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Bureau of Economic Geology, The University of Texas at Austin

Climate Science and Economics

Understanding and Balancing the Climate Debate

Dr. Michelle Michot Foss, CEE-UT

Climate Economics: An Insurance Valuation Problem

- **We are considering buying an insurance option – how much are we willing to pay?**
  - What are the uncertainties – is the science settled?
    - Challenge of "groupthink"
  - How do we perceive, and communicate about, risk?
  - How should we value, in today's dollars, future costs and benefits?
  - Is it better to spend now to protect future generations?
  - What are our energy choices and options?
  - ***Is GHG mitigation policy the best investment?***

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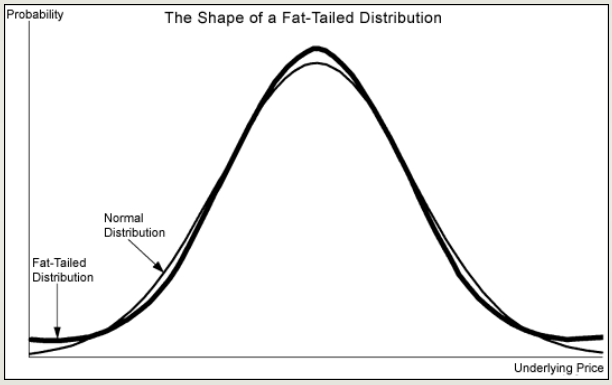
What Should We Be Skeptical About?

- That we know enough to conduct the actuarial analysis
- That we know enough about technology options and costs to make policy
- That we can make sensible policy that is both efficient and effective
- That "climate" is the right priority

Re-casting the Precautionary Principle



http://climateprogress.org/2007/09/11/weitzman-economics-climate-change-catastrophe/

Why Does Climate Change?

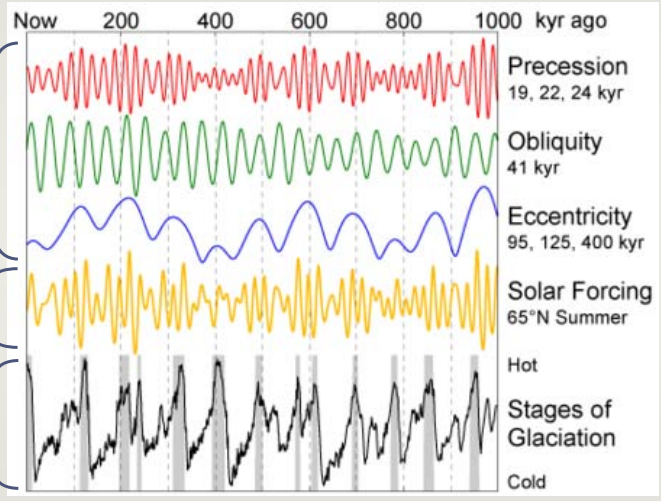
- Over long periods: earth rotation, orbit, electromagnetic fields
- Earth "degassing"
- Variations in solar irradiance (short- to long-term)
- Absorption or desorption of CO_2 depending upon ocean temperatures, oscillations, events
- Clouds, snow/ice cover, aerosols
- Human effects: land use, gases, particulates

Milankovitch Variations

Earth rotational, orbital changes

Long and short term variations in solar irradiance

Coincident glaciation, warming and gas absorption, desorption



http://www.globalwarmingart.com/wiki/Image:Milankovitch_Variations_png

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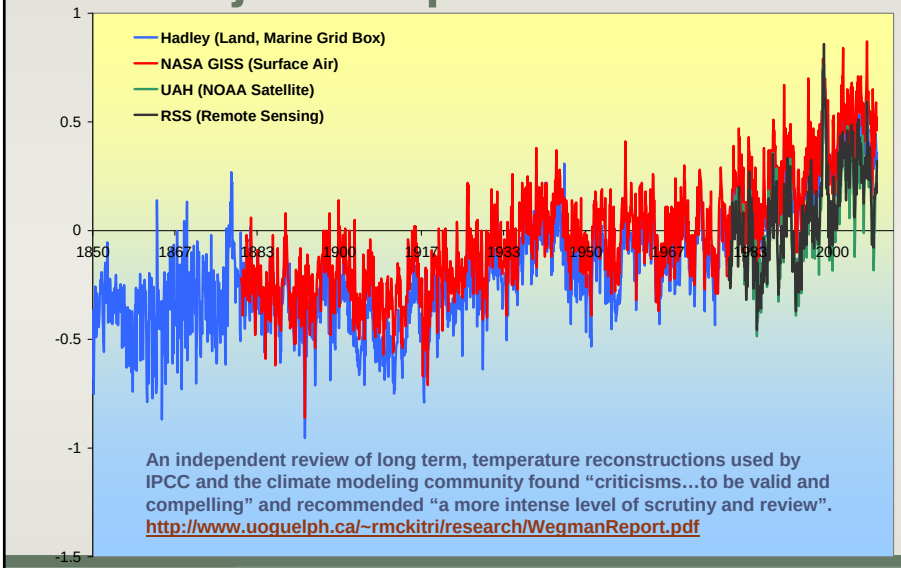
Major Temperature Series



An independent review of long term, temperature reconstructions used by IPCC and the climate modeling community found "criticisms…to be valid and compelling" and recommended "a more intense level of scrutiny and review". http://www.uoguelph.ca/~rmckitri/research/WegmanReport.pdf

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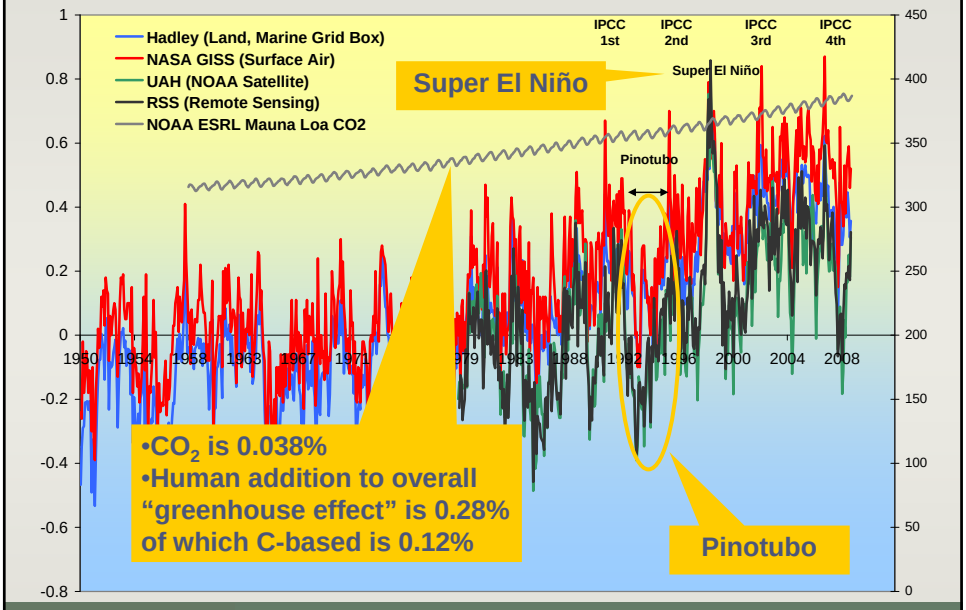

- CO_2 is 0.038%
- Human addition to overall "greenhouse effect" is 0.28% of which C-based is 0.12%

Pinotubo

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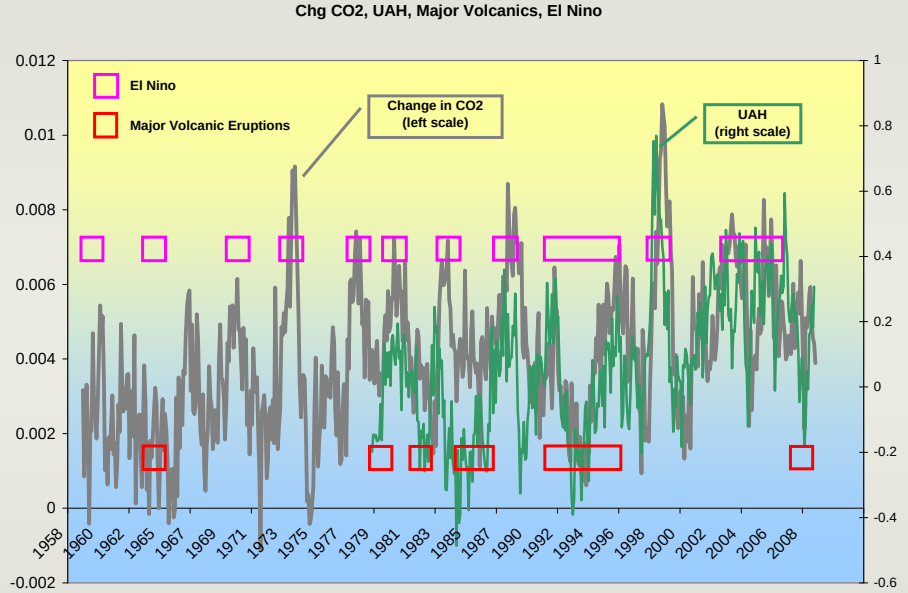

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Chaiten (Chile, 2008)

New research suggests that conductivity of the earth's mantle is linked to molten carbonates, explaining much about the extent of CO2 associated with volcanic activity and enabling further quantification of the carbon cycle. Other lines of research include detection of ionic charges in the atmosphere that appear to be precursors to seismic activity. Danish researchers have linked strength of the earth's magnetic field with tropical precipitation, providing corroboration for Henrik Svensmark's controversial demonstration of linkages between earth's magnetic field and climate.

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See Svensmark, 2008, The Chilling Stars (2nd Edition), Totem Press

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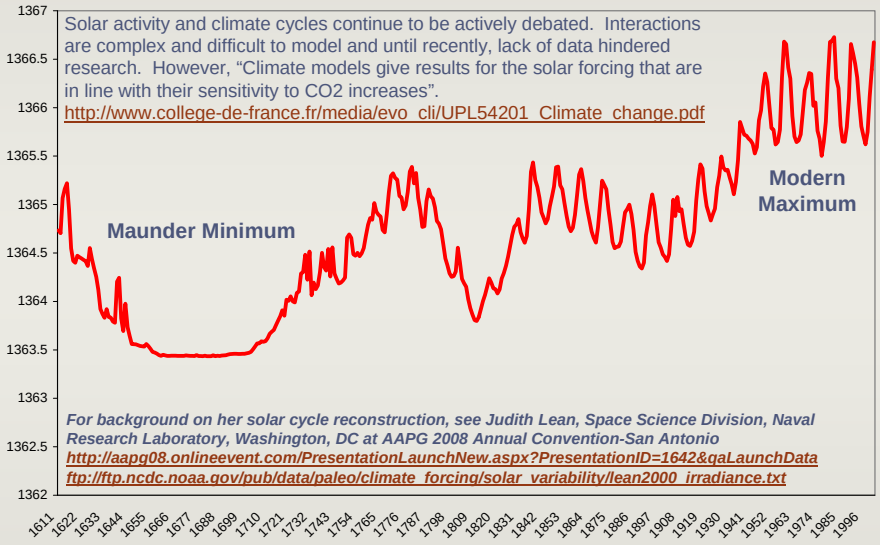
Reconstructed Solar Cycles, 1610-2004

Solar activity and climate cycles continue to be actively debated. Interactions are complex and difficult to model and until recently, lack of data hindered research. However, "Climate models give results for the solar forcing that are in line with their sensitivity to CO2 increases".
http://www.college-de-france.fr/media/evo_cli/UPL54201_Climate_change.pdf



For background on her solar cycle reconstruction, see Judith Lean, Space Science Division, Naval Research Laboratory, Washington, DC at AAPG 2008 Annual Convention-San Antonio
http://aapg08.onlineevent.com/PresentationLaunchNew.aspx?PresentationID=1642&qaLaunchData
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/climate_forcing/solar_variability/lean2000_irradiance.txt

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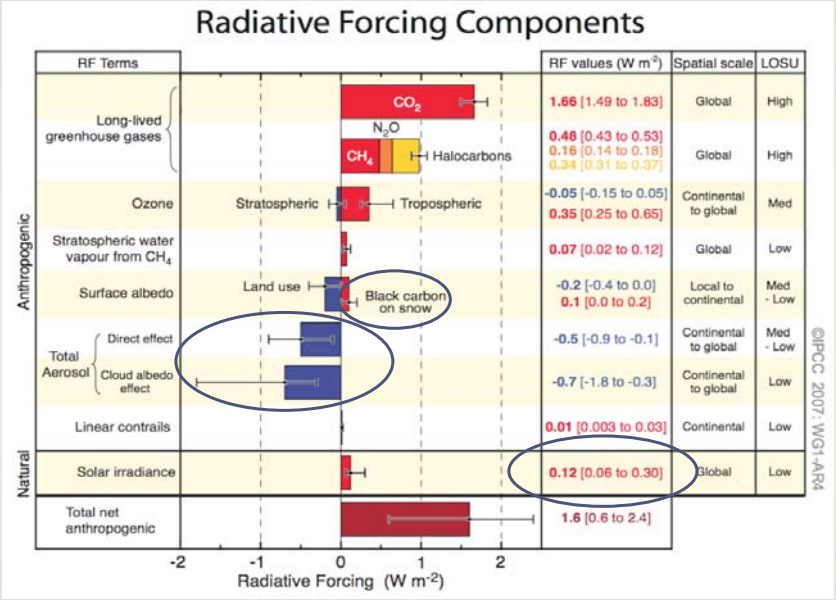
Radiative Forcing Components



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IPCC Fourth Assessment, 2007, copyright protected;
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

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Notes to IPCC Chart

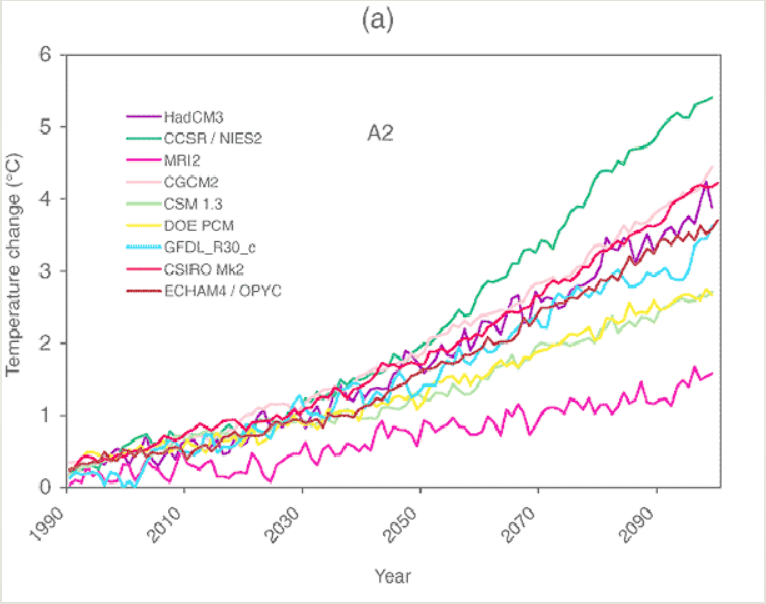
- Cloud albedo effect – see research papers by Richard Lindzen, MIT, Leo Huss Walin Prize for Independent Thinking, 2006; http://www-eaps.mit.edu/faculty/lindzen.htm
  - Argues cloud effects are underweighted
- Black carbon on snow – UC Irvine
  - Research demonstrating that black carbon accounts for up to 30% of Arctic ice loss http://www.today.uci.edu/news/release_detail.asp?key=1621

External forcings in the 20th century simulations:

G: Well-mixed greenhouse gases
O: Tropospheric and stratospheric ozone
SD: Sulfate aerosol direct effects
SI: Sulfate aerosol indirect effects
BC: Black carbon
OC: Organic carbon
MD: Mineral dust
SS: Sea salt
LU: Land use
SO: solar irradiance
VL: Volcanic aerosols

20C3M

Model	G	O	SD	SI	BC	OC	MD	SS	LU	SO	VL
CCSM3	Y	Y	Y	-	Y	Y	-	-	-	Y	Y
GFDL-CM2.0	Y	Y	Y	-	Y	Y	-	-	Y	Y	Y
GFDL-CM2.1	Y	Y	Y	-	Y	Y	-	-	Y	Y	Y
GISS-EH	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
GISS-ER	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
MIROC3.2(medres)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
MIROC3.2(hires)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
MIUB/ECHO-G	Y	-	Y	Y	-	-	-	-	-	Y	Y
MRI-CGCM2.3.2	Y	-	Y	-	-	-	-	-	-	Y	Y
PCM	Y	Y	Y	-	-	-	-	-	-	Y	Y
BCCR-BCM2.0	Y	-	Y	-	-	-	-	-	-	-	-
CCCma-CGCM3.1(T47)	Y	-	Y	-	-	-	-	-	-	-	-
CCCma-CGCM3.1(T63)	Y	-	Y	-	-	-	-	-	-	-	-
CNRM-CM3	Y	Y	Y	-	Y	-	-	-	-	-	-
CSIRO-Mk3.0	Y	-	Y	-	?	?	?	?	?	?	-
ECHAM5/MPI-OM	Y	Y	Y	Y	-	-	-	-	-	-	-
FGOALS-g1.0	Y	-	Y	?	-	-	-	-	-	-	-
GISS-AOM	Y	-	Y	-	-	-	-	Y	-	-	-
INM-CM3.0	Y	-	Y	-	-	-	-	-	-	Y	-
IPSL-CM4	Y	-	Y	Y	-	-	-	-	-	-	-
HadCM3	Y	Y	Y	Y	-	-	-	?	-	-	-
HadGEM-run1	Y	Y	Y	Y	Y	Y	-	Y	Y	-	-
HadGEM-run2	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y
INGV-SXG	Y	Y	Y	-	?	?	?	?	-	?	?
CSIRO-Mk3.5	Y	-	Y	-	-	-	-	?	?	-	-



Note to Climate Model Chart

"A large disparity exists among various climate models in their prediction of global mean surface air temperature when atmospheric CO2 has doubled from present concentrations (figure 1). There are an overwhelming number of reasons why these differences could exist. Although each climate model has been optimized to reproduce observational means, each model contains slightly different choices of model parameter values as well as different parameterizations of under-resolved physics…In order to quantify the uncertainty resulting from a realistic range of model configurations, one needs to estimate a multi-dimensional probability distribution that quantifies how likely different model parameter combinations are given knowledge of the uncertainties in our observations. The computational cost of mapping a multi-dimensional probability distribution for a climate model using traditional means (e.g. Monte-Carlo or Importance Sampling) is impractical requiring 104 to 106 model evaluations for problems involving less than ten parameters."

Economics: One View

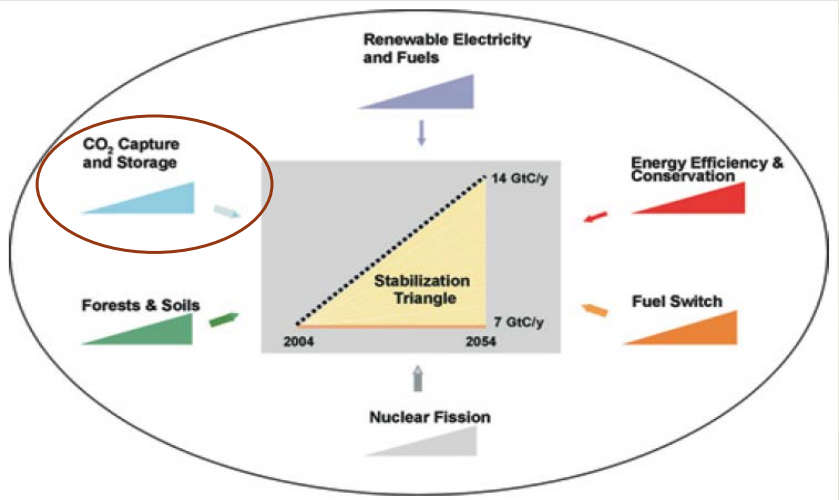
Based on climate model projections "Spending $800 billion over 100 years solely on mitigating emissions would reduce inevitable [modeled] temperature increases by just 0.4 degrees Fahrenheit by the end of this century. Even accounting for the key environmental damage from warming, we would lose money, with avoided damage of just $685 billion for our $800 billion investment."

Bjørn Lomborg, Perspective on Climate Change, Subcommittee on Energy and Air Quality joint hearing, US Congress, March 21, 2007

Stern Review Dominates

- 1% GDP cost by 2050 for mitigation, 5-20% GDP loss if no action
- Sustained argument that low discount rate is justified to protect future generations
  - But future generations will have better technology at lower cost
- PP focus on avoided cost and worst case scenario (GHG forcing dominates)
- Carbon price decline from ~€40 in spring 2008 to ~€8

Stabilization Wedges



Power Gen is Biggest Contributor to GHG (~25%)

Lbs/MWh	CO_2	SO_x	NO_x	Hg
Coal	2,249	13	6	Yes, highest
Oil	1,672	12	4	Yes
Natural Gas	1,135	0.1	1.7	Negligible
Other	Biomass contributes gases. Nuclear, hydroelectric, wind, solar, geothermal do not produce emissions through fuel combustion. Emissions are produced for all power generation facilities as part of full cycle accounting.			

Math Whiz

- Total annual CO2 emitted is 188 bn ton
- 8bn is derived from human activity
  - US produces 2 bn
- Net generation from US coal plants is ~170mm MWh
  - CO2 production is ~2,250 lbs/MWh, or 191mm tons
- **The total atmosphere is 5 quadrillion tons**
  - **We would be removing 0.00000382% if all CO2 from US coal-fired power gen was captured**
  - **We would be removing 0.00016% if all CO2 attributed with human activity were captured or eliminated**

CCS Value Chain

Potential for competing processes

Facilitating Commercial Frameworks (policy, regulatory, financial)

"Finding" cost

Natural CO_2

CO_2 from industry

CO_2 from power production

Cost of captured CO2 vs. natural CO2 production

- Cost of transportation (feasibility, ROW, potential for conversion of existing ROW)
- Storage to mitigate interruptible CO2 supply, demand (3rd party disposal for excess CO2)
- Basis – produced vs. captured, distance from capture to injection
- Forward market for risk management
- Carbon credit system (if needed)
- Insurance, verification

Title Transfer

"Market"
(includes bilateral contracts)

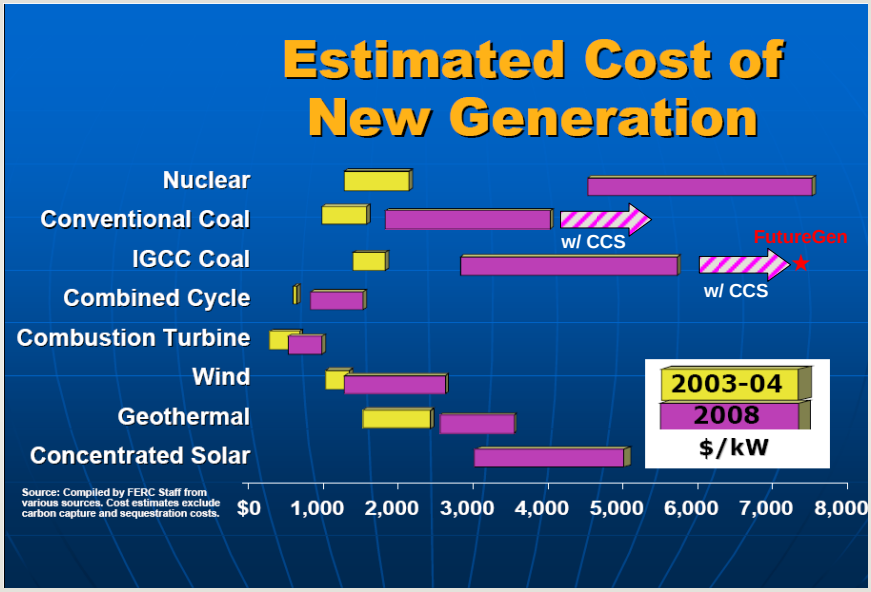
Title Transfer

CO_2 mitigation:
- EOR (emissions verification and liability)
- Industrial (petrochem, food processing, etc)
- Sequestration (brines, other)

Re-capture of CO_2 from refining point sources (development of "closed loop" for petroleum)

CCS (CO2-EOR) Considerations

- Very large variability among all-in cost estimates
  - $65-120/ton capture-injection (~$30 avg in West Texas)
  - Parasitic load issues (roughly 30% of power production)
- Access to new opportunities
- CO2 pipeline ROW procurement
- Liability, title, insurance lacking
  - Legal/regulatory framework must be built



Greenish Brown Jobs

"You have to reinvest in industrial capacity," says Randy Udall, an energy consultant in Carbondale, Colo. "You use wind to revitalize the Rust Belt. You make steel again. You bring it home. We ought to be planting wind turbines as if they were trees."

NY Times, 11/2/08

CEE Review of Green Jobs Outlooks

Investment scenarios of different studies

Studies	New renewables	Investment	Jobs created	Time period
CAP/PERI		$100 billion	2 million	2 years
GI*	~750 GW	>$1.5 trillion	1.2 million	30 years
CEERT (Environment California)**	20% RPS by 2017		200,000 (CA only)	15 years
CEERT (Apollo Alliance)**		$500 billion	5 million	10 years
CEERT (WWF)**			1.3 million	2001-2020

* Our estimate based on the GI scenario of increasing power generation from renewables (excluding conventional hydro) from 3% in 2008 to 40% by 2038. Note that we are not including the GI scenarios for transportation fuels and efficiency investments.

** CEERT study focuses on job creation in California. The range of estimates for green job creation in California is reported as 16,000 to 430,000 by 2020 (p. 9). In this table, we provided, when available, national estimates from the same studies to compare with estimates from other studies.

CEE Review of Green Jobs Outlooks

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CEERT (Environme California)*	20% RPS by		200,000 (CA	15 years
CEERT (Apo Alliance)**				ars
CEERT (WWF)**				2020

"...there is no effort to balance the potential positive impacts with potential negative impacts of job destruction and higher energy costs. In a sense, these studies are cost-benefit analyses without any cost considerations."

* Our estimate based on the GI scenario of increasing power generation from renewables (excluding conventional hydro) from 3% in 2008 to 40% by 2038. Note that we are not including the GI scenarios for transportation fuels and efficiency investments.

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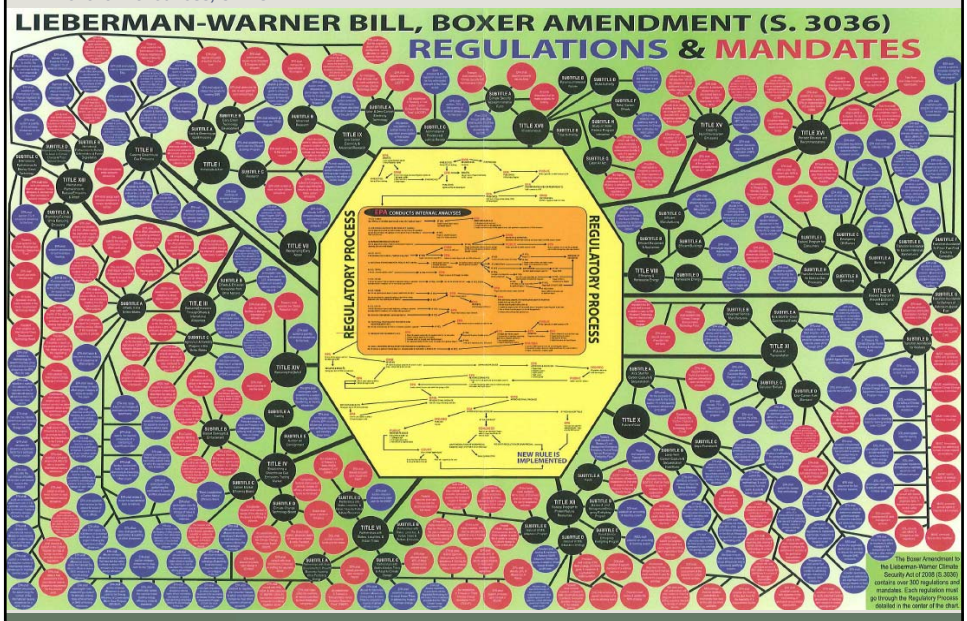

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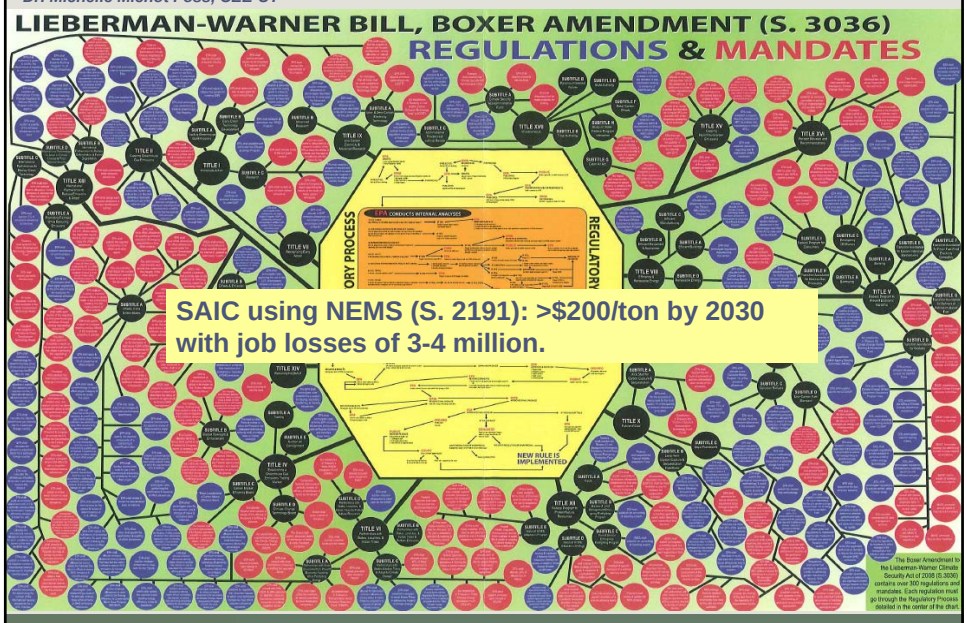

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http://www.accf.org/pdf/NAM/fullstudy031208.pdf

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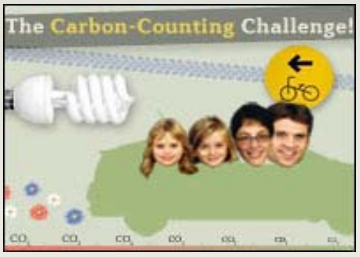

In the end… [the Sheppards] produce about **14 metric tons** of carbon dioxide a year… **40 percent below** what the average North Carolinian produces. [But the] Sheppards fly several times a year... Those trips account for **12.7 metric tons** of carbon emissions per year… **essentially double** the amount of carbon… "If you have family halfway across the world, you have to see them sometime," Claudia says. "I'll make all kinds of sacrifices elsewhere. But how would I change my flying? I can't swim there, you know?" Crawford-Brown gets this kind of reaction a lot, and he's sympathetic. His job — trying to reduce carbon emissions — involves a lot of travel.

- NPR Climate Connections, May 10, 2007

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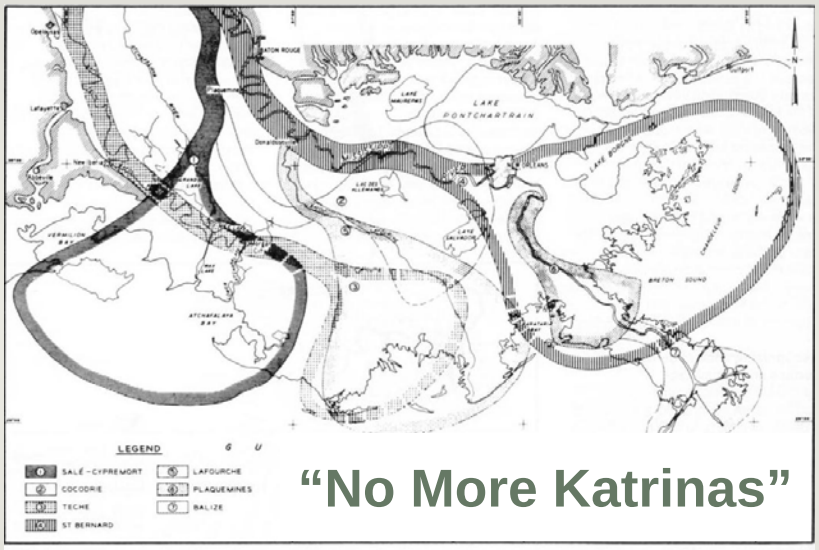

Figure 8
The seven partially overlapping lobes of the Mississippi delta which have developed during the last 5000 years (from Kolb and Van Lopik, Fig. 2, in Shirley, 1966).

"No More Katrinas"

For Further Contemplation

Copenhagen Consensus May 2008

http://www.copenhagenconsensus.com

	SOLUTION	CHALLENGE
1	Micronutrient supplements for children (vitamin A and zinc)	Malnutrition
2	The Doha development agenda	Trade
3	Micronutrient fortification (iron and salt iodization)	Malnutrition
4	Expanded immunization coverage for children	Diseases
5	Biofortification	Malnutrition
6	Deworming and other nutrition programs at school	Malnutrition & Education
7	Lowering the price of schooling	Education
8	Increase and improve girls' schooling	Women
9	Community-based nutrition promotion	Malnutrition
10	Provide support for women's reproductive role	Women
11	Heart attack acute management	Diseases
12	Malaria prevention and treatment	Diseases
13	Tuberculosis case finding and treatment	Diseases
14	R&D in low-carbon energy technologies	Global Warming
15	Bio-sand filters for household water treatment	Water
16	Rural water supply	Water
17	Conditional cash transfers	Education
18	Peace-keeping in post-conflict situations	Conflicts
19	HIV combination prevention	Diseases
20	Total sanitation campaign	Water
21	Improving surgical capacity at district hospital level	Diseases
22	Microfinance	Women
23	Improved stove intervention	Air Pollution
24	Large, multipurpose dam in Africa	Water
25	Inspection and maintenance of diesel vehicles	Air Pollution
26	Low sulfur diesel for urban road vehicles	Air Pollution
27	Diesel vehicle particulate control technology	Air Pollution
28	Tobacco tax	Diseases
29	R&D and mitigation	Global Warming
30	Mitigation only	Global Warming

Sources and Web Links for *Guide to Climate Science and Economics*
General Sources

- National Oceanic and Atmospheric Administration (NOAA)

http://www.research.noaa.gov/climate/

- National Aeronautics and Space Administration (NASA)

http://nasascience.nasa.gov/ (for links to climate research programs and data sets)

- American Association of Petroleum Geologists (AAPG), www.aapg.org, Interactive Forum on Global Climate Change, AAPG Annual Convention, San Antonio, Texas, April 20, 2008

Gerald North, Distinguished Professor of Atmospheric Sciences, Harold J. Haynes Endowed Chair in Geoscience, Texas A&M University, *"Surface Temperature Reconstructions Over the Last 2,000 Years – Data Sources and Interpretations"*
http://aapg08.onlineevent.com/PresentationLaunchNew.aspx?PresentationID=1640&qaLaunchData=
Kurt Cuffey, professor and department chair, Department of Geography, University of California, Berkeley, *"The Evidence for Changing Climate Recorded in Ice Sheets and Mountain Glaciers"*
http://aapg08.onlineevent.com/PresentationLaunchNew.aspx?PresentationID=1641&qaLaunchData=
Judith Lean, Space Science Division, U.S. Naval Research Laboratory, and Fellow-National Academy of Sciences, *"How Variable is the Sun and What are the Links Between This Variability and Climate?"*
http://aapg08.onlineevent.com/PresentationLaunchNew.aspx?PresentationID=1642&qaLaunchData=
Thomas Peterson, Climate Analysis Branch-National Climate Data Center, National Oceanic and Atmospheric Administration, *"Modern Temperature Observations: The Data and Their Interpretation"*
http://aapg08.onlineevent.com/PresentationLaunchNew.aspx?PresentationID=1643&qaLaunchData=
Eric Barron, Dean, Jackson School of Geosciences, the University of Texas at Austin,
http://aapg08.onlineevent.com/PresentationLaunchNew.aspx?PresentationID=1644&qaLaunchData=

- The Nobel Laureate Meetings at Lindau: Physics, June 29-July 4, 2008, Lindau, Germany, http://www.lindau-nobel.de/WebHome.AxCMS?ActiveID=1012

Panel Discussion, Climate Changes and Energy Challenges
http://nobellaureate.feedroom.com/index.jsp?auto_band=x&rf=sv&fr_story=60d8eeecb63502e7f7b041331a3c1a6f30c9766f&skin=showcase

- O.G. Sorokhtin, et.al., 2007, *Global Warming and Global Cooling*, Vol. 5: Evolution of Climate on Earth, Elsevier Science

Sources for Specific Slides
These sources and links generally follow the order of slides in the presentation.

- Global Warming Art, Dr. Robert Rhode, compiler

http://www.globalwarmingart.com/wiki/Global_Warming_Art:About

Courtesy of Dr. Eric Barron, former dean, Jackson School of Geosciences, University of Texas at Austin and current director, National Center for Atmospheric Research (NCAR), Boulder http://www.ncar.ucar.edu/ (NCAR is a National Science Foundation program, http://www.nsf.gov/)

- Dr. Matt Rogers, Colorado State University, Department of Atmospheric Science, CloudSat

http://cloudsat.atmos.colostate.edu/home (supported by NASA and affiliated with NASA's Jet Propulsion Laboratory, http://www.jpl.nasa.gov/index.cfm)

Matt's lecture on cloud formation:

http://aim.hamptonu.edu/outreach/AK-2006/handouts/ppts/Cloud%20Formation.ppt

- Danish National Space Center (DNSC), http://www.space.dtu.dk/english.aspx

DNSA sun-climate research including advances by Svensmark and FriisChristensen (1996) on the connections between cosmic radiation, cloud formation and climate and DNSA observations regarding peak solar activity during the 20th century

http://www.space.dtu.dk/English/Research/Research_sections/Sun_Climate.aspx

Also see Svensmark, *The Chilling Stars*, 2008 2nd edition, Totem Books.

- Research on soot

News announcements on NASA research:

http://www.giss.nasa.gov/research/news/20030513/

http://www.nasa.gov/centers/goddard/news/topstory/2003/0509pollution.html

http://www.nasa.gov/centers/goddard/news/topstory/2003/1223blacksoot.html (animation)

University of California-Irving research:

Flanner, et.al, Present-day climate forcing and response from black carbon in snow, *J of Geophysical Research*, Vol 112, D11202, doi:10.1029/2006JD008003, 2007

- General – Intergovernmental Panel on Climate Change (IPCC) – for all IPCC documents and scientific papers http://www.ipcc.ch/

Level of scientific understanding:

http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

- Institute of Geophysics, Jackson School of Geosciences, University of Texas at Austin, climate research program

http://www.ig.utexas.edu/research/overview/climate.htm?PHPSESSID=22eb0577bbc36f8792ec94ba35d490aa

Uncertainties in model predictions of future climate (Dr. Charles Jackson):

http://www.ig.utexas.edu/people/staff/charles/uncertainties_in_model_predictio.htm

- Major temperature, CO_2, solar and sea ice data series:

HADCRUT3 Global Temperature	
Source:	Climatic Research Unit, UEA; Met Office Hadley Centre
Data URL:	http://www.cru.uea.ac.uk/cru/data/temperature/

Reference:	*P. Brohan, J.J. Kennedy, I. Harris, S.F.B. Tett and P.D. Jones, Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J. Geophys. Res, 111, D12106, doi:10.1029/2005JD006548.*
GISTEMP Global Temperature	
Source:	NASA Goddard Institute for Space Studies
Data URL:	http://data.giss.nasa.gov/gistemp/
Reference:	See: GISTEMP references page
UAH NSSTC Lower troposphere temperature	
Source:	UAH National Space Science and Technology Center
Data URL:	http://vortex.nsstc.uah.edu/public/msu/t2lt/
Reference:	*John Christy, NSSTC, University of Alabama in Huntsville*
RSS Lower troposphere temperature	
Source:	Remote Sensing Systems
Data URL:	http://www.ssmi.com/msu/msu_data_description.html
Reference:	MSU data are produced by Remote Sensing Systems and sponsored by the NOAA Climate and Global Change Program. Data are available at www.remss.com.
SIDC Sunspot Number (SSN)	
Source:	Solar Influences Data Analysis Center (SIDC), Royal Observatory of Belgium
Data URL:	http://sidc.oma.be/sunspot-data/
Reference:	*SIDC-team, World Data Center for the Sunspot Index, Royal Observatory of Belgium, Monthly Report on the International Sunspot Number, online catalogue of the sunspot index*
PMOD Composite Total Solar Irradiance (TSI)	
Source:	Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center
Data URL:	ftp://ftp.pmodwrc.ch/pub/data/irradiance/composite/
Reference:	*C. Fröhlich, 2006, "Solar Irradiance Variability Since 1978: Revision of the {PMOD} Composite During Solar Cycle 21", Space Science Rev. in press 2006*
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NOAA ESRL CO_2 at Mauna Loa	
Source:	NOAA Earth System Research Laboratory
Data URL:	http://www.esrl.noaa.gov/gmd/ccgg/trends/
Reference:	*Dr. Pieter Tans, NOAA/ESRL*
JISAO PDO Index	
Source:	University of Washington Joint Institute for the Study of Atmosphere and Ocean
Data URL:	http://jisao.washington.edu/pdo
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http://www.ycsg.yale.edu/climate/index.html
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