Energy Resources, Economics and Environmental Effects

UCC501 Sustainable Energy, Fall 2014

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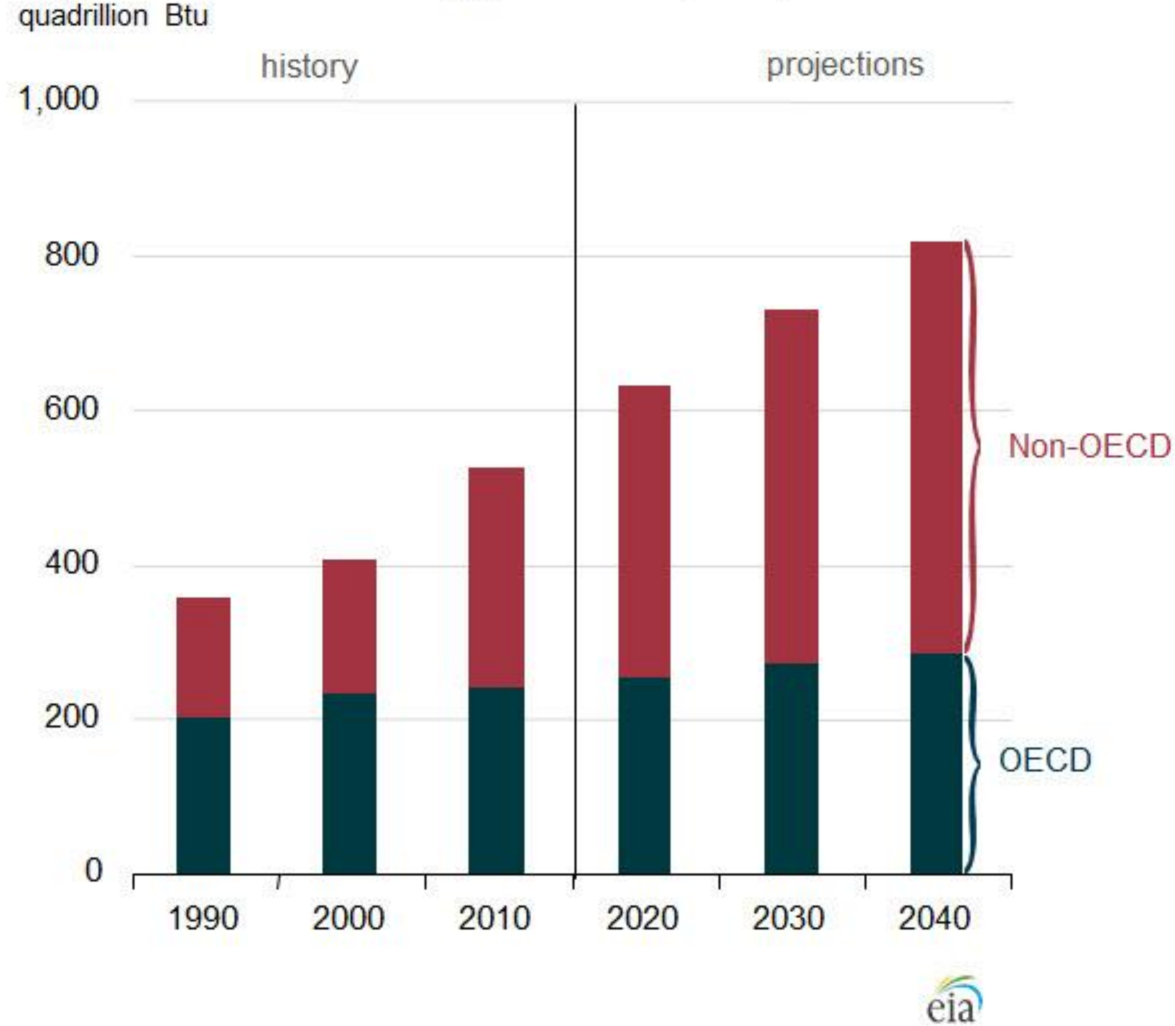
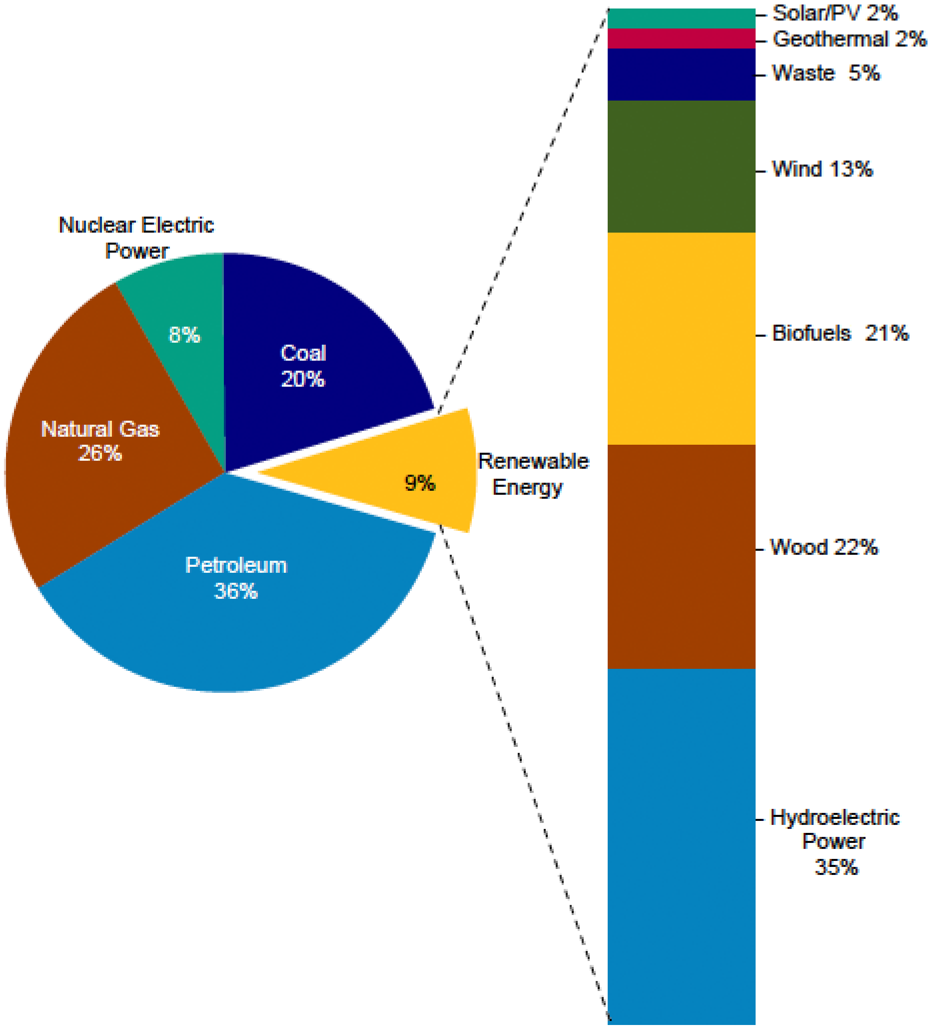
Contents

- Energy consumption
- Energy efficiency
- Energy storage and infrastructure
- Climate change basics
- Green House Gases
- Modeling the climate

Figure 1. World energy consumption, 1990-2040



Renewable Energy as Share of Total Primary Energy Consumption, US 2011



The Multi-dimensionality of the Energy Problem

- 5 Ds:
  - Discovery
  - Definition (basic research)
  - Development (R&D)
  - Demonstration (pilot & commercial scale)
  - Deployment (at scale)
- Energy options (fossil, nuclear, solar etc.)
- Scales from 1kW< to >1GW
- End uses (thermal, mechanical, electromagnetic, etc.)
- Sustainability attributes
- Performance metrics including efficiency

Efficiency: The Win-Win Option?

"Increasing the efficiency of providing a specific energy service yields a sustainable pathway for both reducing demand and lowering energy supply and resource needs"

Is it true?

Remember Jevons…

Other Examples

- Combined heat and power to increase resource utilization efficiency
- Integrated high efficiency building designs
- Hybrid energy use with distributed generation
- Hybrid electric vehicles utilizing renewable fuels and electricity
- Manufacturing processes that use less materials and energy

Energy Chains and Efficiencies

A linked or connected set of energy efficiencies from extraction to use:

$$OverallEfficiency = n_{overall} = \prod_{i=1}^{n} n_i$$

$$\eta_{overall} = \eta_{gas\,extraction}\eta_{gas\,processing}\eta_{gas\,transmission}\eta_{power\ plant}\eta_{electricity\,transmission}\eta_{distribution}\eta_{motor}$$

for example for compressed air energy storage (CAES):

$$\eta_{overall} \equiv \frac{Work\,output}{Work\,input} = \frac{W_{turbine}}{W_{compressor}} = \eta_{turbine}\eta_{compressor}$$

Energy Storage

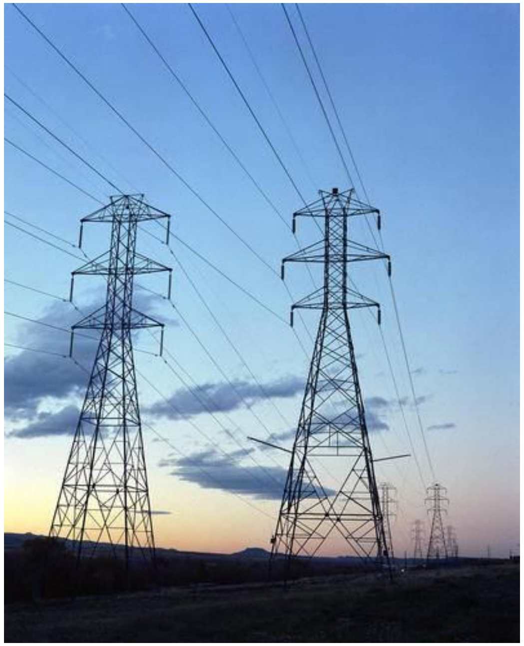
- Energy resource not always where or when it is needed --> storage
- Energy storage mediates between variable sources and variable loads
- Without storage, energy generation must equal energy consumption
- Energy storage works by moving energy through time

Energy Infrastructure

- Large and entrenched

US:

- 400,000+ miles of gas and oil pipelines
- 160,000+ of high voltage transmission lines
- 176,000 gasoline stations
- 1000's of oil and gas wells drilled annually in the US and Canada



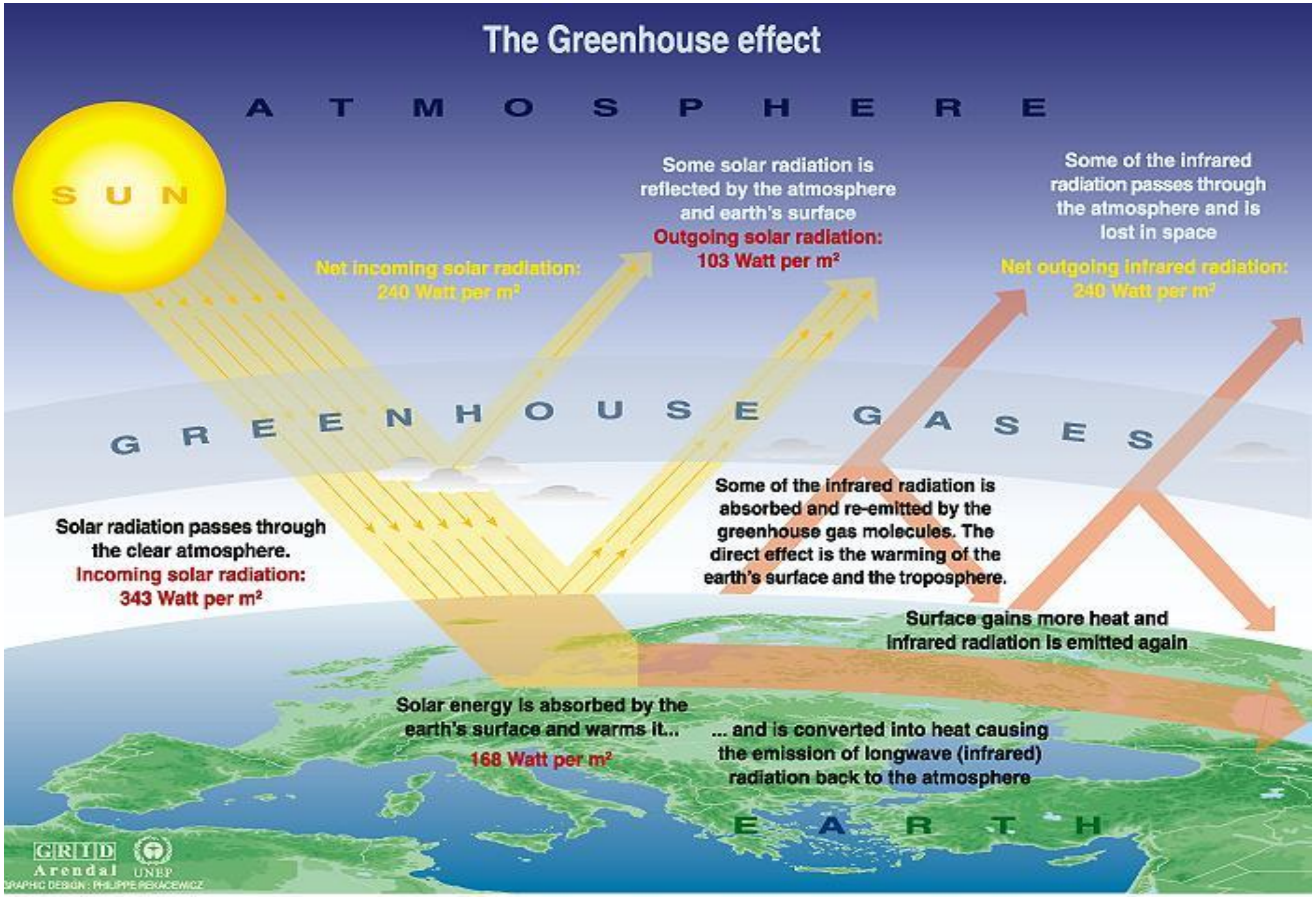
Supply + Demand = Benefit + Impact

2 'Bitter' truths

- Large-scale and cheap energy provision is a key ingredient in our Western Civilization soup.
  - Without it, OUR life would not be as we know it
  - White's Law (1973): "*Culture advances as the quantity and quality of energy used increases*"
- Very messy, very fast: Energy, environment and politics tangle into a Gordian knot:
  - Cheap and easy energy is more often than not polluting AND climate forcing
  - The status quo will reach the limits to growth one way or another – meeting Earth's carrying capacity in population/pollution/resource and can force national and personal rush for survival

- Sen. McCain's quest for a temporary gas tax repeal – 2008
- UAE's subsidized cost of liquid fuels

Climate Change Basics



Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

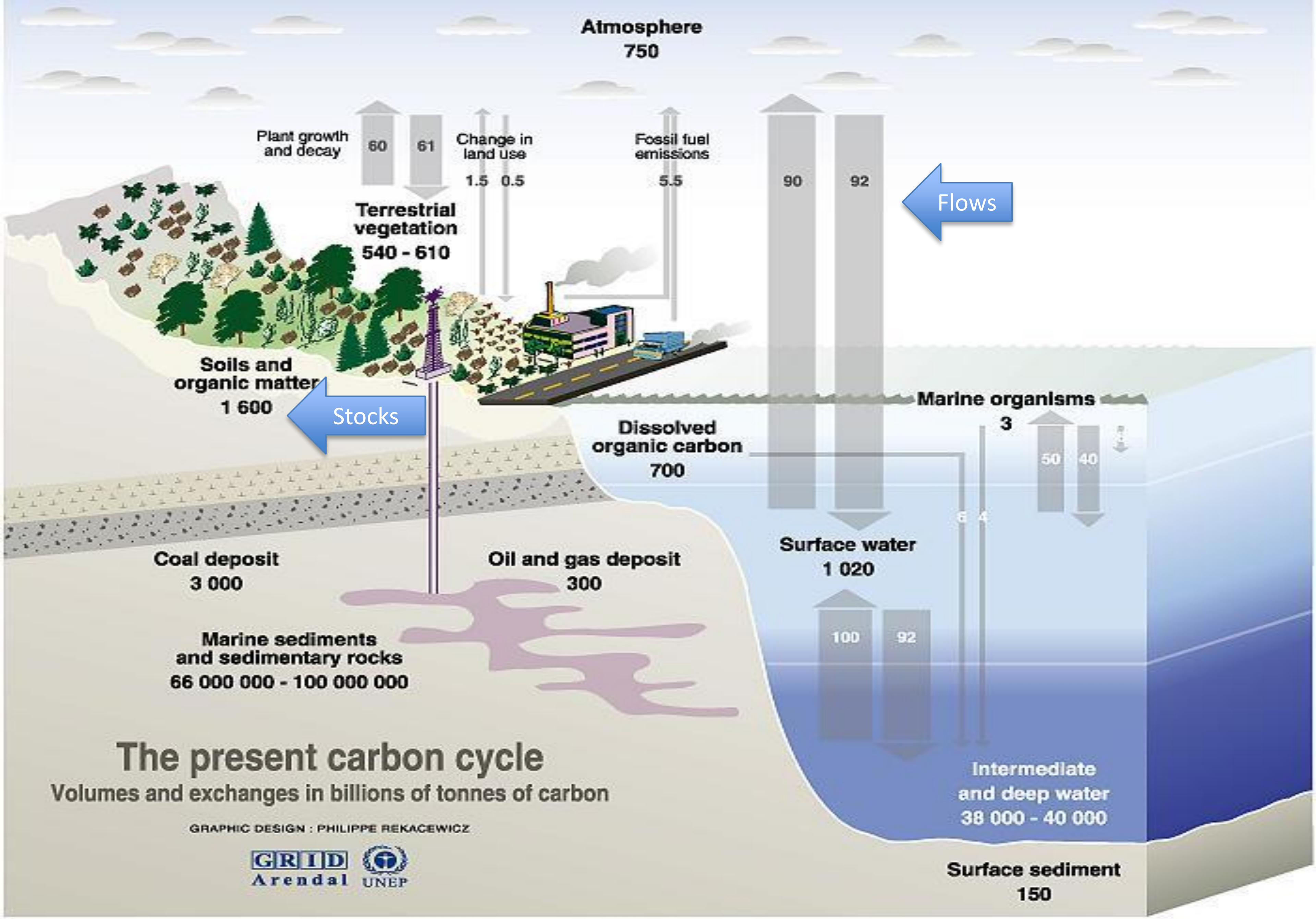
Source: UNEP

Climate Skeptics?

“The burning of fossil fuels sends about seven gigatons of CO_2 per year into the atmosphere, which sounds like a lot. Yet the biosphere and the oceans send about 1900 gigatons and 36 000 gigatons of CO_2 per year into the atmosphere – . . . one reason why some of us are sceptical about the emphasis put on the role of human fuel-burning in the greenhouse gas effect. Reducing man-made CO_2 emissions is megalomania, exaggerating man’s significance. Politicians can’t change the weather.”

Dominic Lawson, Independent

Is there something wrong? What? (note numbers and flows)



Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Combating Climate Skeptics

- Skeptical Science: http://www.skepticalscience.com

- Real Climate blog: http://www.realclimate.org

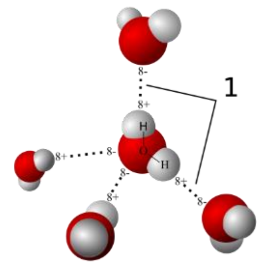
Weather vs. Climate

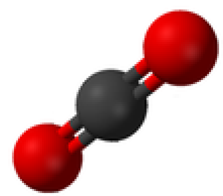
- Weather is determined by the short term observable variations of the atmosphere. It is a local event spatially and temporally.

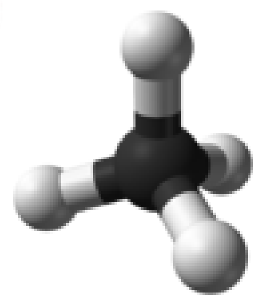
- Climate is the long-term sequence of weather events. It is characterized by average and variance. Climate is a macroscopic characteristic of a region.

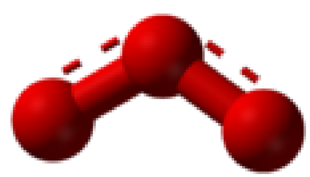
Meet your GHGs

- H_2O
- CO_2
- CH_4
- N_2O
- CFC-11
- O_3 (troposphere – local)





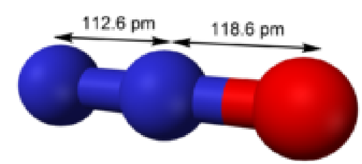




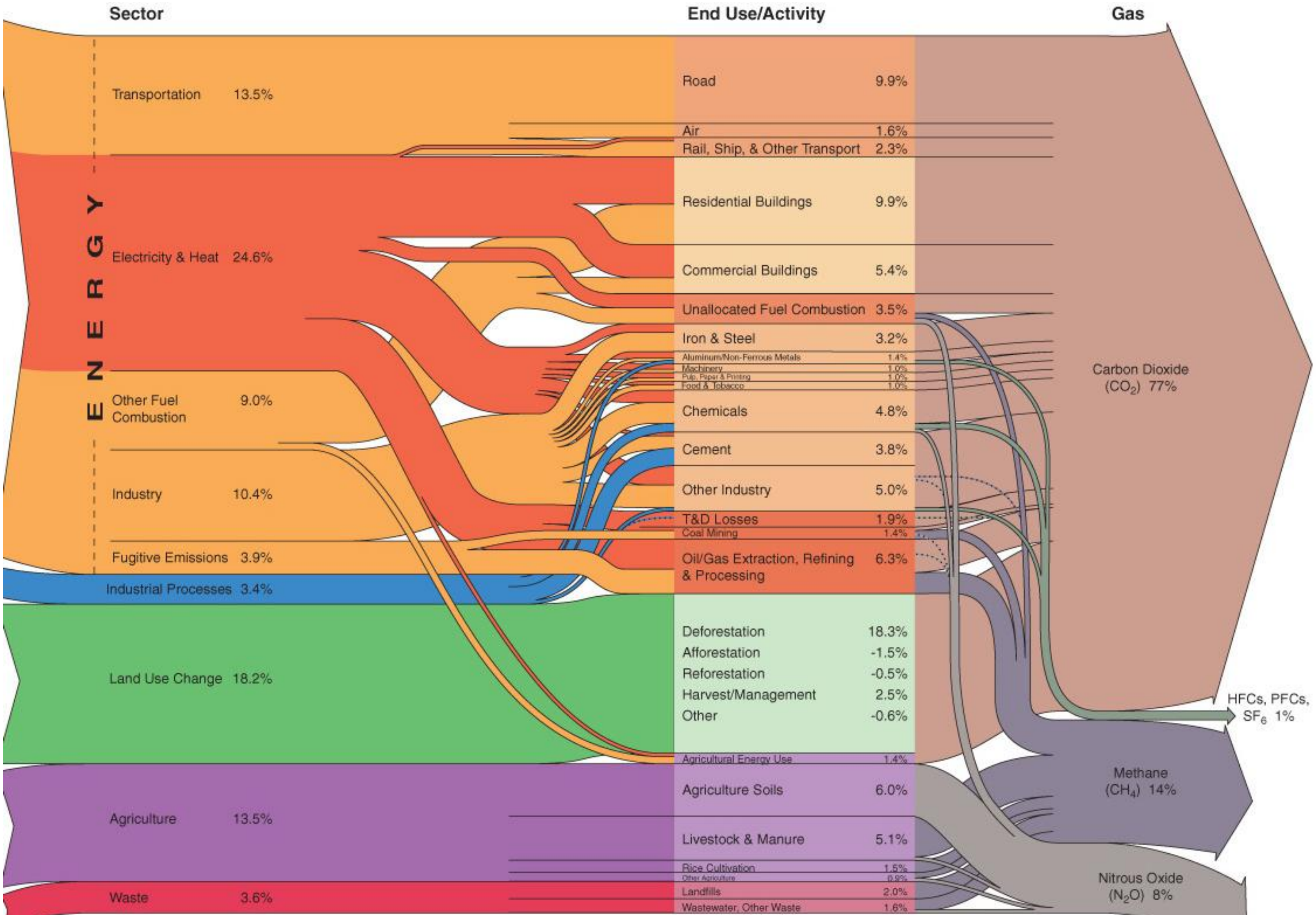
What about CO? Is it a GHG?

No –

BUT it has a greenhouse effect by "scavenging" the hydroxyl from the atmosphere that would break-up CH_4 and O_3 (and of course it is oxidized to CO_2)

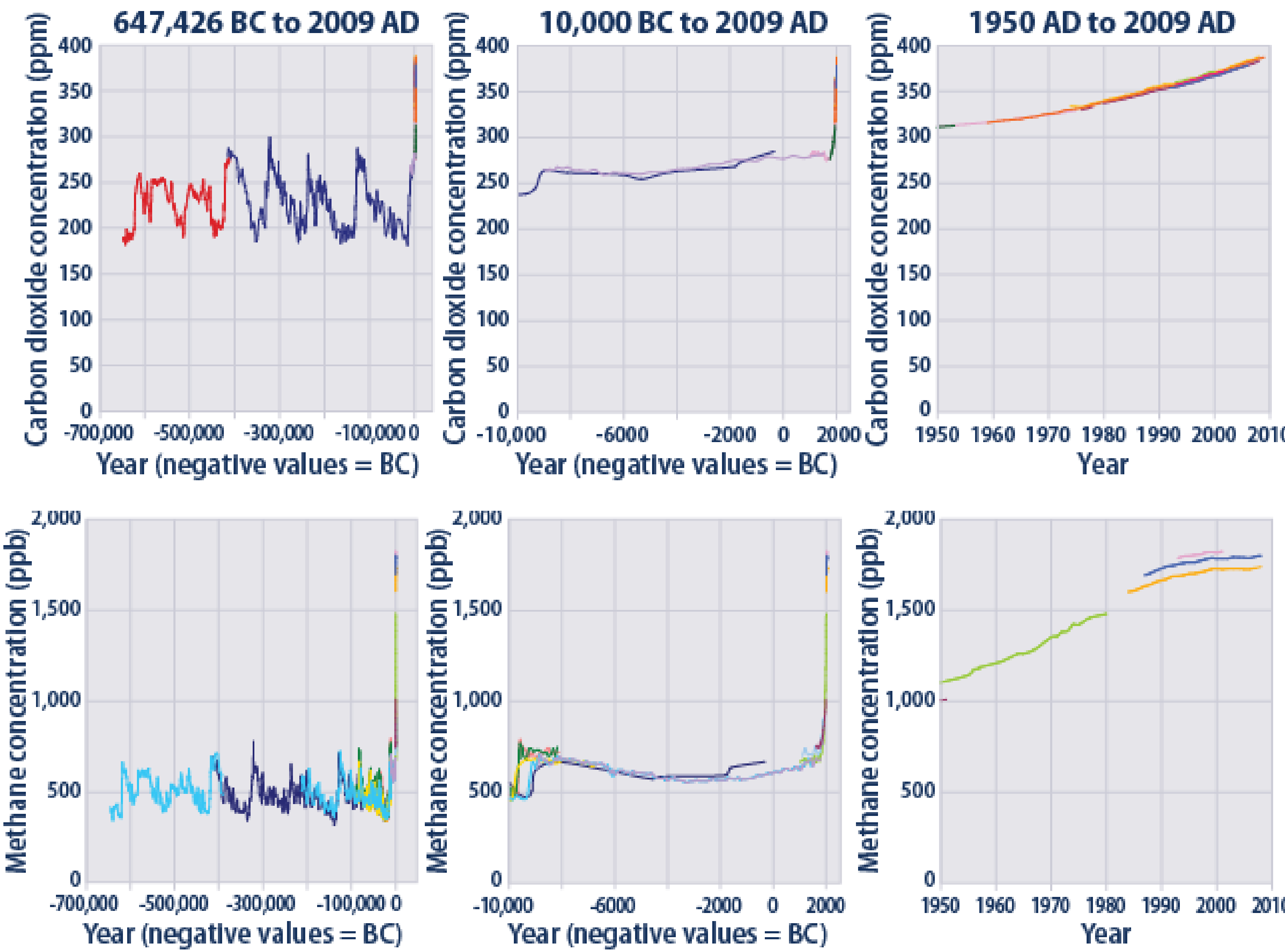


Global GHG Emissions Flows



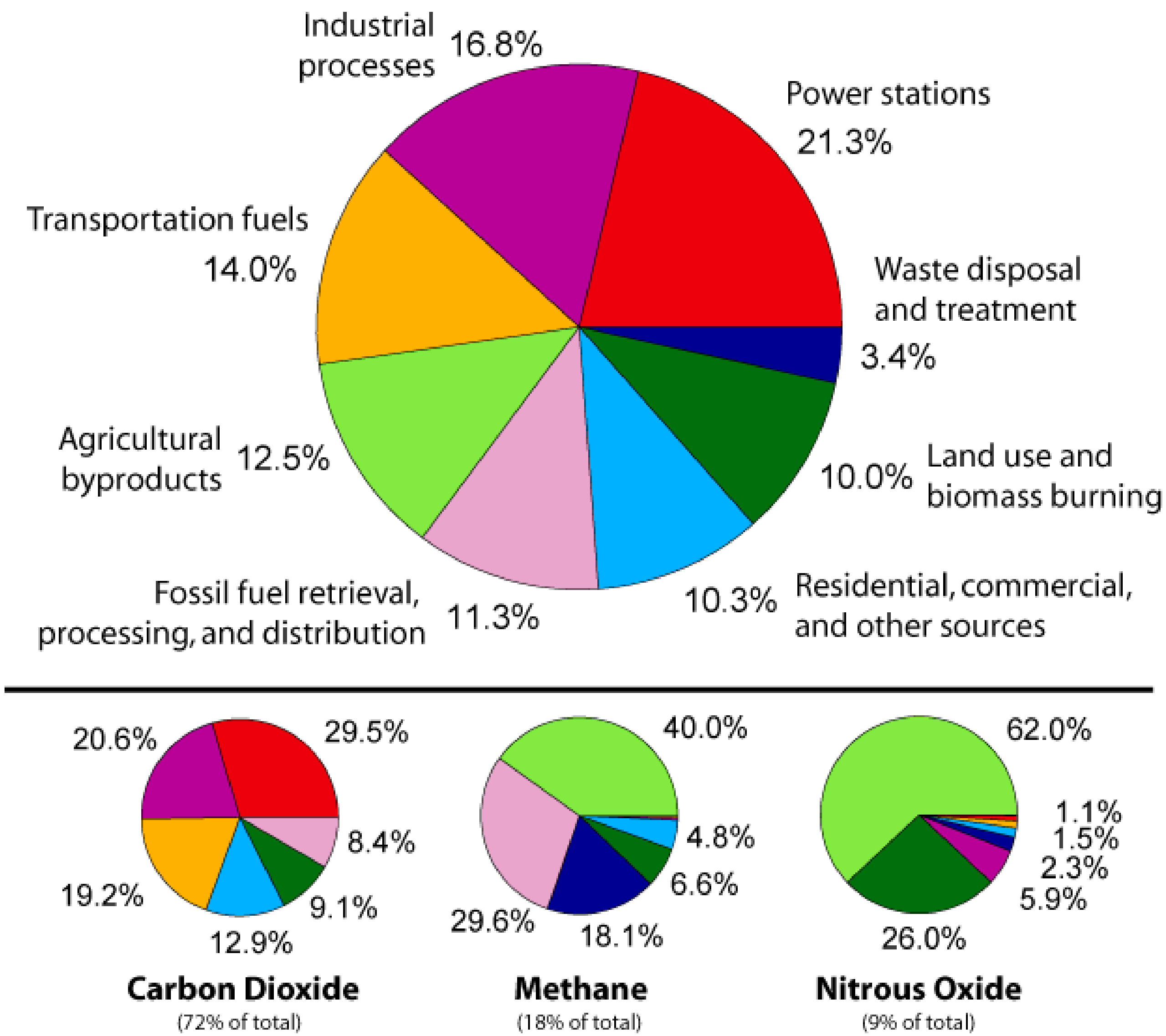
Source: http://cait.wri.org/figures.php?page=/World-FlowChart

Historic GHG Concentrations in the Atmosphere

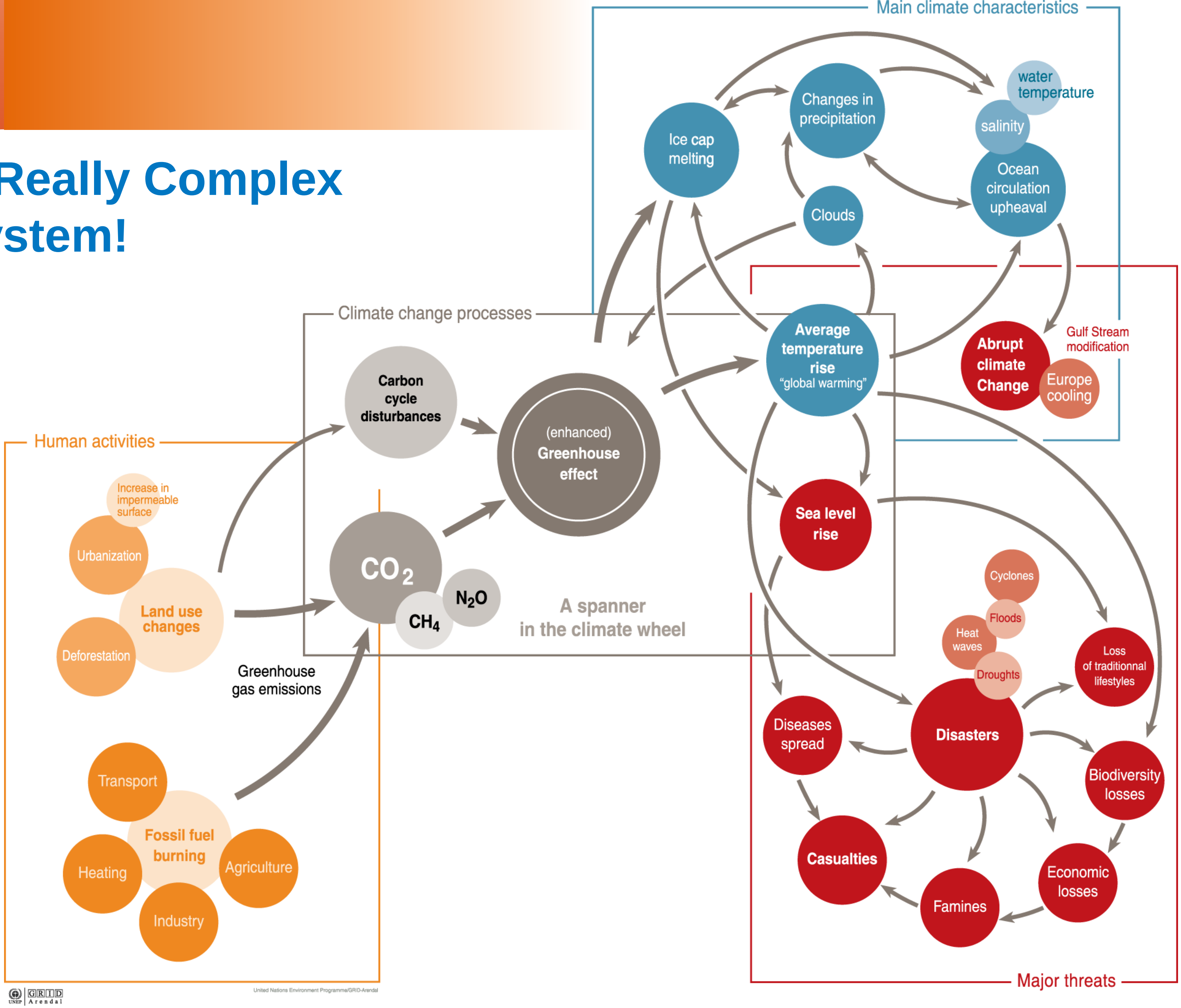


Source: EPA

Annual Greenhouse Gas Emissions by Sector



A Really Complex System!

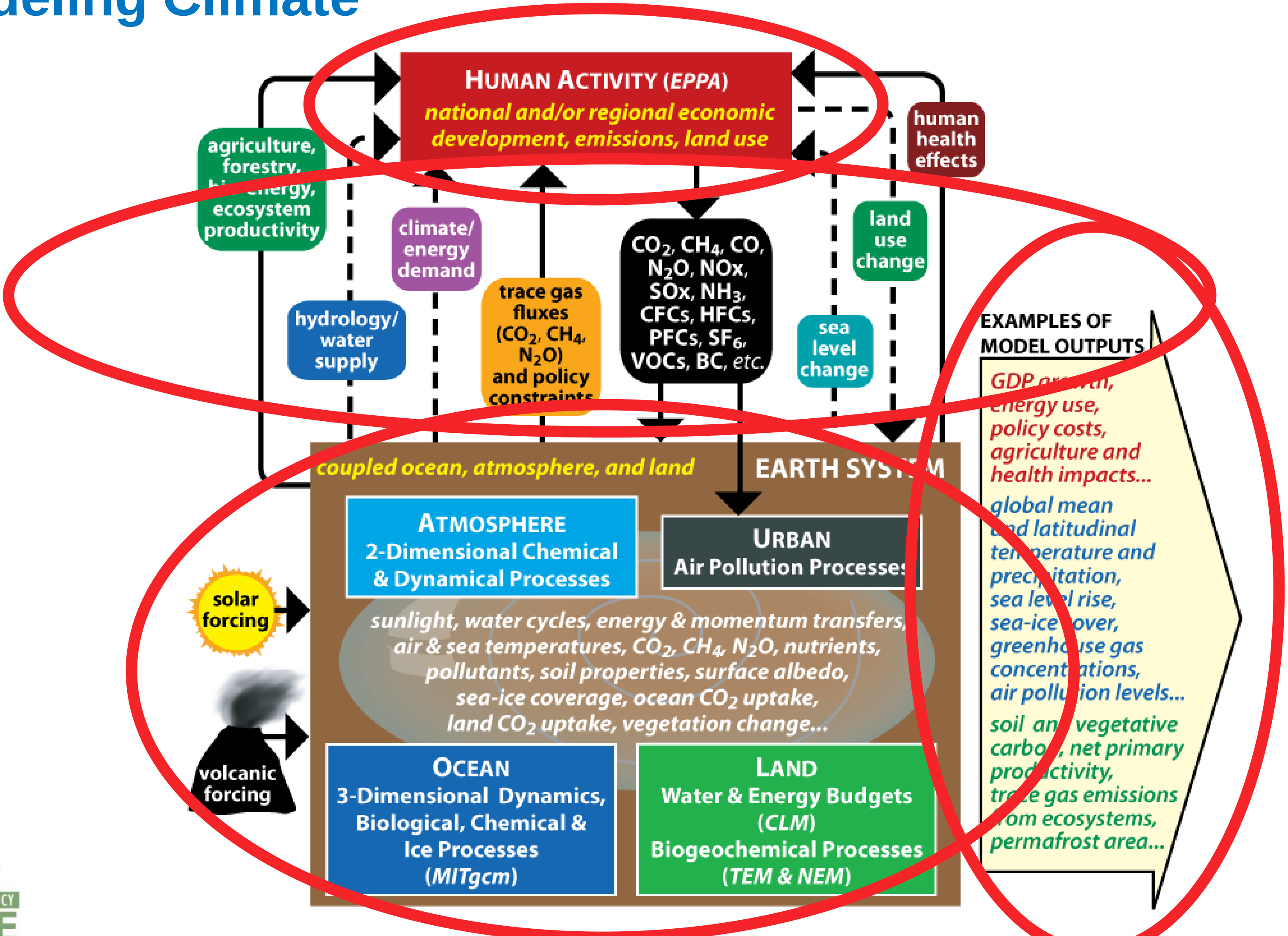


Source: UNEP

Modeling the Climate

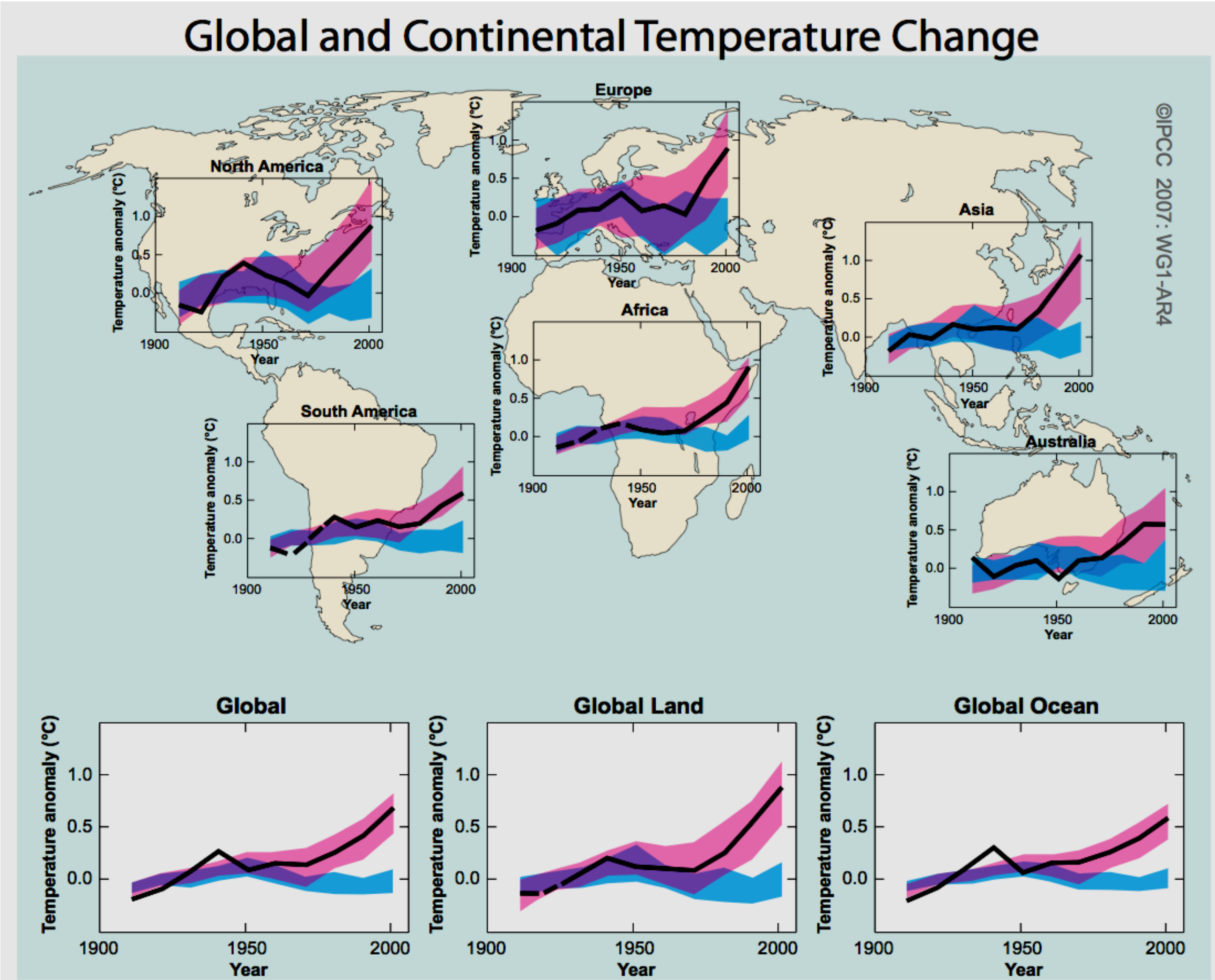
- Two types of models:
  - – Global Circulation Models (GCMs)
  - – Integrated Carbon Economy Models
    - http://www.forio.com/simulation/climate-development/

Modeling Climate



MIT INTEGRATED GLOBAL SYSTEM MODEL

How have global & continental temperatures changed over the past century (1906 – 2005), and why?



Ref: IPCC 4th Assessment, Summary for Policymakers, 2007

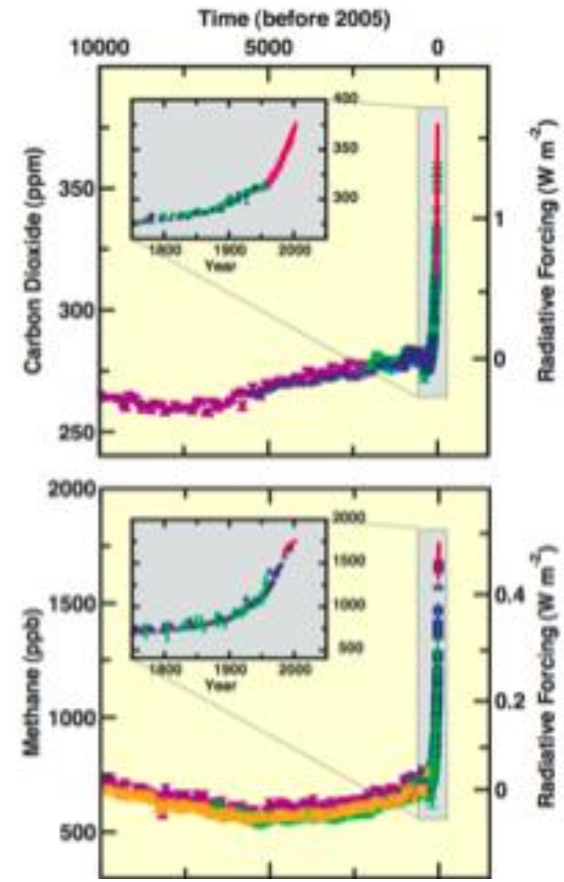
Black lines: observed changes.

Blue bands: range for 19 model simulations using natural forcings.

Red bands: range for 51 model simulations using natural and human forcings.

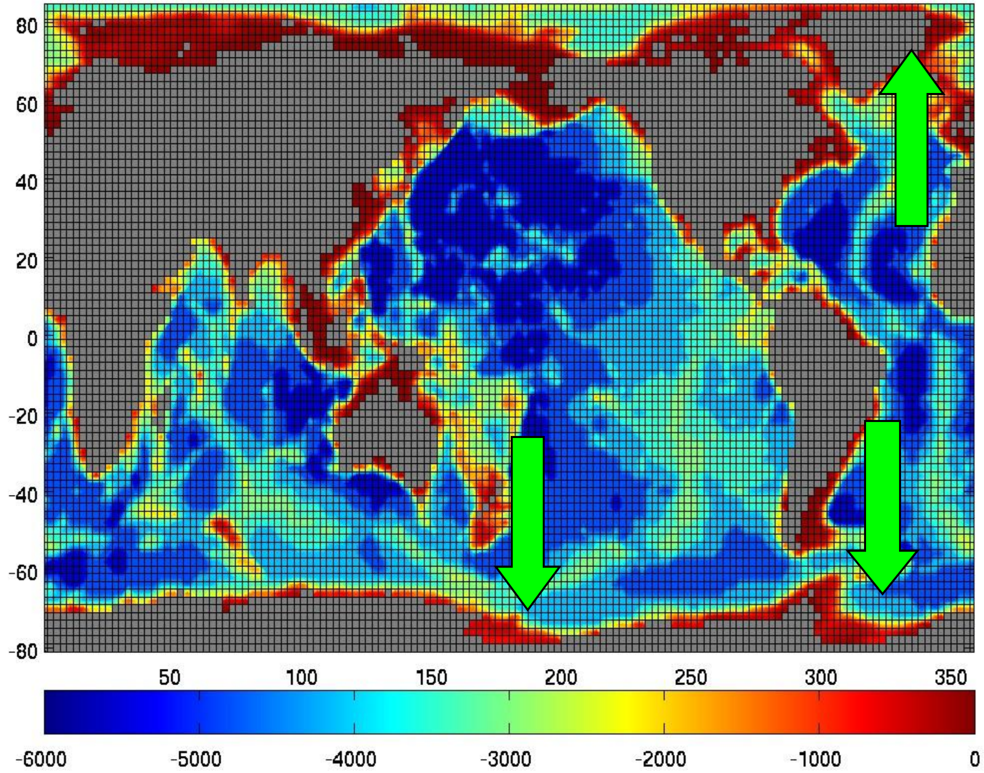
Climate Change

- Climate change has been verified beyond reasonable doubt
- Questions remain about extent and timing of impacts
- The climate and economy interactions need to be modeled



Source: IPCC 2007

Is the Deep Ocean Carbon & Heat Sink Stable?



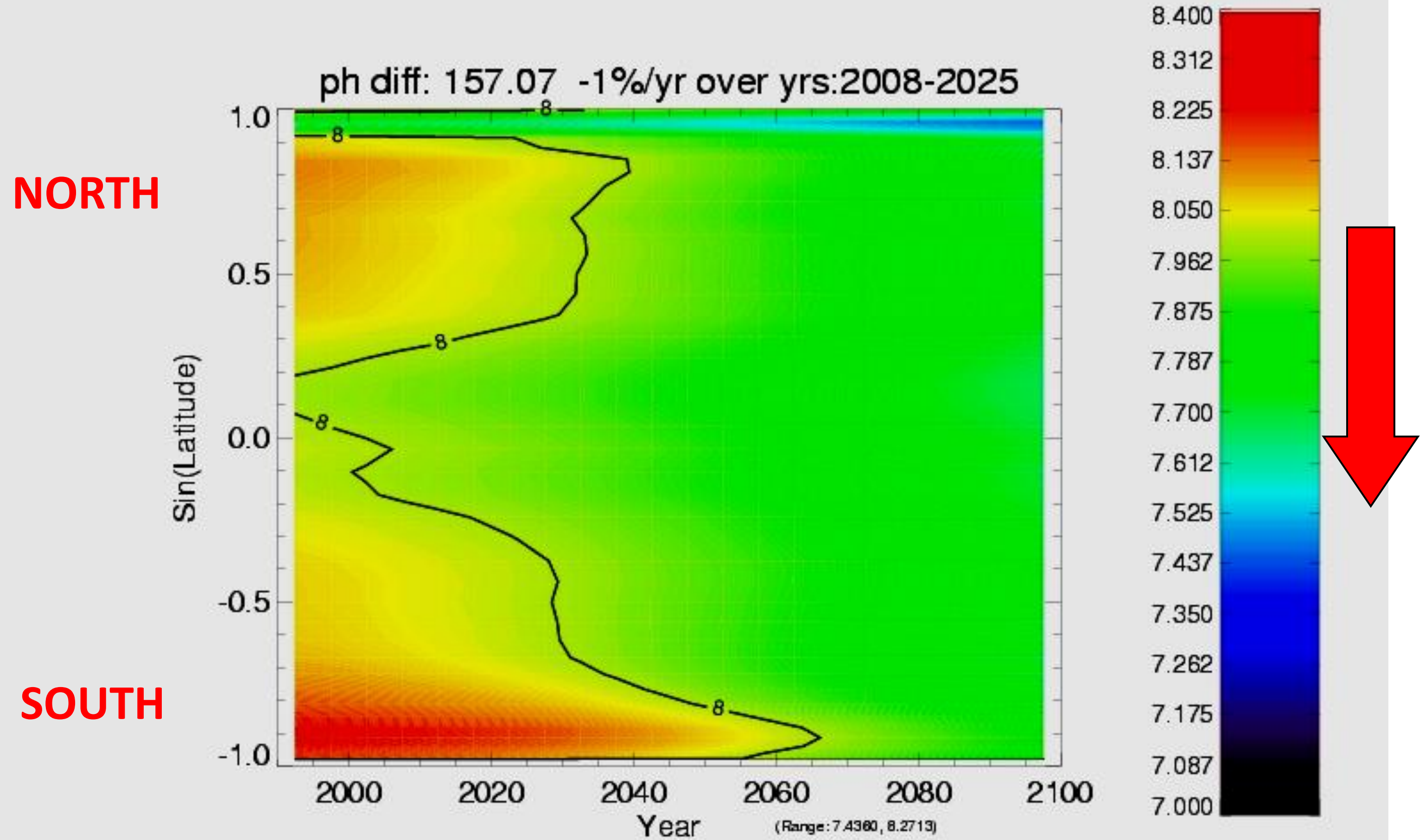
OCEAN BOTTOM DEPTHS (meters)
(MIT 3D OCEAN MODEL)

OVERTURN DRIVEN BY SINKING WATER IN THE POLAR SEAS (Norwegian, Greenland, Labrador,Weddell, Ross)

SLOWED BY DECREASED SEA ICE & INCREASED FRESH WATER INPUTS INTO THESE SEAS

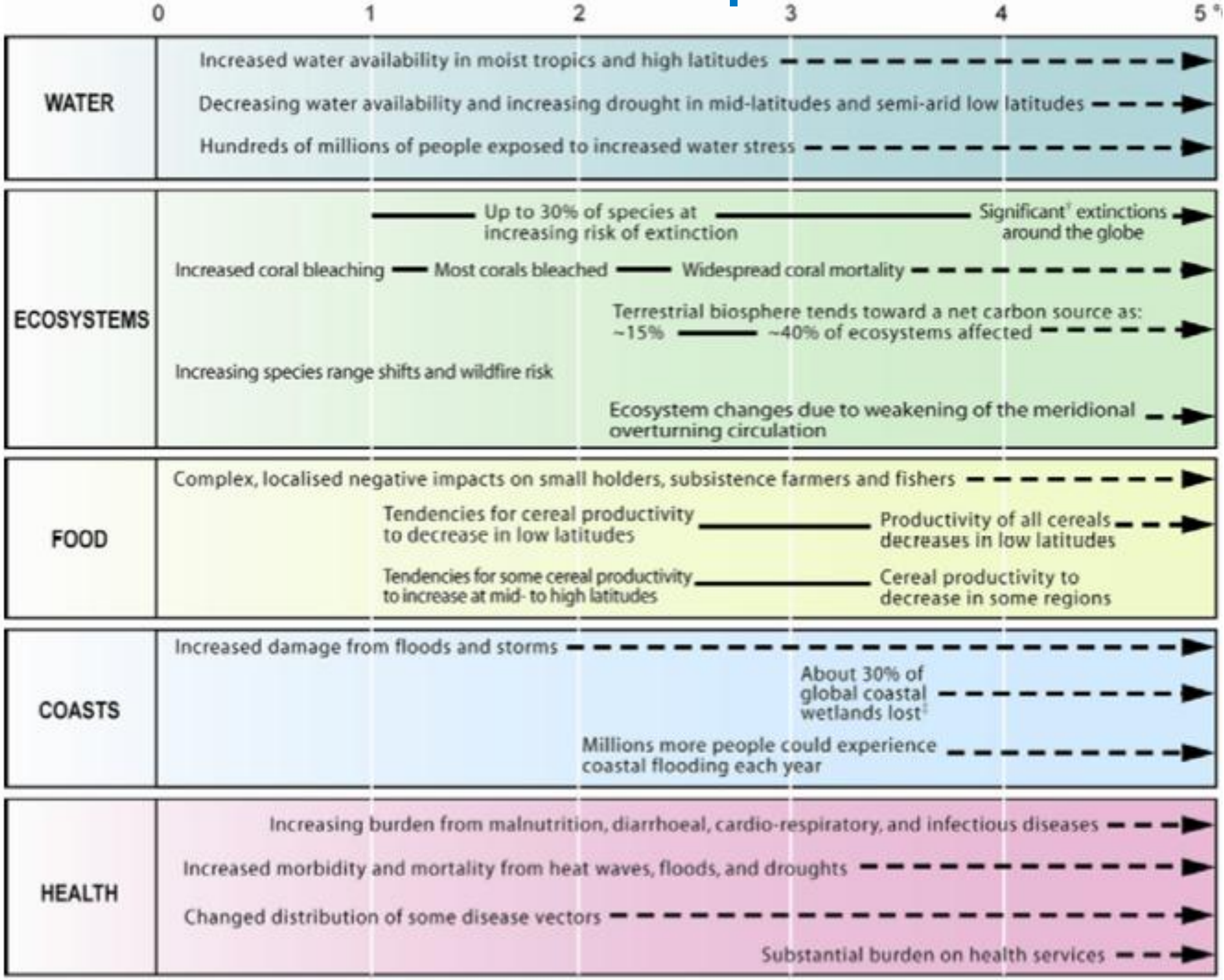
INCREASED RAINFALL, SNOWFALL & RIVER FLOWS, & DECREASED SEA ICE, EXPECTED WITH GLOBAL WARMING

Oceanic Acidity



A DROP IN pH OF 0.5 or GREATER COULD LEAD TO DECIMATION OF CALCAREOUS PHYTOPLANKTON

Impacts: Failure cannot be an option



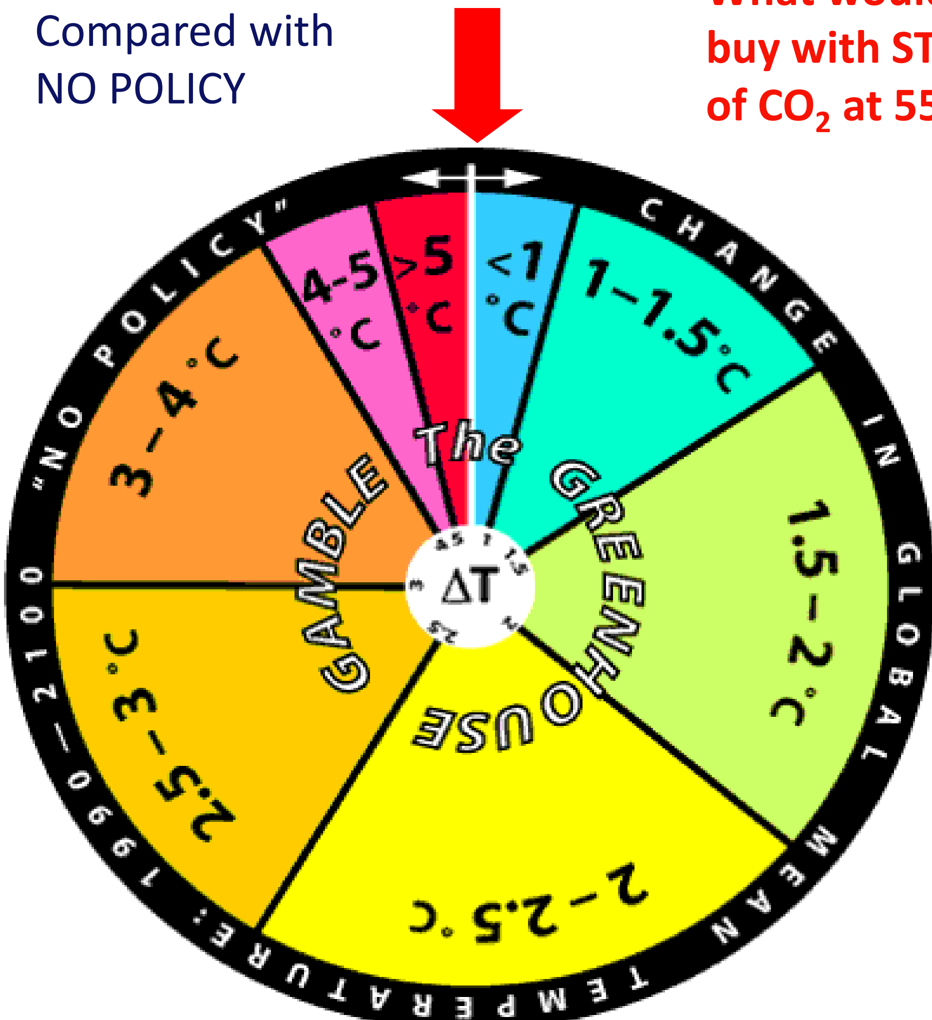
Source: IPCC AR4 2007

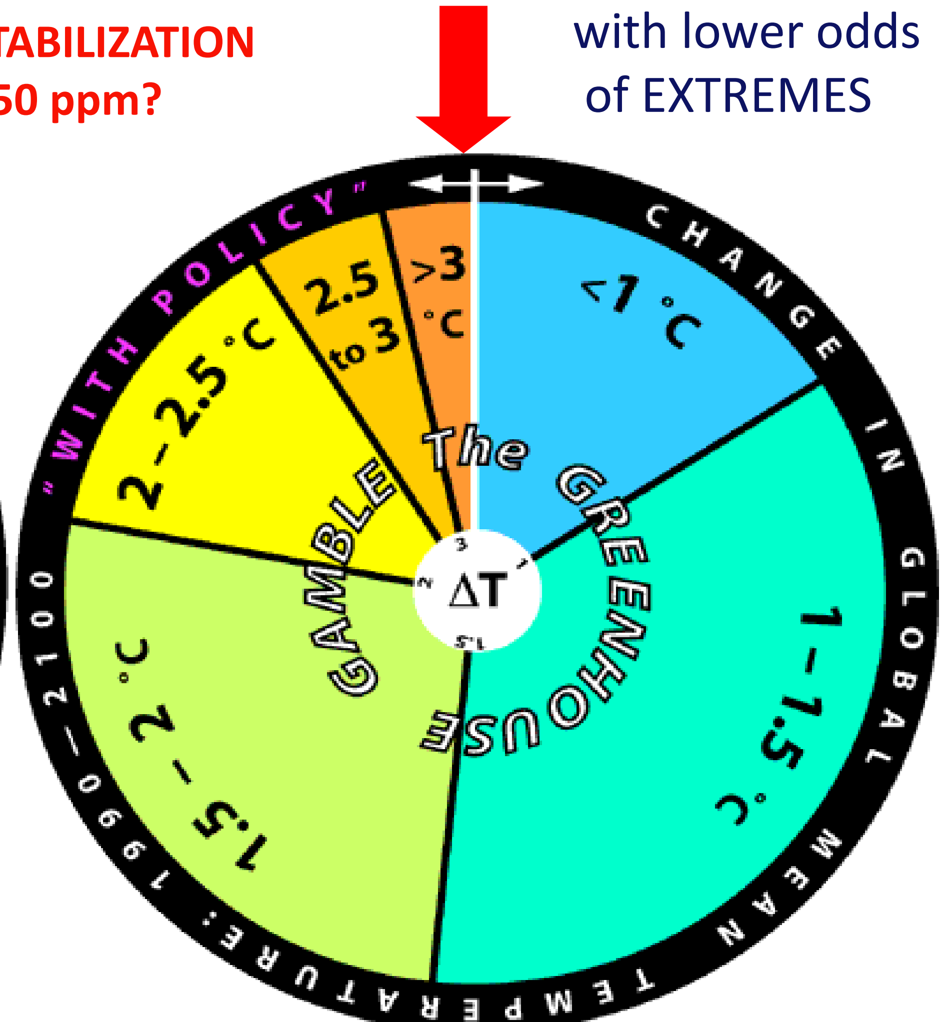
The Value of Climate Policy

Compared with
NO POLICY

What would we
buy with STABILIZATION
of CO_2 at 550 ppm?

A NEW WHEEL
with lower odds
of EXTREMES





http://web.mit.edu/globalchange/

Questions/Comments?

Multiple Scales of Energy

Energy E (in BTU, joules(J) or cal)
Power $P = dE/dt$ (BTU/hr, Watts(W))
thermal – t or th or electric - e

- macro level – global scale
  E = 1 to 1000 quad = 10^{15} BTU $\approx$ 1 exajoule = 10^{18} J

- meso level – process or central station power plant level
  E = 10000 to 1 million BTU or 1,000 kJ to 100,000 kJ
  P = 100 KW t or e to 1000 MW t or e

- micro level – e.g. individual buildings or vehicles
  E = 1 – 10000 BTU to 1000 J to 10 kJ
  P = 1 Watt (W) to 100 kW

Energy Equivalent Conversions

	Million Btu (British thermal units)	Giga (10^9) Joules	TOE (Metric Tons of Oil Equivalent)	TCE (Metric Tons of Coal Equivalent)
Million Btu (British thermal units)	1.00000	0.94782	39.68320	27.77824
Giga (10^9) Joules	1.05506	1.00000	41.86800	29.30760
TOE (Metric Tons of Oil Equivalent)	0.02520	0.02388	1.00000	0.70000
TCE (Metric Tons of Coal Equivalent)	0.03600	0.03412	1.42857	1.00000

Mass Equivalent Conversions

	Short Tons	Kilograms	Metric Tons	Long Tons	Pounds
Short Tons	1.00000	0.00110	1.10231	1.12000	0.00050
Kilograms	907.18470	1.00000	1000.00000	1016.04700	0.45359
Metric Tons	0.90718	0.00100	1.00000	1.01605	0.00045
Long Tons	0.89286	0.00098	0.98421	1.00000	0.00045
Pounds	2000.00000	2.20462	2204.62272	2240.00030	1.00000

Volume Equivalent Conversions

	Barrels	U.S. Gallons	Liters	Cubic Feet	Cubic Meters
Barrels	1.00000	0.02381	0.00629	0.17811	6.28981
U.S. Gallons	42.00000	1.00000	0.26417	7.48049	264.17200
Liters	158.98730	3.78541	1.00000	28.31676	1000.00000
Cubic Feet	5.61460	0.13368	0.03531	1.00000	35.31478
Cubic Meters	0.15899	0.00379	0.00100	0.02832	1.00000

Scale Conversions

Prefix	Kilo-	Mega-	Giga-	Tera-	Peta-
Numerical Equivalent	Thousand (10^3)	Million (10^6)	Billion (10^9)	Trillion (10^12)	Quadrillion (10^15)
Also Referred to As			Million Kilo-, Thousand Mega-	Billion Kilo-	

Energy and Power Scaling

• food	250 kcal/candy bar
• average daily requirement	2000-3000 kcal/day = 100 W
• human heart	2 W
• running	300 W
• 1 horsepower	750 W
• 757 jet plane	1 – 10 MW
• automobile	50-150kW
• space shuttle	1 GW
• Typical electric generating plant	1000 MW
• 1 wind turbine	1-3 MW
• laptop computer	10 W
• cell phone	2 W

US energy consumption per year:

100 quads or Q=106,000,000,000,000,000,000,000 J (~ 3.5 TW)

Worldwide energy consumption per year (2008/EIA data):

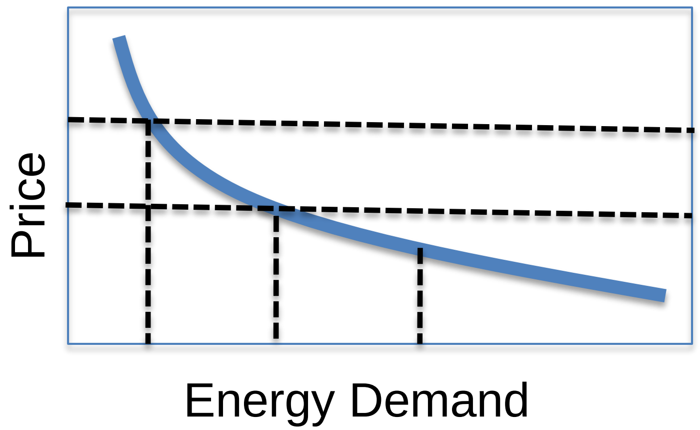
619 quads or Q = 656,000,000,000,000,000,000,000 J (~ 20TW)

11808 Mtoe or 476 quads (BP/2010) (~16TW) no biomass included

12852 Mtoe or 518 quads (Enerdata/2010) (~17.4TW)

What Drives the Growth of Energy Needs?

- *Jevons Paradox*
  - *The growth in efficiency in the utilization of a resource tends to increase its extraction rate*



Measures of Global Warming

- **Radiative Forcing:** Measure of the change in the balance of incoming and outgoing energy in the Earth-atmosphere system at a point in time.

- **Radiative Forcing Index**: Ratio of total RF for an activity over the RF of CO_2 emitted by the same activity.

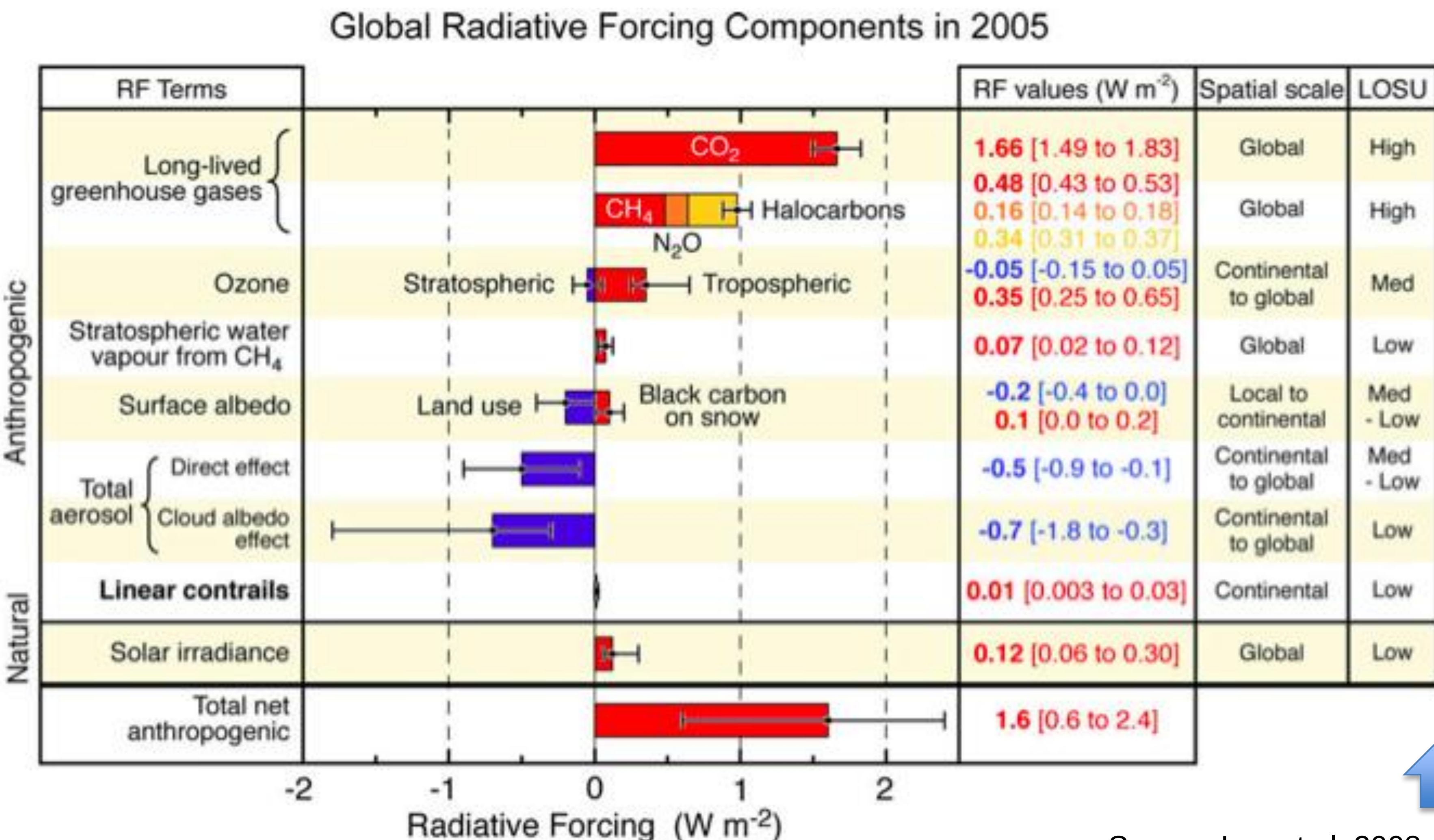
- **Global Warming Potential**: Time integrated RF of a pulse emission over a period of time (usually cited GWP100)

Global Warming Potential

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]$1.4x10^{-5}$	1	1	1	1
Methane[c]	CH_4	12[c]	$3.7x10^{-4}$	21	72	25	7.6
Nitrous oxide	N_2O	114	$3.03x10^{-3}$	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990

Source: IPCC

GHG Components



Source: Lee et al. 2008