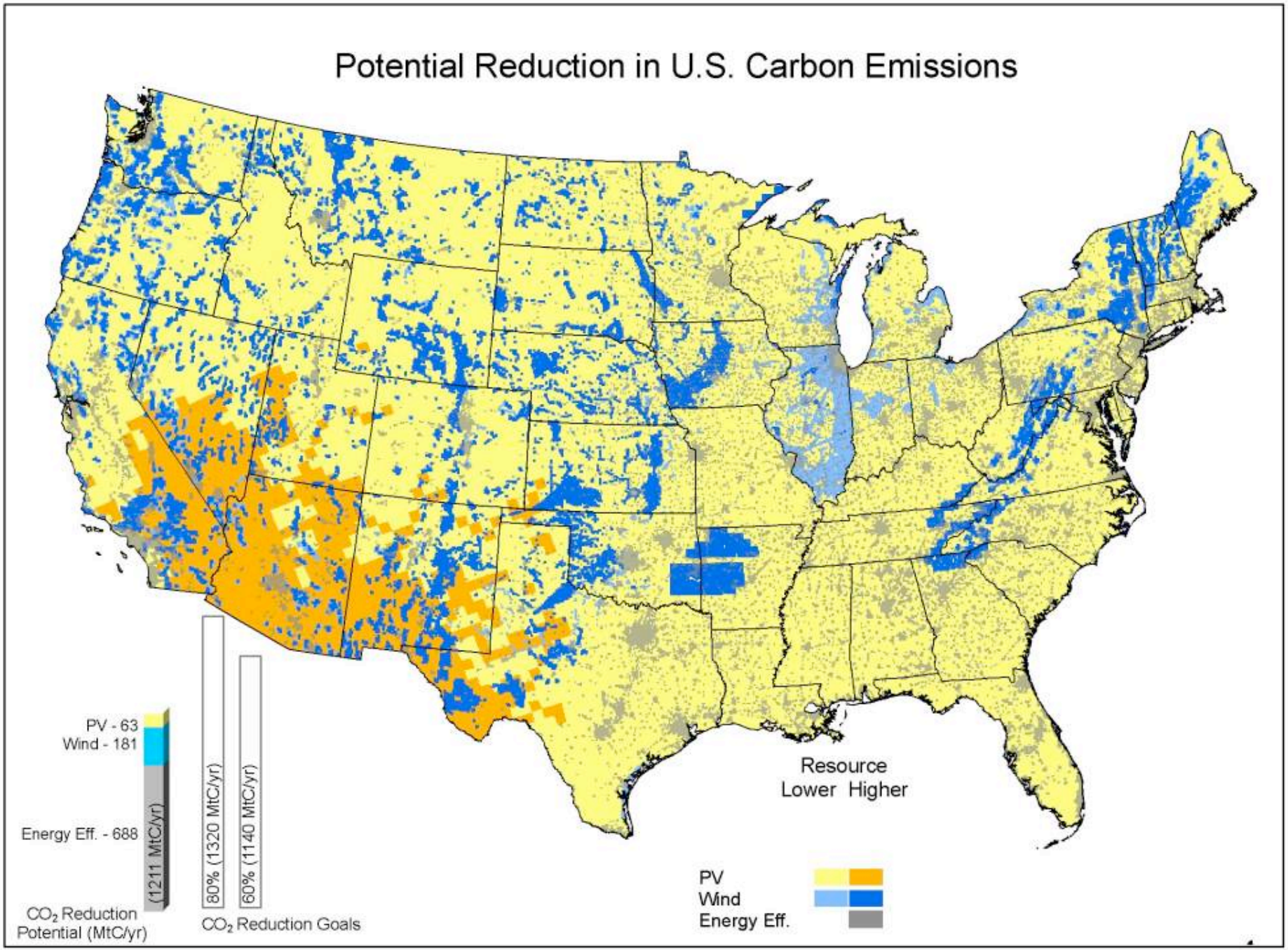
Savings: 83 MtC/yr

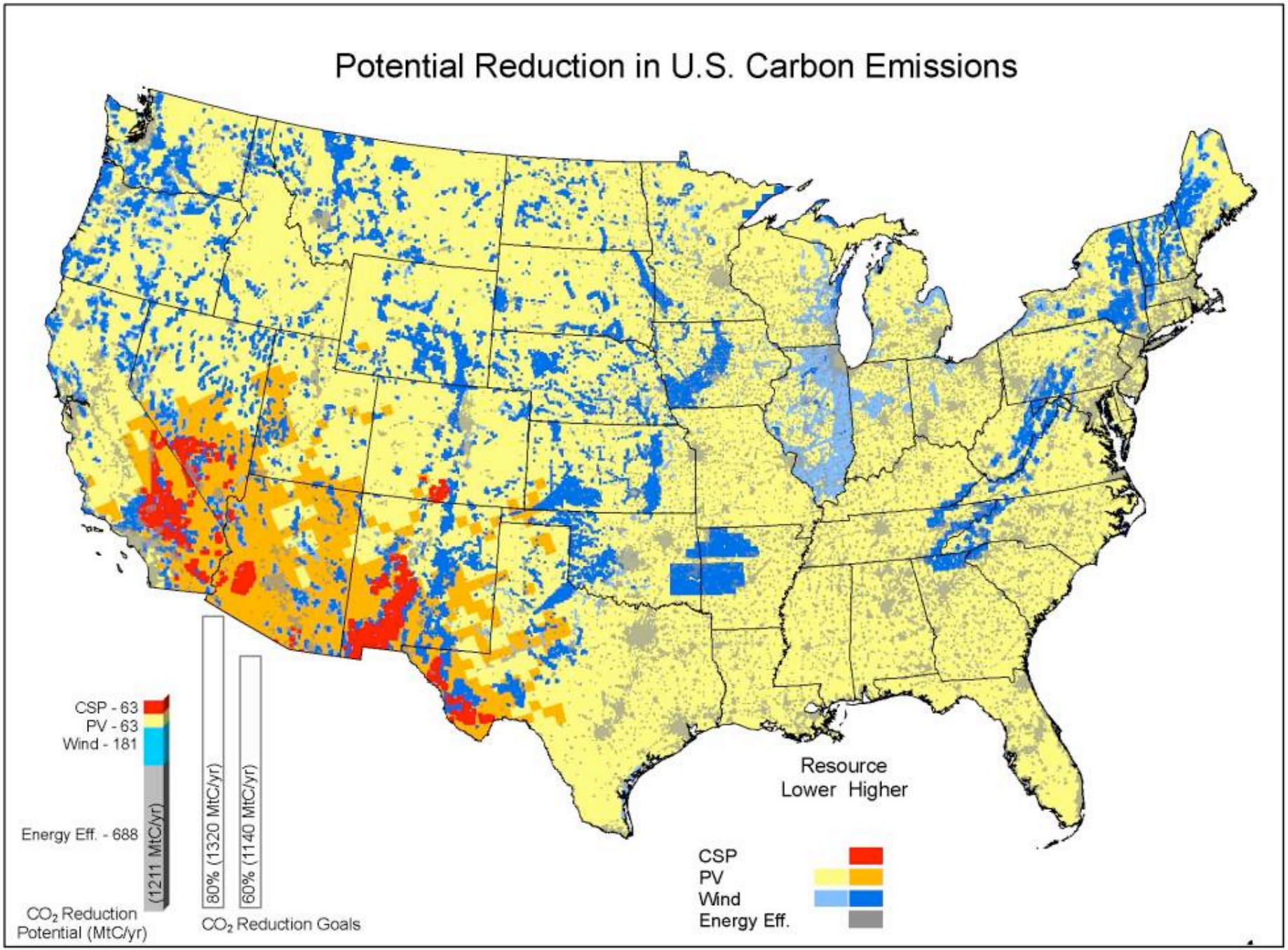
Putting It All Together

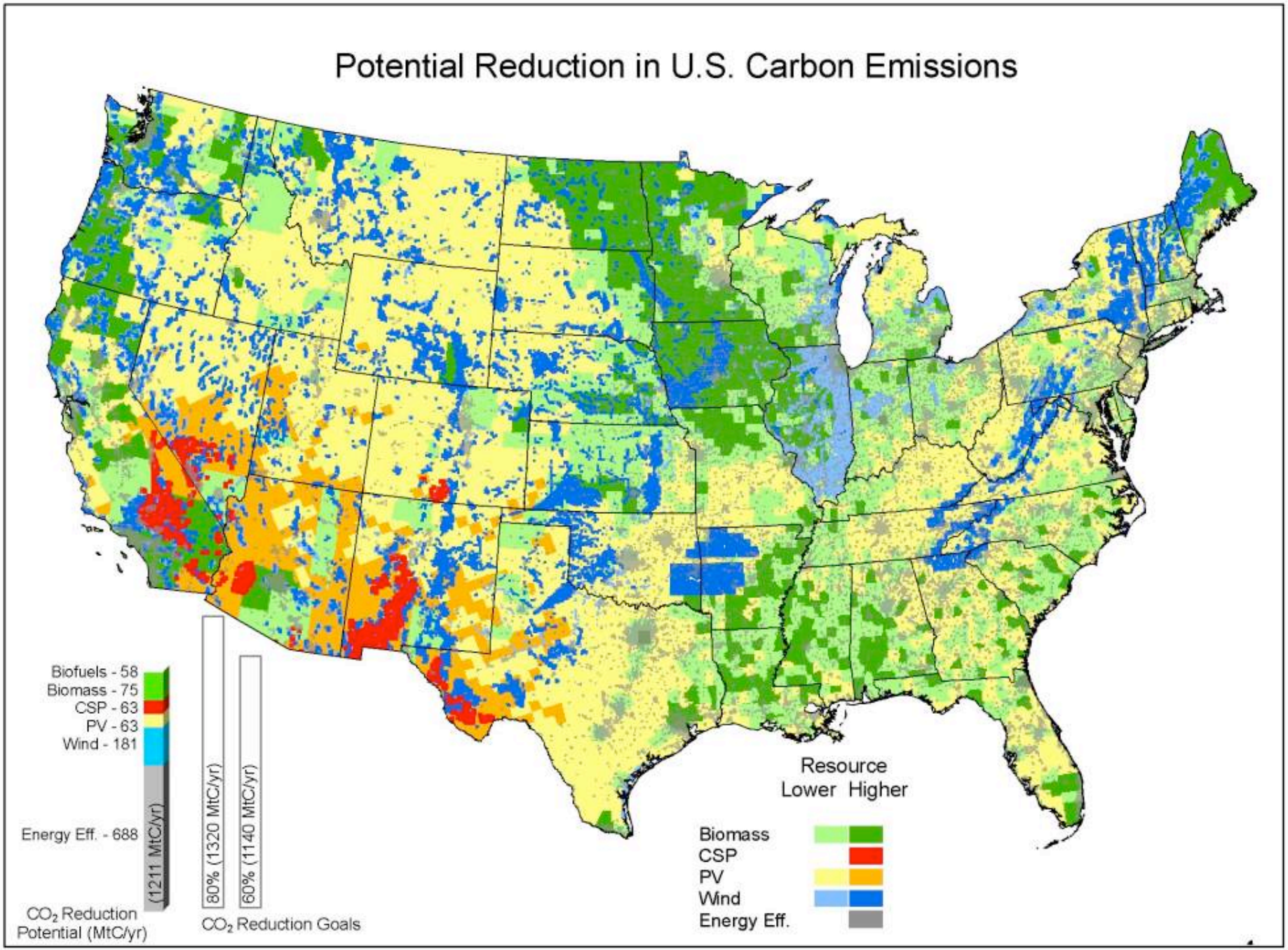

Potential Reduction in U.S. Carbon Emissions
Resource
Lower Higher
80% (1320 MtC/yr)
60% (1140 MtC/yr)
CO_2 Reduction Potential (MtC/yr)
CO_2 Reduction Goals

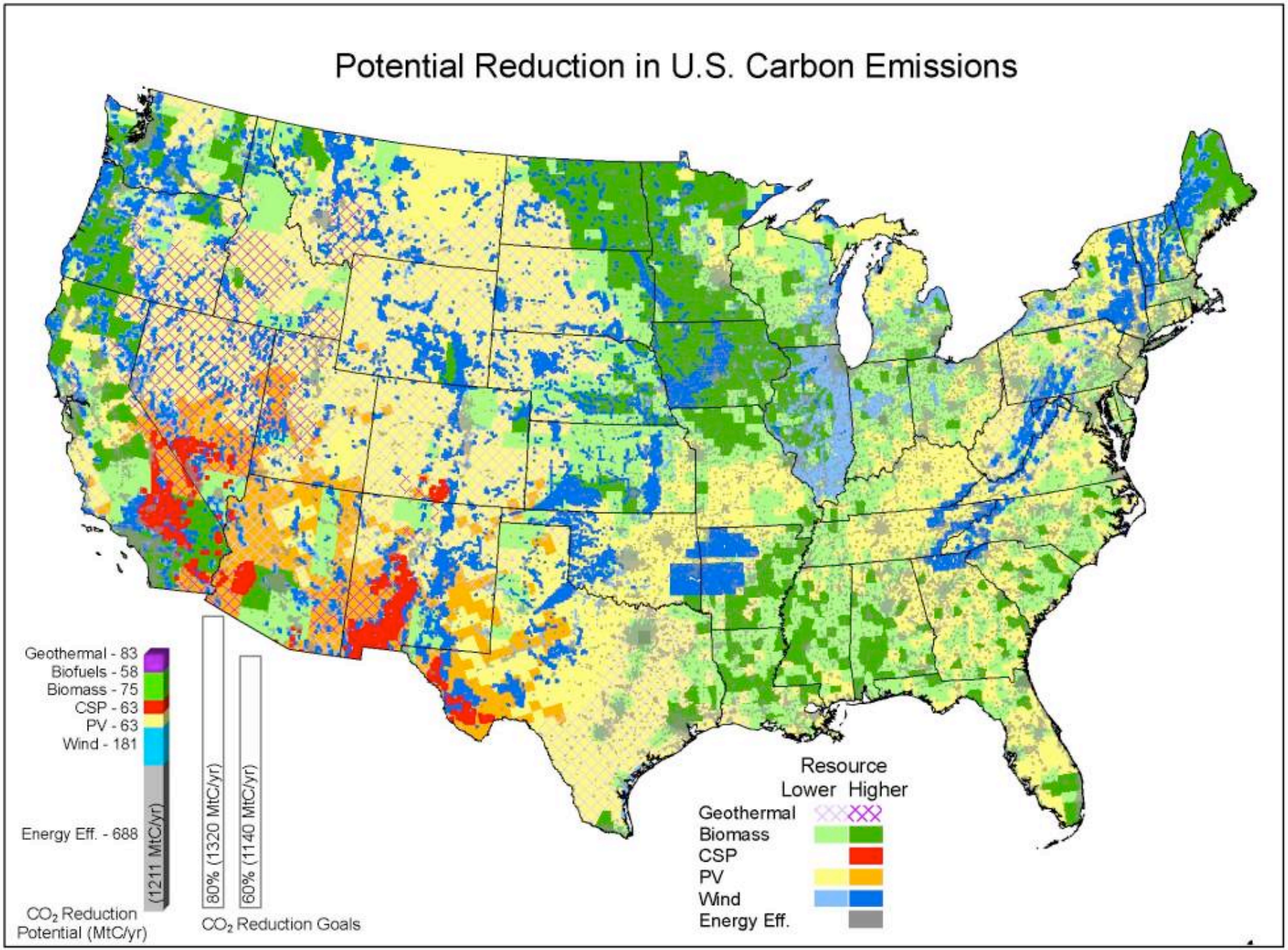

Potential Reduction in U.S. Carbon Emissions
Resource
Lower Higher
Energy Eff. - 688
(1211 MtC/yr)
80% (1320 MtC/yr)
60% (1140 MtC/yr)
CO_2 Reduction Potential (MtC/yr)
CO_2 Reduction Goals
Energy Eff.


Potential Reduction in U.S. Carbon Emissions
Wind - 181
Energy Eff. - 688
(1211 MtC/yr)
CO_2 Reduction Potential (MtC/yr)
80% (1320 MtC/yr)
60% (1140 MtC/yr)
CO_2 Reduction Goals
Resource
Lower Higher
Wind
Energy Eff.

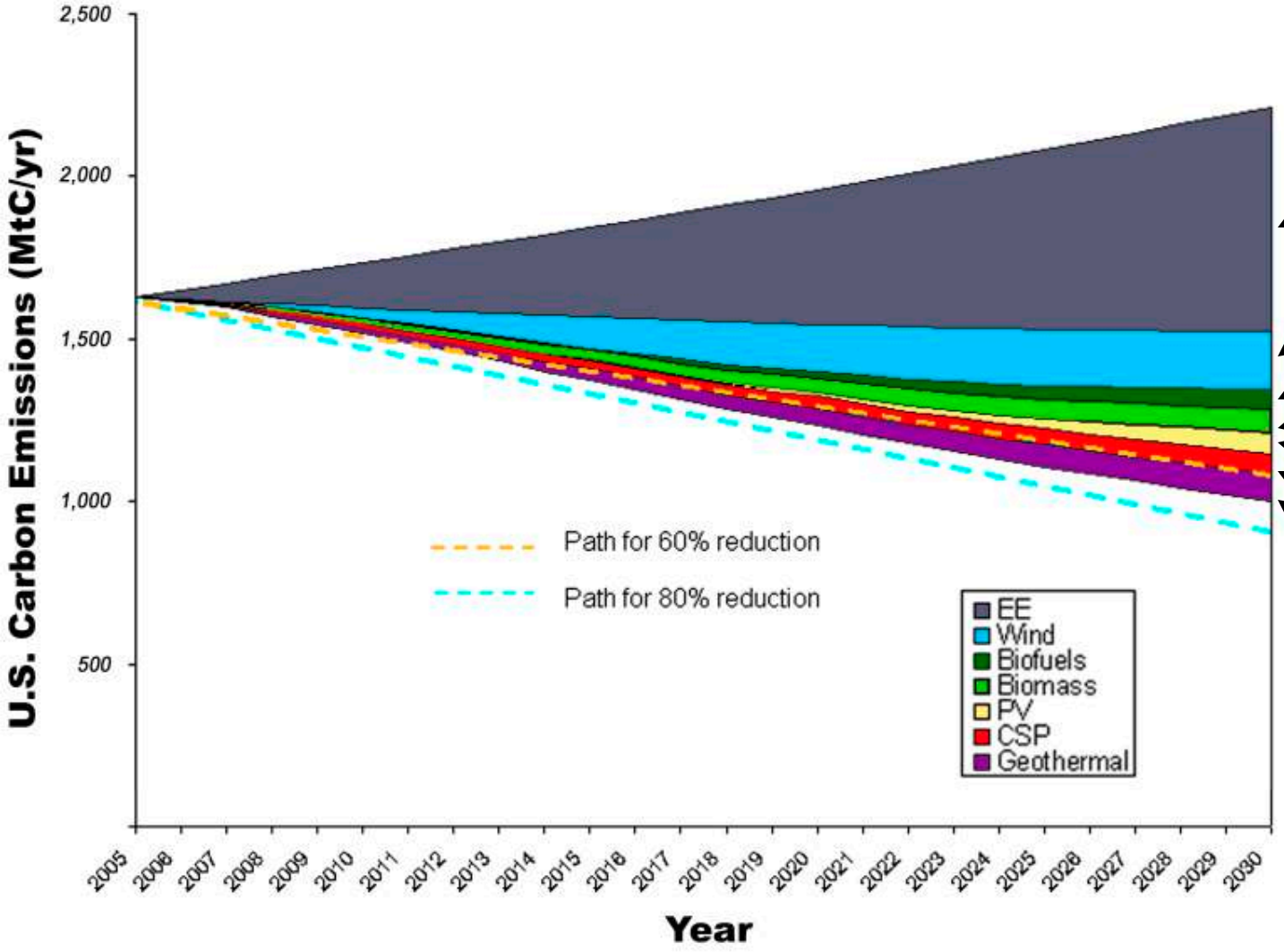

Potential Reduction in U.S. Carbon Emissions
PV - 63
Wind - 181
Energy Eff. - 688
(1211 MtC/yr)
CO2 Reduction Potential (MtC/yr)
80% (1320 MtC/yr)
60% (1140 MtC/yr)
CO2 Reduction Goals
Resource
Lower Higher
PV
Wind
Energy Eff.


Potential Reduction in U.S. Carbon Emissions
CSP - 63
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
CSP
PV
Wind
Energy Eff.


Potential Reduction in U.S. Carbon Emissions
Biofuels - 58
Biomass - 75
CSP - 63
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
Biomass
CSP
PV
Wind
Energy Eff.


Potential Reduction in U.S. Carbon Emissions
Geothermal - 83
Biofuels - 58
Biomass - 75
CSP - 63
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
Geothermal
Biomass
CSP
PV
Wind
Energy Eff.

Potential U.S. Carbon Reductions



What does it cost?

-$108B/yr

$0B/yr

$9B/yr

$3B/yr

$5B/yr

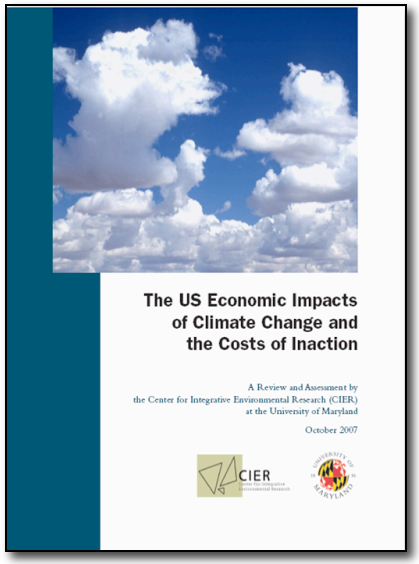
$7B/yr

$2B/yr

Total:
Savings of $82B/yr

57% Energy Efficiency, 43% Renewables

Cost of Inaction



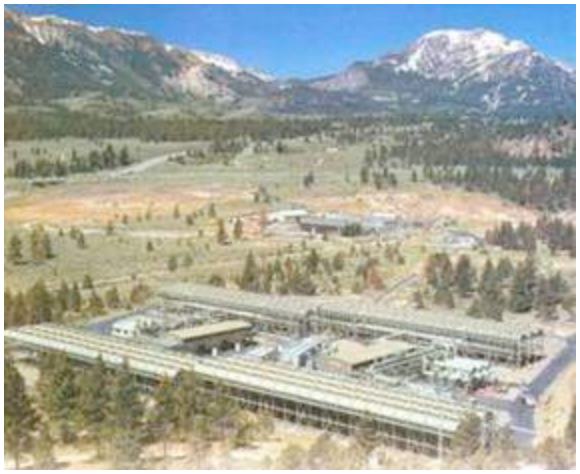
"Delayed action (or inaction) will most likely be the most expensive policy option"

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

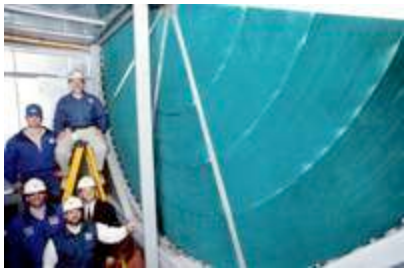
	Cost in billions of 2006 dollars				
	2025	2050	2075	2100	U.S. Regions Most at Risk
Hurricane Damages	$10	$43	$142	$422	Atlantic & Gulf Coast states
Real Estate Losses	$34	$80	$173	$360	Atlantic & Gulf Coast states
Energy-Sector Costs	$28	$47	$82	$141	Southeast & Southwest
Water Costs	$200	$336	$565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

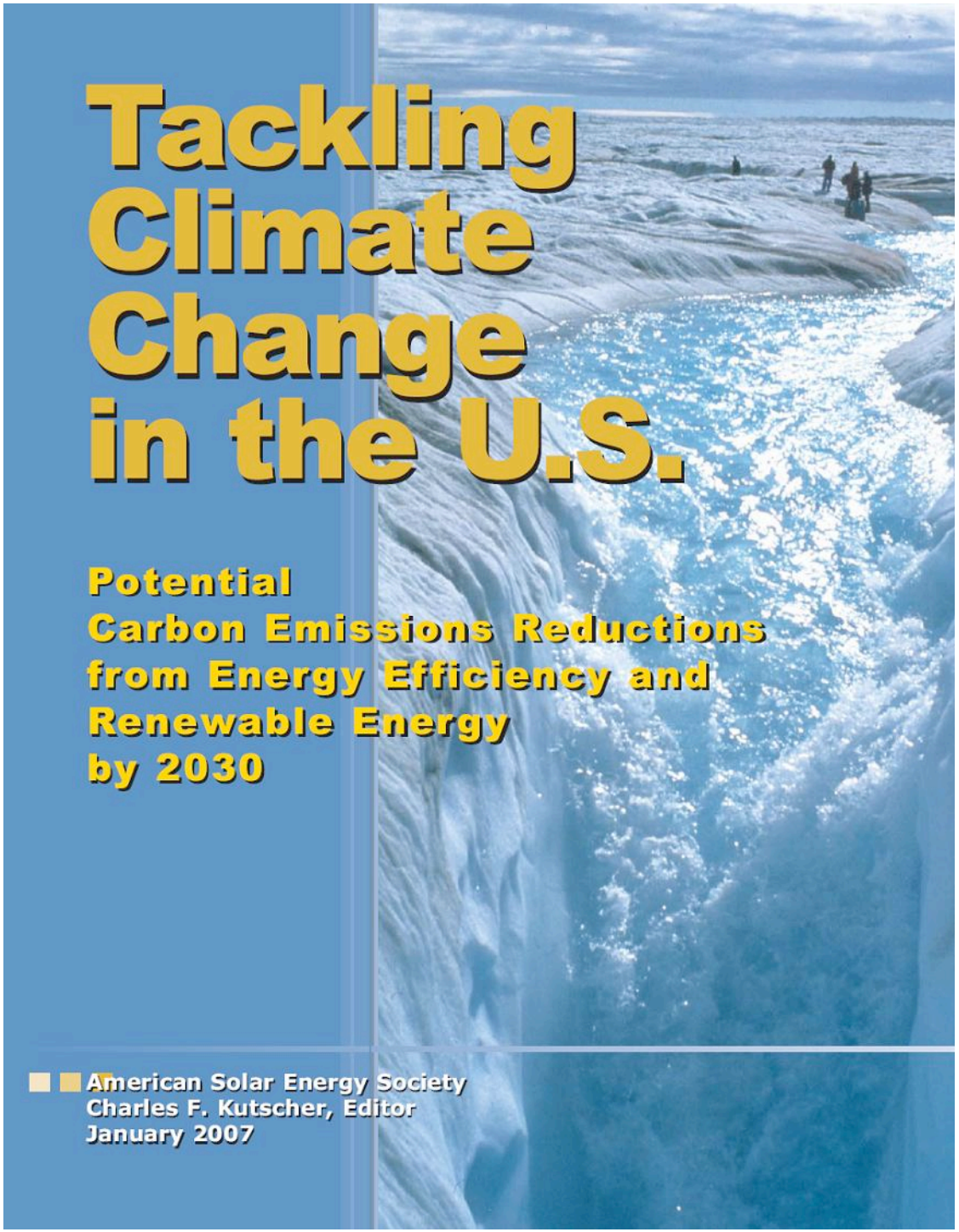
Ackerman & Stanton, 2008

Stern Review: Cost of action ≅ 1% of world GDP
Cost of inaction = 5% to 20% of world GDP



Houston, we have a solution!

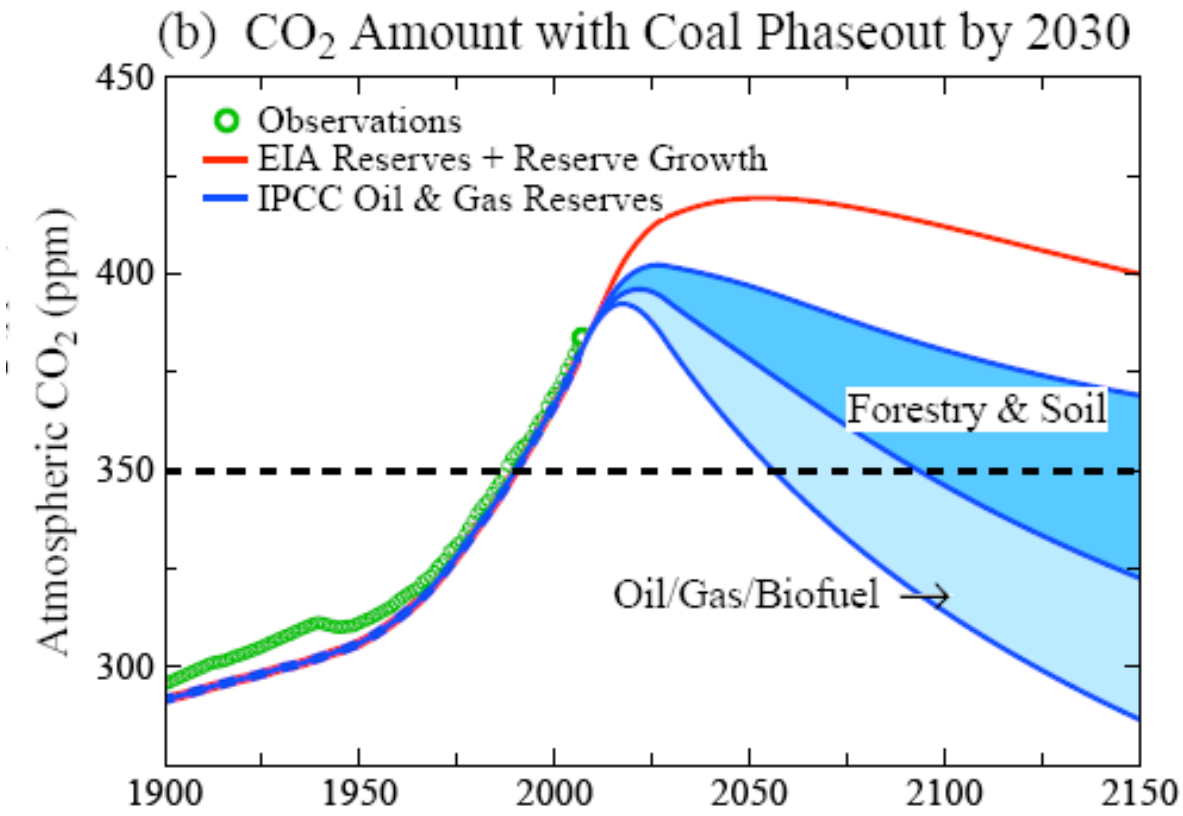




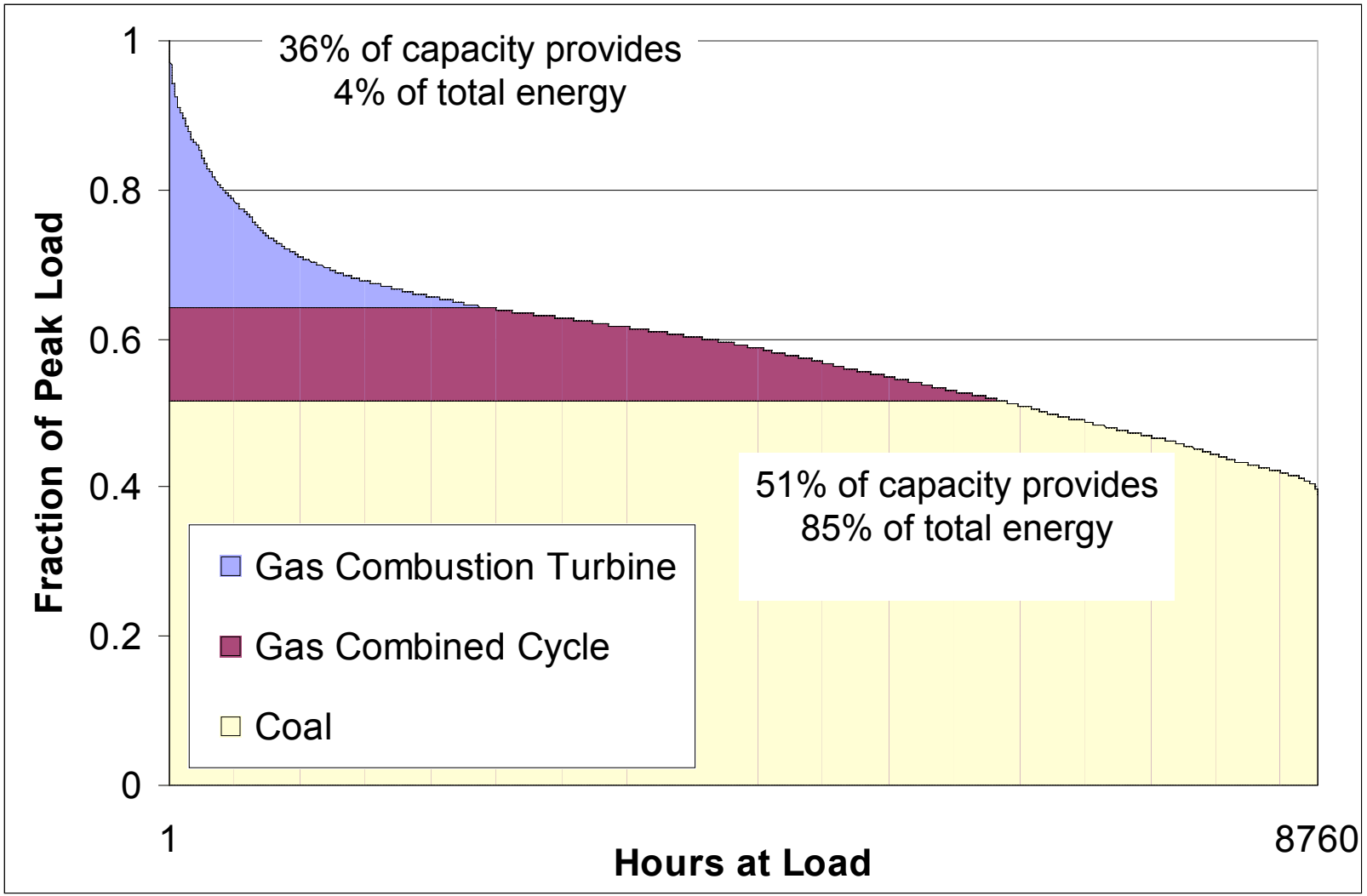
ASES report released Jan. 31, 2007

Available at: www.ases.org/climatechange

Read:
- Appendix: “The Science and Challenges Of Global Warming”
- “Overview and Summary of the Studies”


(b) CO_2 Amount with Coal Phaseout by 2030
Observations
EIA Reserves + Reserve Growth
IPCC Oil & Gas Reserves
Forestry & Soil
Oil/Gas/Biofuel
Atmospheric CO_2 (ppm)
450
400
350
300
1900
1950
2000
2050
2100
2150

Load Duration Curve



Options for Near-Term Phaseout of Coal Emissions in the United States

June 2009
****DRAFT****

Pushker A. Kharecha[1,#], Charles F. Kutscher[2], James E. Hansen[1], Edward Mazria[3]

[1] NASA Goddard Institute for Space Studies & Columbia University Earth Institute
[2] National Renewable Energy Laboratory
[3] 2030 Inc. / Architecture 2030

Read:

http://www.columbia.edu/~jeh1/2009/UScoalphaseout_draft.pdf