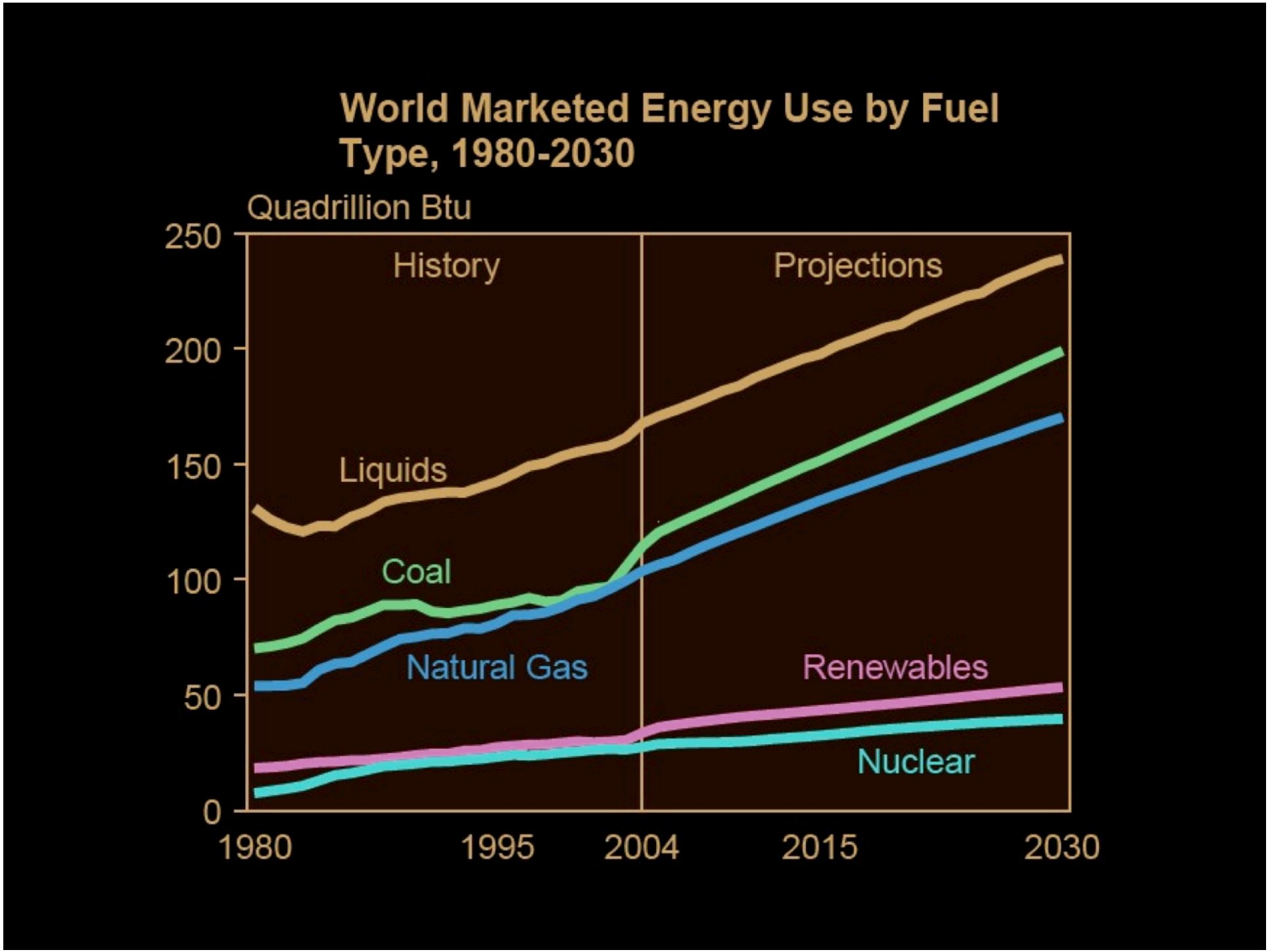
Sustainable energy – without the hot air

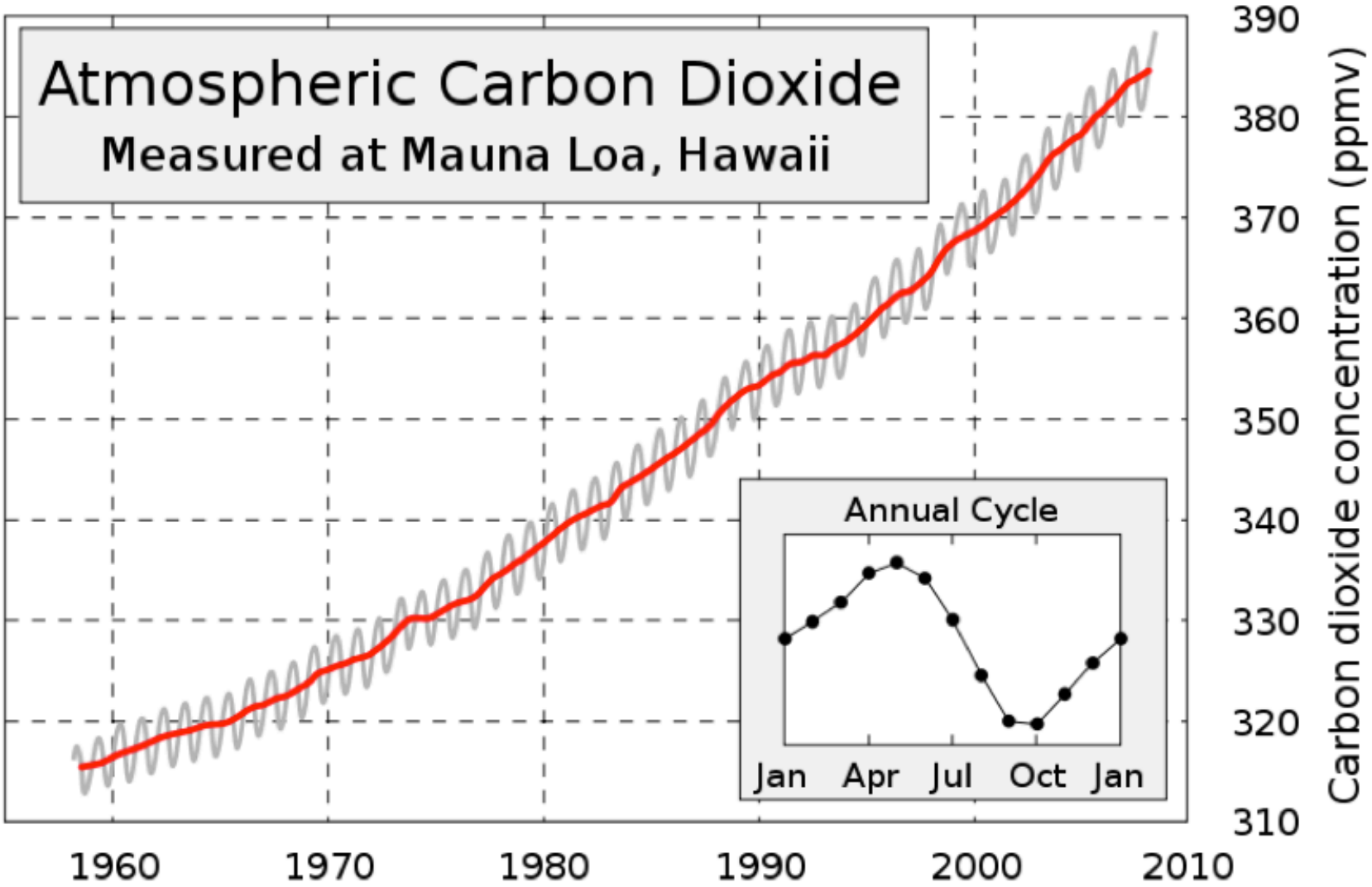

World Marketed Energy Use by Fuel Type, 1980-2030
Quadrillion Btu
250
200
150
100
50
0
History
Projections
Liquids
Coal
Natural Gas
Renewables
Nuclear
1980
1995
2004
2015
2030

- Aumento CO2? Colpa nostra?

- Cambiamenti climatici?

- Possiamo adattarci? Possiamo rimediare?

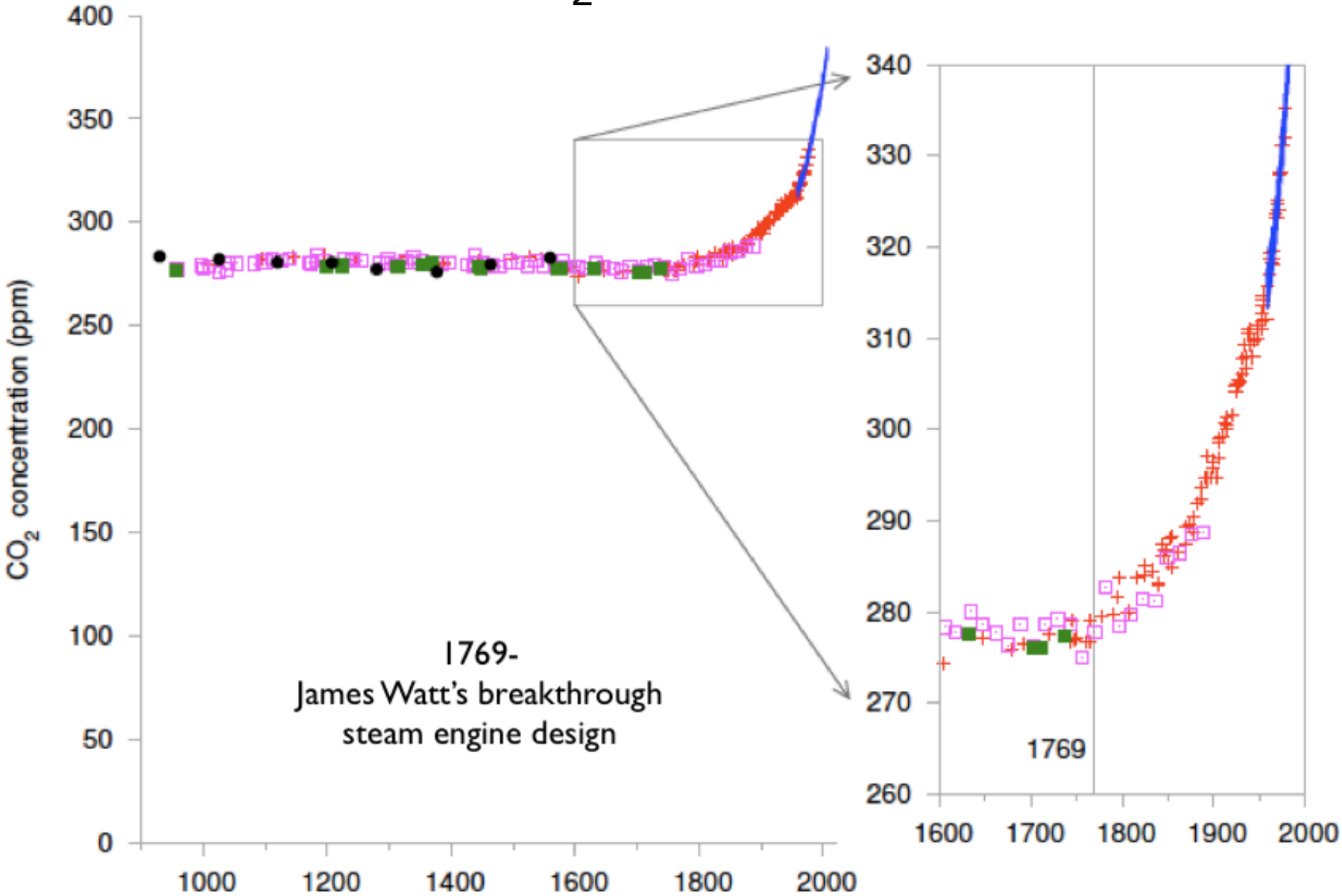
The Keeling Curve: CO_2 *is* increasing



Data available at: ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_mm_mlo.txt

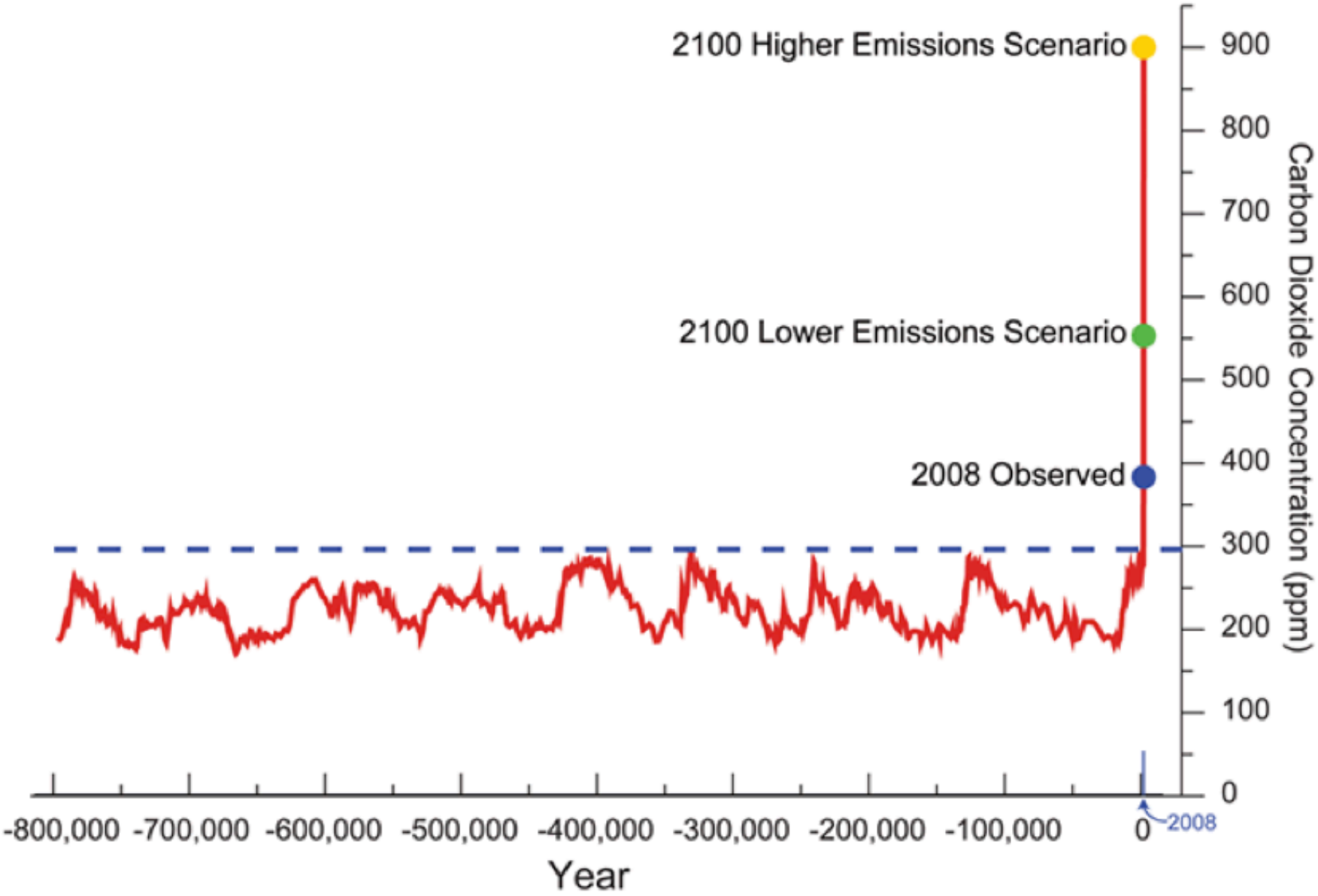
Image created by Robert A. Rohde / Global Warming Art

CO_2 atmosferica



from "Sustainable Energy Without the Hot Air, David Mackay

Atmospheric CO_2 over 800,000 years

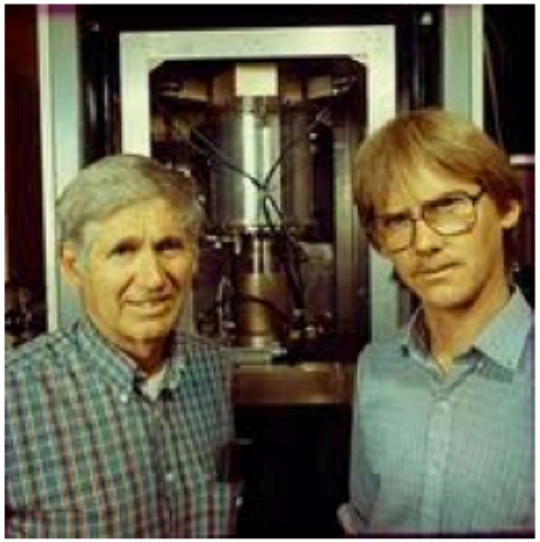


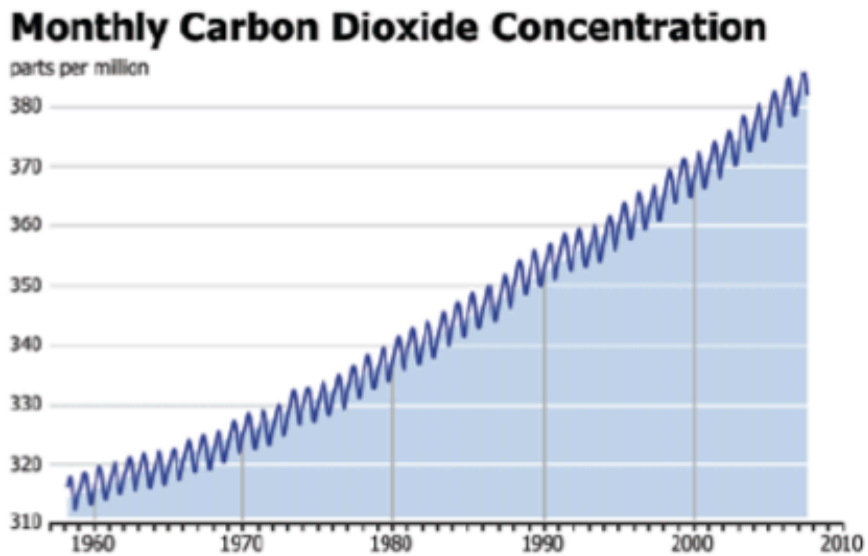
The second Keeling curve: Oxygen decrease

$$CH_n + O_2 \longrightarrow CO_2 + n/2H_2O$$

$\downarrow$ $\uparrow$

If CO_2 is increasing,
then O_2 must be decreasing,
and ***it is***

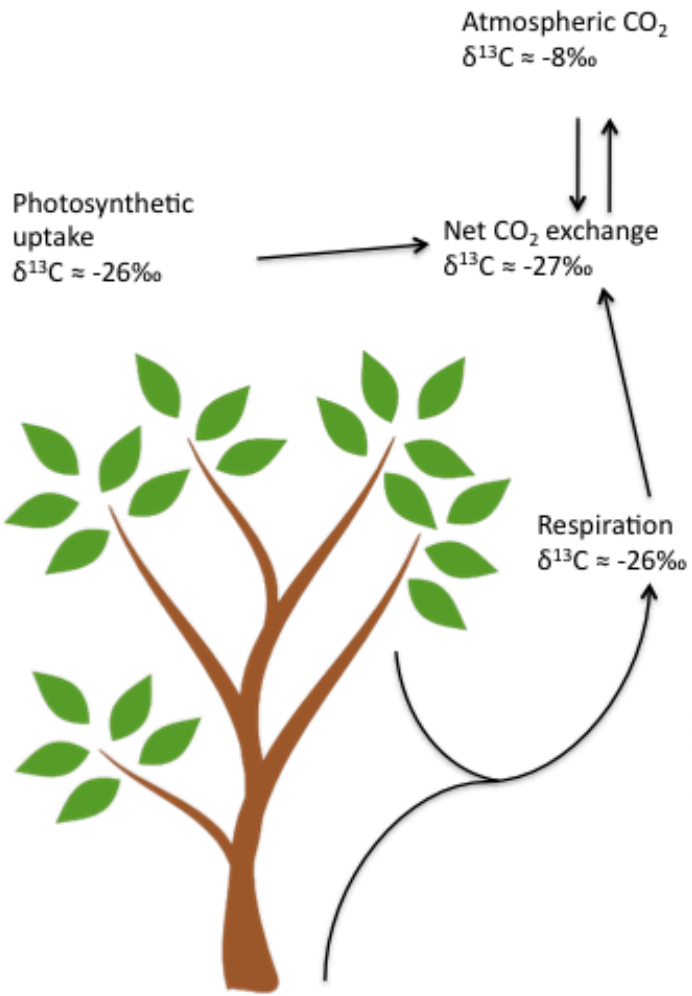


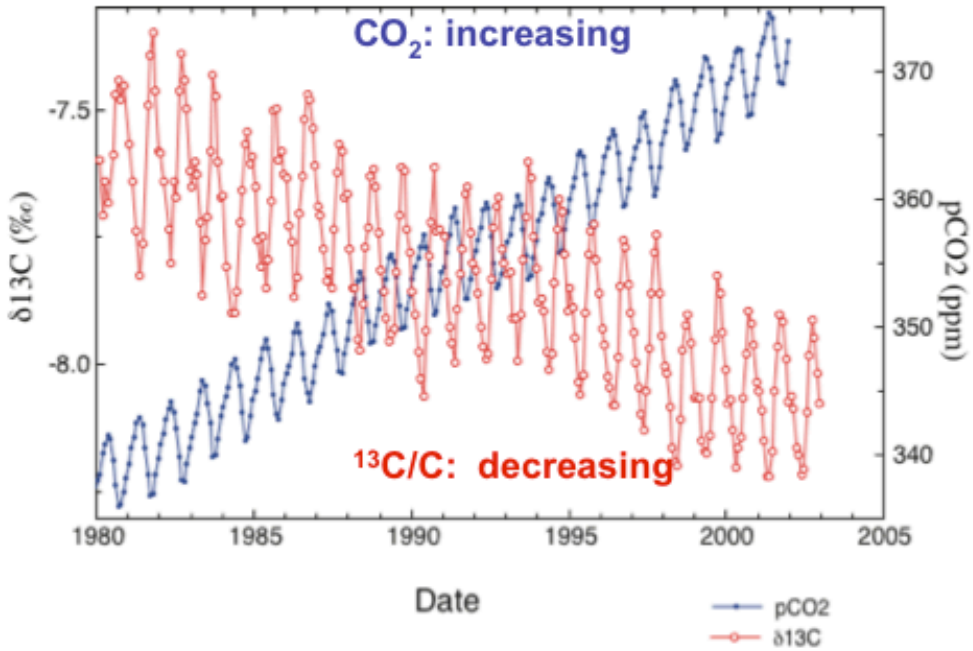


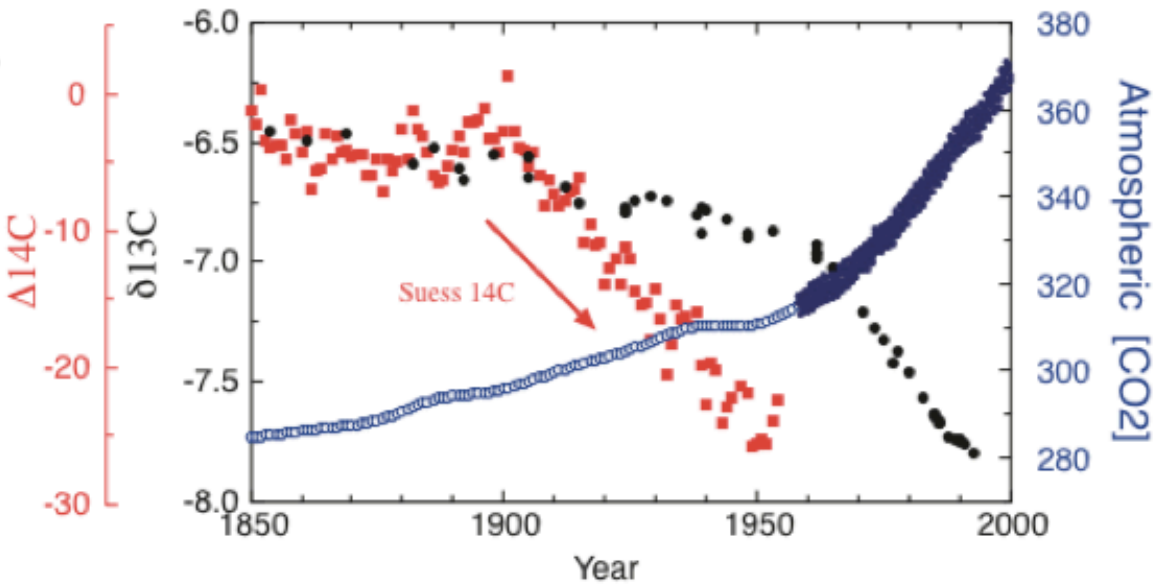
Keeling RF Nature 1996
Scripps Institute "Explorations" Magazine January 2008

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

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

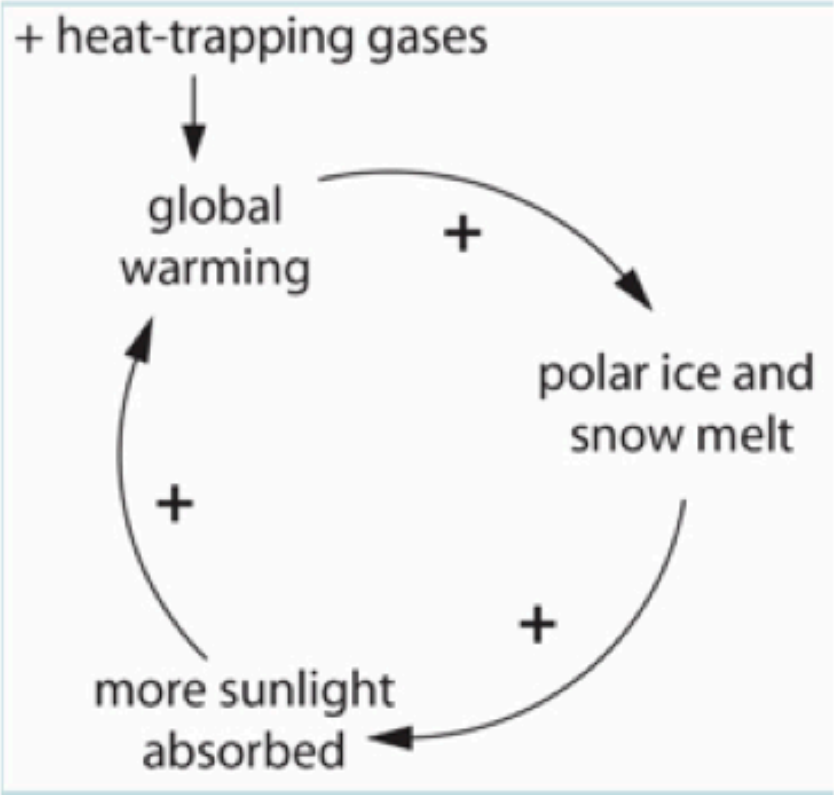


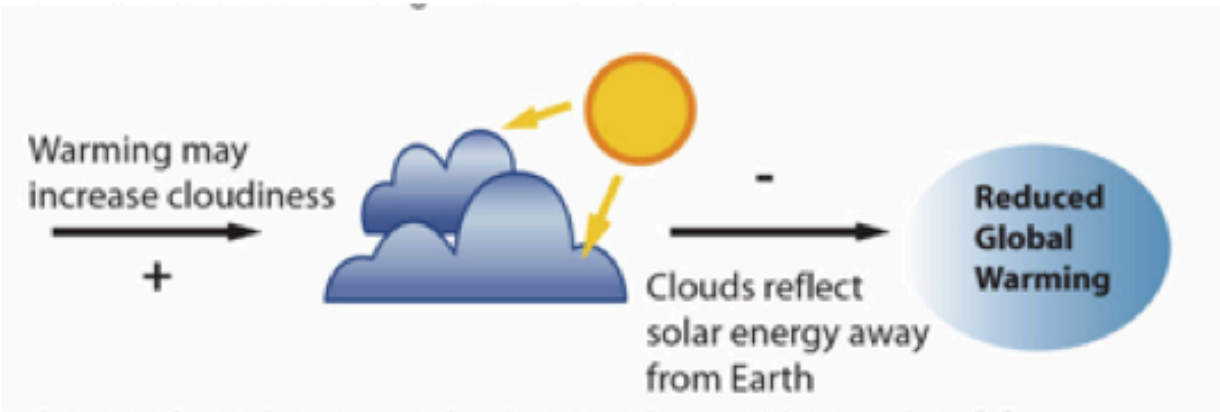




see for instance, Ghosh and Brand, International Journal of Mass Spectrometry (2003) vol. 228 pp. 1-33

Feedback


+ heat-trapping gases
global warming
+
polar ice and snow melt
+
more sunlight absorbed
+


Warming may increase cloudiness
+
-
Clouds reflect solar energy away from Earth
Reduced Global Warming

Trasmissione del calore: irraggiamento

Stefan-Boltzmann

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

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

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

Effetto serra

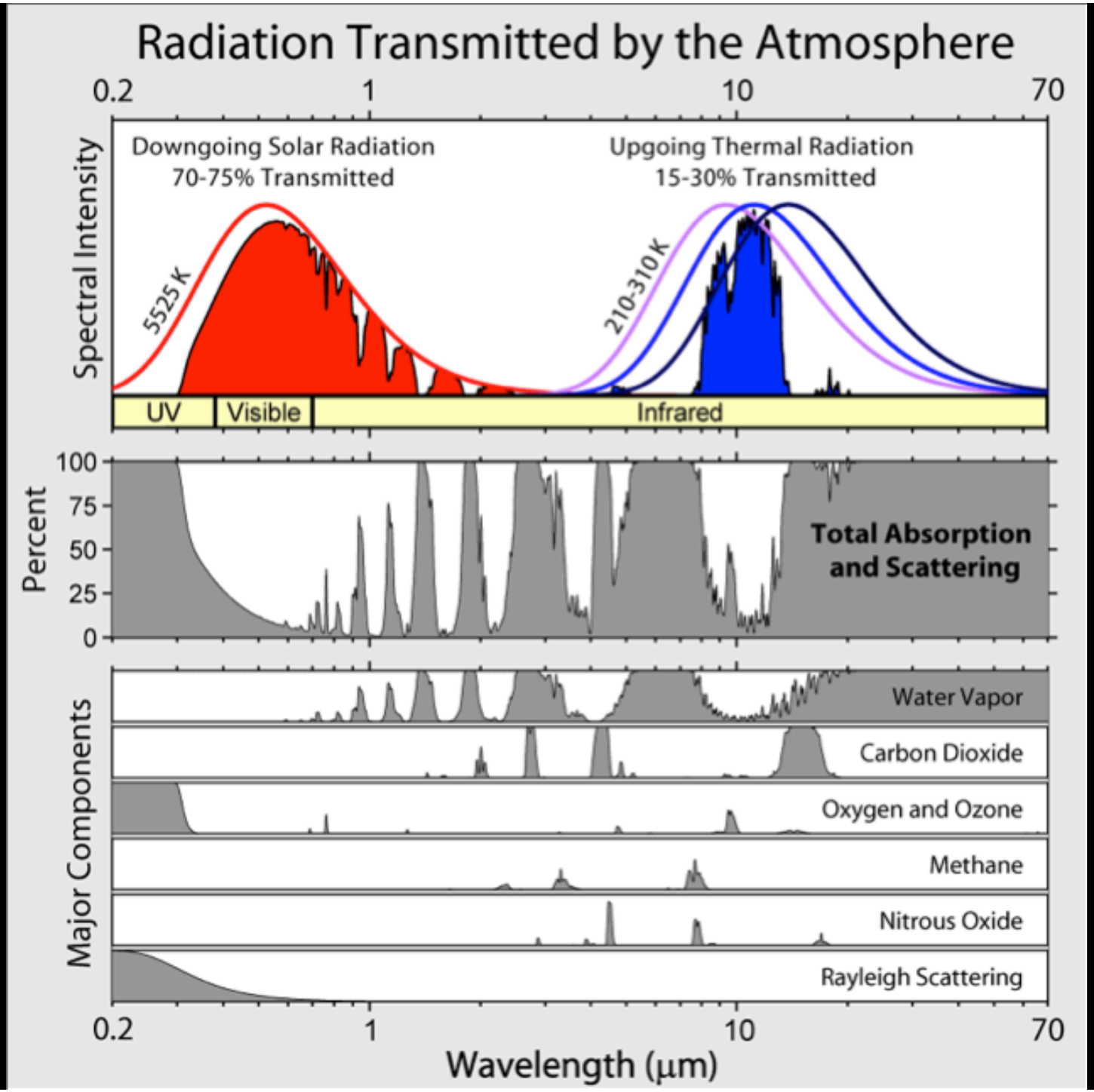
$$P_r = \sigma \varepsilon A T^4 = P_{sun}$$

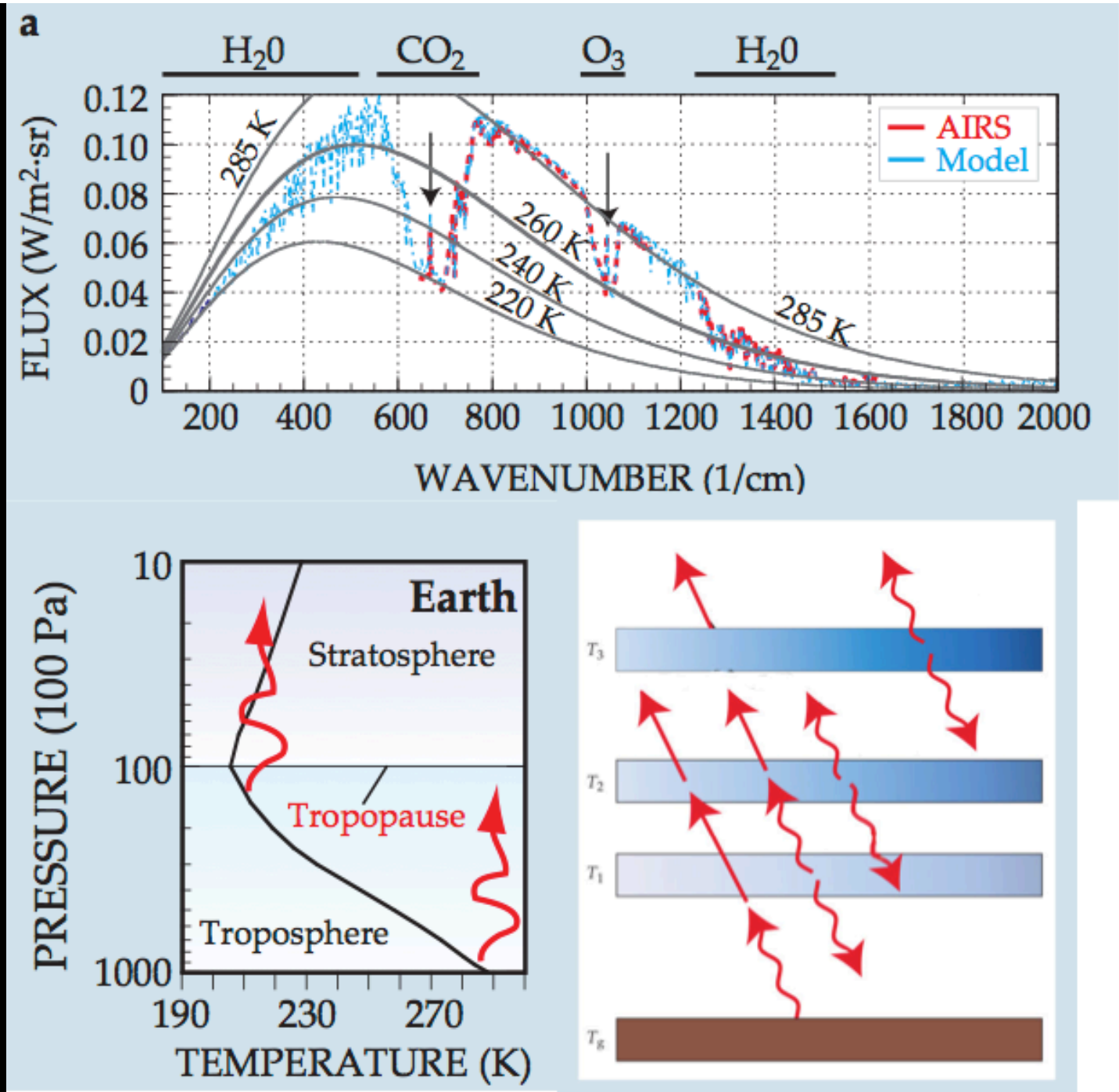
$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

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

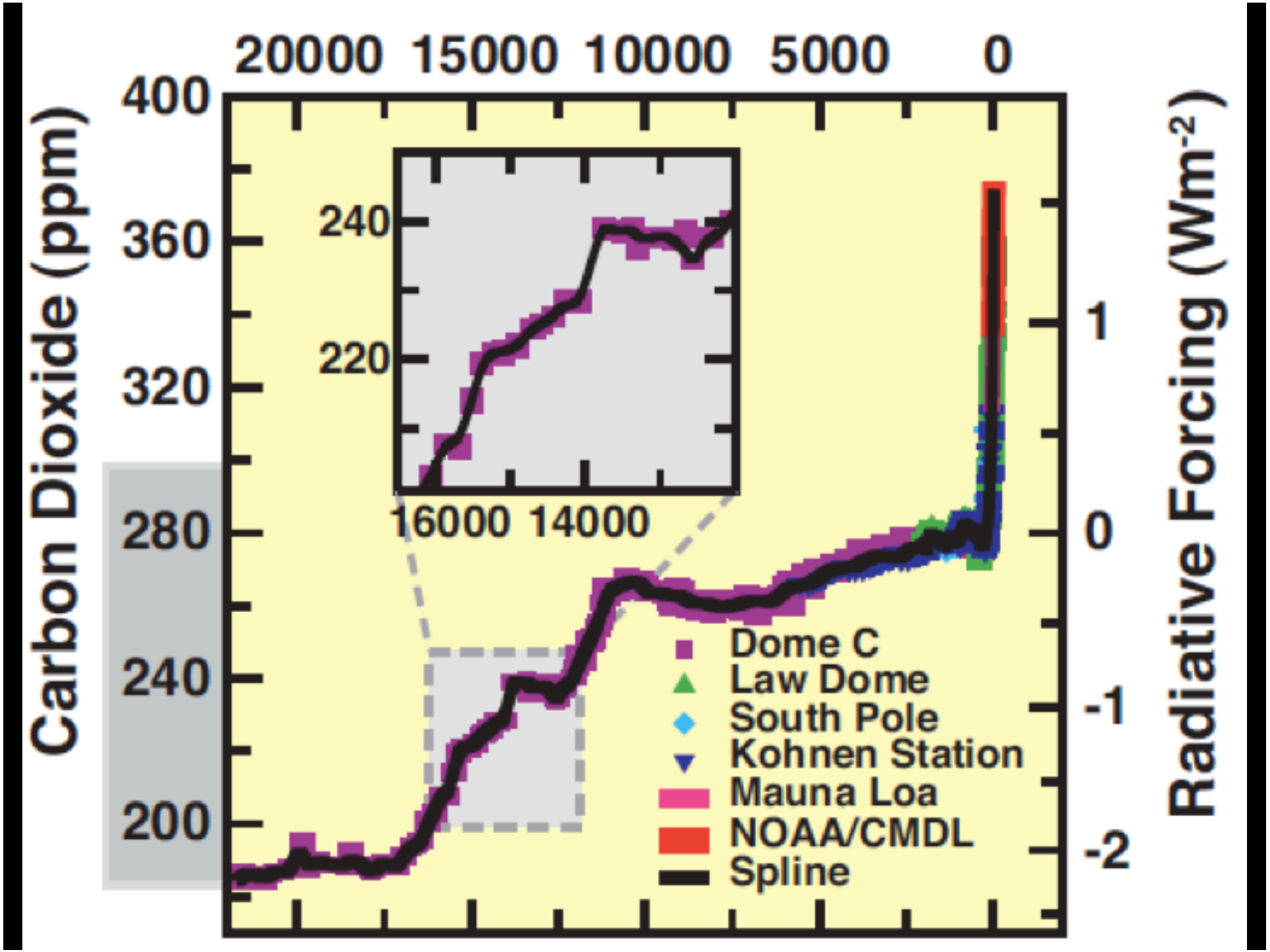
$$\frac{P_{sun}}{A} = 250 \frac{W}{m^2}$$

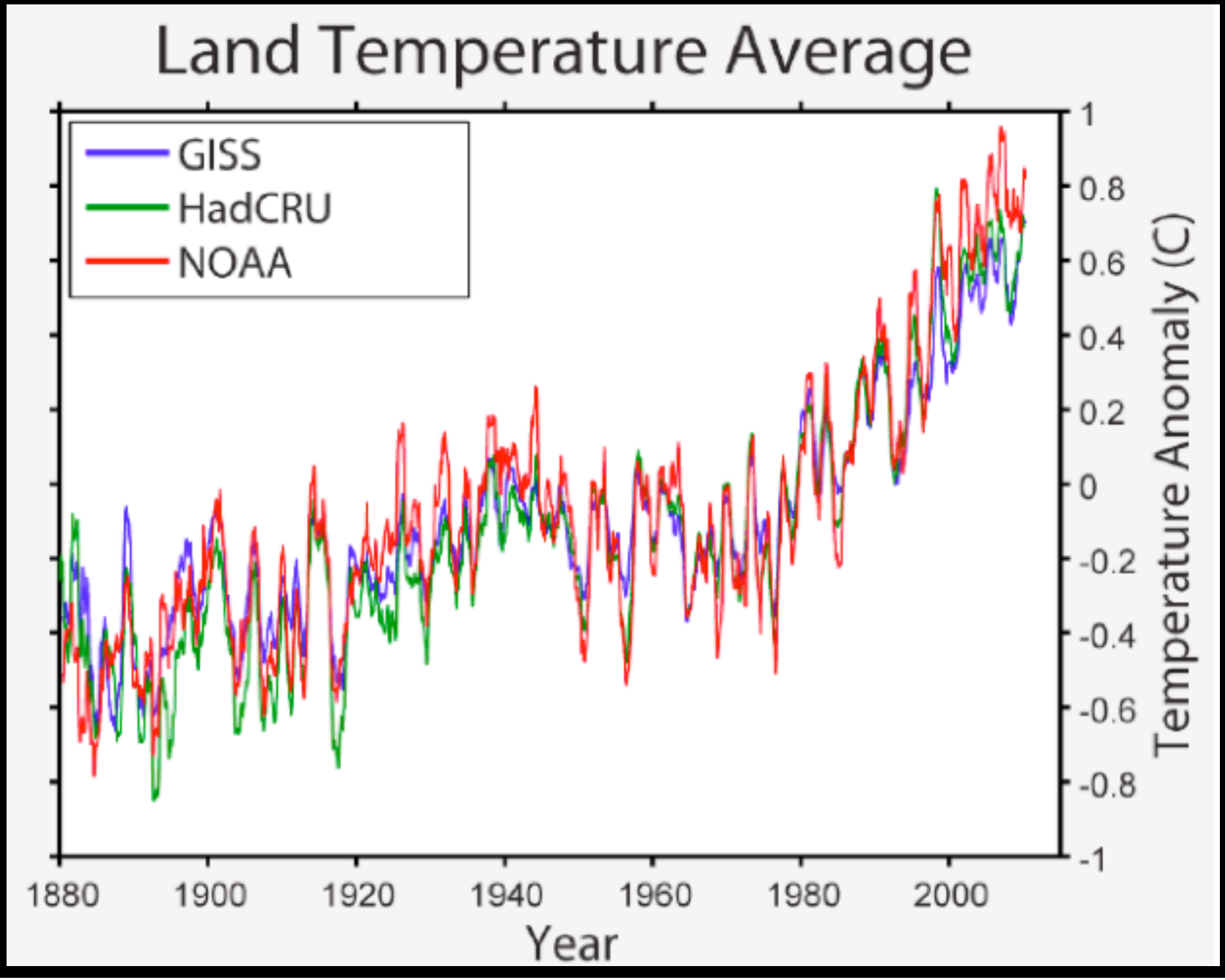
$$T = \sqrt[4]{\frac{P_{sun}}{\sigma \varepsilon A}} = \sqrt[4]{\frac{250 \frac{W}{m^2}}{\varepsilon \times 5.67 \times 10^{-8} \frac{W}{m^2 K^4}}} = \begin{cases} \xrightarrow{\varepsilon = 1} 258K \left(-15C\right) \\ \xrightarrow{\varepsilon = 0.6} 293K \ \left(20C\right) \end{cases}$$

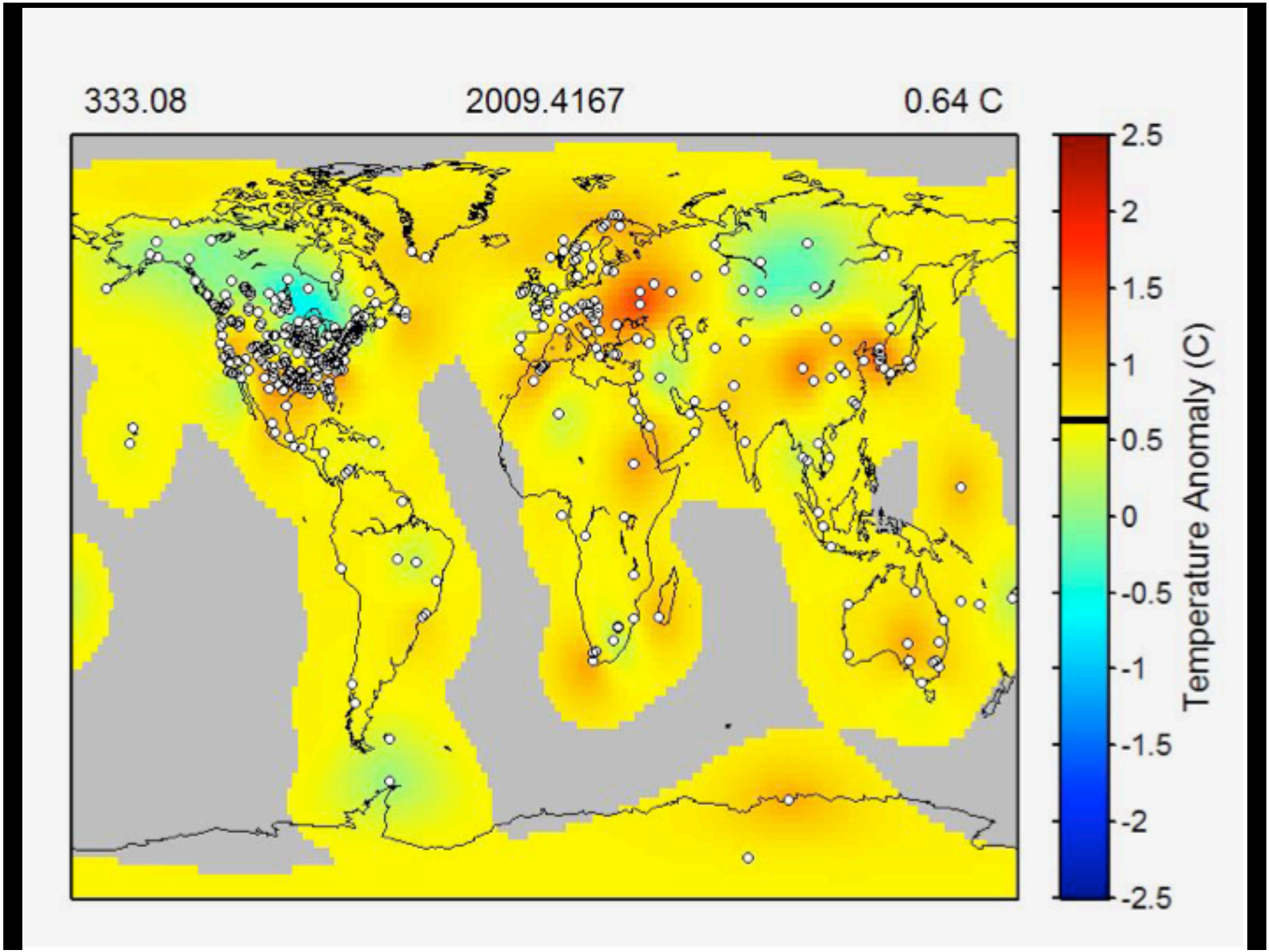

Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent
100
75
50
25
0
Total Absorption
and Scattering
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
Wavelength (μm)

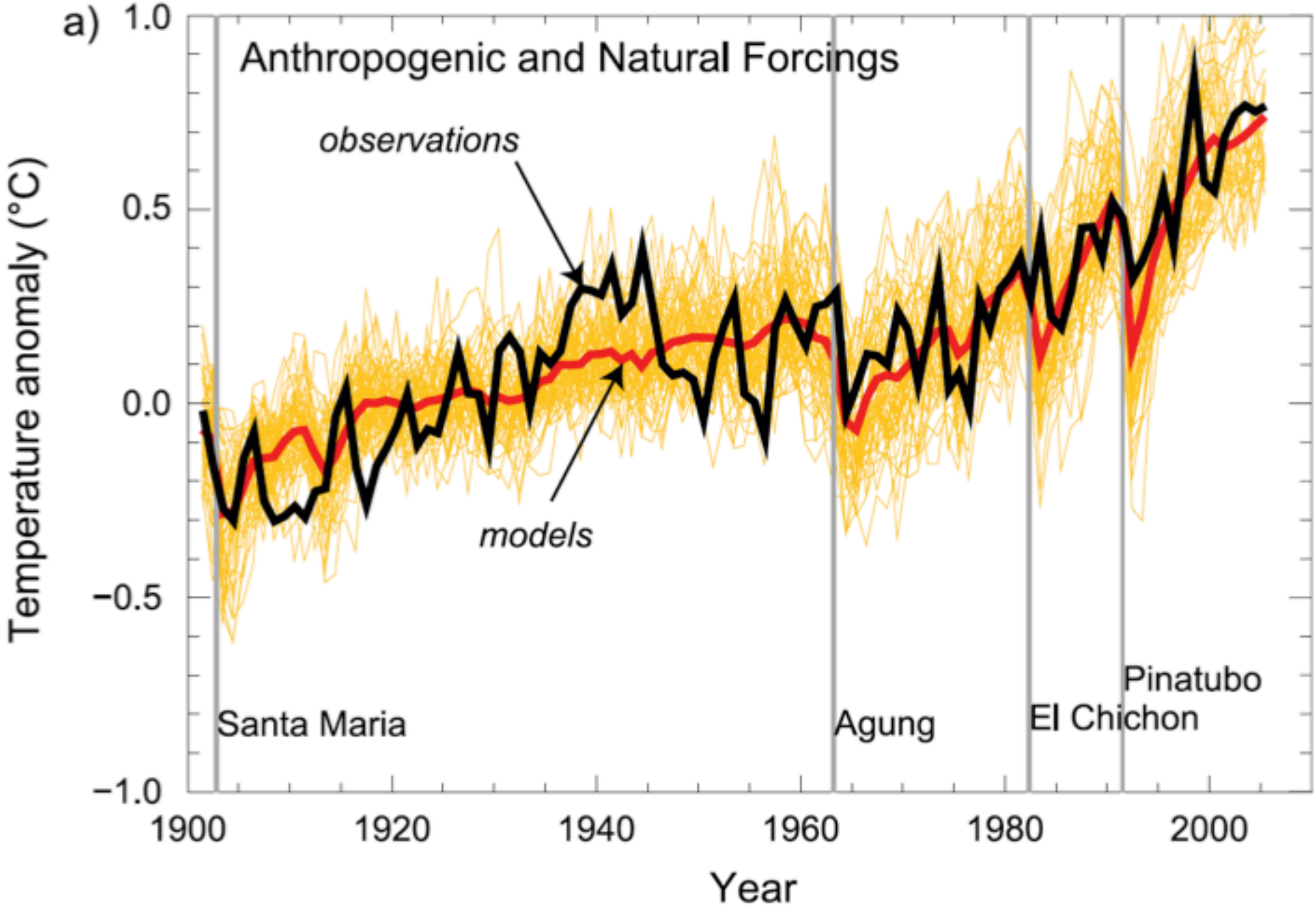


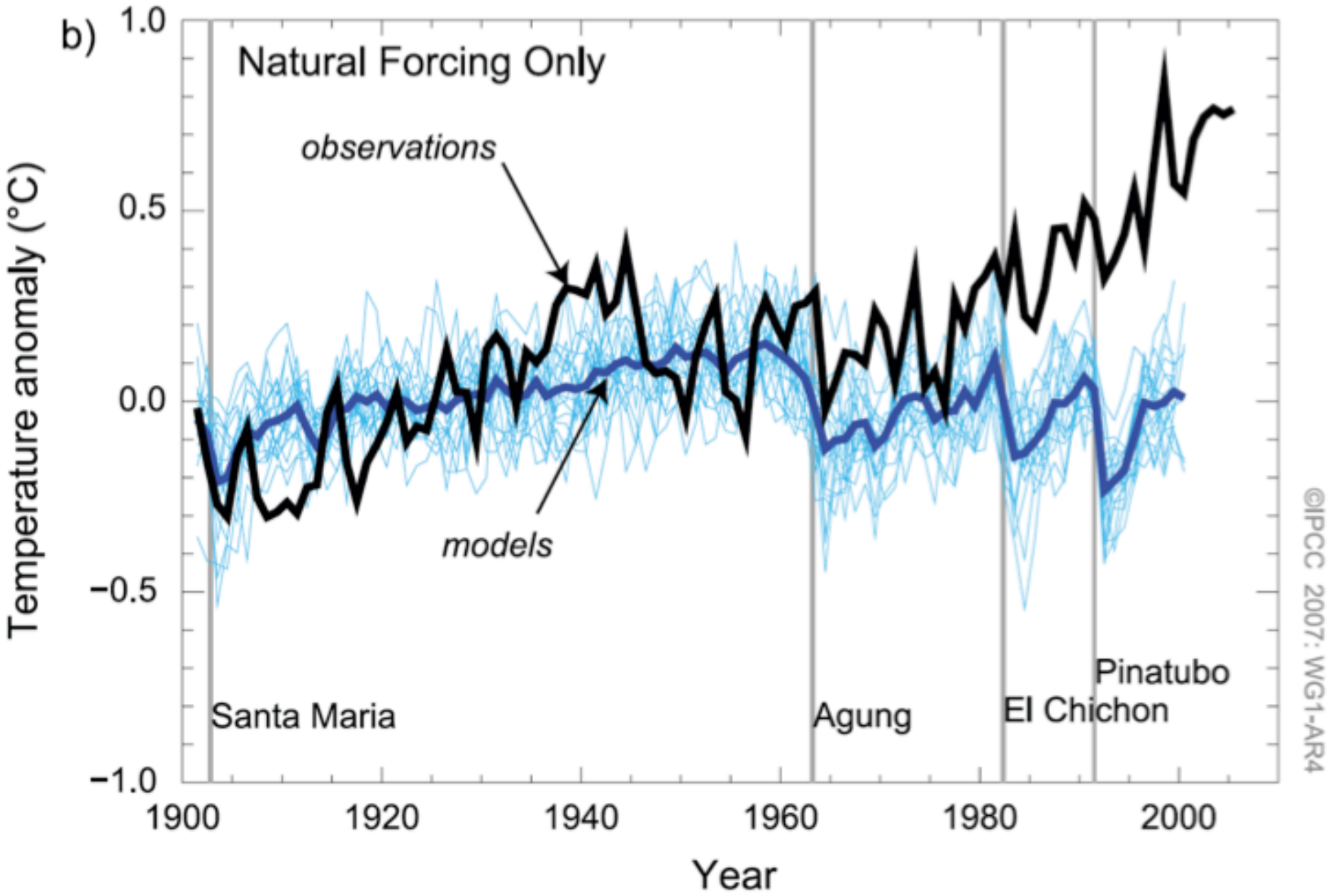
from R. T. Pierrehumbert, Physics Today, January 2011


20000
15000
10000
5000
0
400
360
320
280
240
200
Carbon Dioxide (ppm)
240
220
16000
14000
1
0
-1
-2
Radiative Forcing (Wm-2)
Dome C
Law Dome
South Pole
Kohnen Station
Mauna Loa
NOAA/CMDL
Spline


Land Temperature Average
GISS
HadCRU
NOAA
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Temperature Anomaly (C)
1880
1900
1920
1940
1960
1980
2000
Year

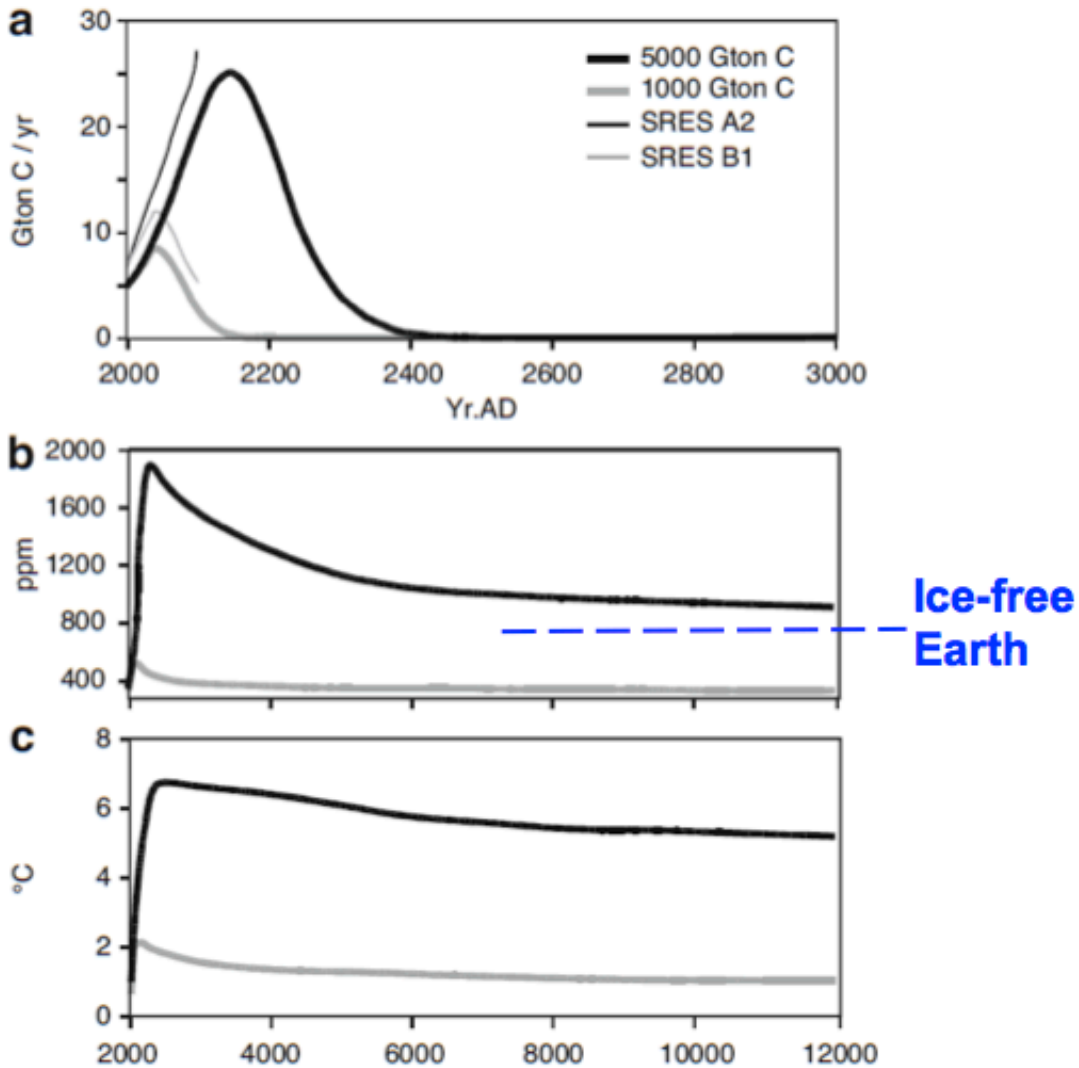

333.08
2009.4167
0.64 C
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Temperature Anomaly (C)

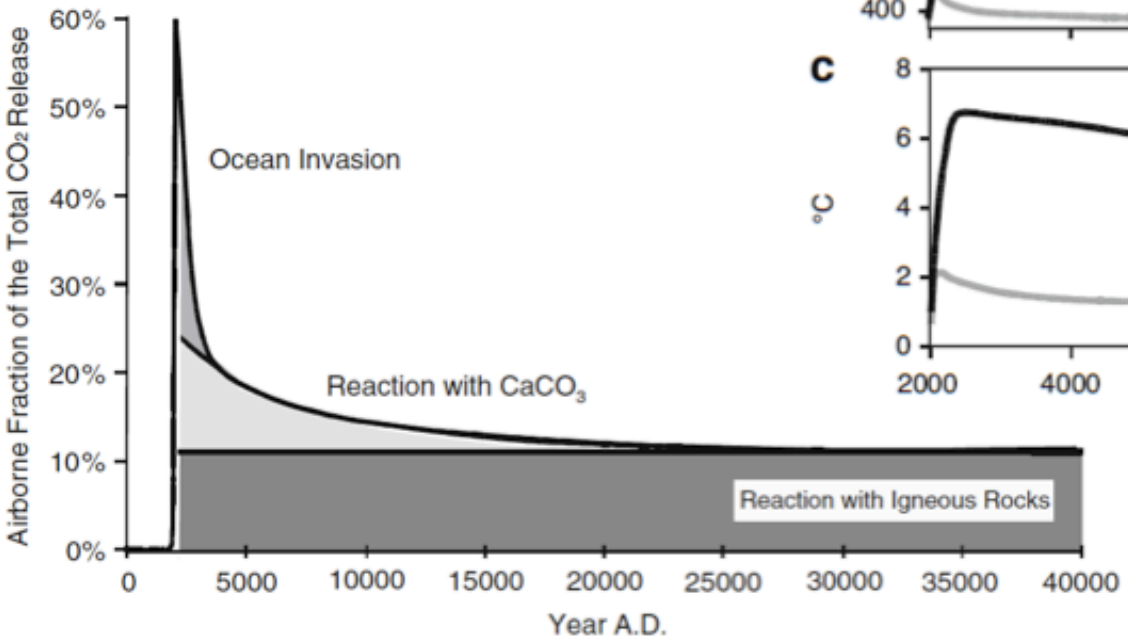

a)
Anthropogenic and Natural Forcings
observations
models
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year


b)
Natural Forcing Only
observations
models
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
1900
1920
1940
1960
1980
2000
Year
Santa Maria
Agung
El Chichon
Pinatubo
©IPCC 2007: WG1-AR4

Best case:
1000Gt CO_2 emitted

Worst case:
5000Gt CO_2 emitted





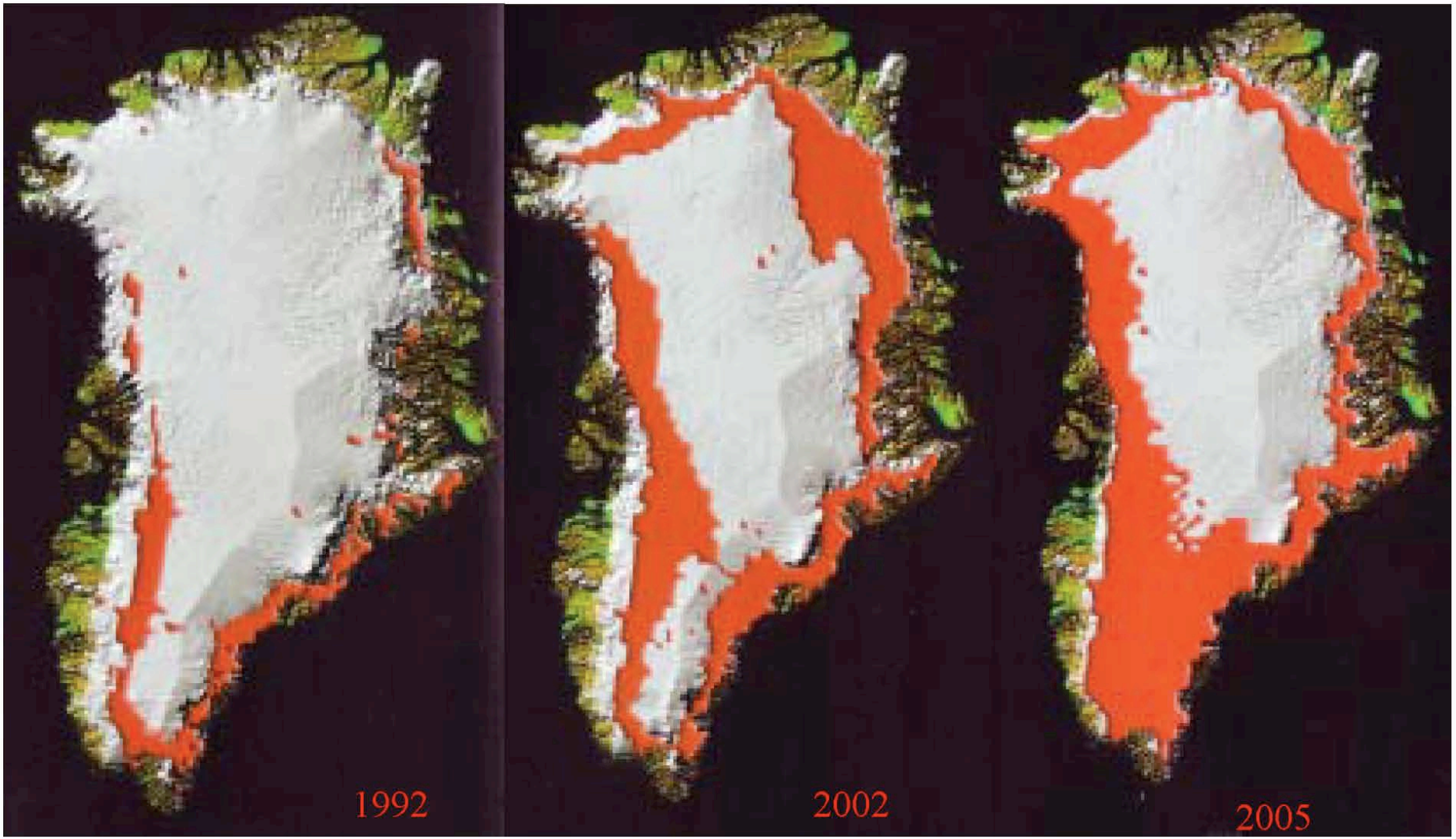
Archer & Brovkin, 2007

Muir Glacier, Alaska

August 1941

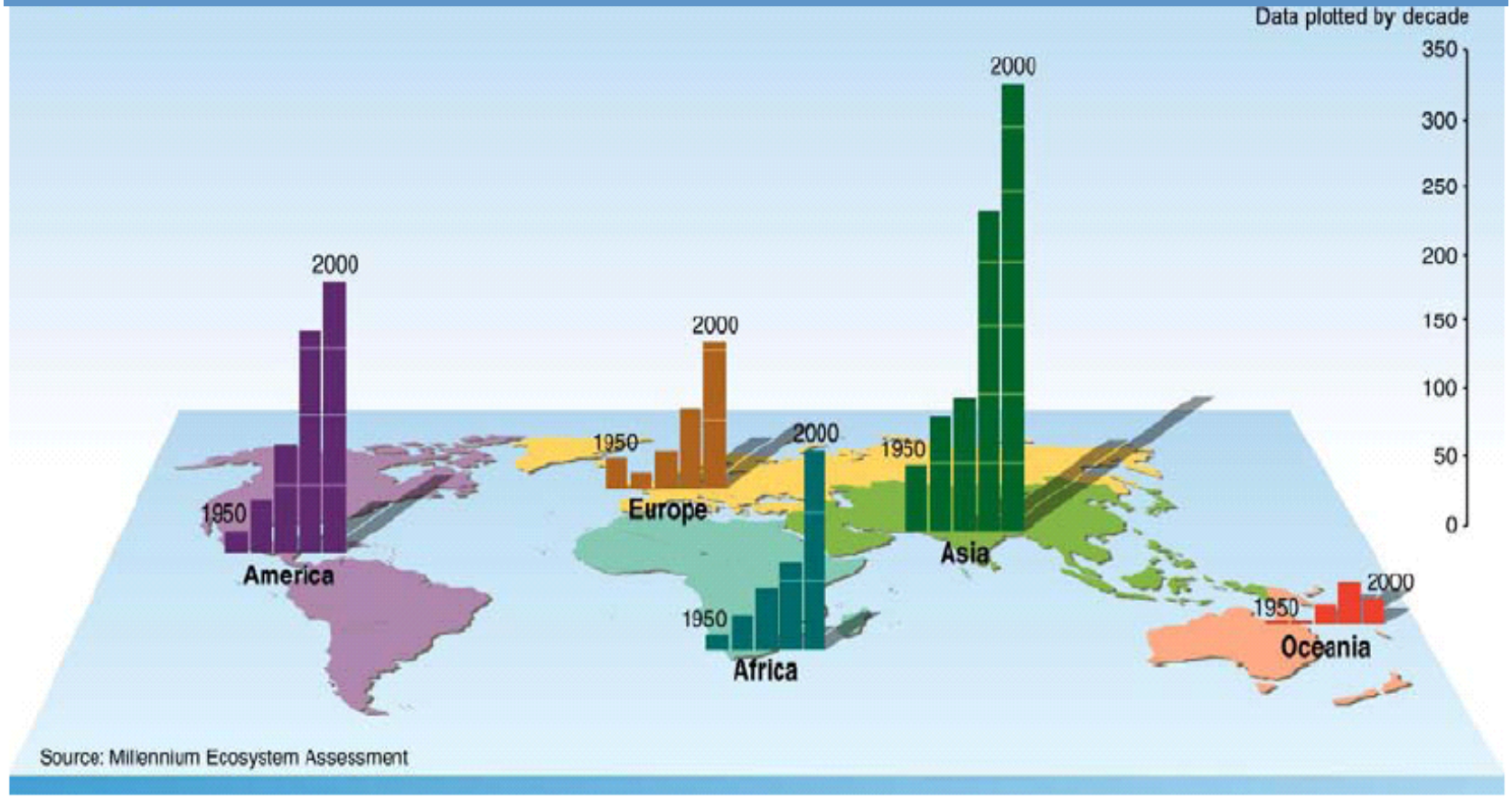
August 2004

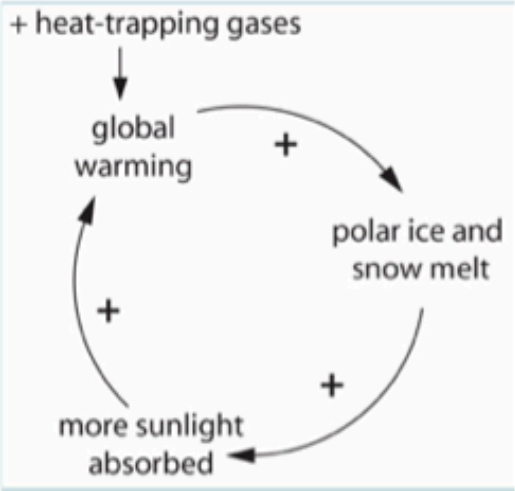
Surface melting on Greenland is expanding

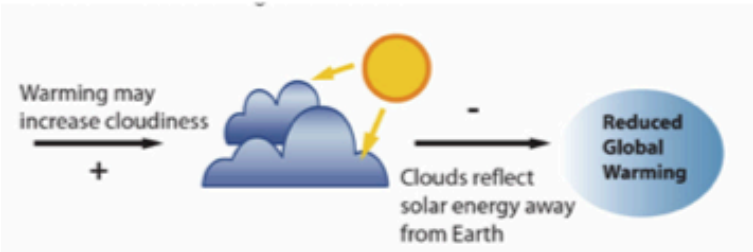


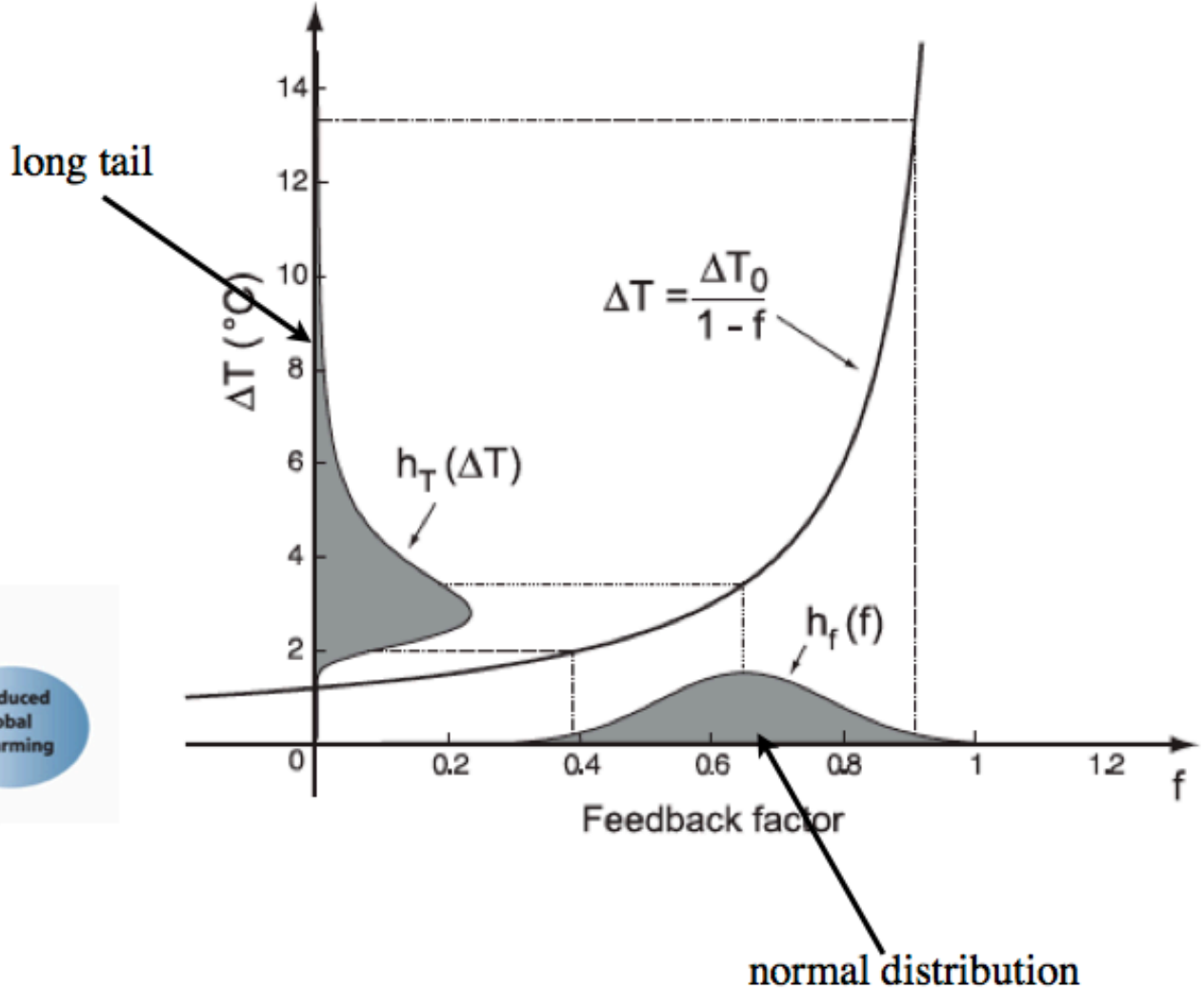

0°
Africa
South America
Atlantic Ocean
Madagascar
30°
30°
Falkland Islands
Weddell Sea
60°
Antarctica
Indian Ocean
90°W
90°E
60°
60°
45°
45°
30°
30°
SOUTH POLE
75°
120°
Ross Sea
120°
Pacific Ocean
150°
Tasmania
Australia
150°
New Zealand
180°

Major floods per decade, 1950-2000



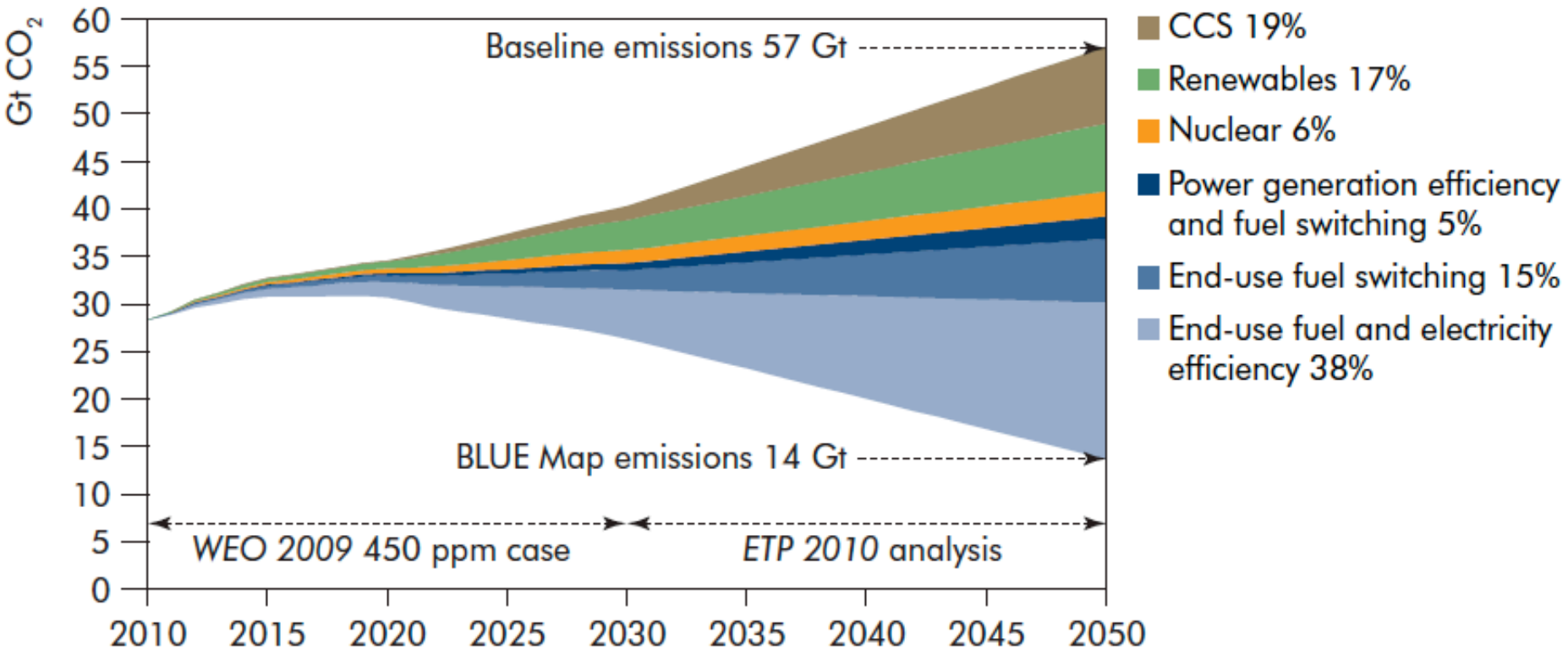




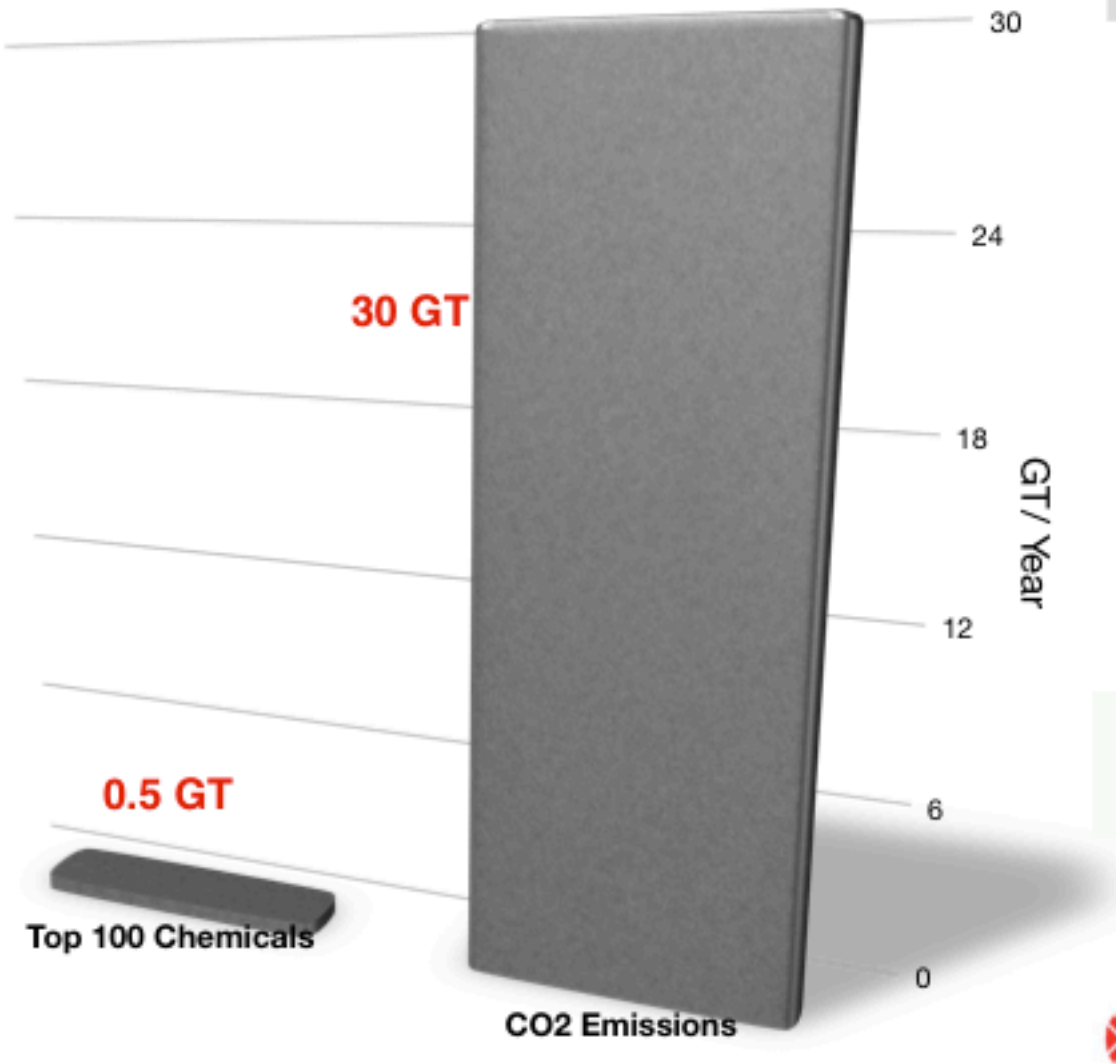


"Why is climate sensitivity so unpredictable?", Roe and Baker, Science **318**, 629 (2007)

Possibili soluzioni



Problema o opportunità?



Saudi Aramco — 8.2 M bpd

National Iranian Oil Company NIOC

PEMEX

IRAQ

ExxonMobil — 2.5 M bpd

bp

CNPC PetroChina

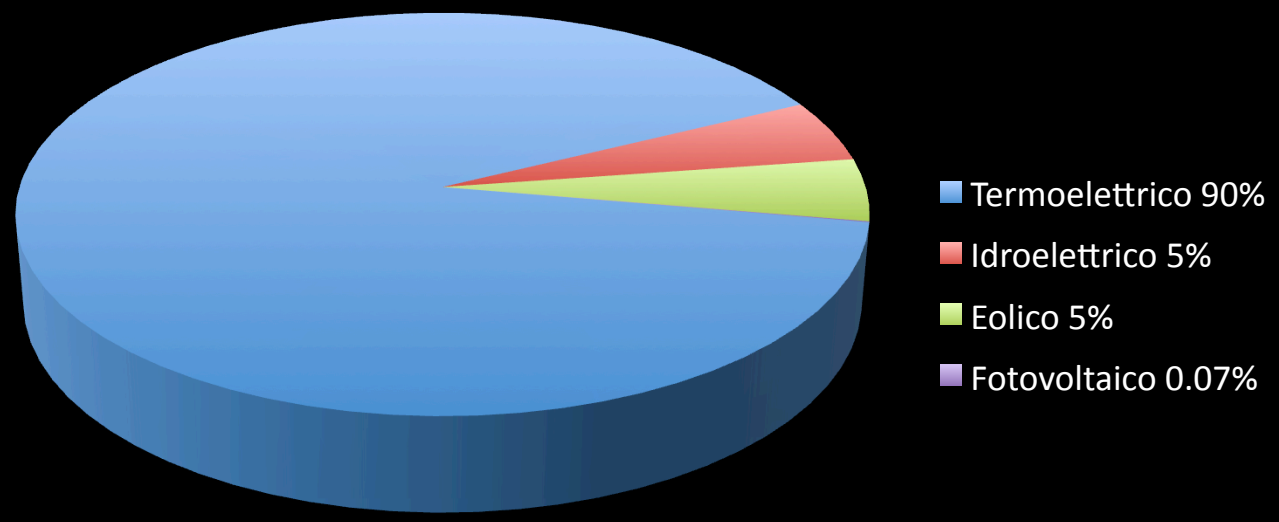
ADNOC Abu Dhabi

Kuwait

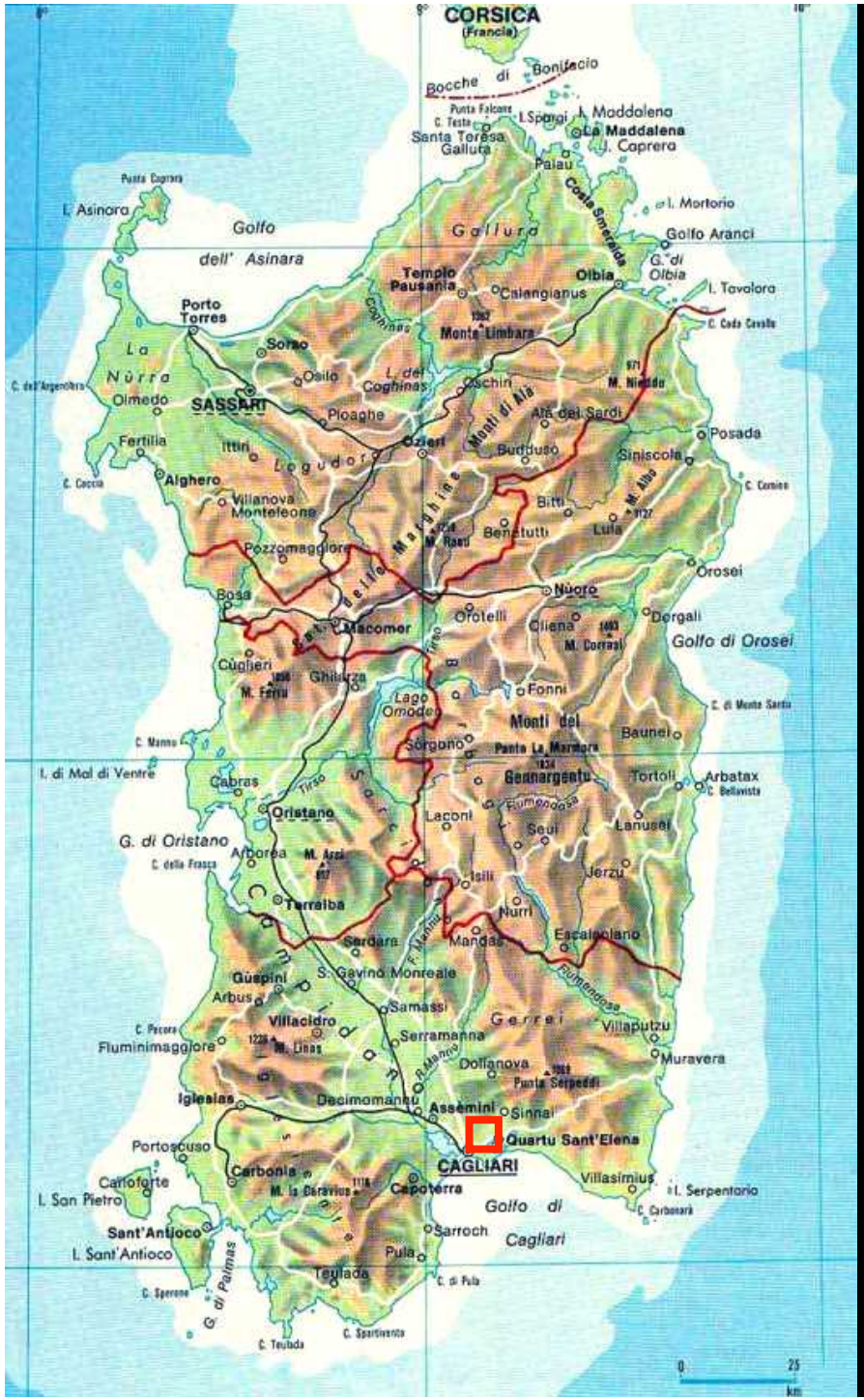
PDVSA Venezuela

bpd = barrels per day

Produzione energetica in Sardegna
(potenza elettrica media 1.5GW)



2008



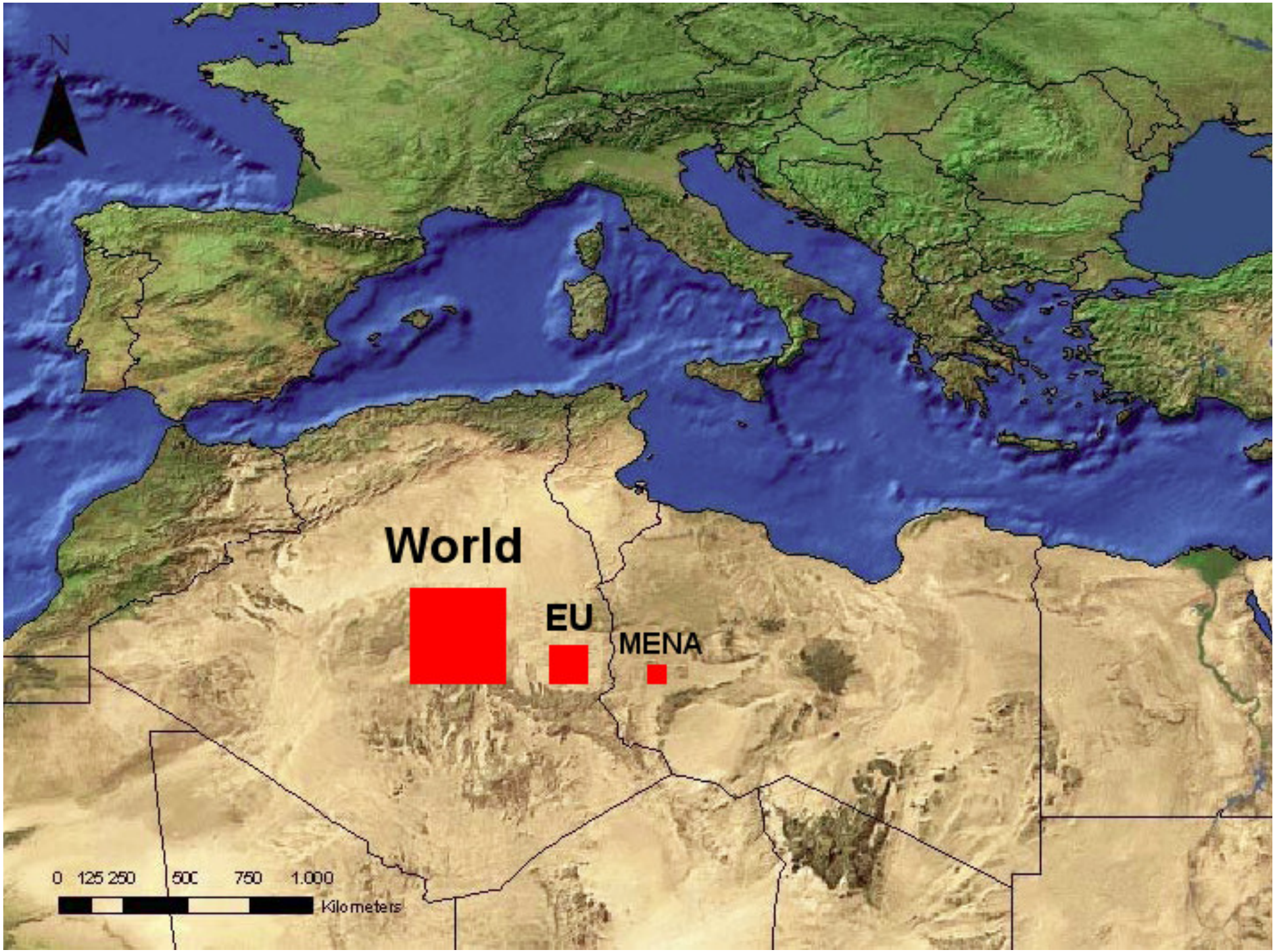
Fabbisogno = 1.5 GW
(≈1000 W/ab)

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

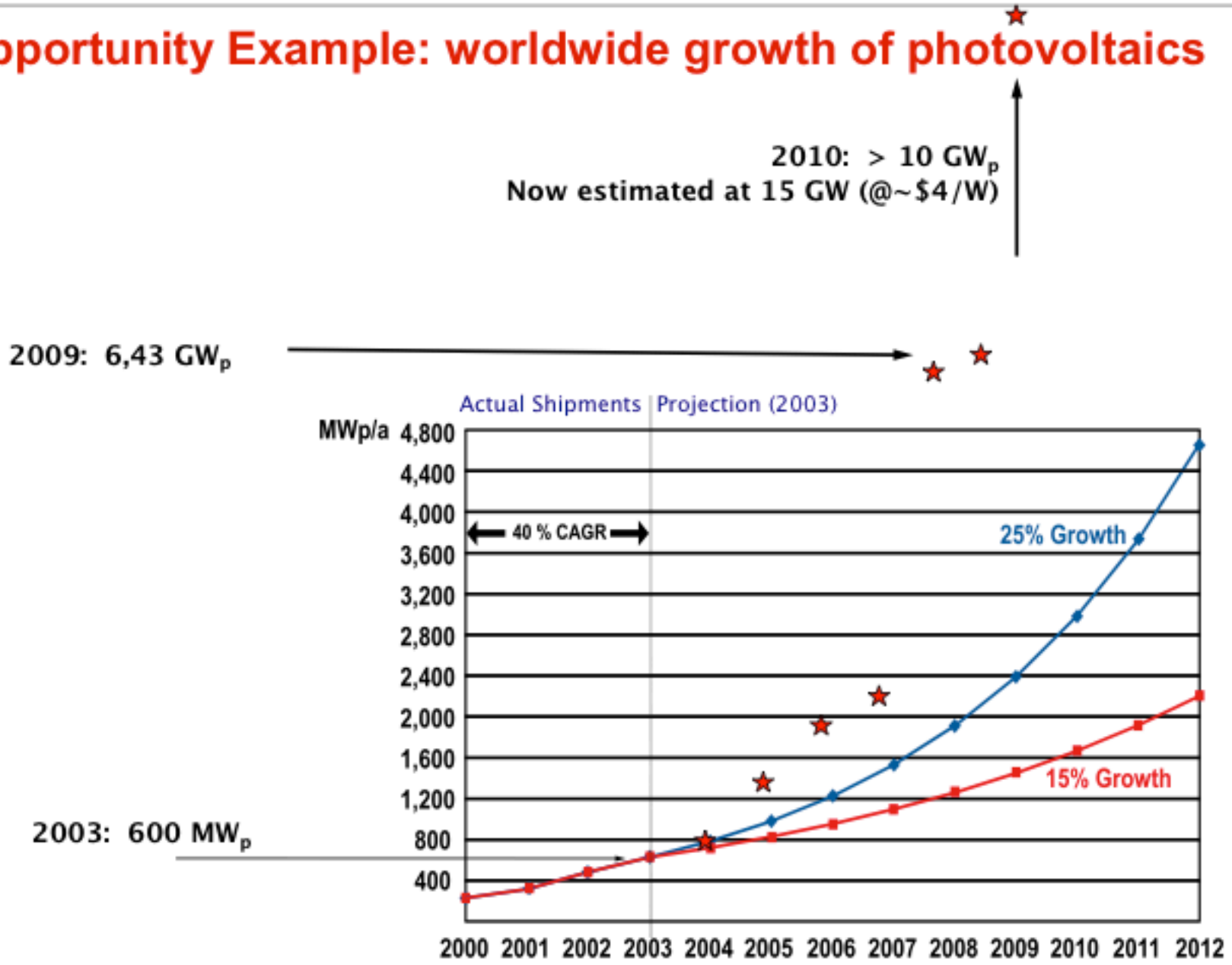
Potenza media cella solare
= 250W/m^2 × 0.10 = 25 W/m^2

Area necessaria =
fabbisogno/potenza media cella

= 60 km^2 (8km×8km, ≈40 m^2/ab)

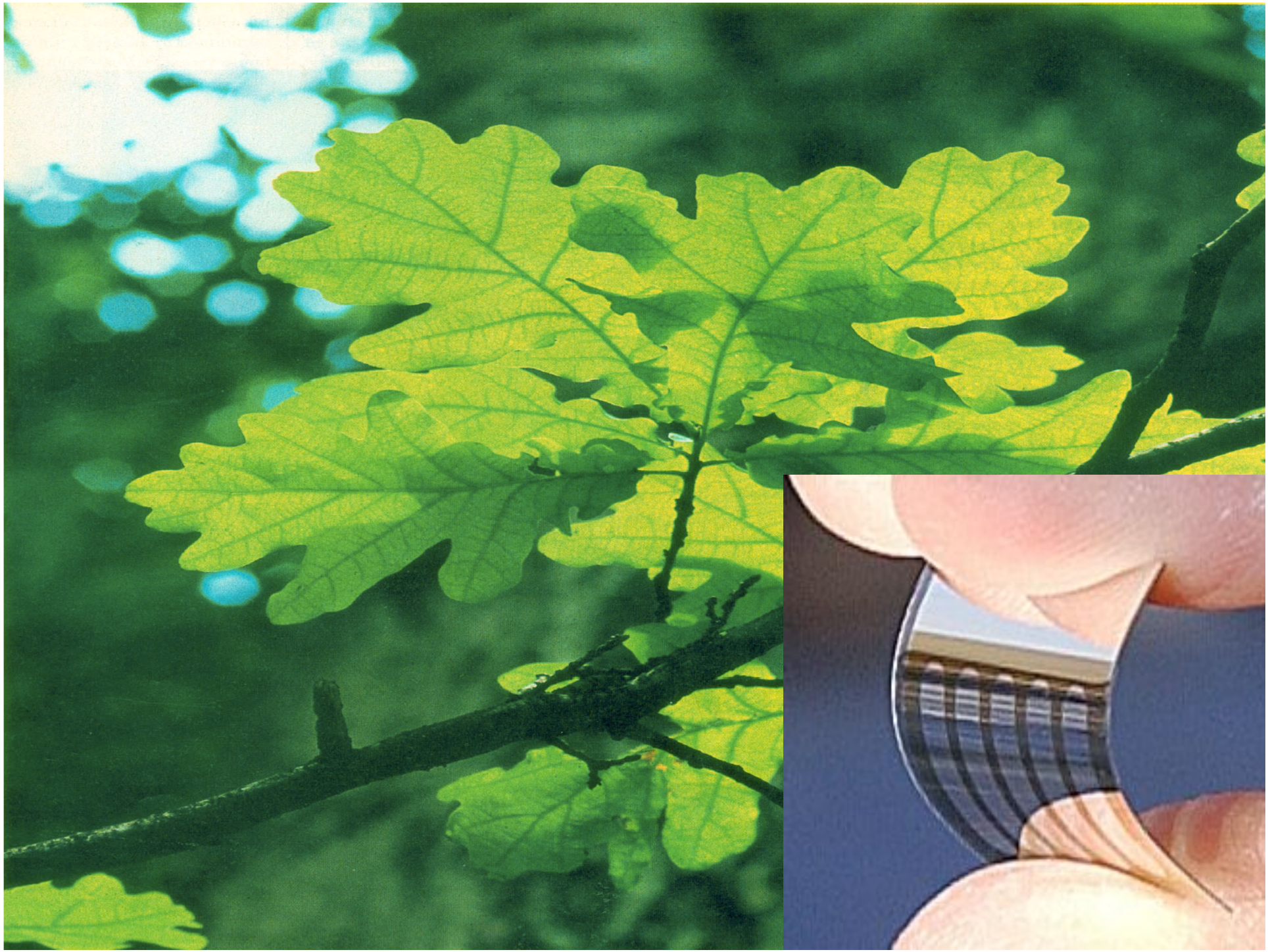

N
World
EU
MENA
0 125 250 500 750 1.000
Kilometers

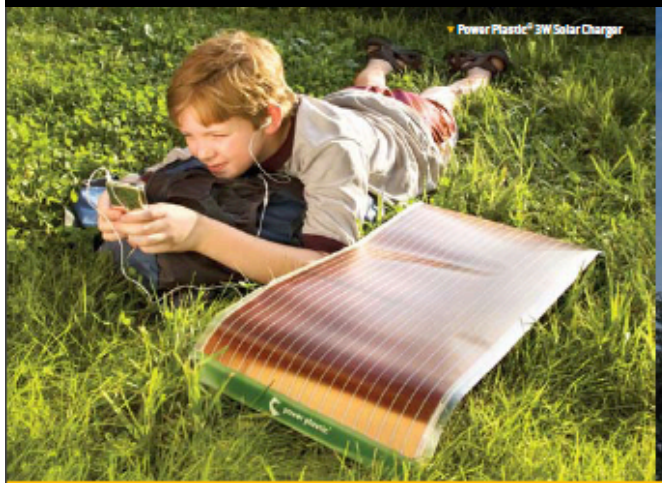
Opportunity Example: worldwide growth of photovoltaics



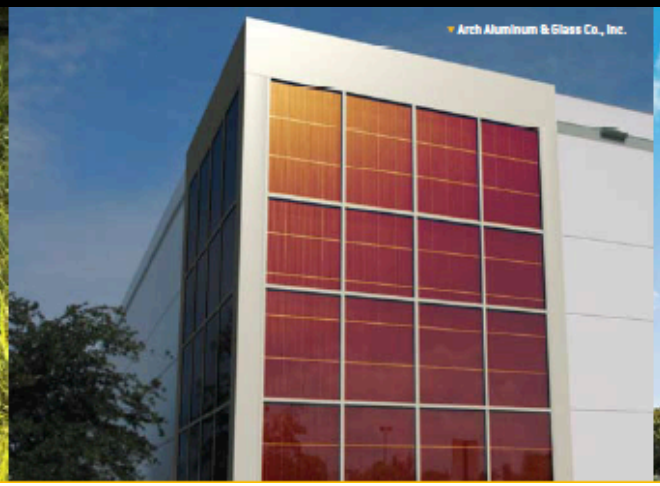
Courtesy Eicke Weber, Fraunhofer Institute for Solar Energy

Sources: 2000-2003 Strategies Unlimited, 2006 EPIA "solar generation", 2007 LBBW Report, 2010 SolarBuzz



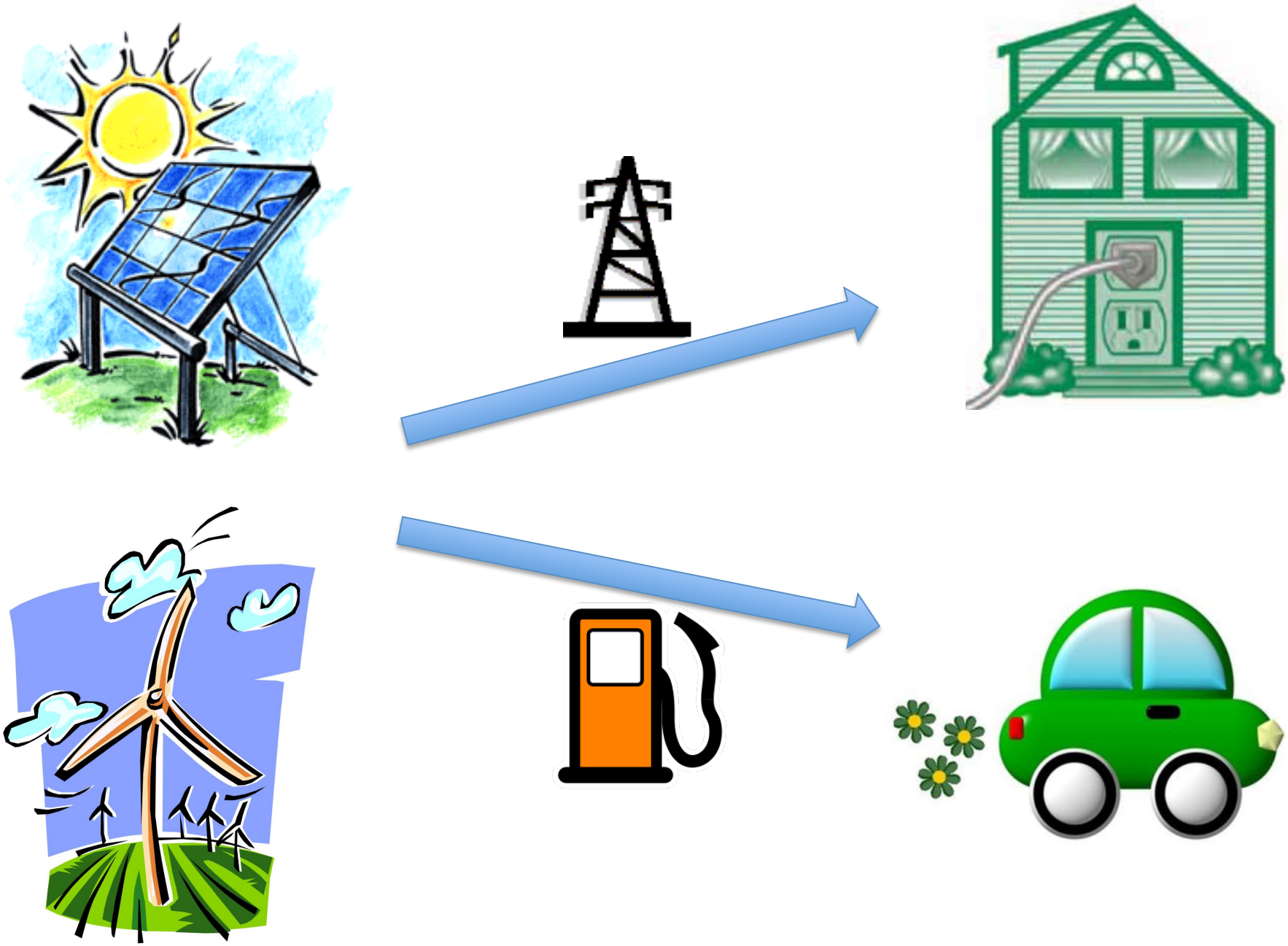


▼ Power Plastic® 3W Solar Charger



▼ Arch Aluminum & Glass Co., Inc.

▼ Transit Shelter, San Francisco, California



Solar Technology Evolution

Solar Thermal:

Harness heat

Steam engine

~25 meV

Single Gap Photovoltaic:

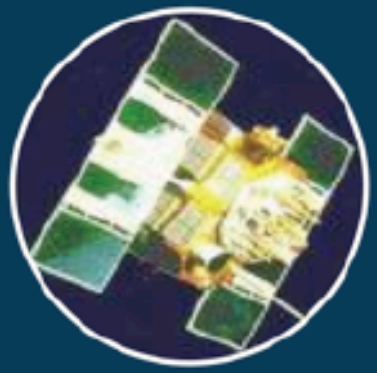
Silicon and Thin Film

~1eV

Photoelectric effect

Up to 24% efficiency

$4-5/W



Multigap cells:

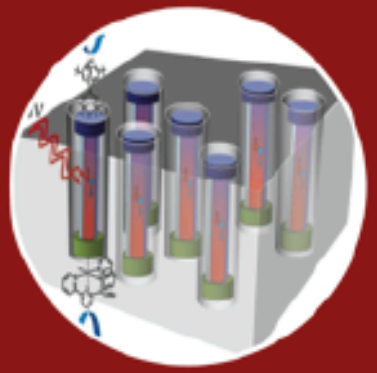
Semiconductor processing

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

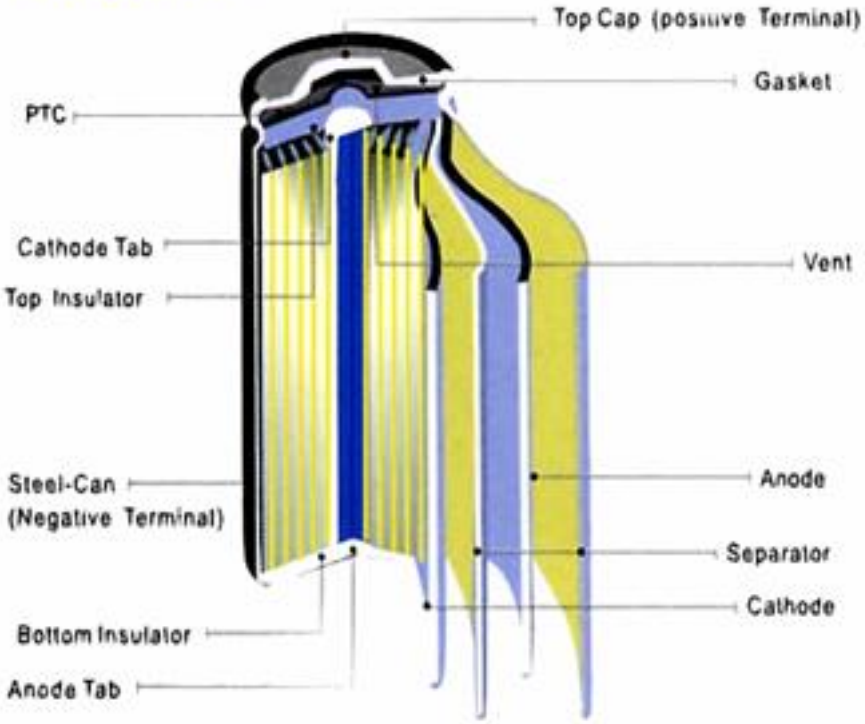
Energia potenziale

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

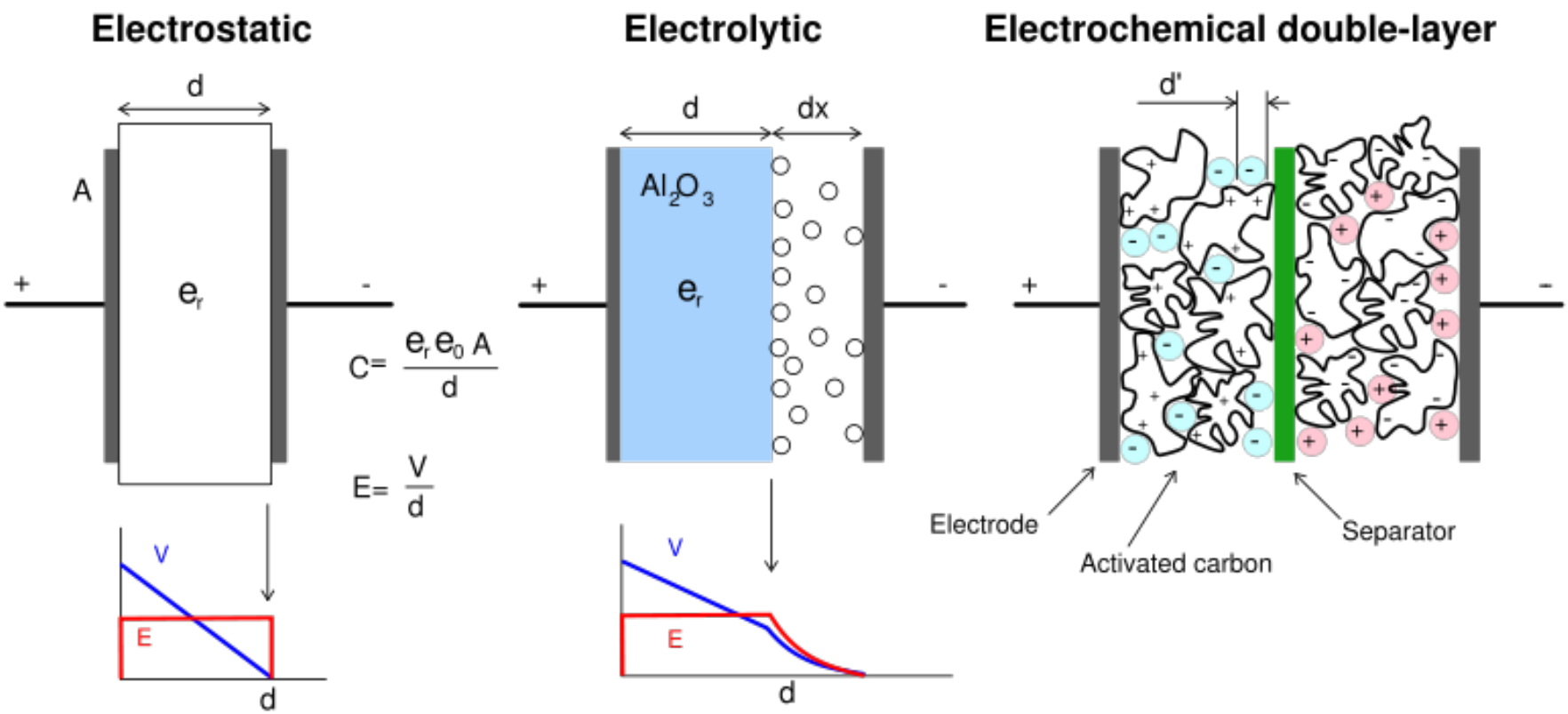
$$V = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r}$$

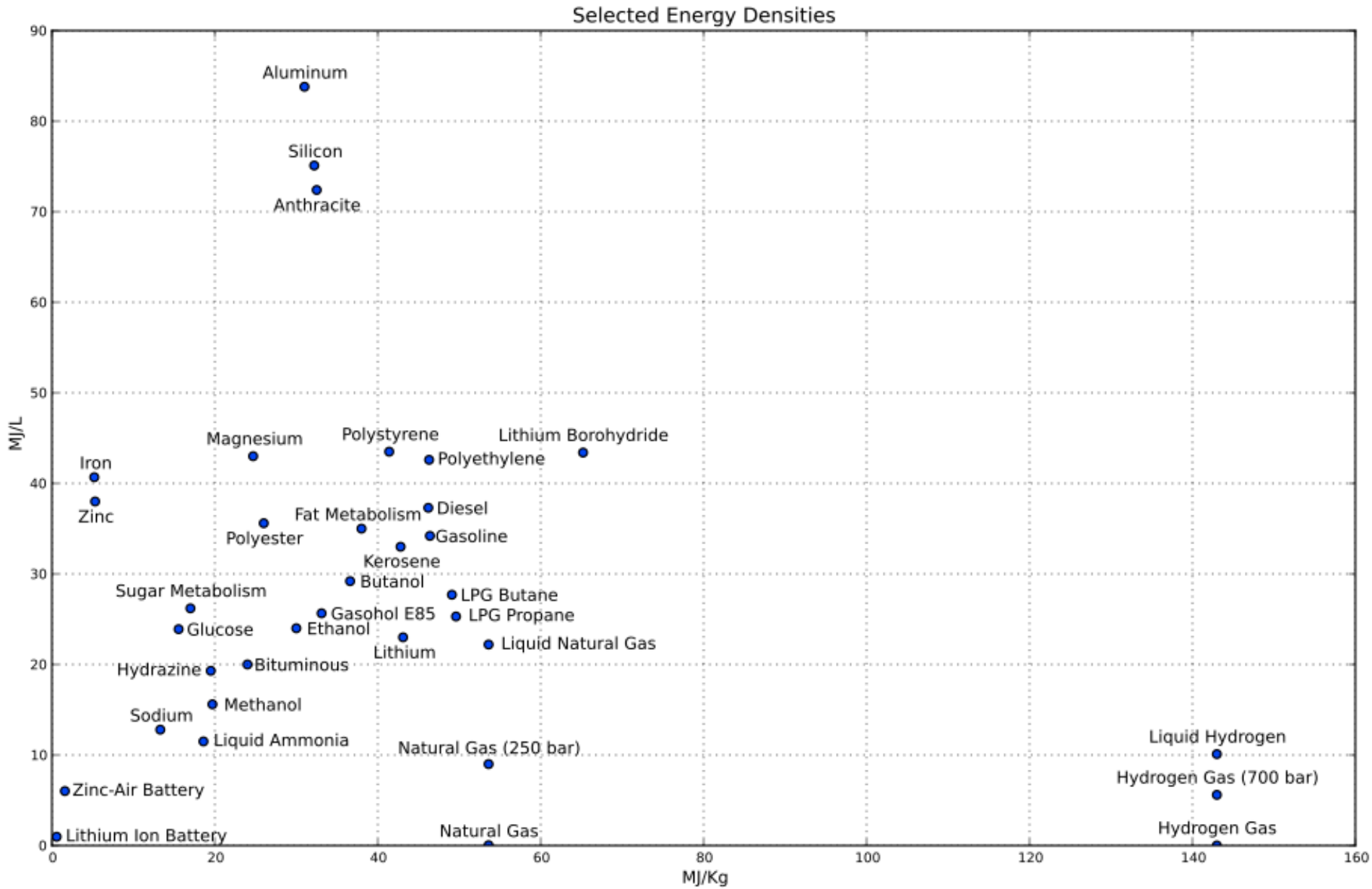
$$U = L = q_2 V = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r} \qquad \frac{1}{4\pi\varepsilon_0} = \left(8.99\cdot 10^9 Nm^2/C^2\right)$$

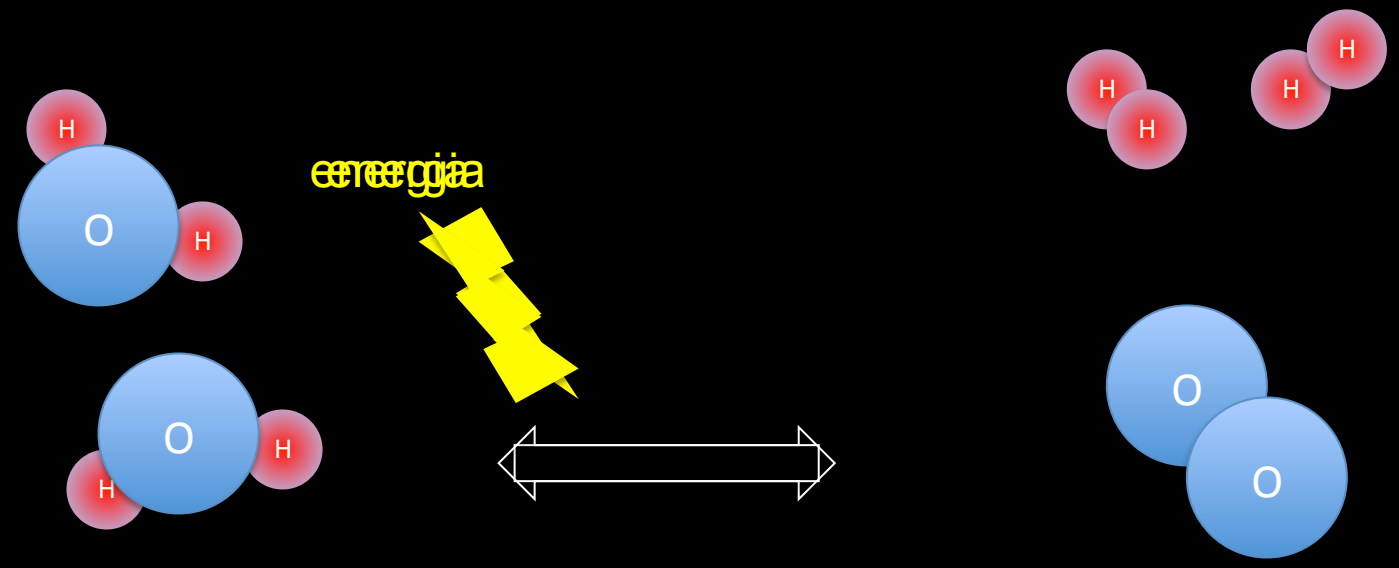
STRUCTURE


Top Cap (positive Terminal)
Gasket
PTC
Cathode Tab
Vent
Top Insulator
Steel-Can
(Negative Terminal)
Anode
Separator
Cathode
Bottom Insulator
Anode Tab

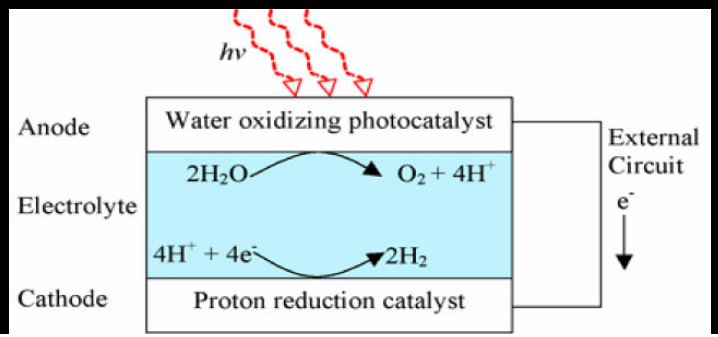

BALANCE
MONITOR
BOOSTCAP
ULTRACAPACITORS
Maxwell
TECHNOLOGIES
WWW.MAXWELL.COM
CAUTION
DO NOT REVERSE POLARITY
430 F | 16 V
BMOD2600-16
TEMP
V2
V1
COMM
LOGIC OUTPUTS
MODULE BALANCE CABLES MUST BE
INSTALLED FOR SERIES APPLICATIONS.
SEE INSTRUCTION MANUAL FOR DETAILS
DO NOT OPEN | DO NOT PUT IN FIRE
IMPROPER USE MAY RESULT IN PERSONAL
INJURY AND/OR EQUIPMENT DAMAGE


Electrostatic
Electrolytic
Electrochemical double-layer
d
A
+
-
e_r
$C = \frac{e_r e_0 A}{d}$
$E = \frac{V}{d}$
V
E
d
dx
Al_2O_3
d'
Electrode
Activated carbon
Separator

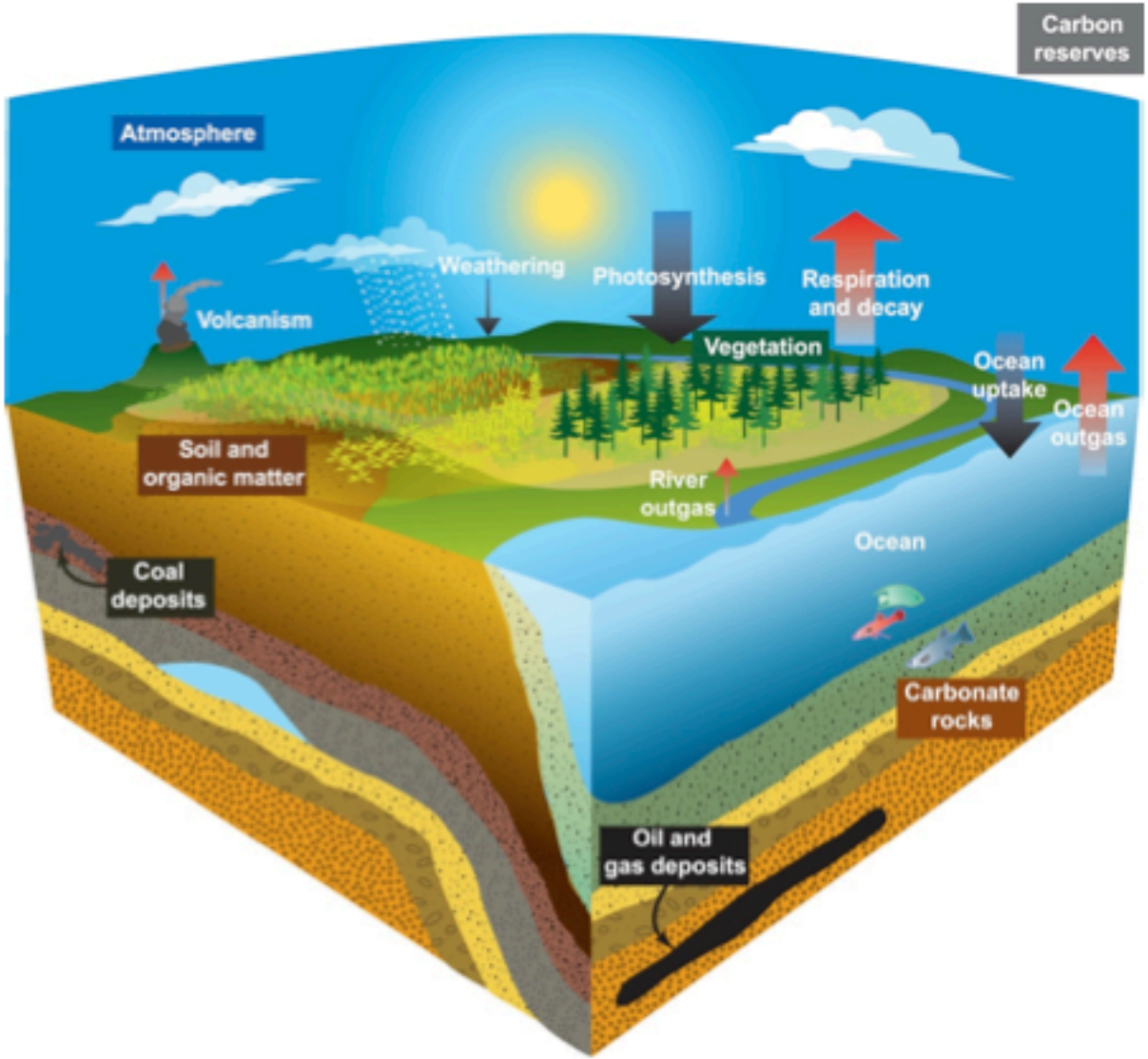

Selected Energy Densities
MJ/L
MJ/Kg
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120
140
160
Aluminum
Silicon
Anthracite
Magnesium
Polystyrene
Lithium Borohydride
Polyethylene
Iron
Zinc
Fat Metabolism
Diesel
Polyester
Gasoline
Kerosene
Butanol
Sugar Metabolism
LPG Butane
Gasohol E85
LPG Propane
Glucose
Ethanol
Lithium
Liquid Natural Gas
Hydrazine
Bituminous
Methanol
Sodium
Liquid Ammonia
Natural Gas (250 bar)
Liquid Hydrogen
Hydrogen Gas (700 bar)
Zinc-Air Battery
Lithium Ion Battery
Natural Gas
Hydrogen Gas


H
O
H
O
H
H
energia
H
H
H
H
O
O

$2\ H_2O$ $2\ H_2 + O_2$


hν
Anode
Water oxidizing photocatalyst
2H₂O
O₂ + 4H⁺
Electrolyte
4H⁺ + 4e⁻
2H₂
Cathode
Proton reduction catalyst
External
Circuit
e⁻

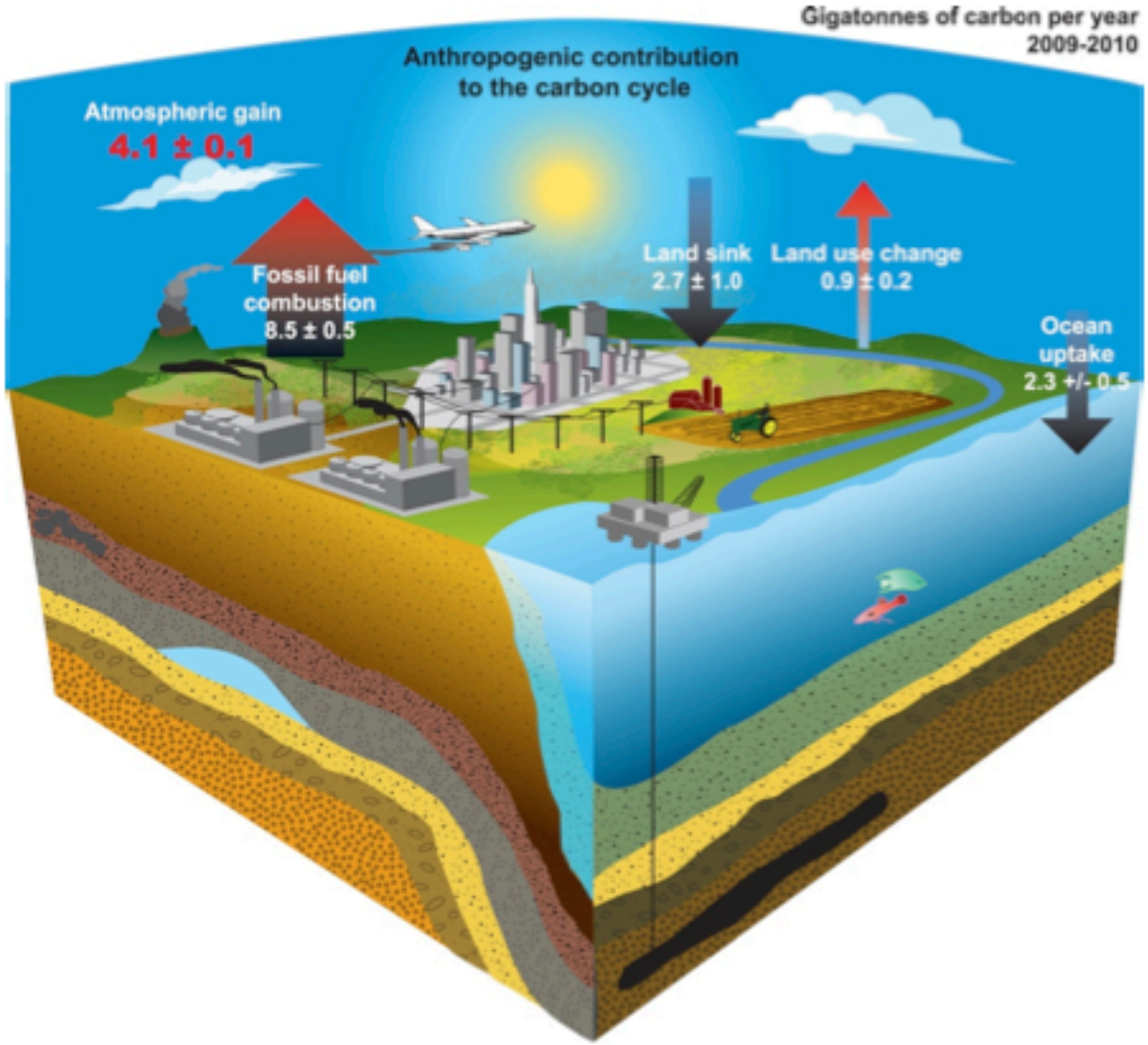
Carbon Cycle 1.0: relatively stable geochemical cycles



50,000 BC - 1750 CE

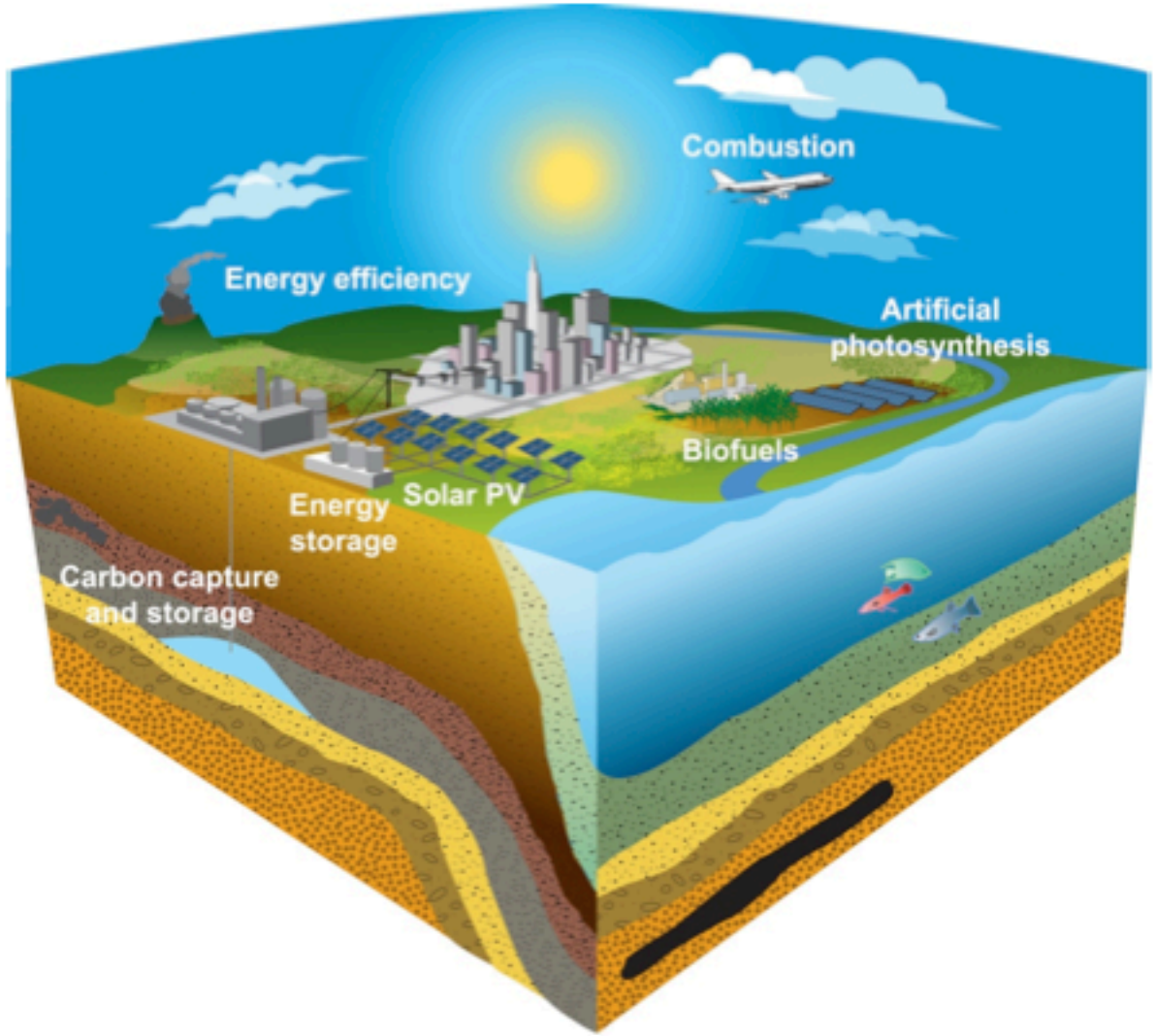
average net atmospheric gain: **0.0 ± 0.02** gigatons carbon per year

Carbon Cycle 1.x: An increasingly perturbed system



Net flux of C due to human activity ~100X 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