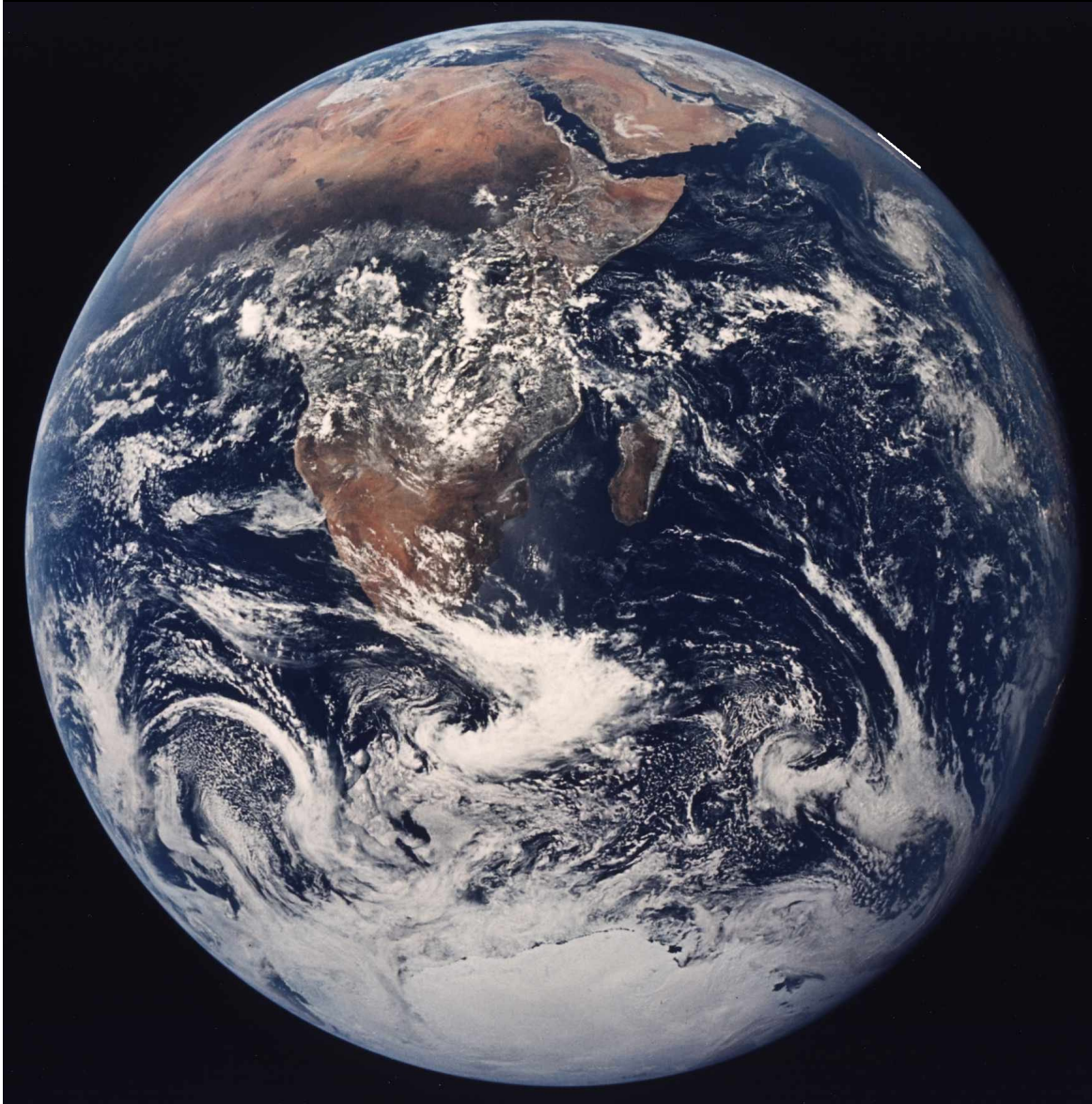
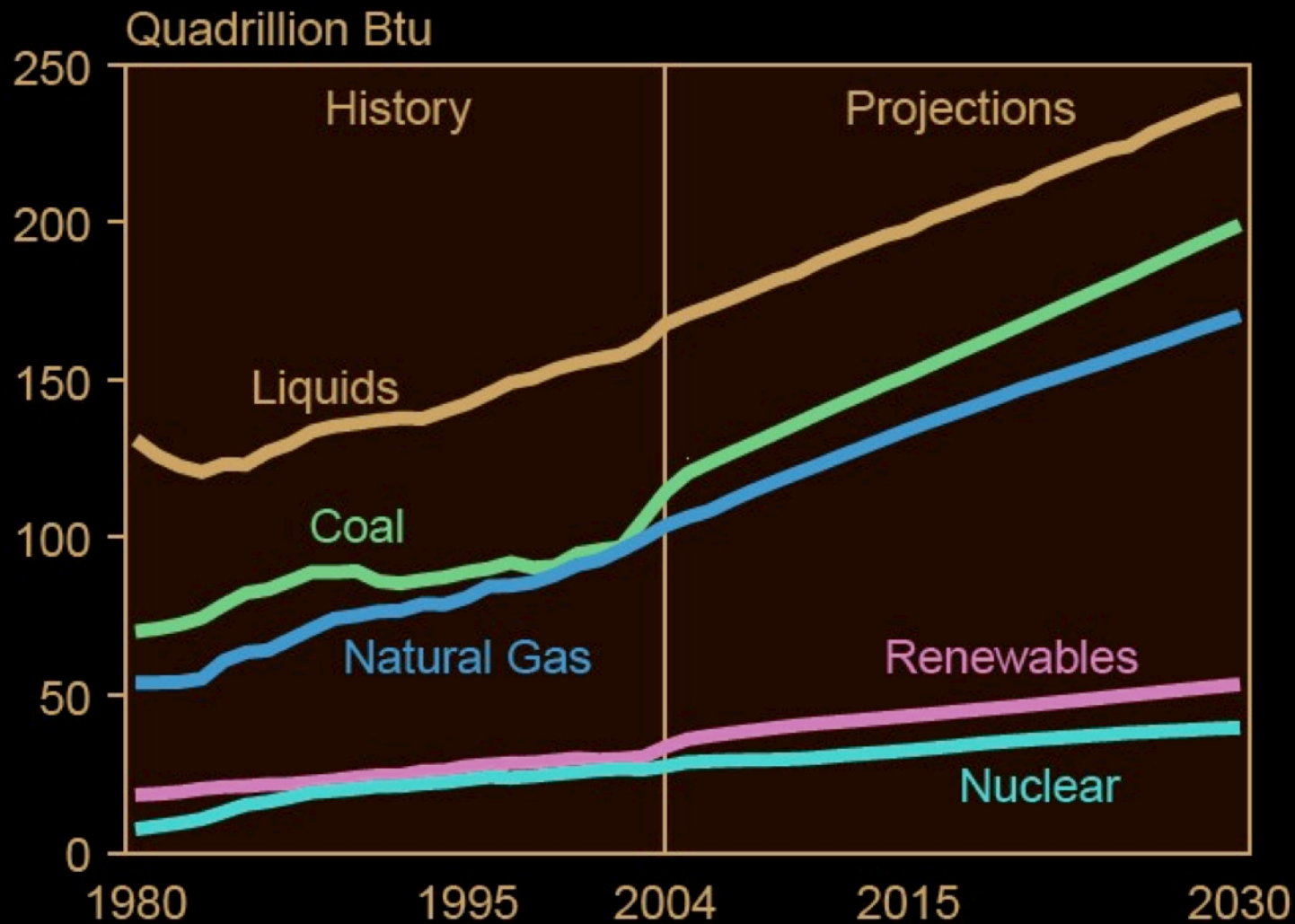


Sustainable energy – without the hot air

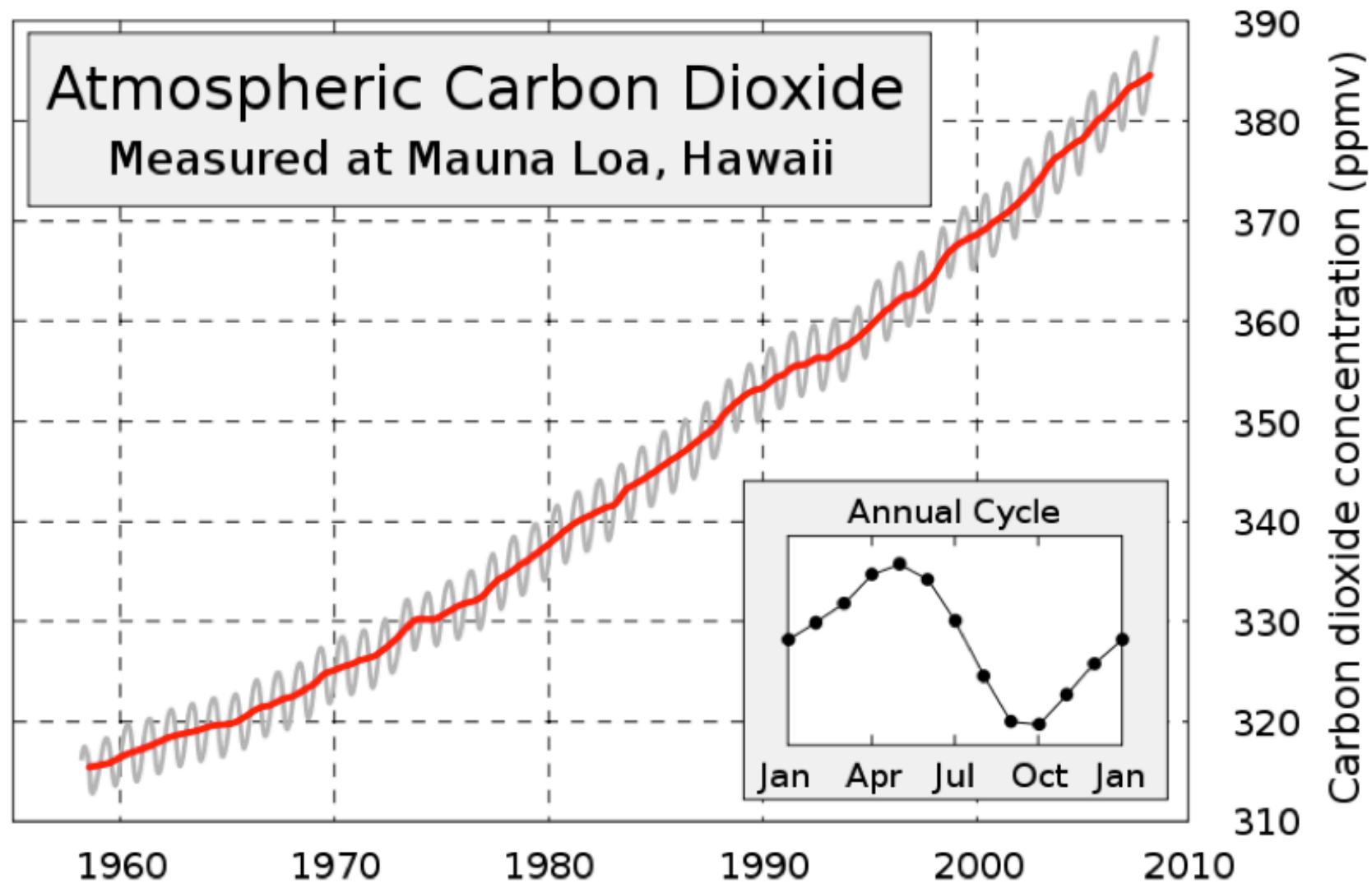


World Marketed Energy Use by Fuel Type, 1980-2030

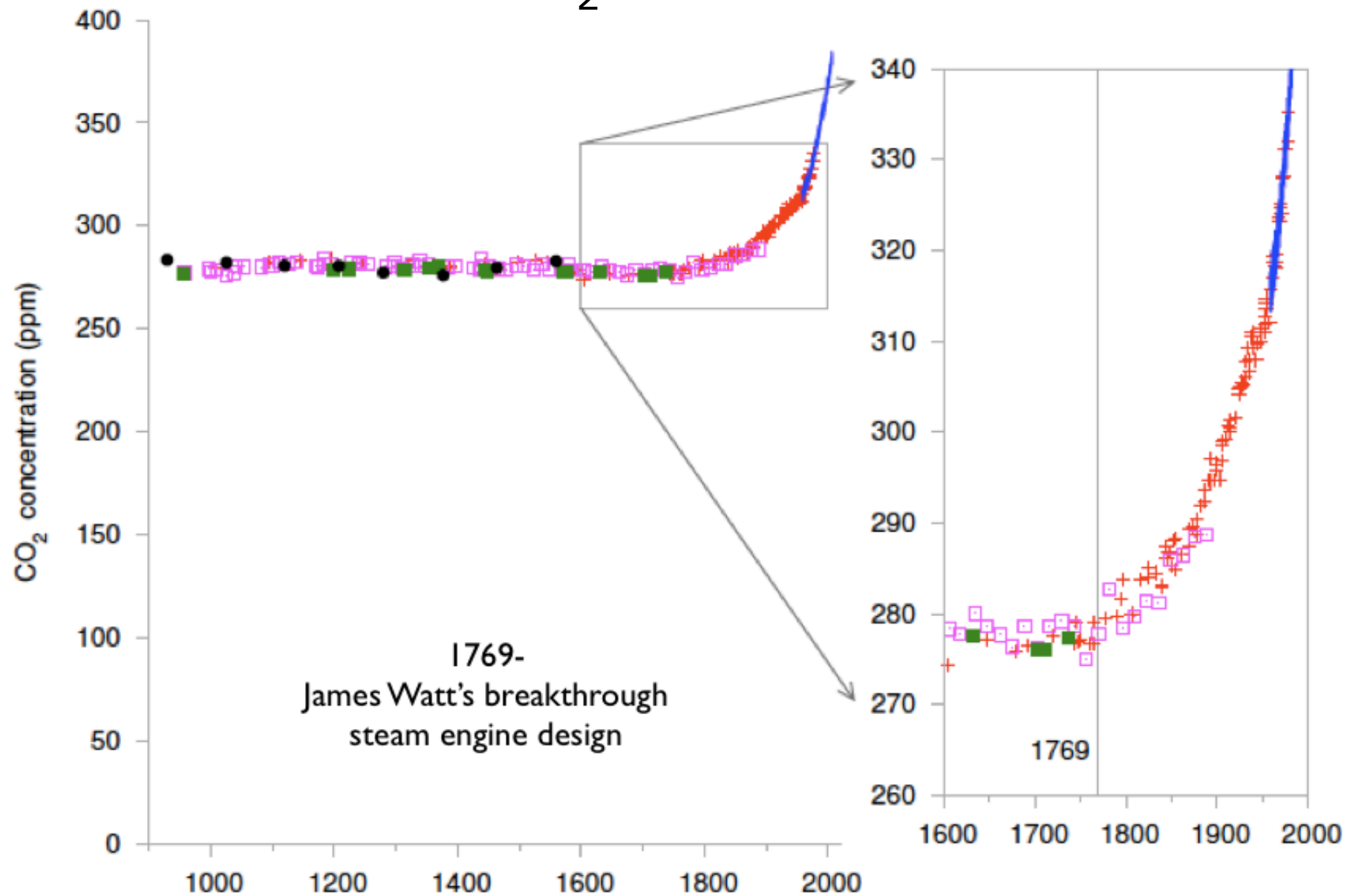


- Aumento CO₂? Colpa nostra?
- Cambiamenti climatici?
- Possiamo adattarci? Possiamo rimediare?

The Keeling Curve: CO₂ *is* increasing

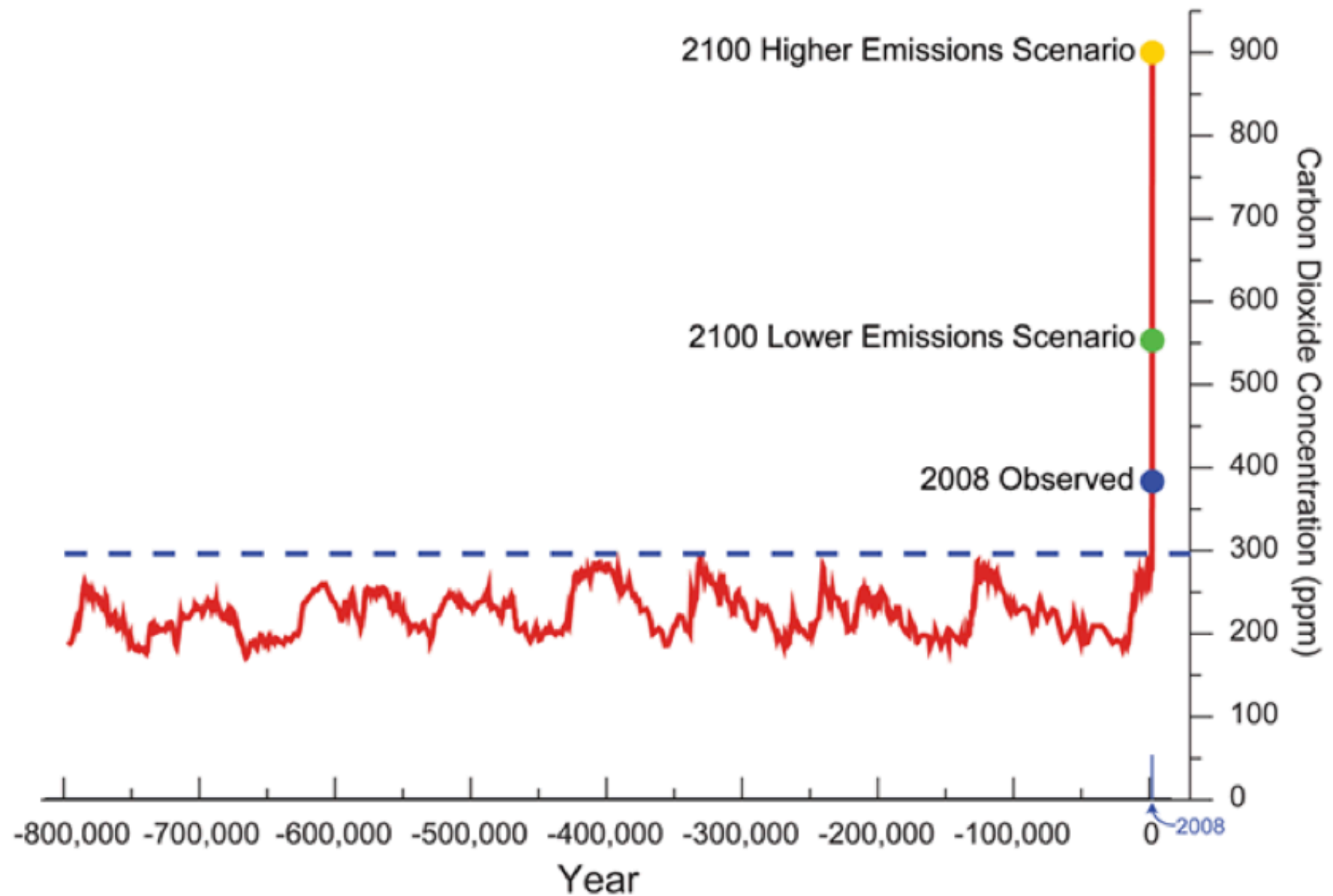


CO₂ atmosferica

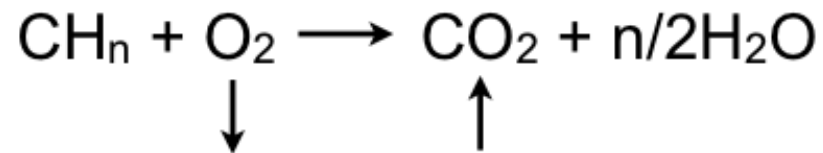


from "Sustainable Energy Without the Hot Air, David Mackay

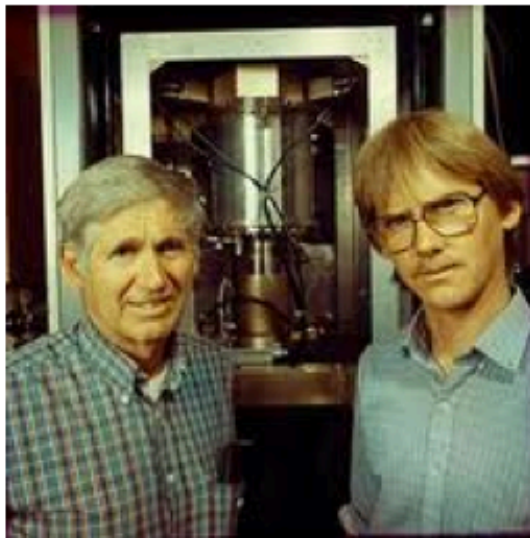
Atmospheric CO₂ over 800,000 years



The second Keeling curve: Oxygen decrease

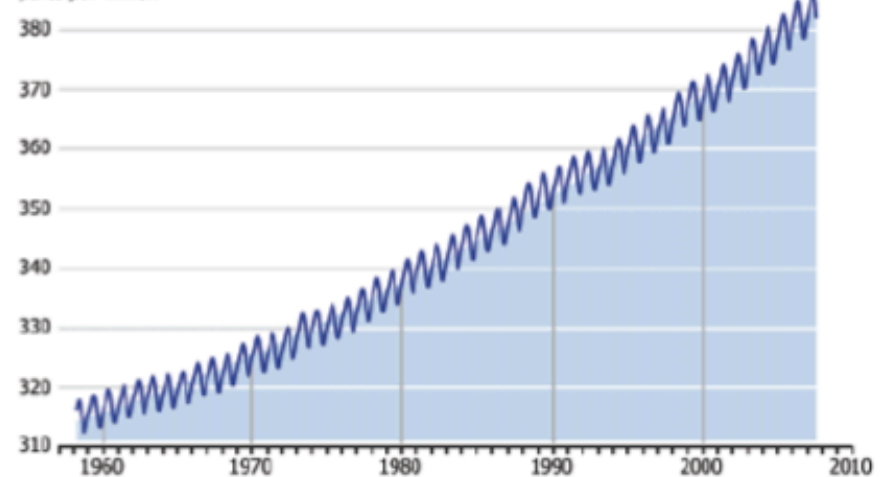


If CO₂ is increasing,
then O₂ must be decreasing,
and *it is*



Monthly Carbon Dioxide Concentration

parts per million

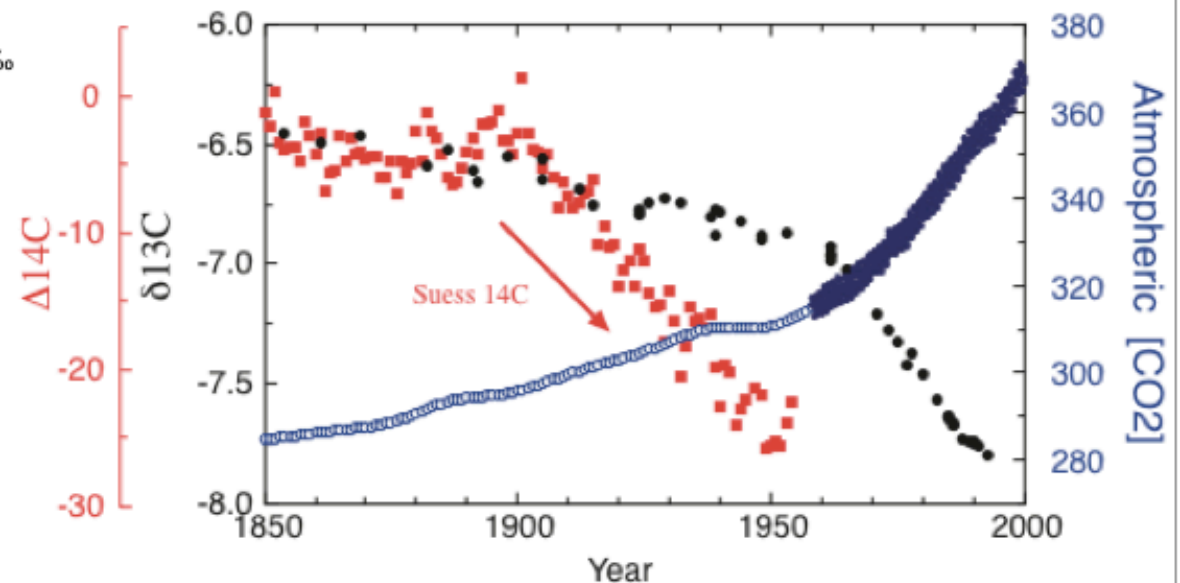
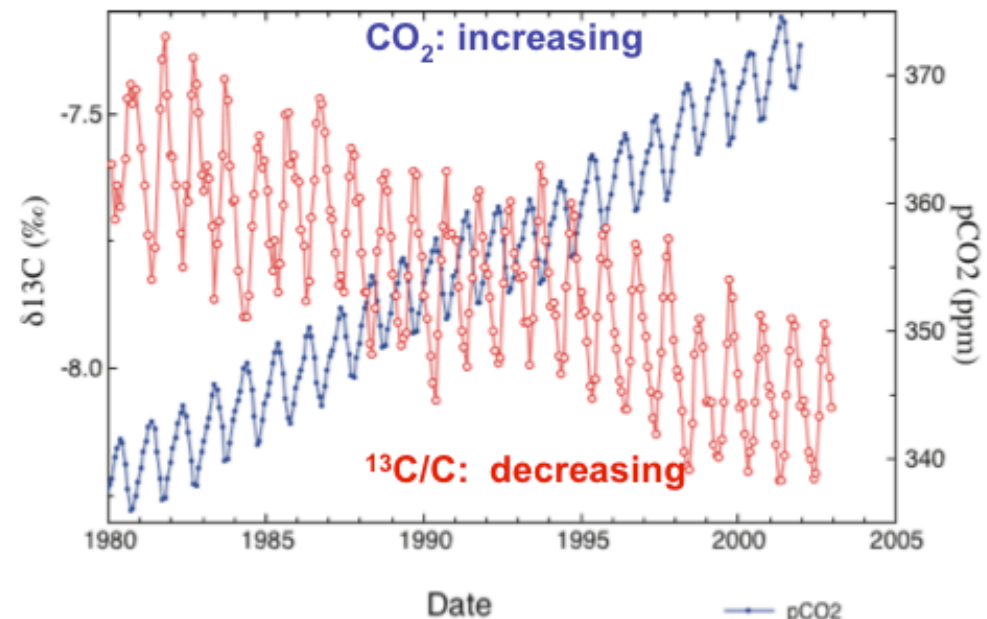
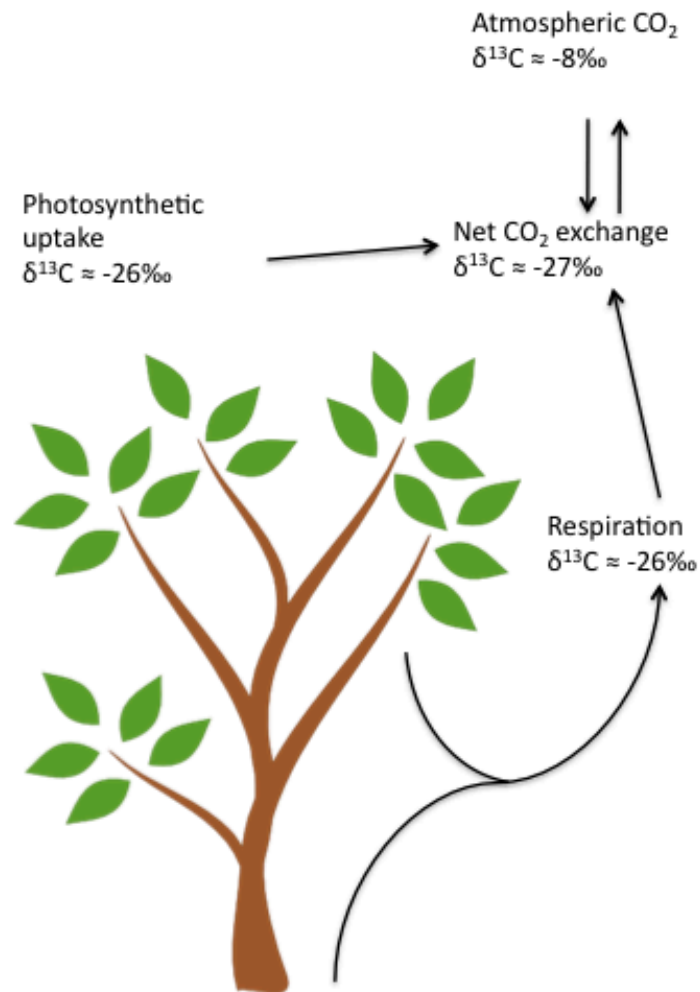


Keeling RF Nature 1996

Scripps Institute "Explorations" Magazine January 2008

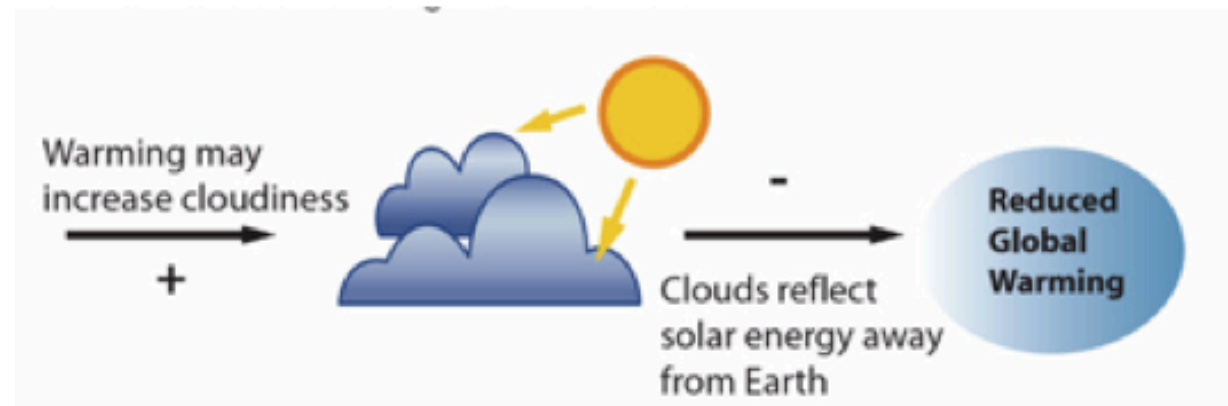
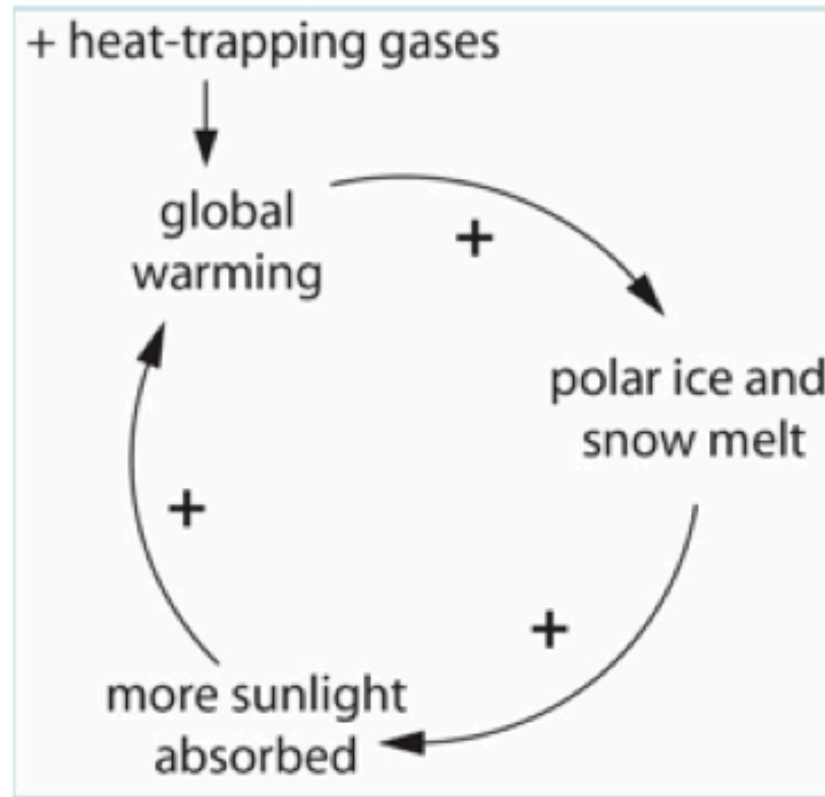
Isotopic enhancement of ^{12}C : a signature of fossil fuel emissions

$$\delta^{13}\text{C}_{\text{sample}} = \left[\left(\frac{^{13}\text{C}/^{12}\text{C}_{\text{sample}}}{^{13}\text{C}/^{12}\text{C}_{\text{standard}}} \right) - 1 \right] \times 1000$$



see for instance, Ghosh and Brand, International Journal of Mass Spectrometry (2003) vol. 228 pp. 1-33

Feedback



Trasmissione del calore: irraggiamento

Stefan-Boltzmann

$$P_r = \sigma \varepsilon A T^4 \qquad \sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

$$P_a = \sigma \varepsilon A T_{amb}^4$$

$$P_{net} = \sigma \varepsilon A (T_{amb}^4 - T^4)$$

Effetto serra

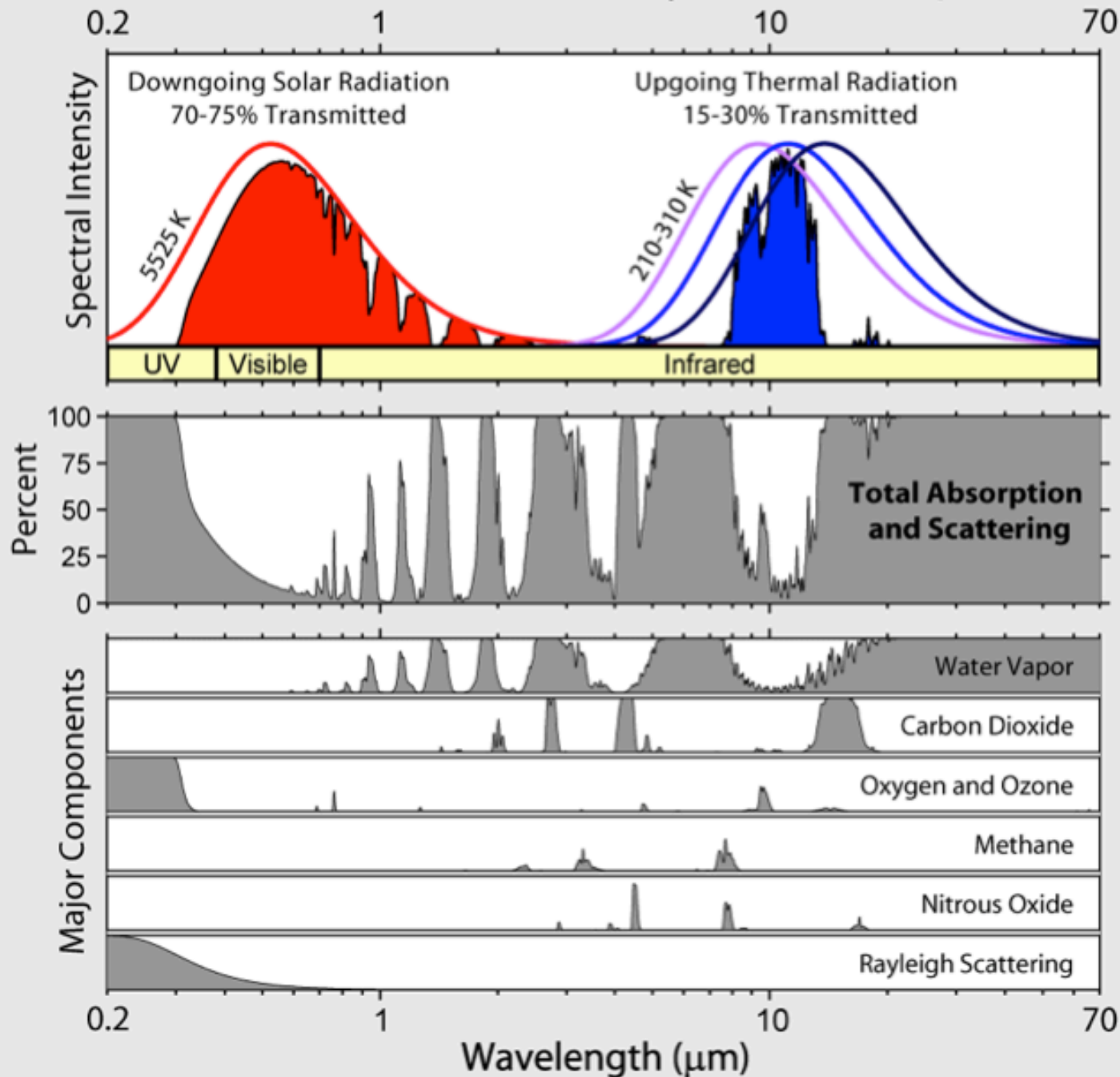
$$P_r = \sigma \varepsilon A T^4 = P_{sun} \qquad \sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

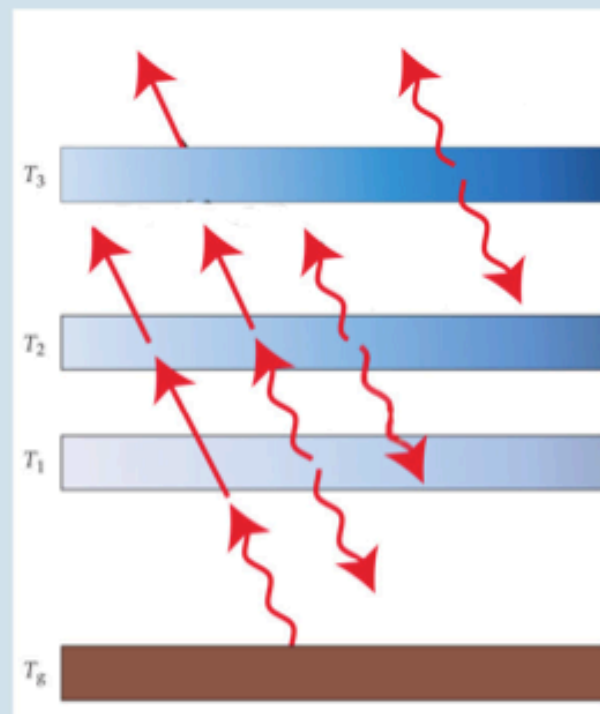
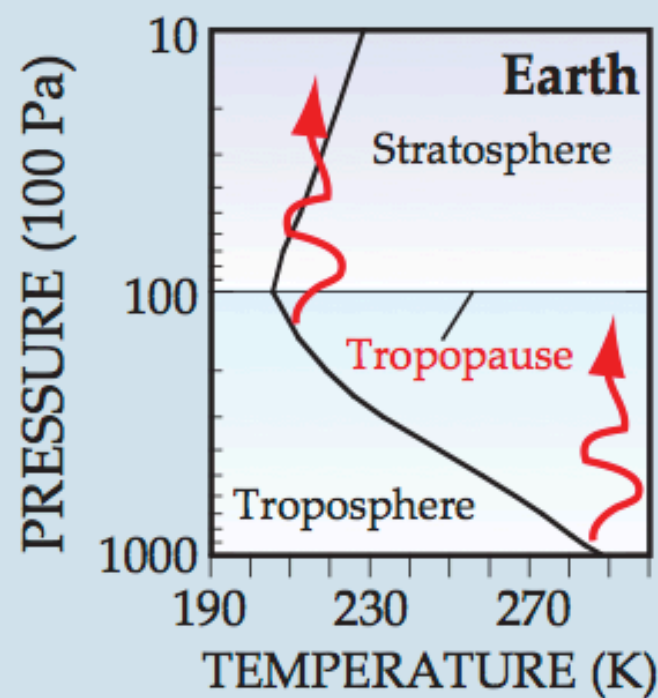
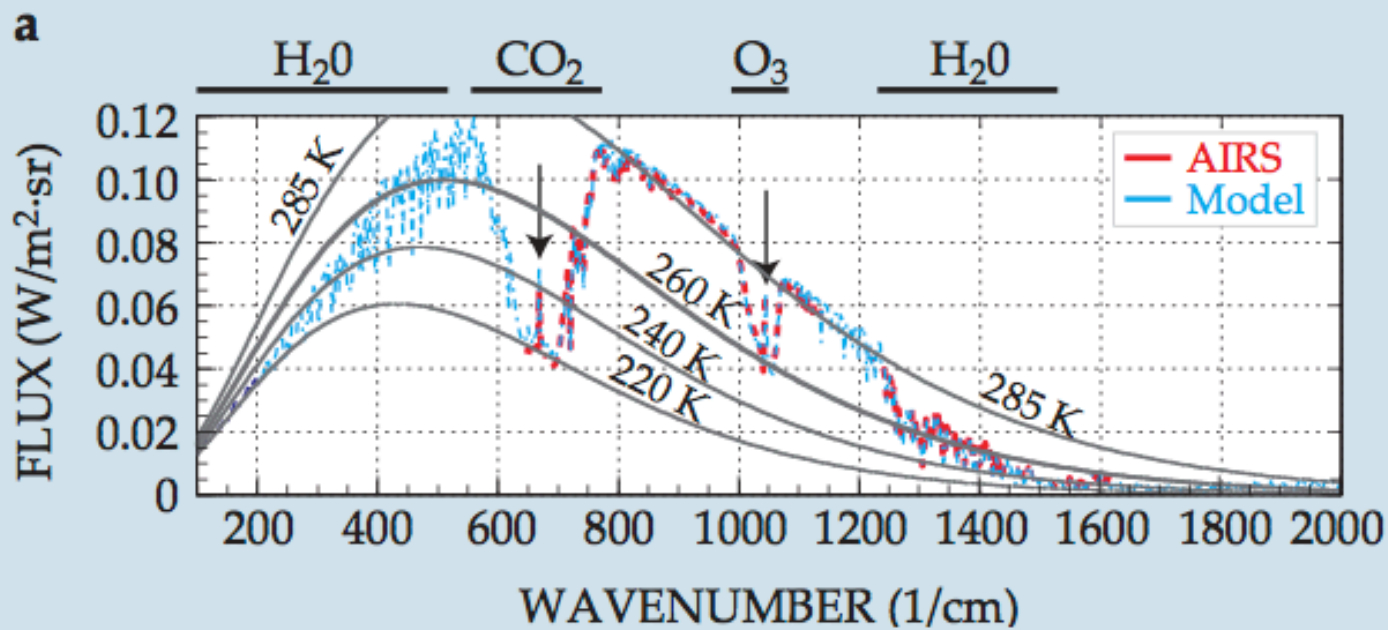
$$T = \sqrt[4]{\frac{P_{sun}}{\sigma \varepsilon A}}$$

$$\frac{P_{sun}}{A} = 250 \frac{W}{m^2}$$

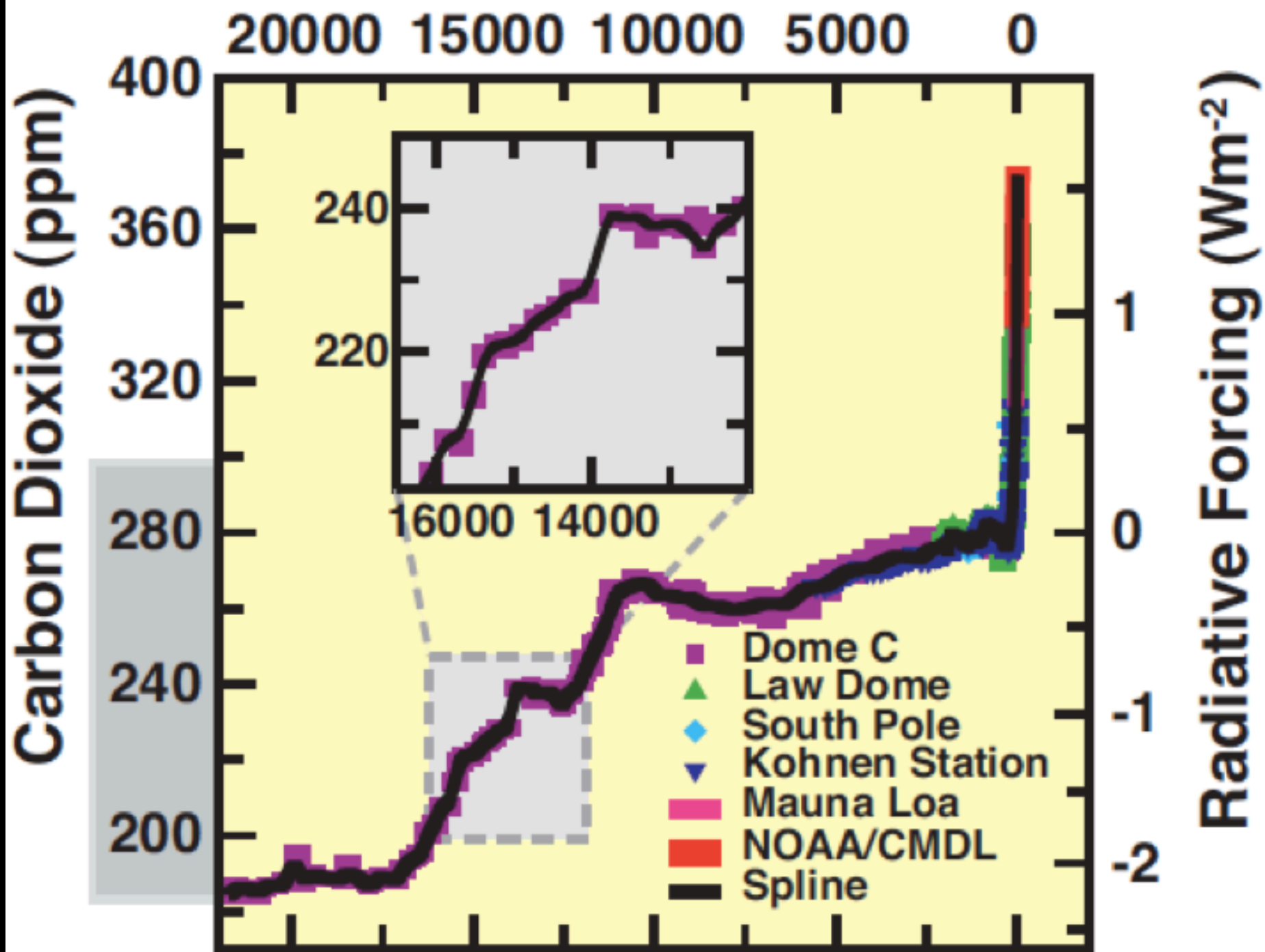
$$T = \sqrt[4]{\frac{P_{sun}}{\sigma \varepsilon A}} = \sqrt[4]{\frac{250 \frac{W}{m^2}}{\varepsilon \times 5.67 \times 10^{-8} \frac{W}{m^2 K^4}}} = \begin{cases} \varepsilon = 1 \rightarrow 258K (-15C) \\ \varepsilon = 0.6 \rightarrow 293K (20C) \end{cases}$$

Radiation Transmitted by the Atmosphere

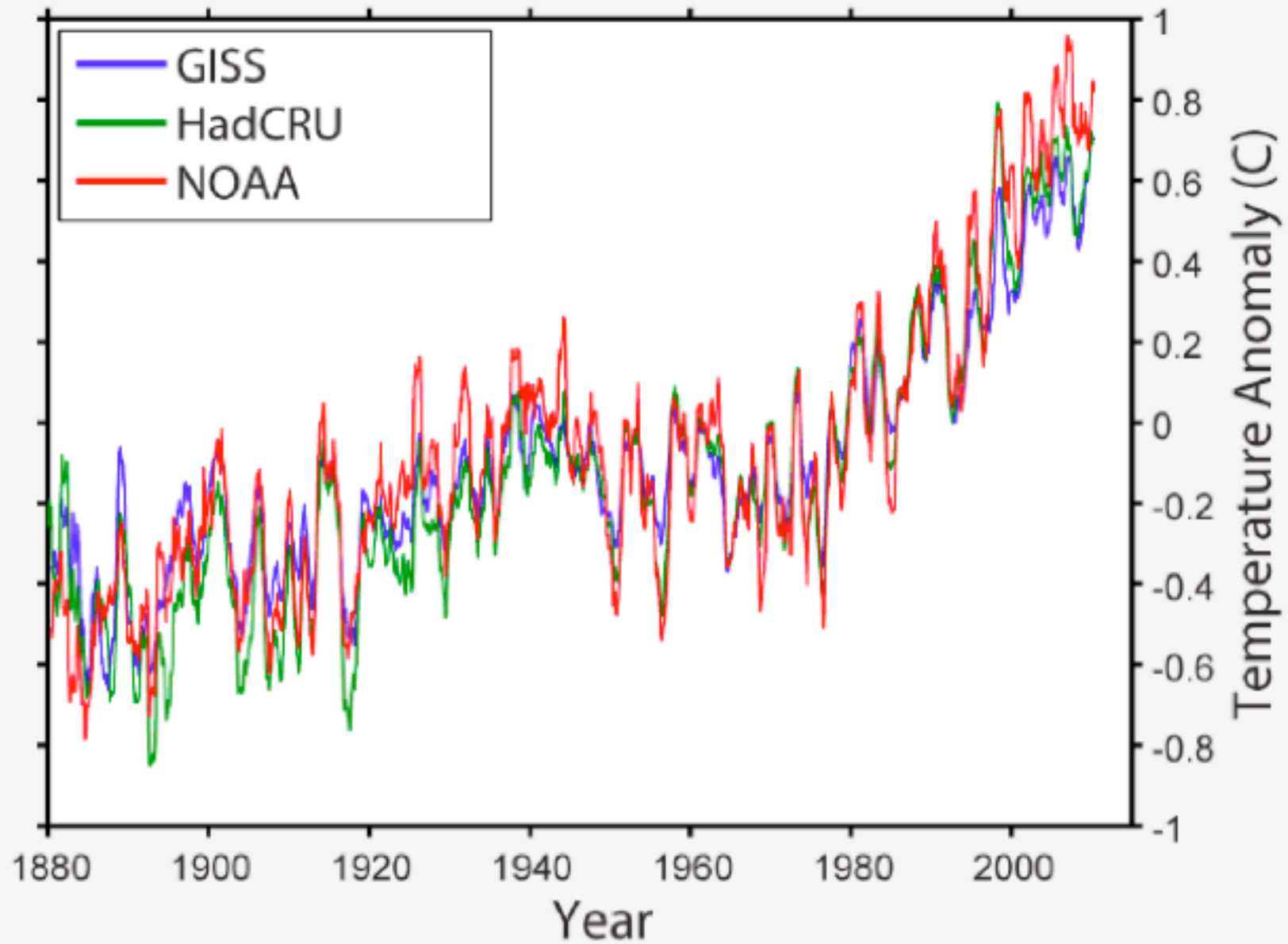




from R. T. Pierrehumbert, Physics Today, January 2011



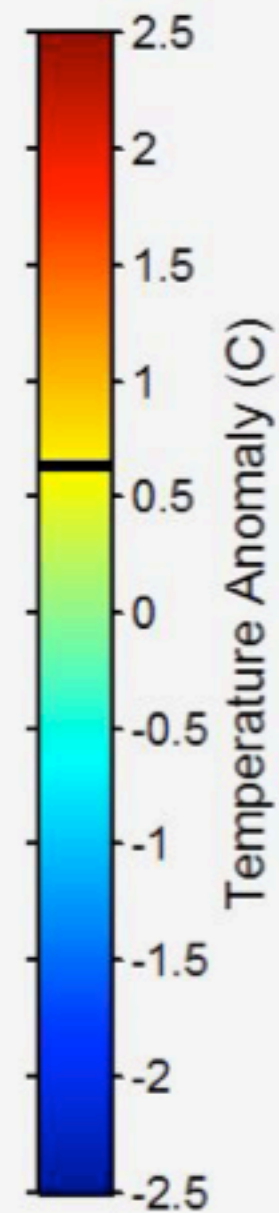
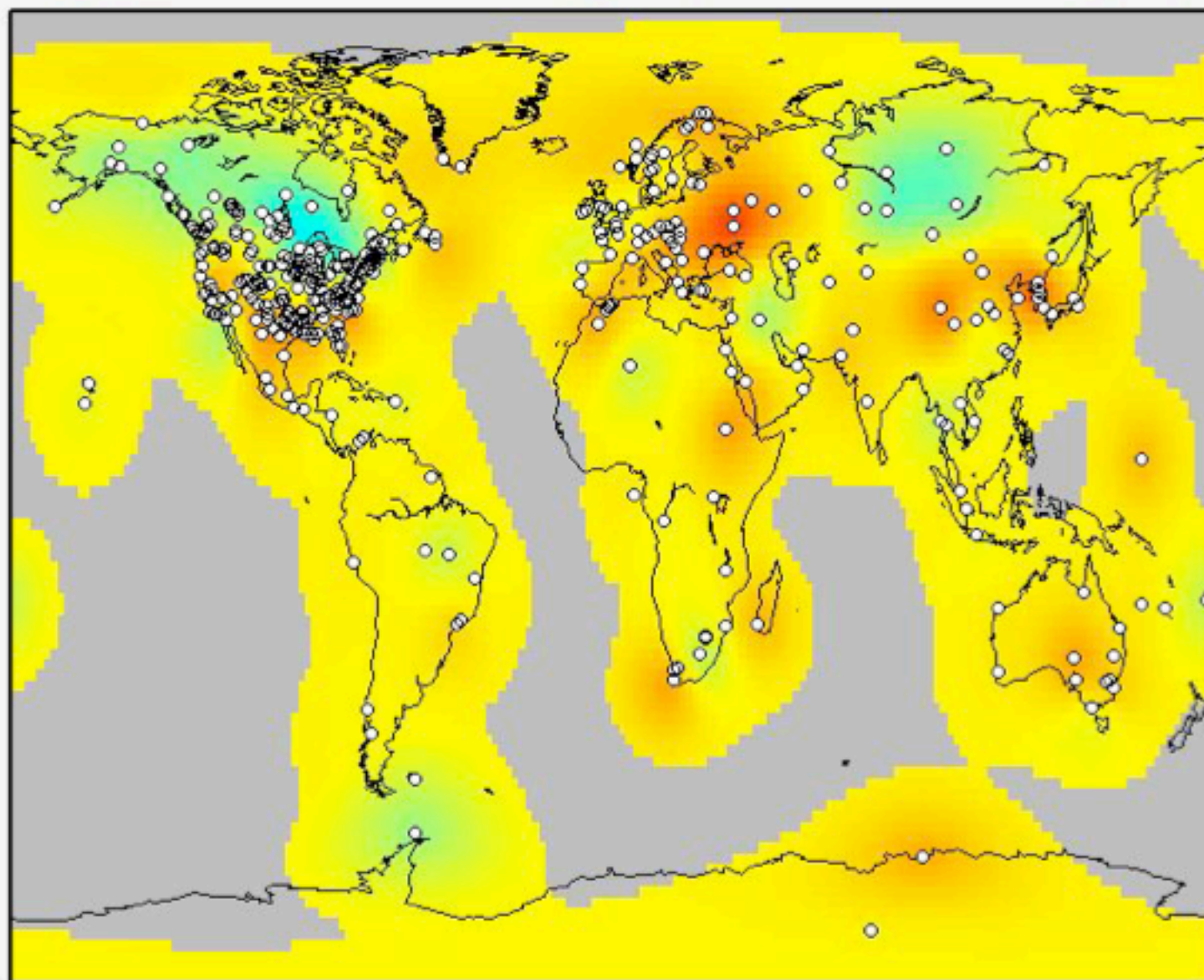
Land Temperature Average

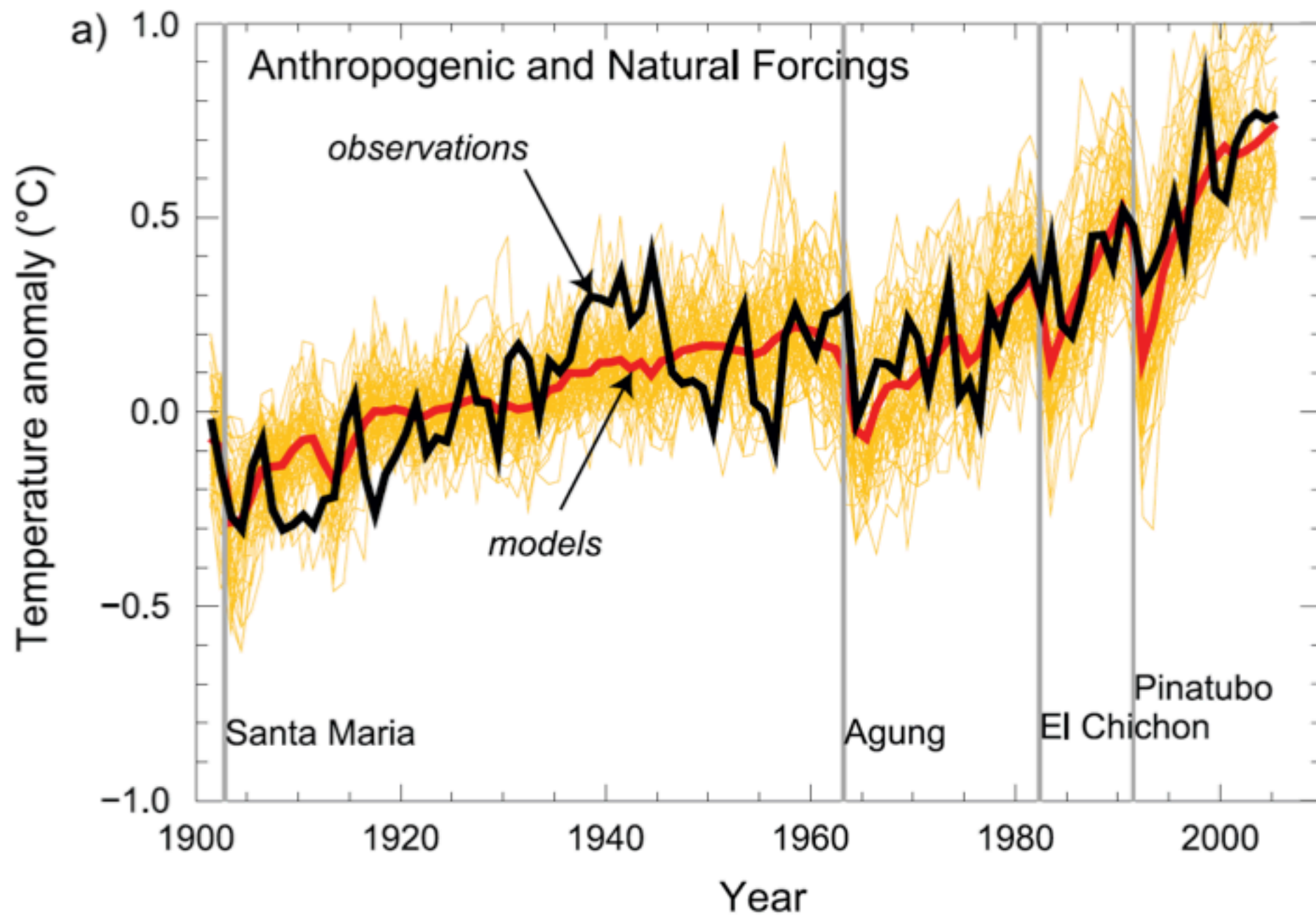


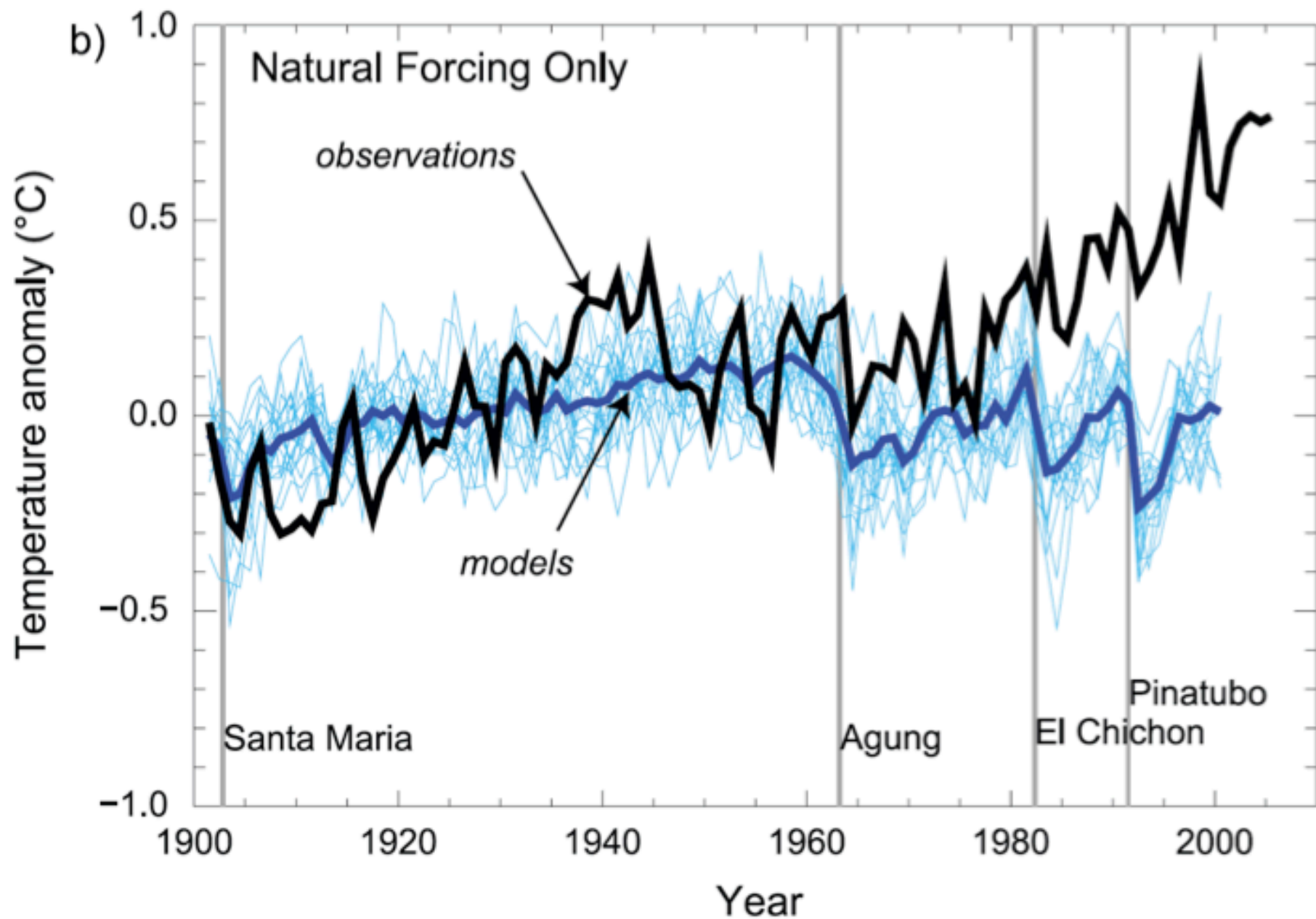
333.08

2009.4167

0.64 C

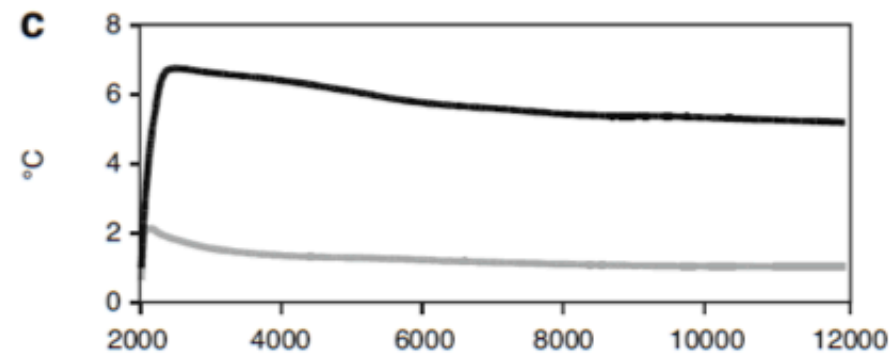
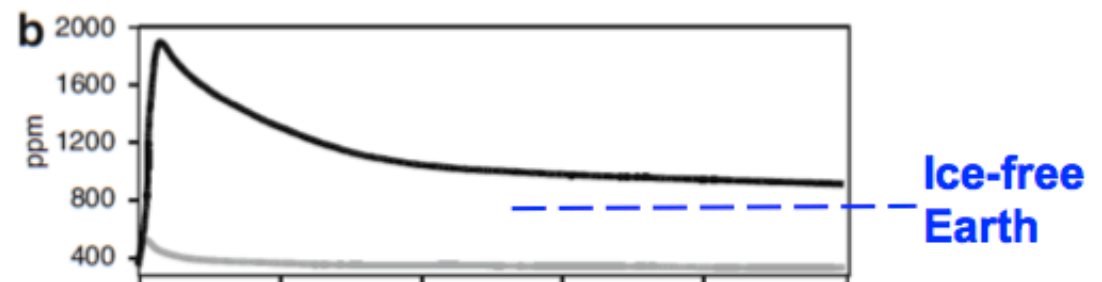
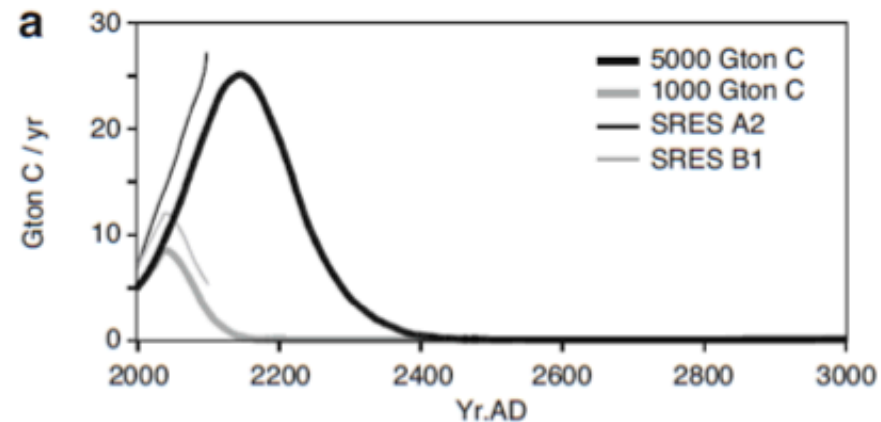
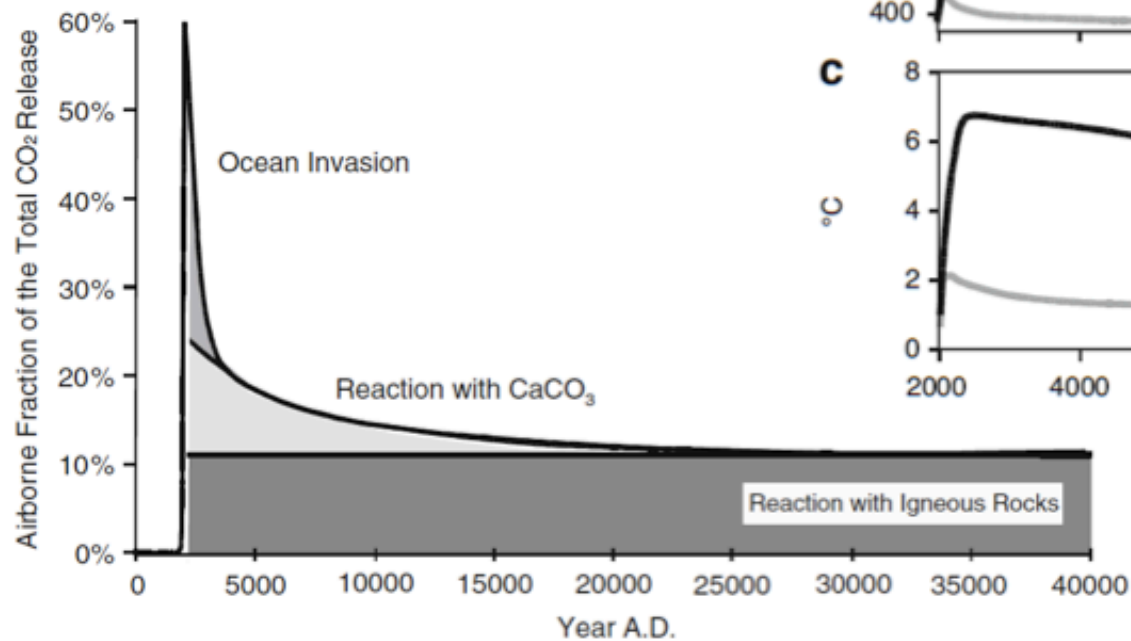






Best case:
1000Gt CO₂ emitted

Worst case:
5000Gt CO₂ emitted



Archer & Brovkin, 2007

Muir Glacier, Alaska

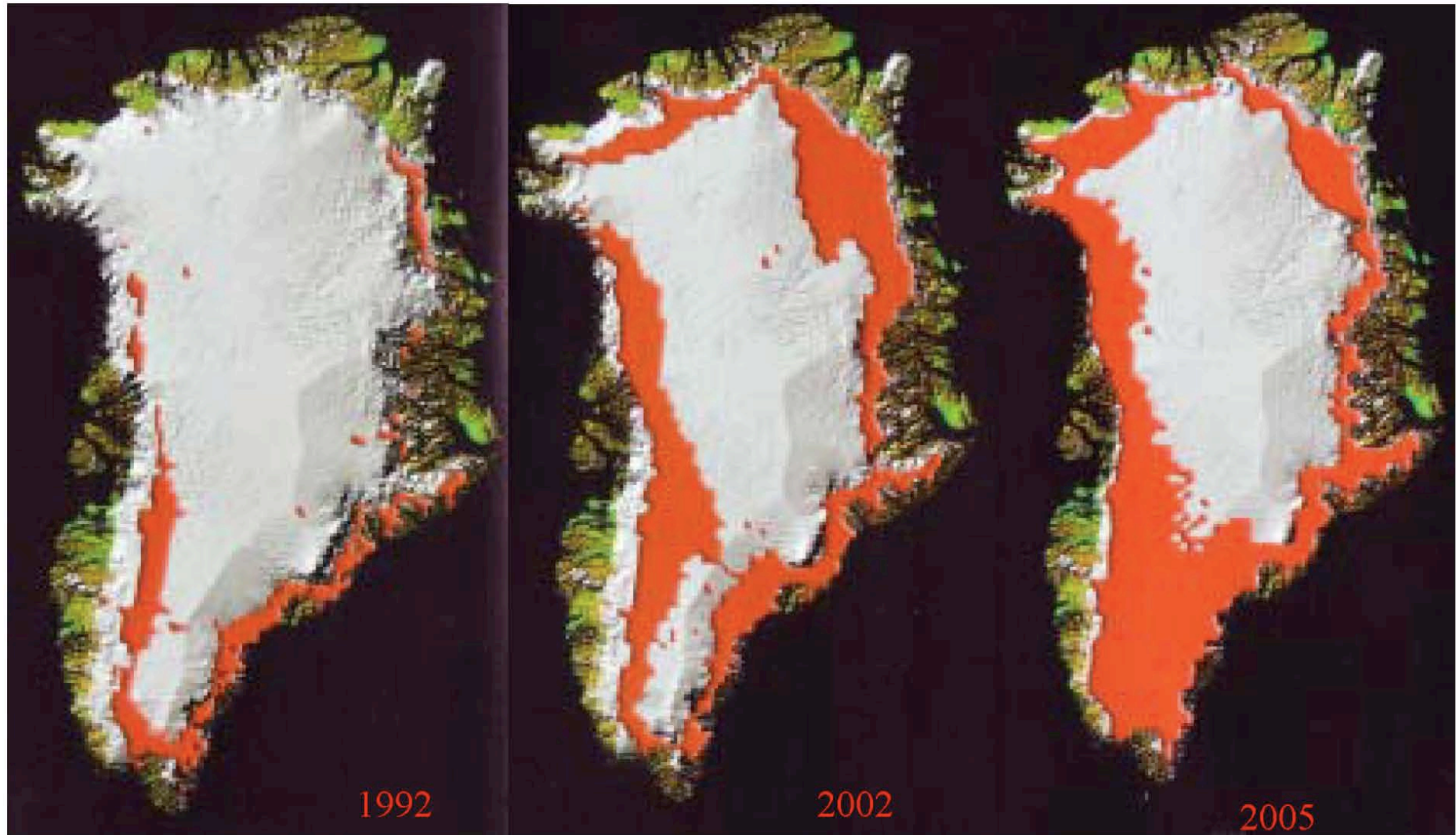
August 1941



August 2004

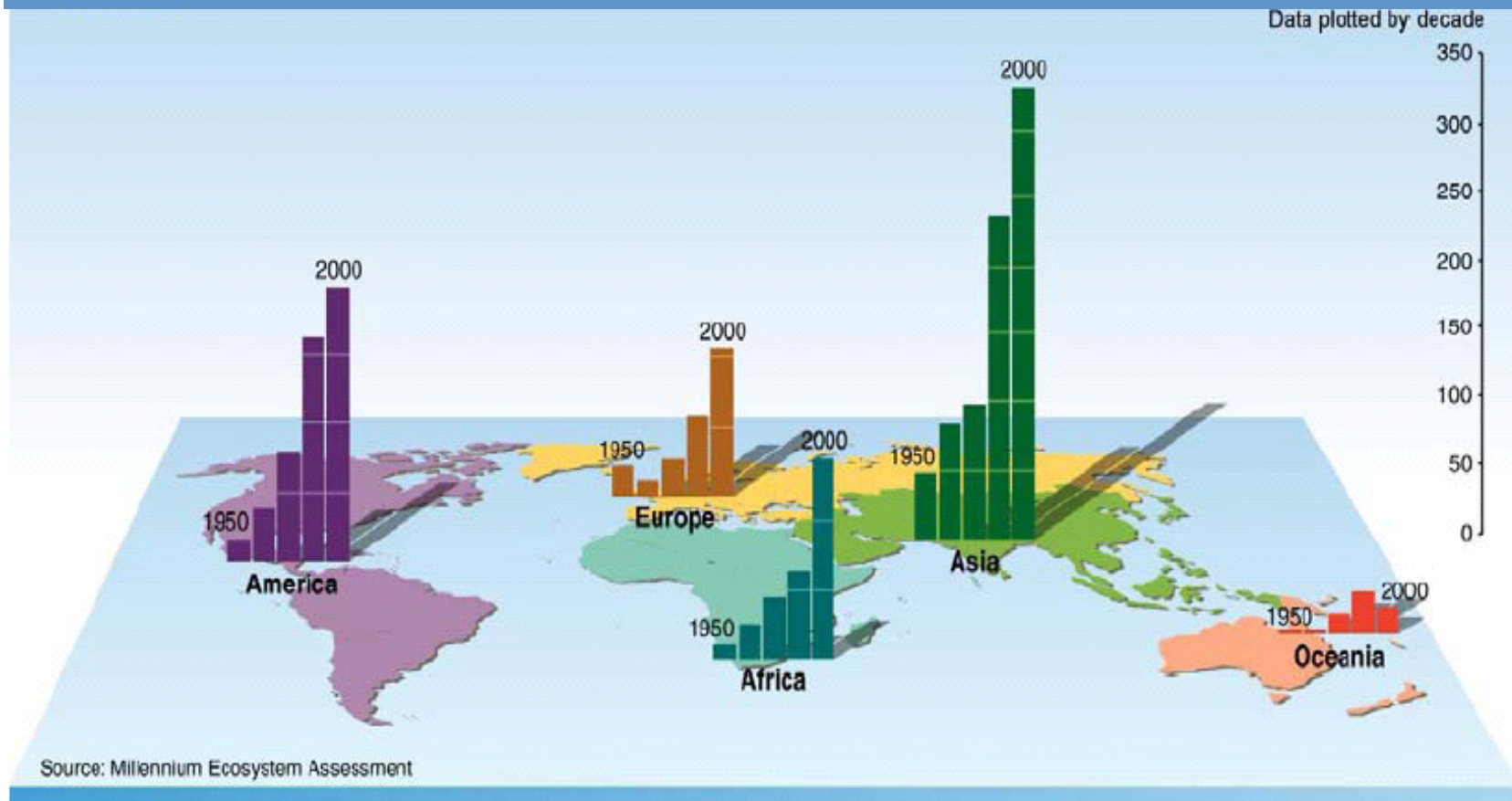


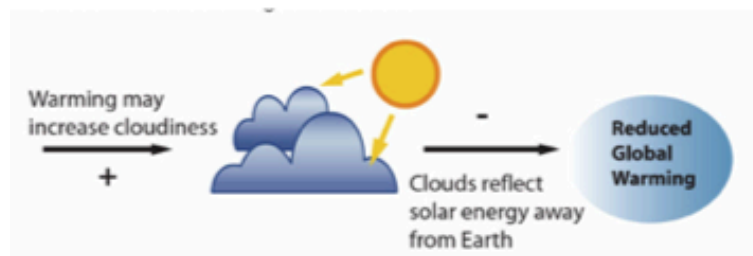
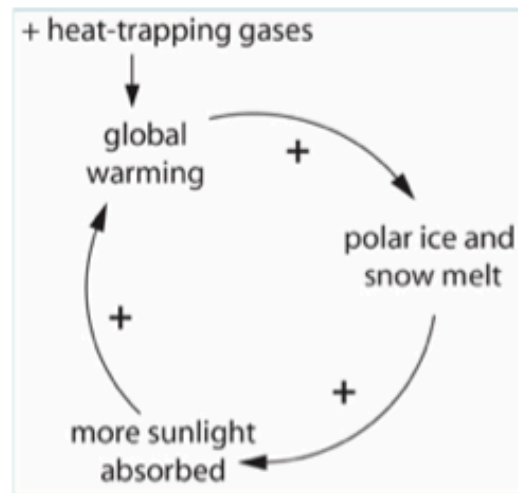
Surface melting on Greenland is expanding



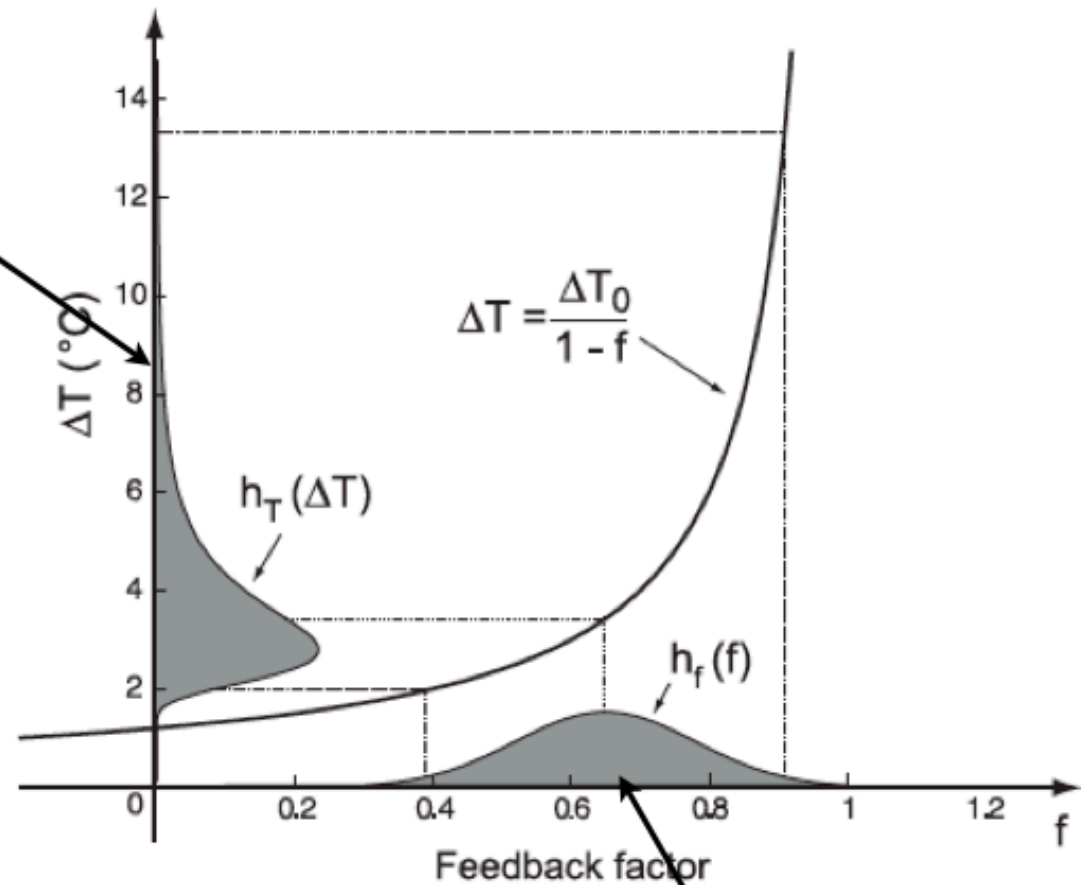


Major floods per decade, 1950-2000



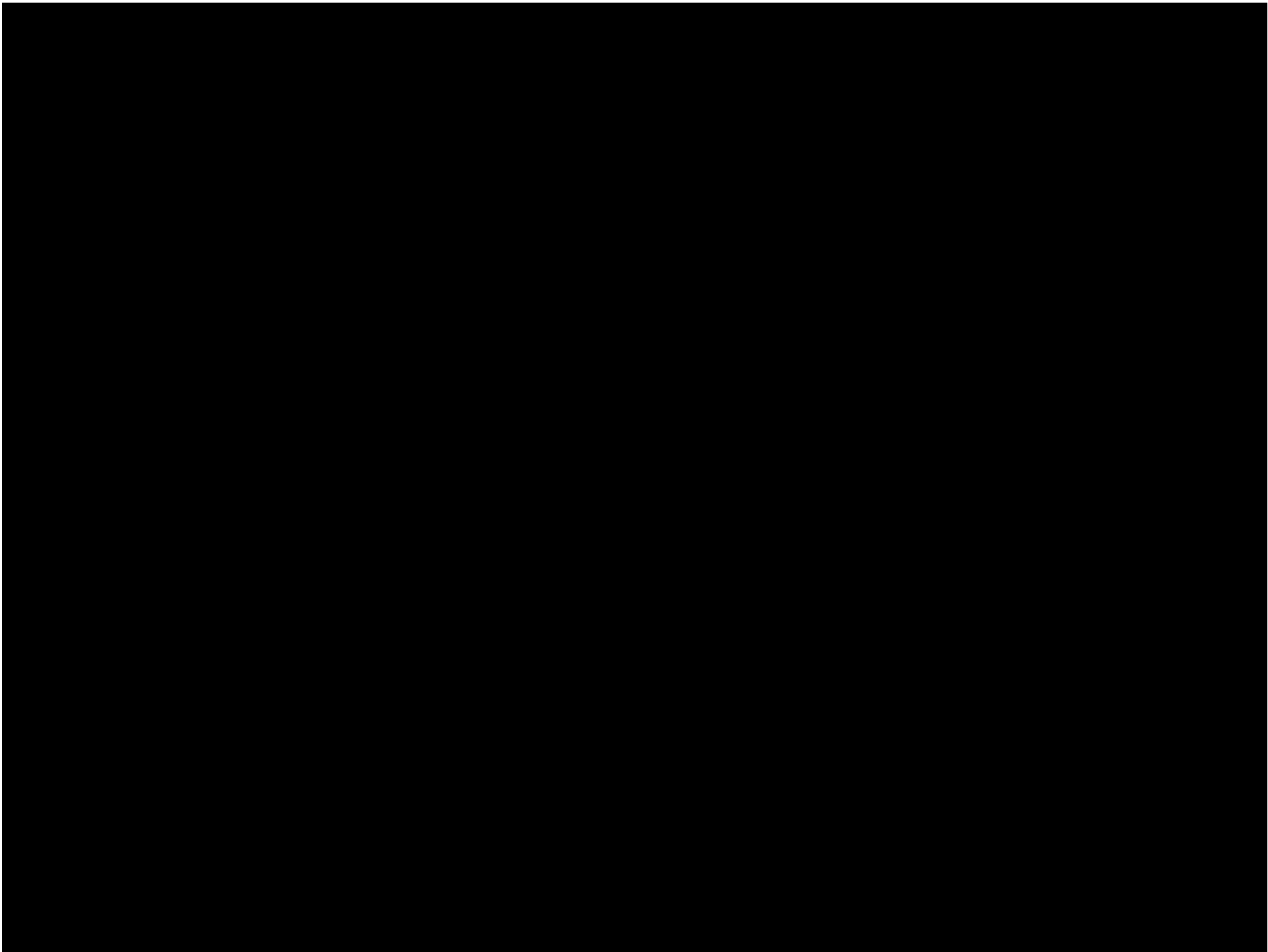


long tail

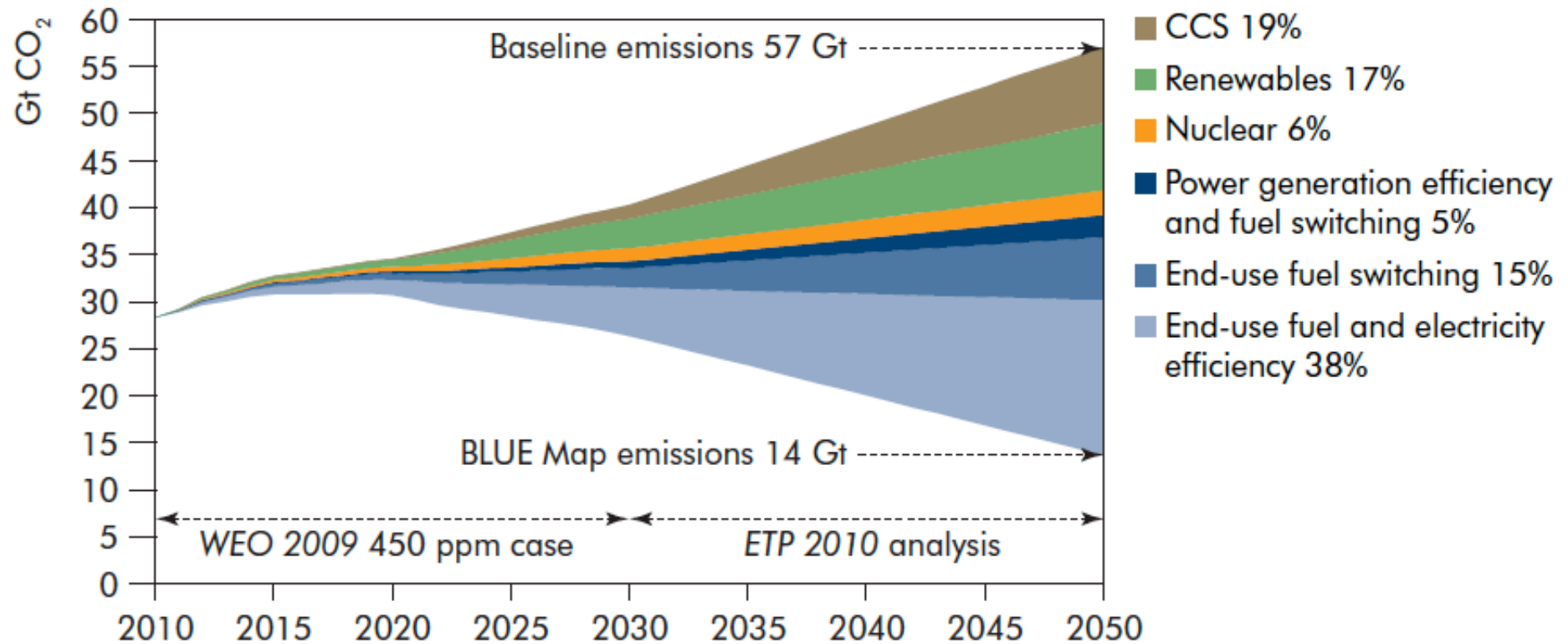


normal distribution

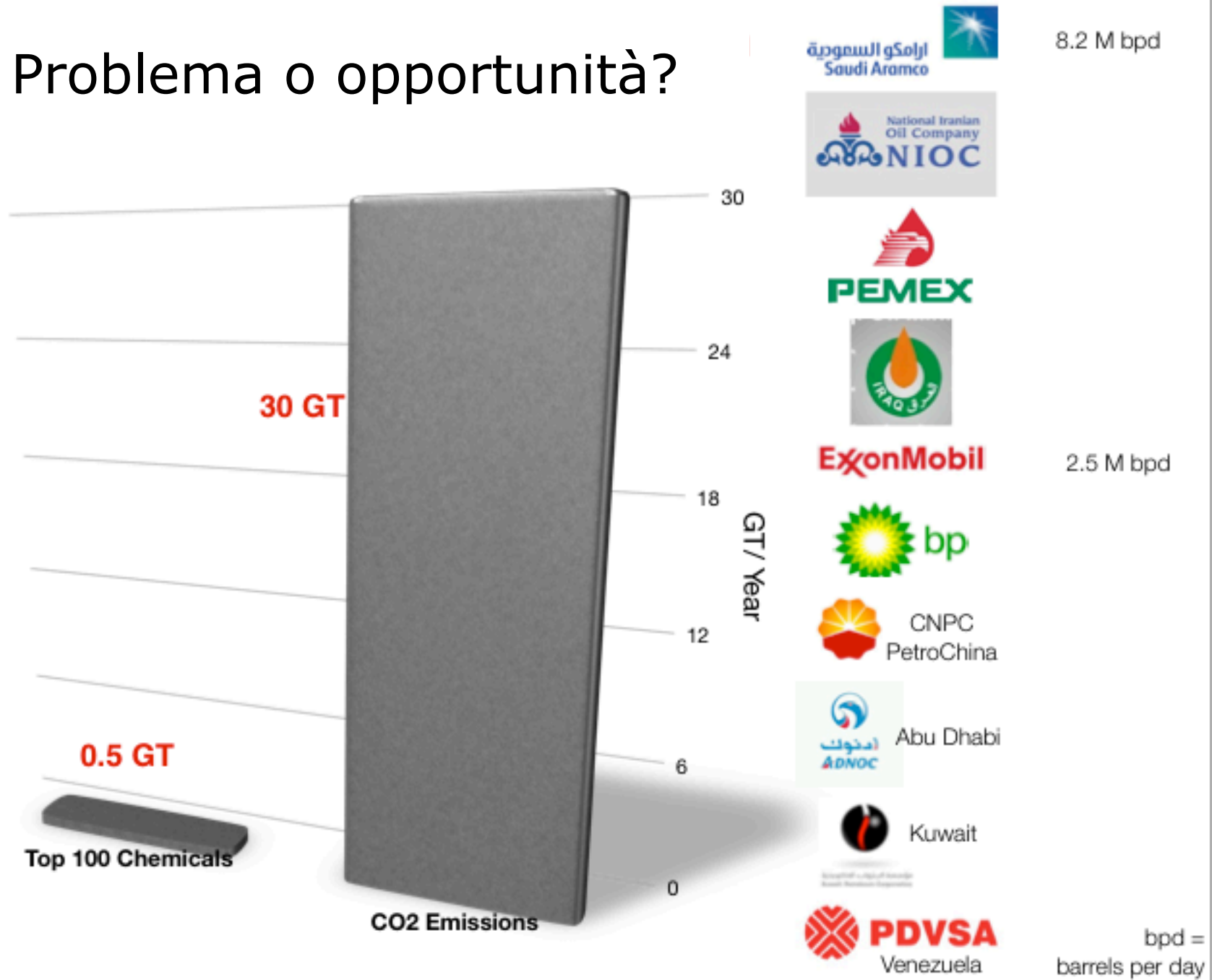
"Why is climate sensitivity so unpredictable?", Roe and Baker, *Science* **318**, 629 (2007)



Possibili soluzioni

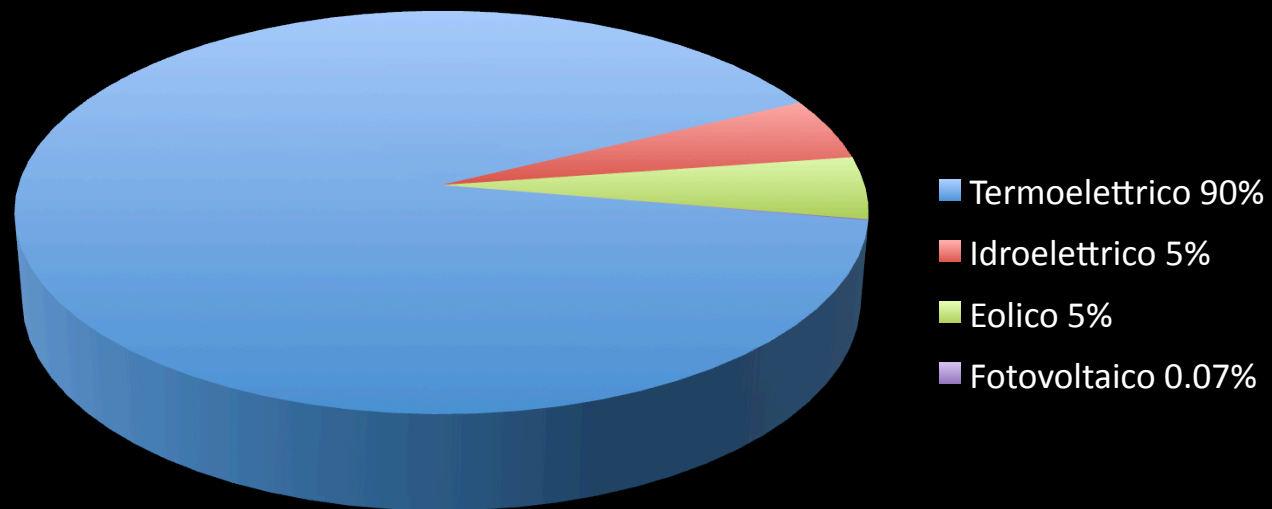


Problema o opportunità?

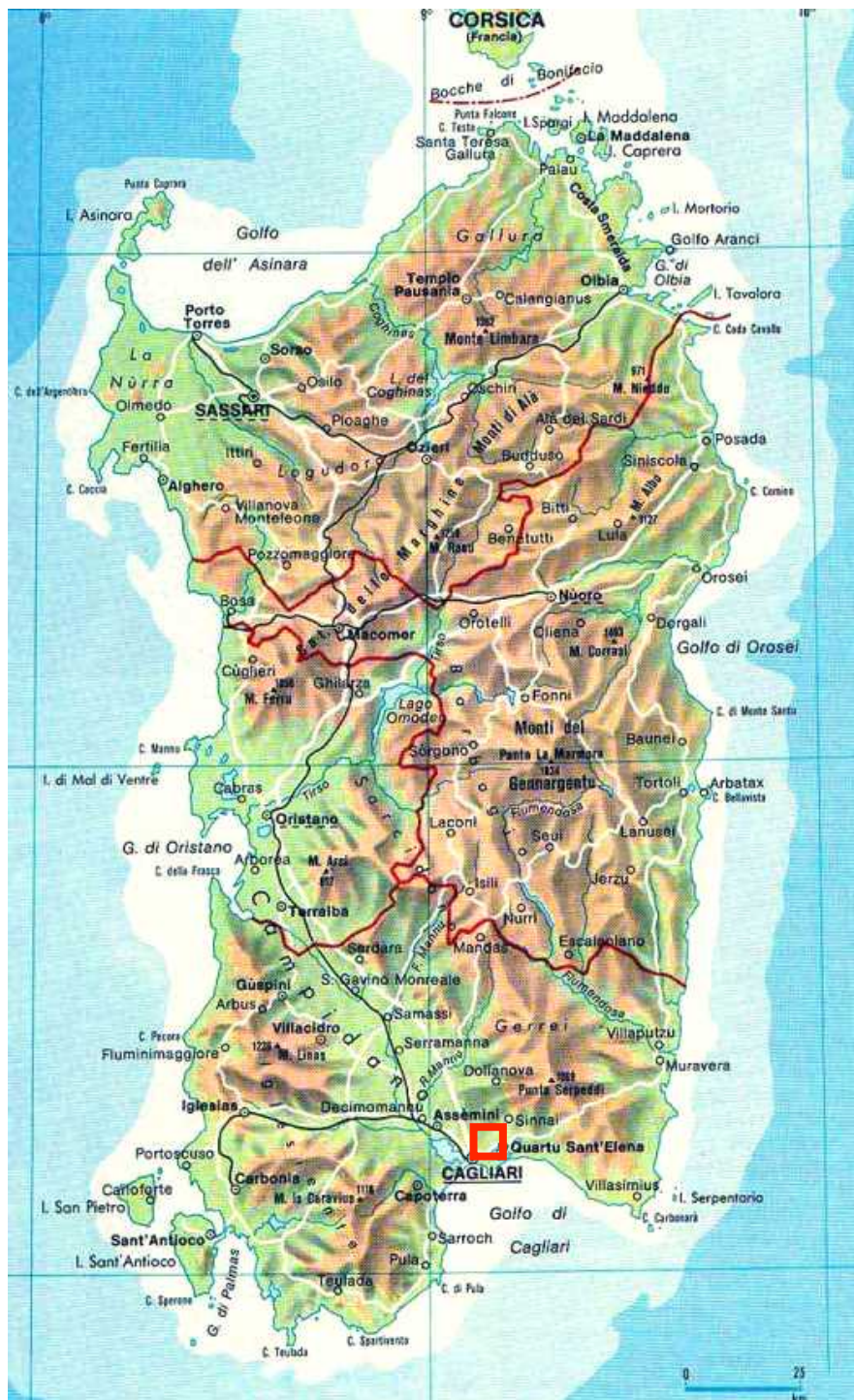


Produzione energetica in Sardegna

(potenza elettrica media 1.5GW)



2008



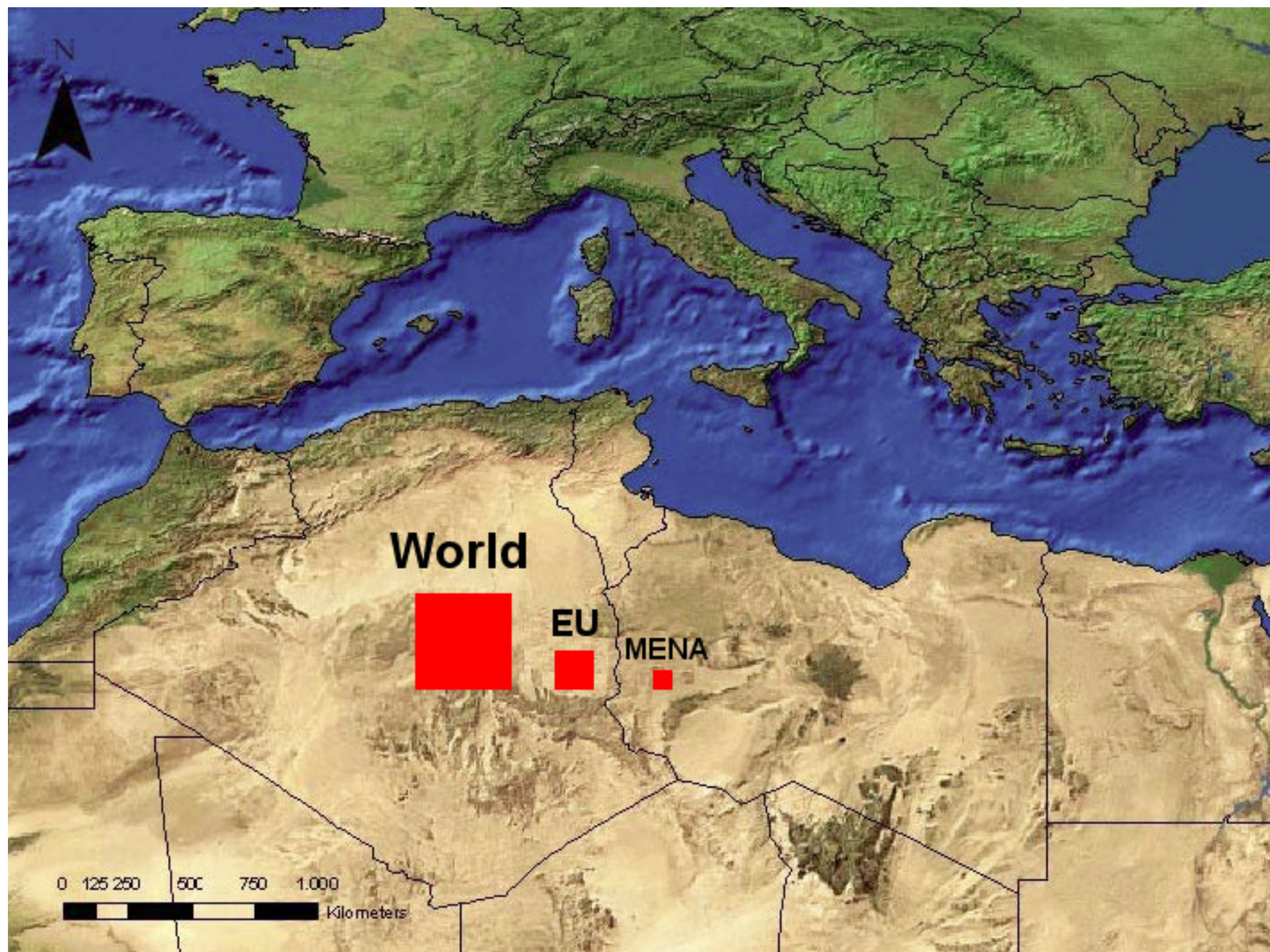
Fabbisogno = 1.5 GW
($\approx 1000 \text{ W/ab}$)

Intensità max del Sole: 1000 W/m^2
Intensità media del Sole: 250 W/m^2

Potenza media cella solare
= $250 \text{ W/m}^2 \times 0.10 = 25 \text{ W/m}^2$

Area necessaria =
fabbisogno/potenza media cella

= 60 km^2 ($8 \text{ km} \times 8 \text{ km}$, $\approx 40 \text{ m}^2/\text{ab}$)

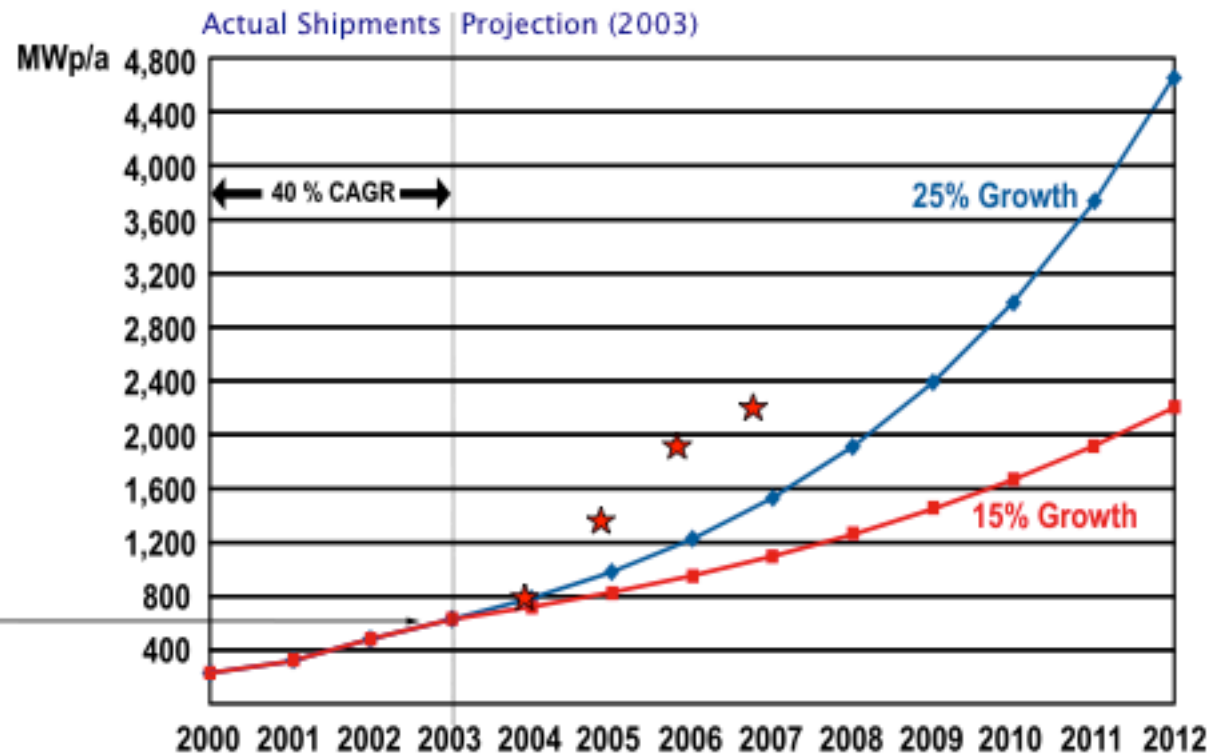


Opportunity Example: worldwide growth of photovoltaics

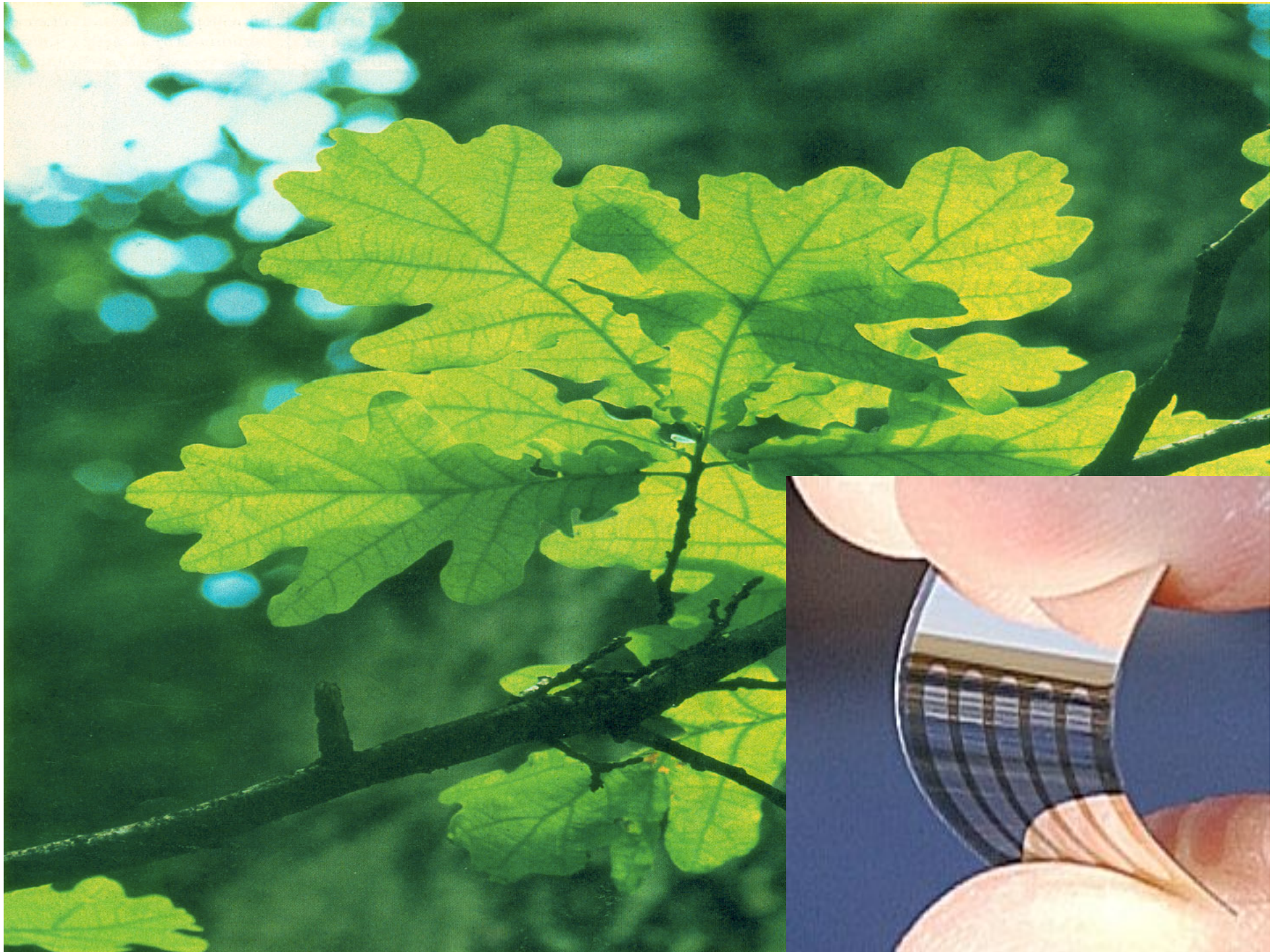
2010: > 10 GW_p
Now estimated at 15 GW (@~\$4/W)

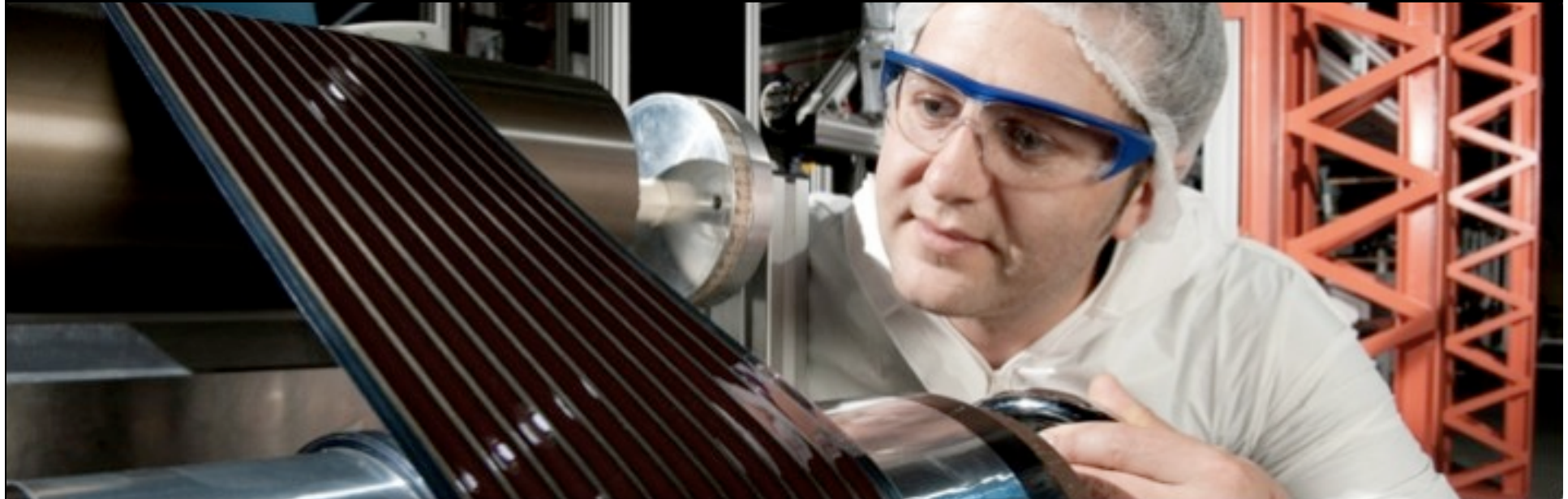
2009: 6,43 GW_p

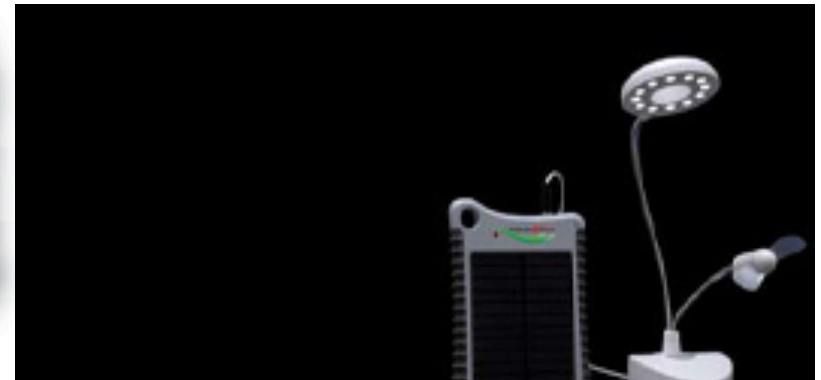
2003: 600 MW_p



Courtesy Eicke Weber, Fraunhofer Institute for Solar Energy
Sources: 2000–2003 Strategies Unlimited, 2006 EPIA "solar generation", 2007 LBBW Report, 2010 SolarBuzz



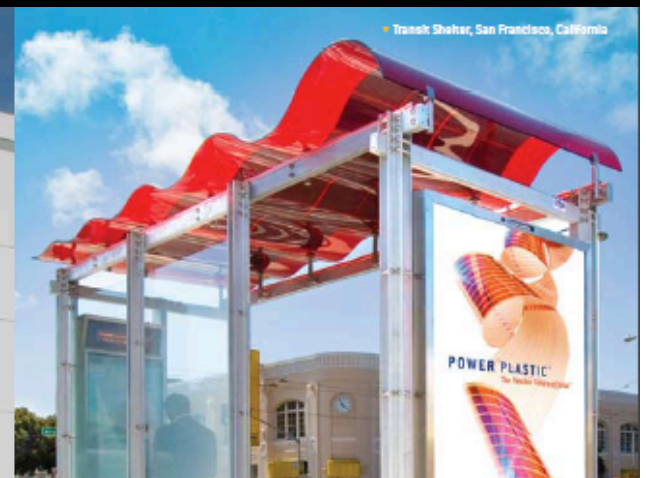




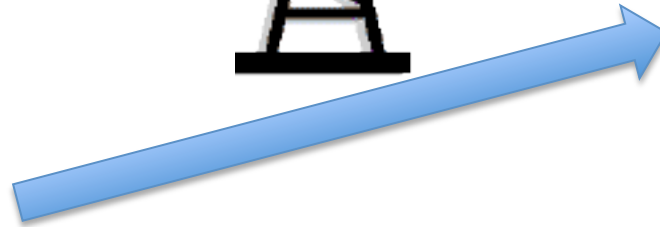
Power Plastic® 3W Solar Charger



Arch Aluminum & Glass Co., Inc.



Transit Shelter, San Francisco, California



Solar Technology Evolution



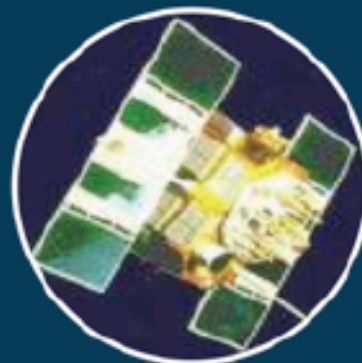
Solar Thermal:

Harness heat
Steam engine
~25 meV



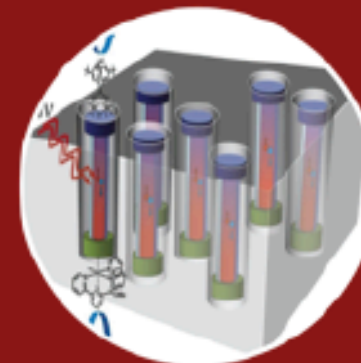
Single Gap Photovoltaic:

Silicon and Thin Film
~1eV
Photoelectric effect
Up to 24% efficiency
\$4-5/W



Multigap cells:

Semiconductor processing
Artificial materials
~Up to 40% efficiency
\$350-1000s\$/W
Concentration?



Solar Fuel:

Artificial
Photosynthesis
Enabled by
nanomaterials

climbing the thermodynamic ladder

Densità energetica

Benzina = 10kWh/l (12kWh/kg)

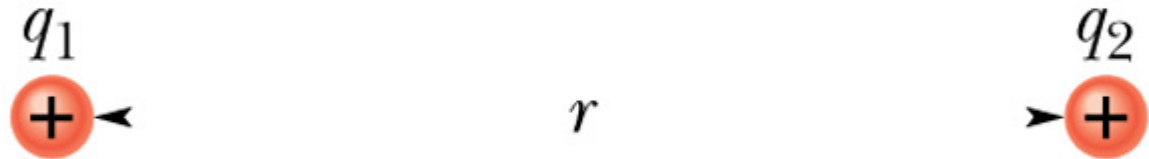
Batterie? = 0.25 – 0.4kWh/kg

Acqua? (diga di 100m) = 0.00028kWh/kg

Idrogeno? = 39kWh/kg

Energia potenziale

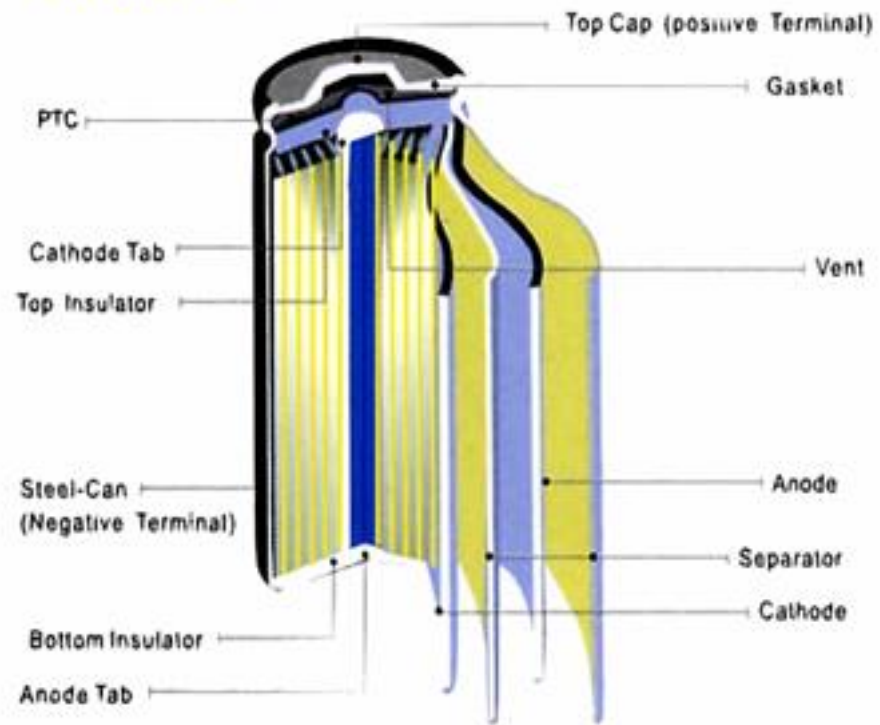
L'energia potenziale di un sistema di cariche puntiformi fisse è uguale al lavoro svolto da un agente esterno per portare il sistema nella configurazione indicata, spostando ciascuna carica da una distanza infinita alla propria posizione



$$V = \frac{1}{4\pi\epsilon_0} \frac{q_1}{r}$$

$$U = L = q_2 V = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} \quad \frac{1}{4\pi\epsilon_0} = (8.99 \cdot 10^9 \text{ Nm}^2 / \text{C}^2)$$

STRUCTURE





BALANCE
10 W MAX

BOOSTCAP
ULTRACAPACITORS
44 F / 48V
BM002600-48
MAXWELL TECHNOLOGIES, ALBANY, NY
DO NOT REVERSE POLARITY

Maxwell
TECHNOLOGIES
WWW.MAXWELL.COM

CAUTION
MODULAR BALANCE CABLES MUST BE
INSTALLED FOR CORRECT APPLICATIONS.
DO NOT EXCEED MAXIMUM VOLTAGE.
DO NOT EXCEED MAXIMUM CURRENT.
DO NOT EXCEED MAXIMUM TEMPERATURE.
DO NOT EXCEED MAXIMUM HUMIDITY.
DO NOT EXCEED MAXIMUM ALTITUDE.
DO NOT EXCEED MAXIMUM VIBRATION.
DO NOT EXCEED MAXIMUM SHOCK.

+

10 W MAX

BALANCE

BOOSTCAP
ULTRACAPACITORS
430 F / 16V
BM002600-16
MAXWELL TECHNOLOGIES, ALBANY, NY
DO NOT REVERSE POLARITY

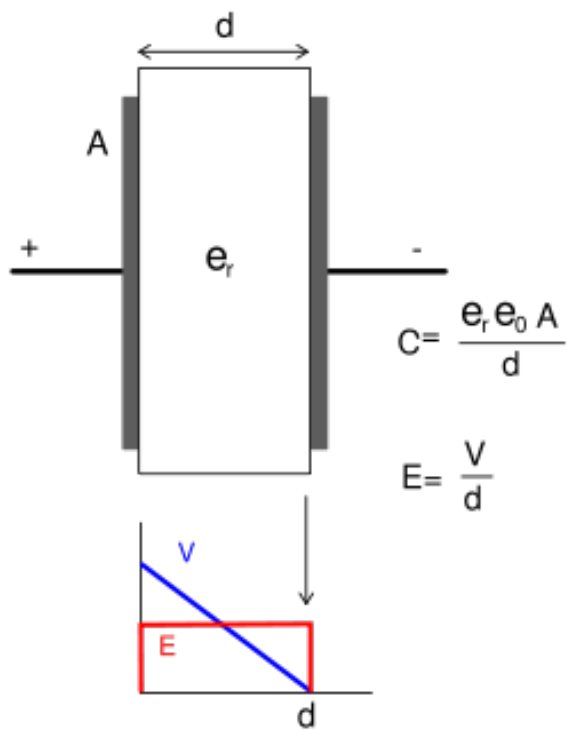
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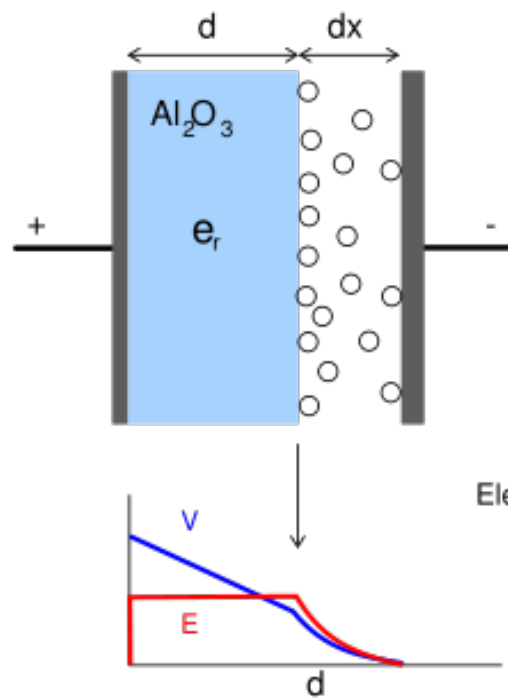
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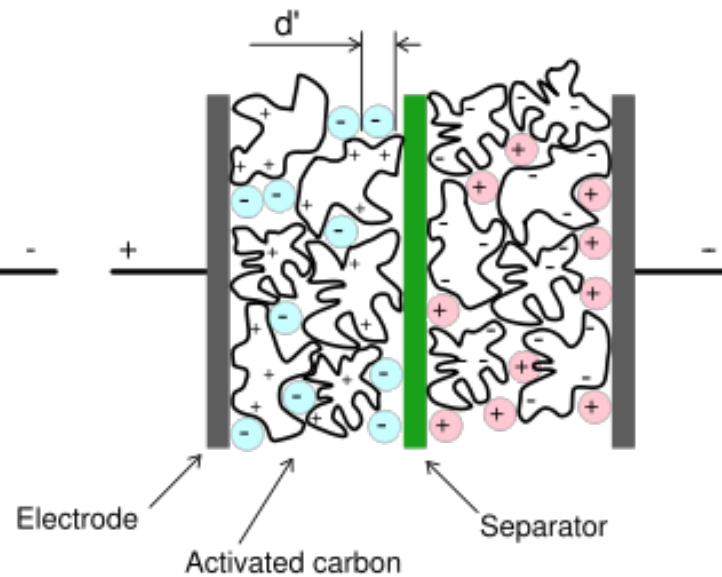
Electrostatic



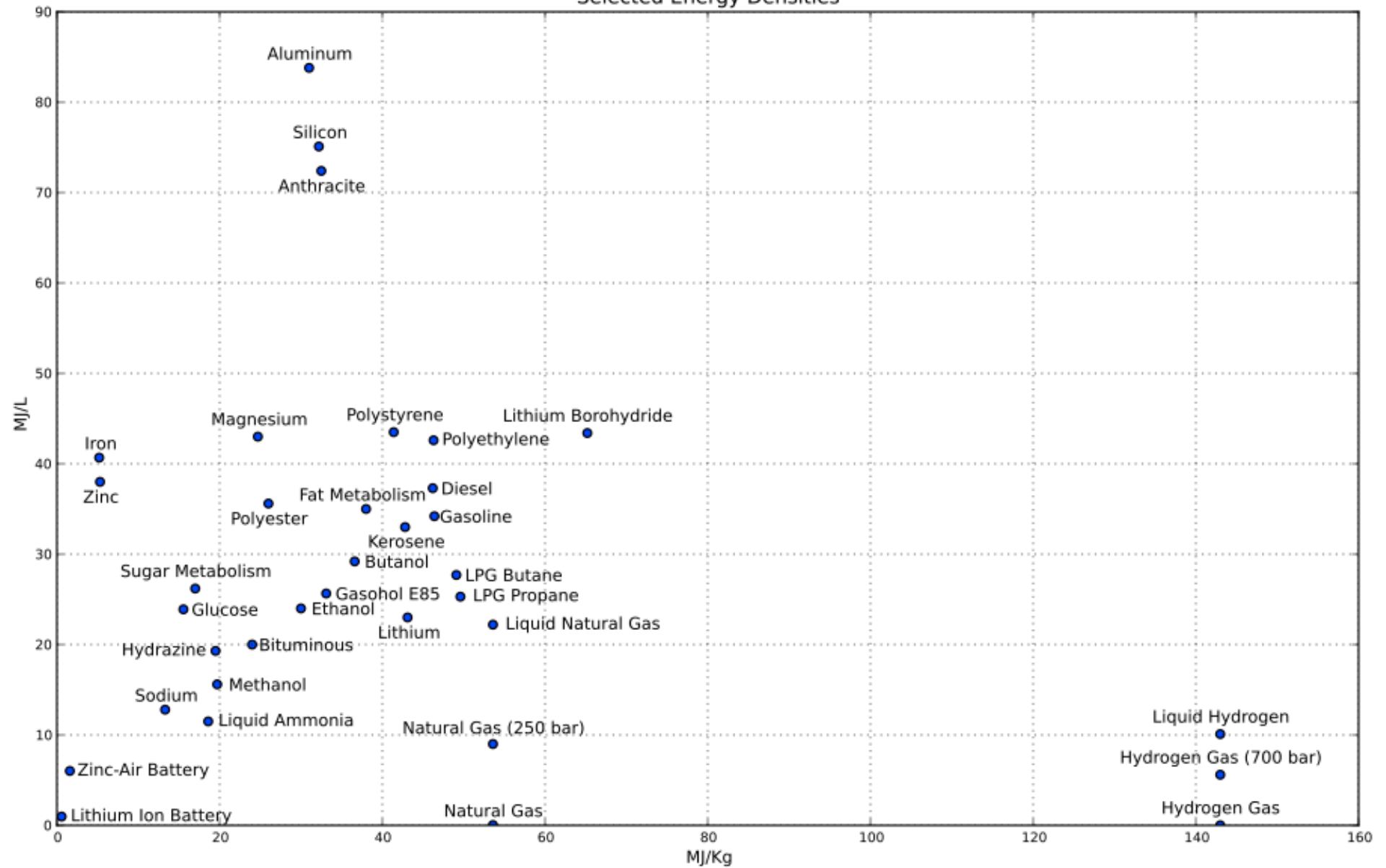
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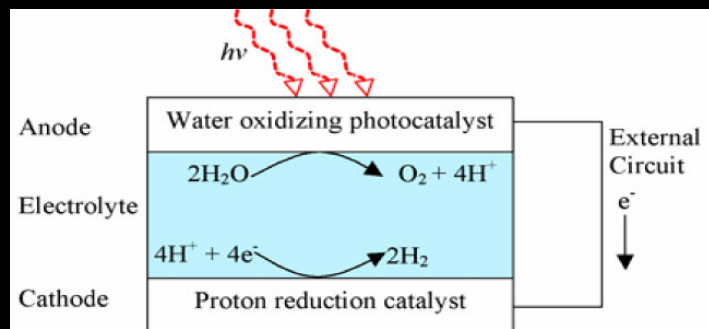
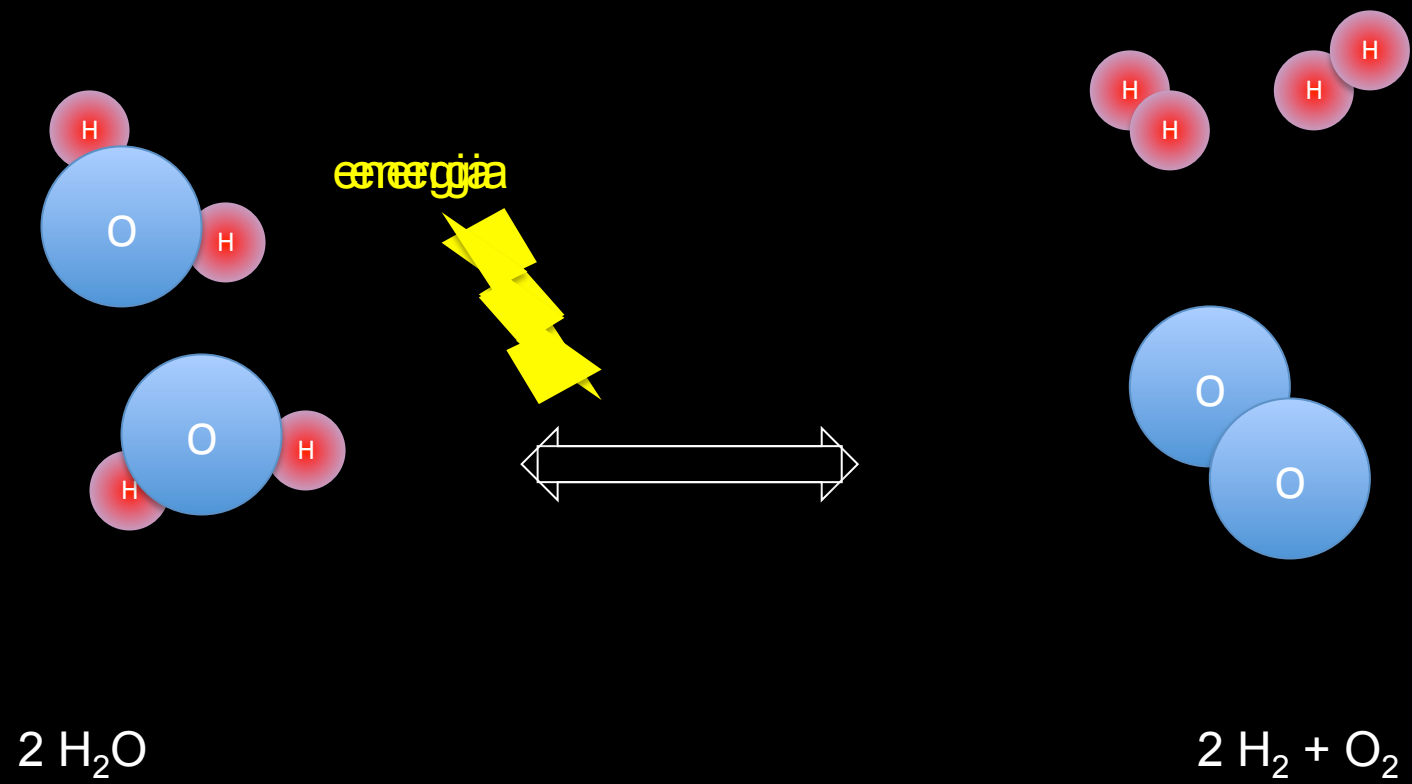


Electrochemical double-layer

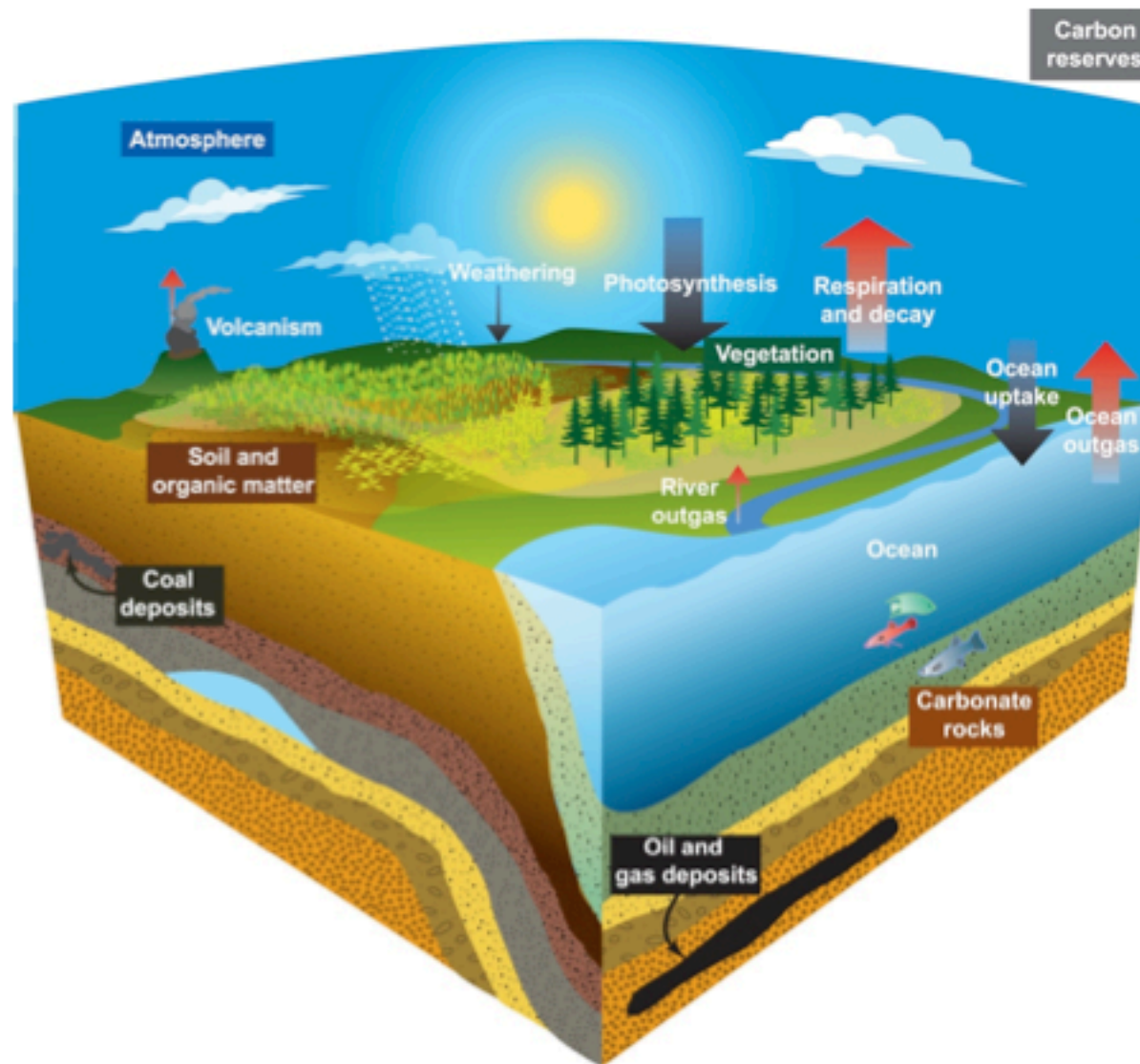


Selected Energy Densities





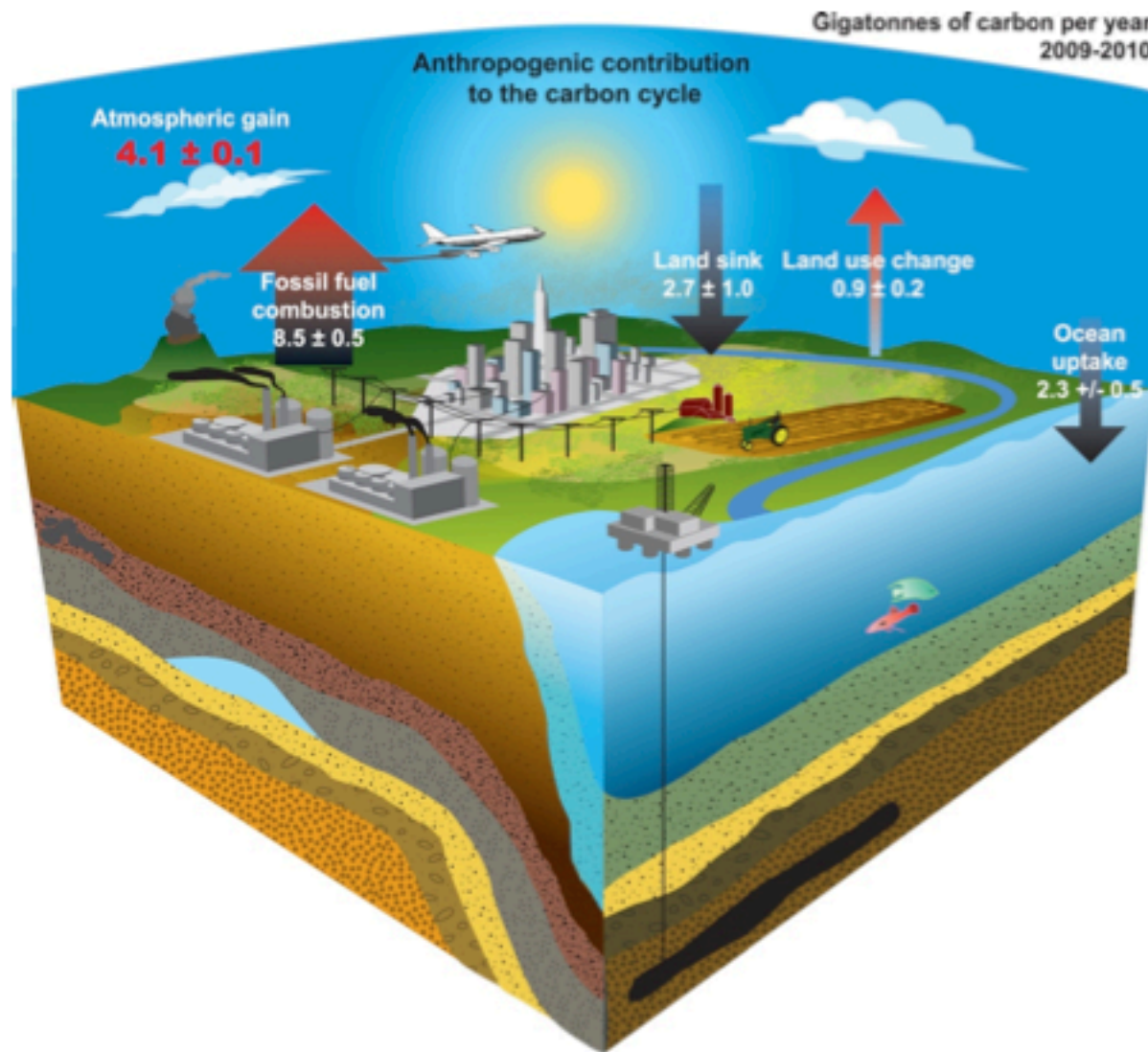
Carbon Cycle 1.0: relatively stable geochemical cycles



50,000 BC - 1750 CE

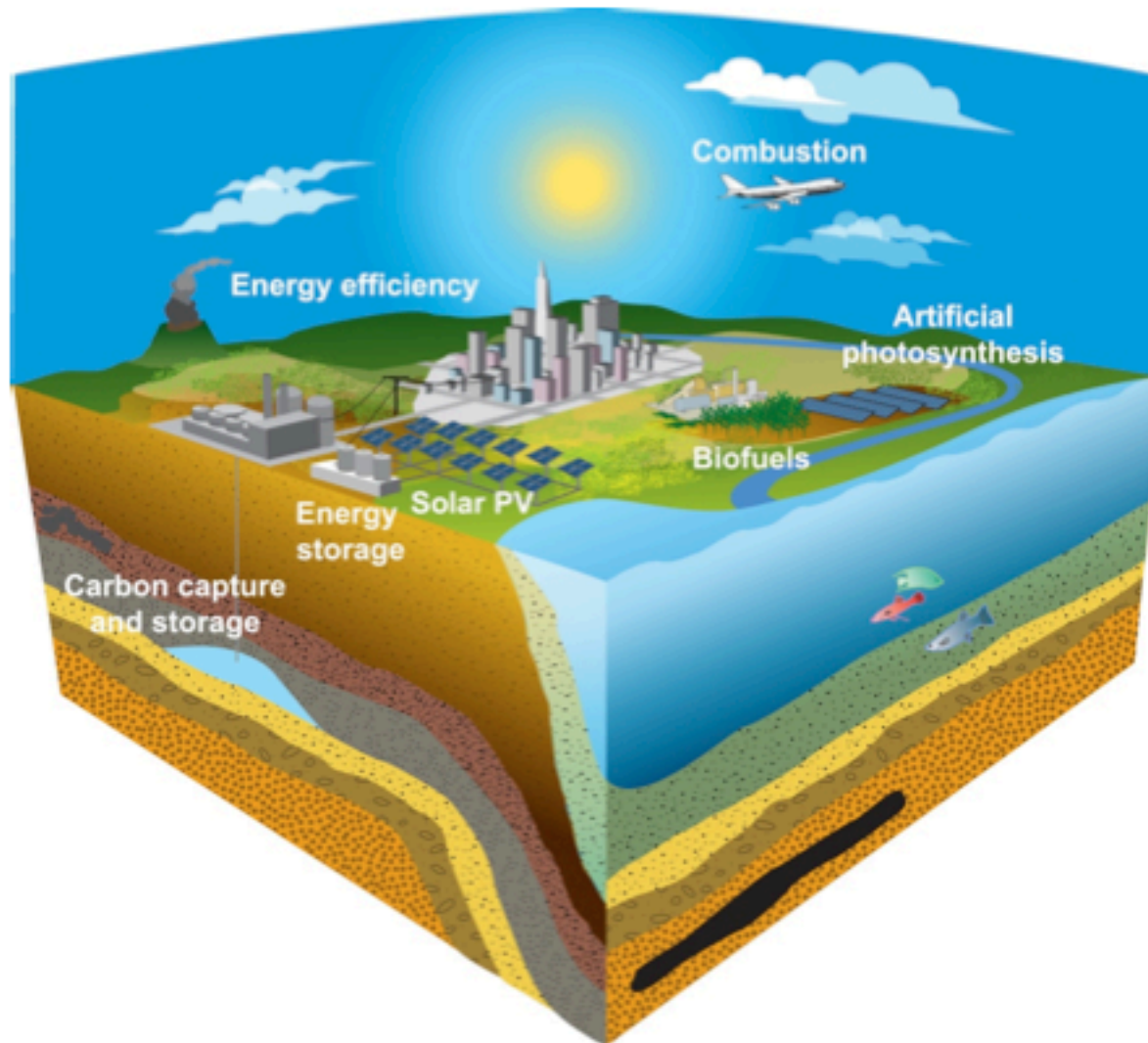
average net atmospheric gain: 0.0 ± 0.02 gigatons carbon per year

Carbon Cycle 1.x: An increasingly perturbed system



Net flux of C due to human activity $\sim 100\times$ natural geological flux

Carbon Cycle 2.0: Restoring balance to the carbon cycle



Balance can be restored while allowing for growth in population and wellbeing