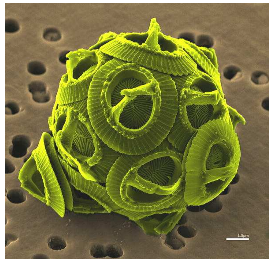
Climate/Energy: Acidification

TEAC8, http://tinyurl.com/zprh78l (2015) http://tinyurl.com/hhlrd4o

What we must know to prevent oceanic extinctions, on track to occur by 2050.



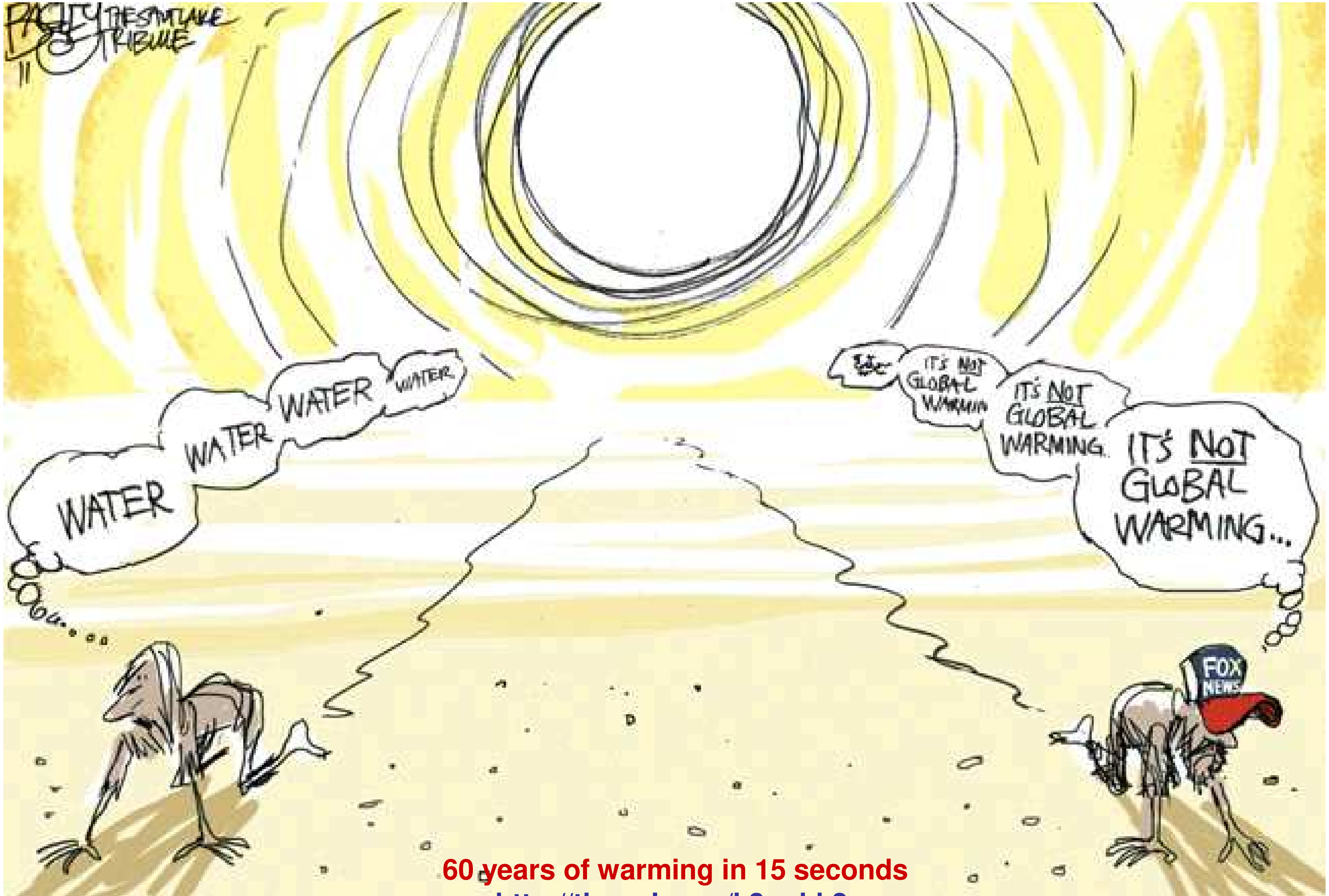
"Let's work the problem.
Let's not make things worse by guessing."

Eugene Kranz,
Apollo 13
Flight Director,
April 1970.

OOPS

Dr. Alexander Cannara
cannara@sbcglobal.net
650-400-3071
17 Jan. 2018

Why Energy From Fire Must Go

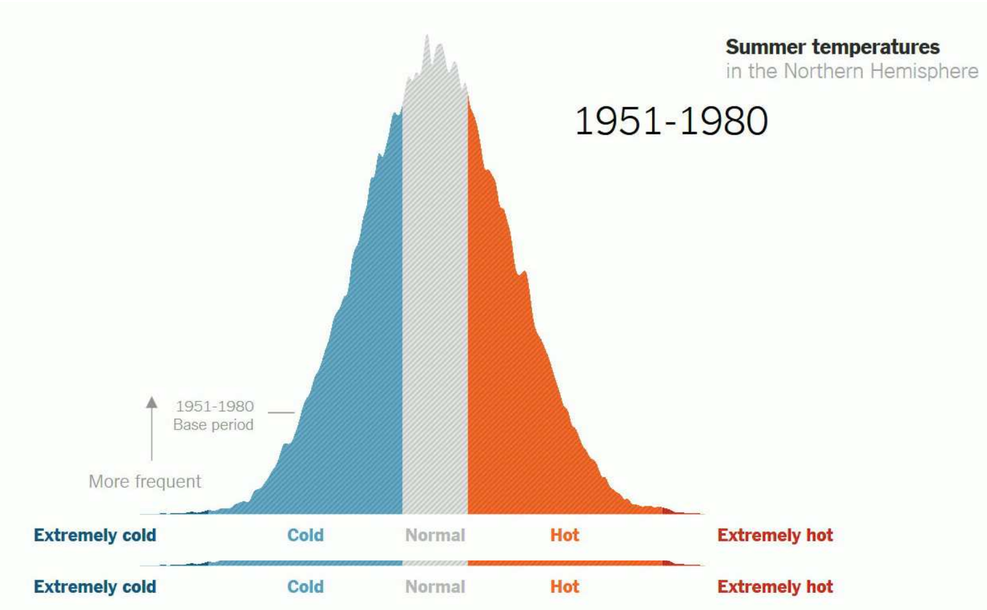


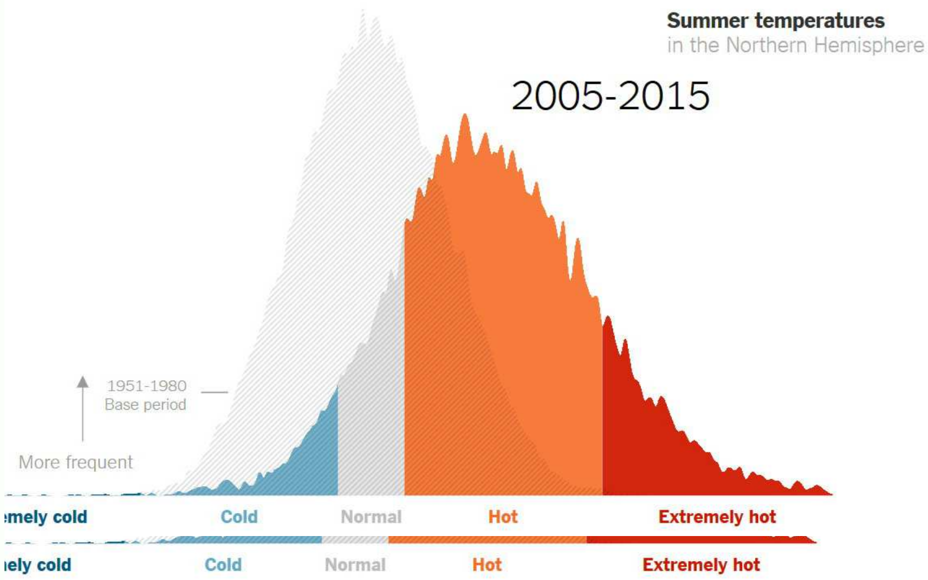
60 years of warming in 15 seconds

http://tinyurl.com/k3guhk2

Warming (1951-2015)

http://tinyurl.com/yaaewjkm
(note animation)

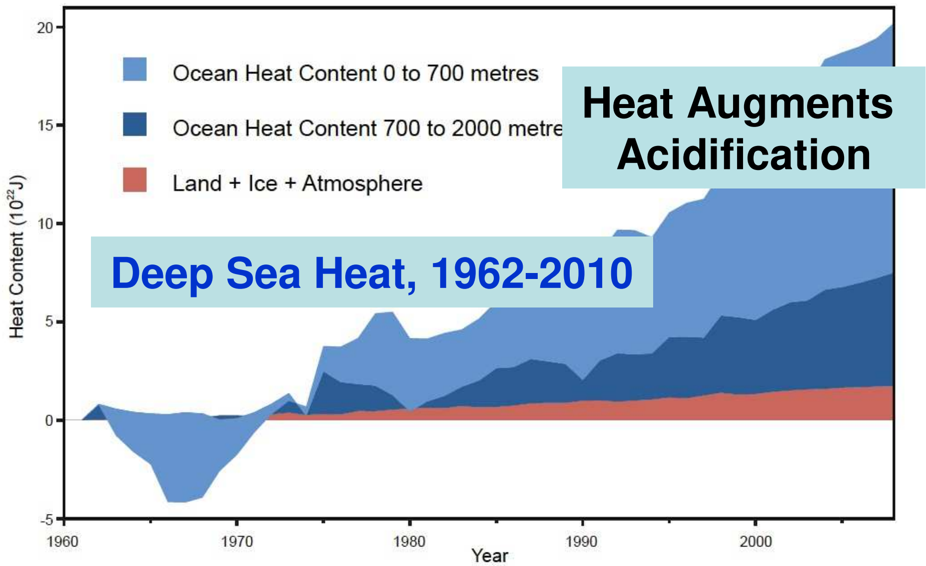


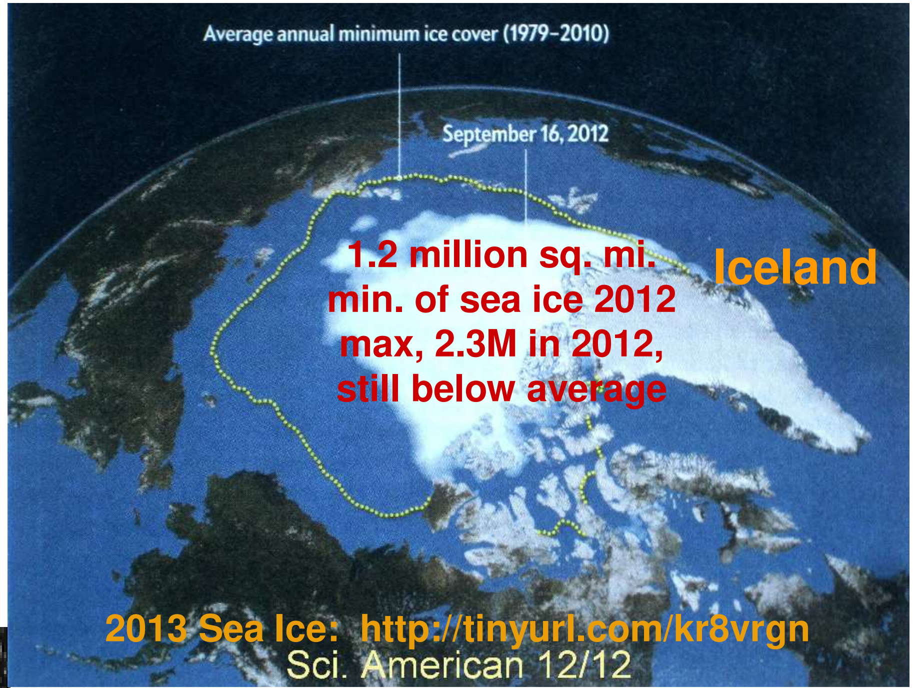


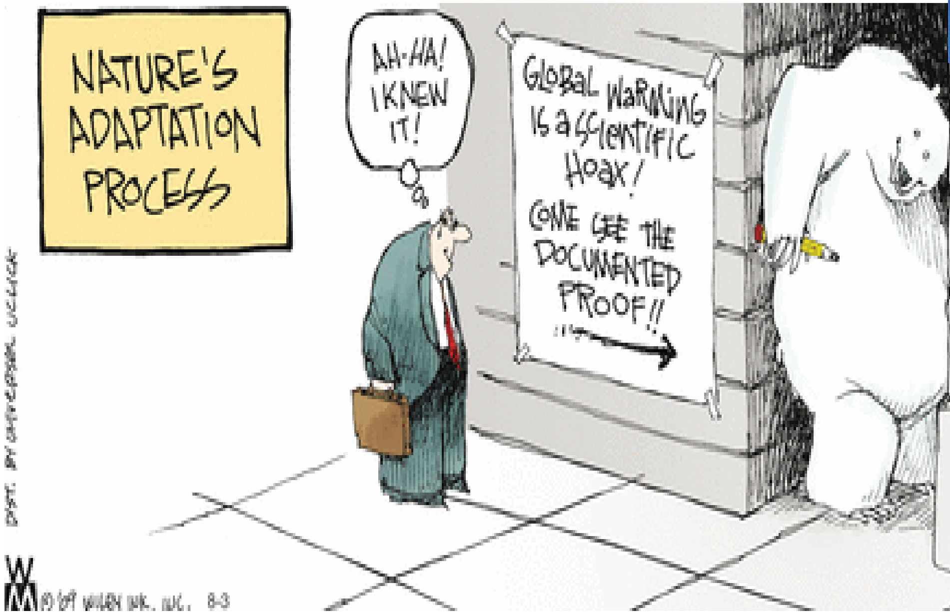
Extraordinarily hot summers (red), that were virtually unheard-of in the 1950s, have become commonplace.

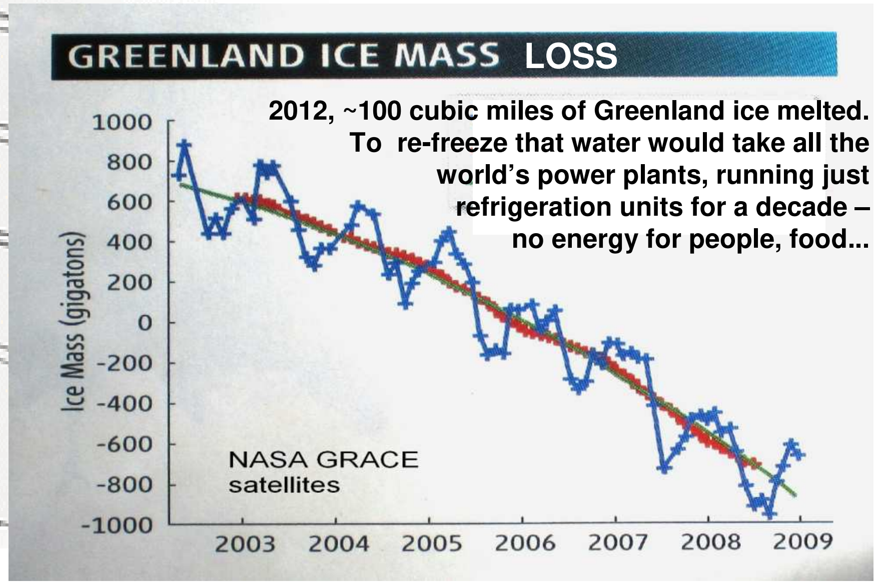
Northern Hemisphere

Emissions Effects: Sea Warming

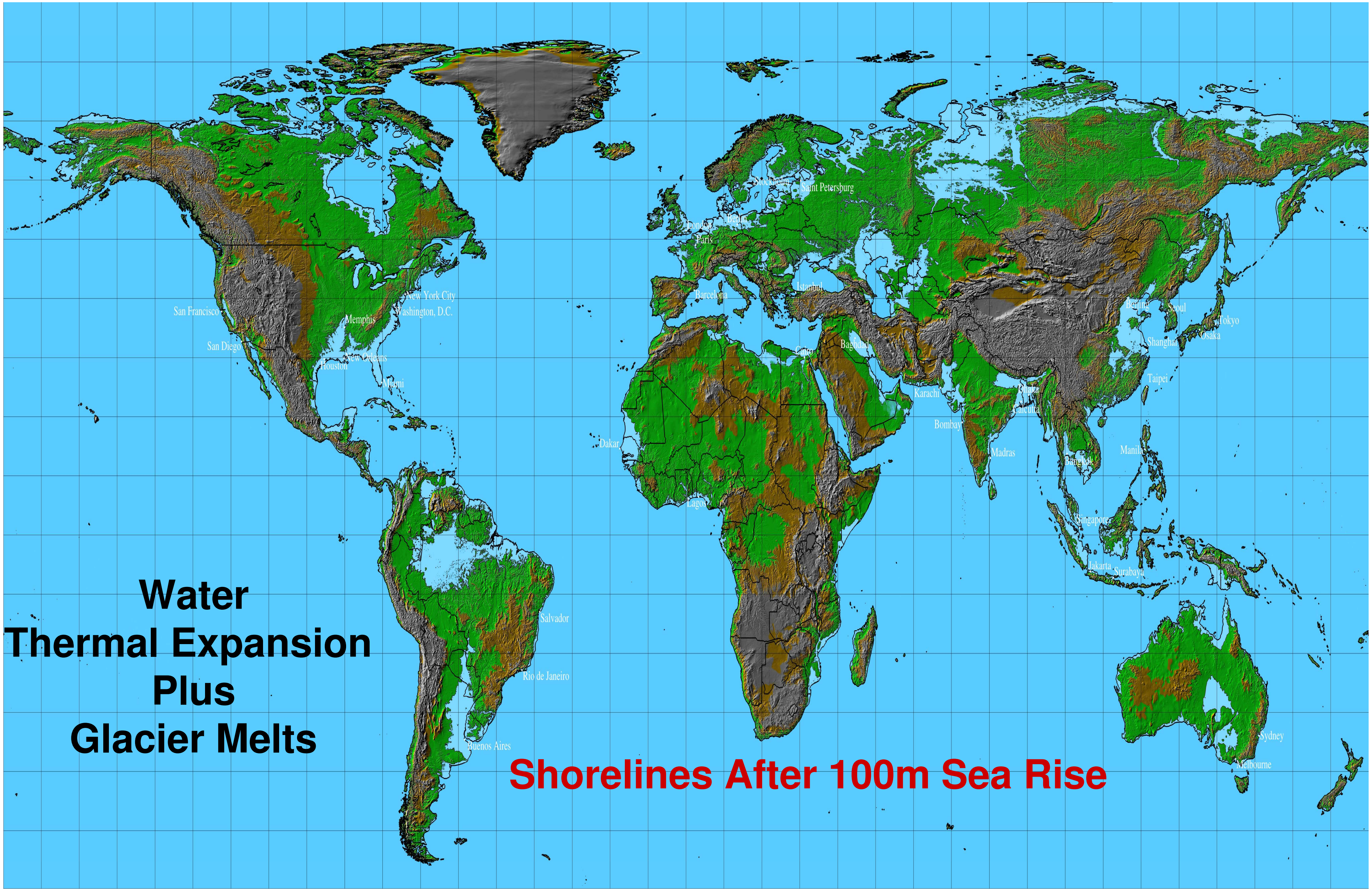






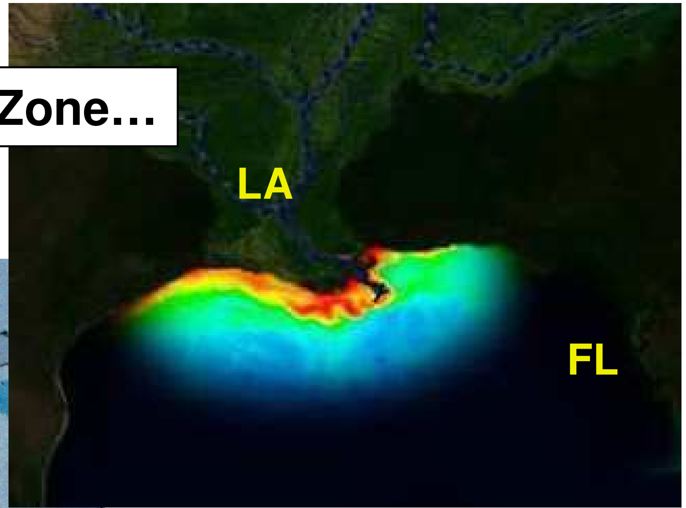


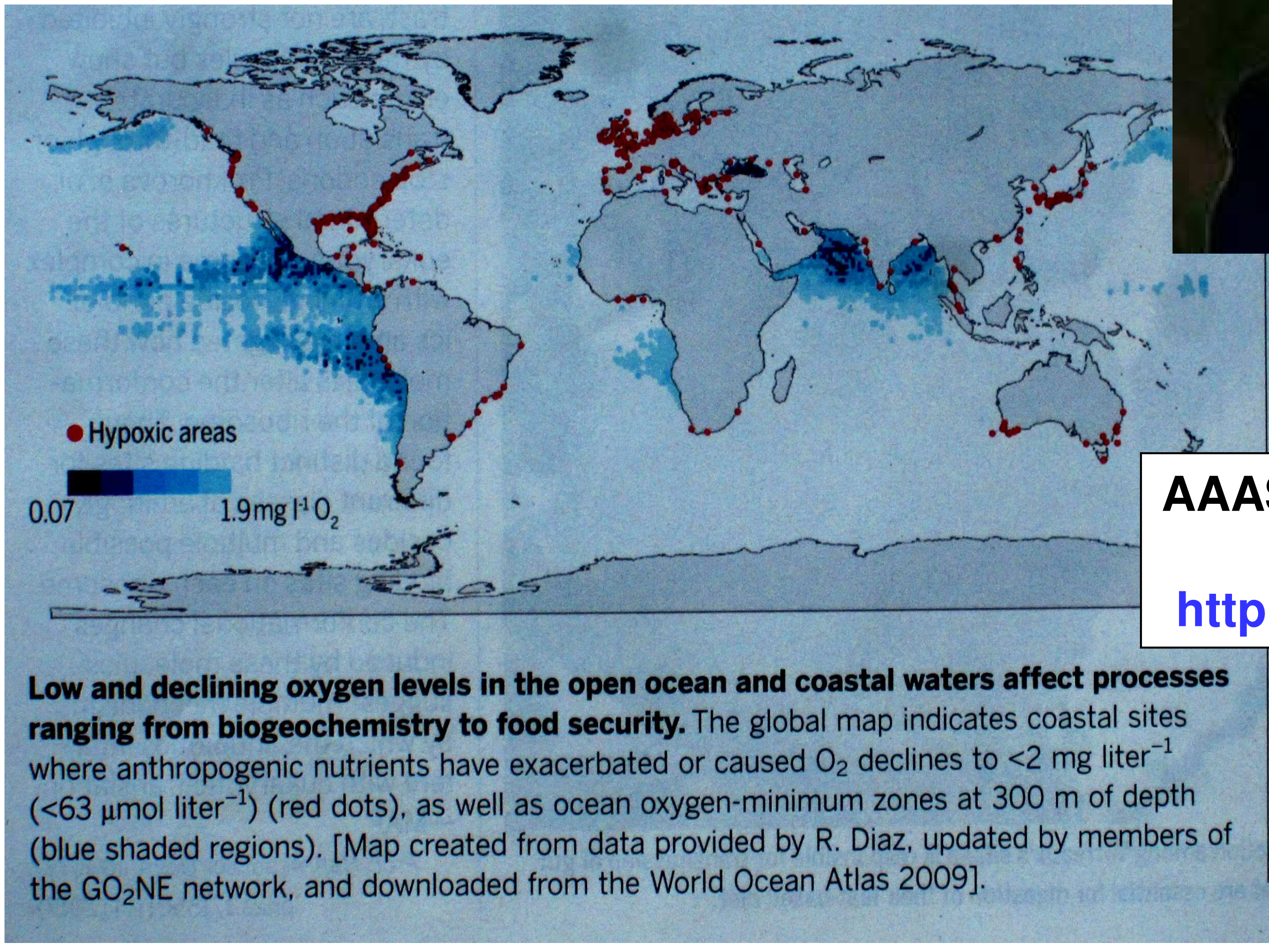
Warming => Sea Rise



Oceanic Oxygen Loss & Extinctions

Gulf of Mexico & Mississippi Dead Zone…

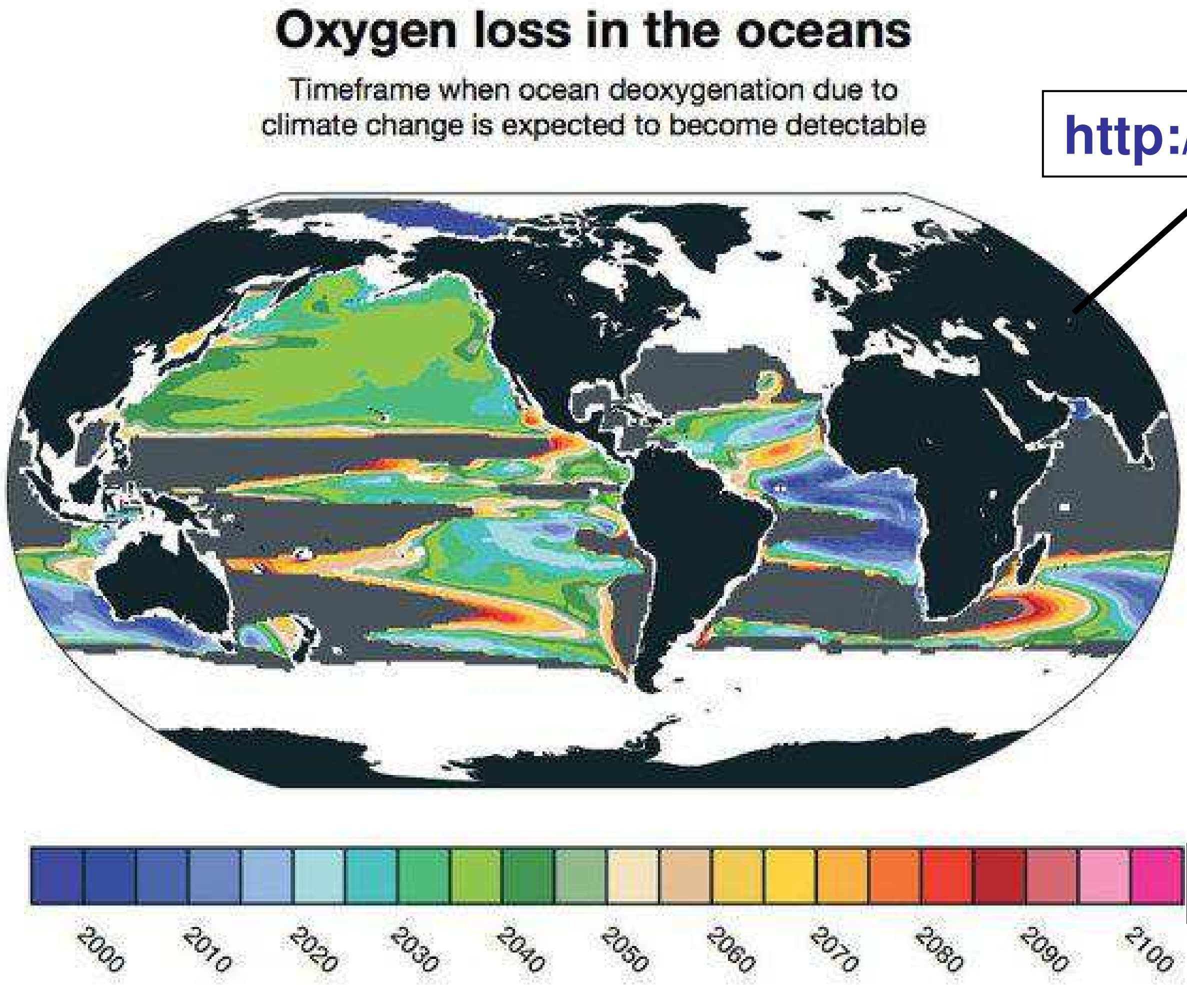




Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security. The global map indicates coastal sites where anthropogenic nutrients have exacerbated or caused O_2 declines to <2 mg liter^{-1} (<63 μmol liter^{-1}) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions). [Map created from data provided by R. Diaz, updated by members of the GO_2NE network, and downloaded from the World Ocean Atlas 2009].

AAAS Science 5 Jan 2018 p46
and
http://tinyurl.com/yd6mkoec

Oceanic Oxygen Loss & Extinctions



http://tinyurl.com/z8dahhk

Dark gray = unaffected until 2100+

Likely detection dstes

Fluvial chemical threats: http://tinyurl.com/yd6mkoec and...
"A short history of ocean acidification science in the 20th century: a chemist's view", P. Brewer, 2013, www.biogeosciences.net/10/7411/2013/

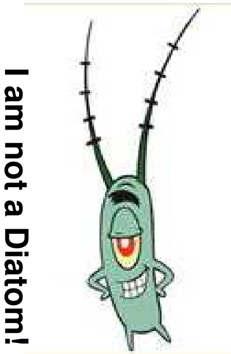
Warming/Acidification Warnings

While Each CO_2 Molecule Stays in Air, It Heats Air ~100,000 Times More Than The Energy Released When Its C Was Burned

- Tyndall & Chamberlin (1800s)…
  - **www.aip.org/history/climate/co2.htm**
  - **https://theconversation.com/life-on-earth-was-nothing-but-slime-for-a-boring-billion-years-23358**
  - **"How Oxygen Stifled Animal's Emergence", AAAS Science, 31 Oct. 2014, p537.**
- Arrhenius (1896, 1905)…

$CO_2 + H_2O \Rightarrow H_2CO_3$ = Carbonic Acid

I am not a Diatom!



On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground

Svante Arrhenius

Philosophical Magazine and Journal of Science
Series 5, Volume 41, April 1896, pages 237-276.

LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

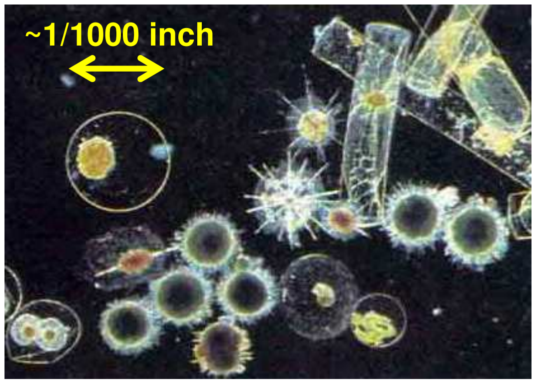
XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

***"Carbonic Acid" is what CO_2 makes when combined with water* – soda pop.**

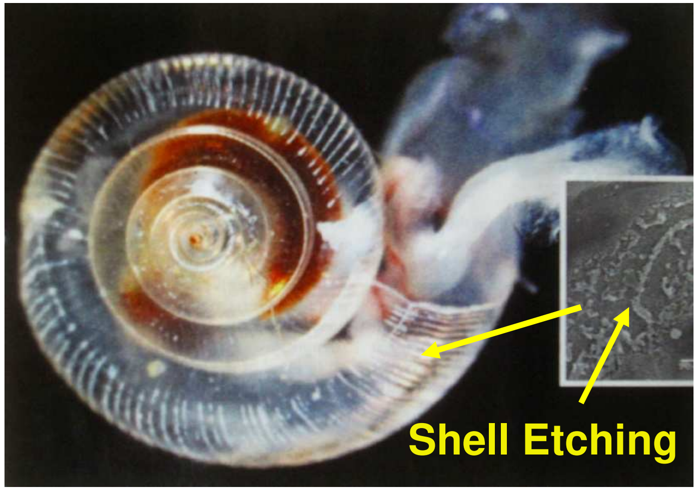
Since seas dissolve CO_2 well, they become more acidic every year we overload the natural Carbon Cycle (among plants, air, water & land) by burning fossil Carbon compounds made millions of years ago by plants, especially ocean Plankton…



Plankton are the initial prey for almost all fish larvae. Their Carbonate shells sink when they die, removing Carbon to sea floors & they make most of our Oxygen.

Acidification

"Lethal Seas" -- PBS Nova 2015



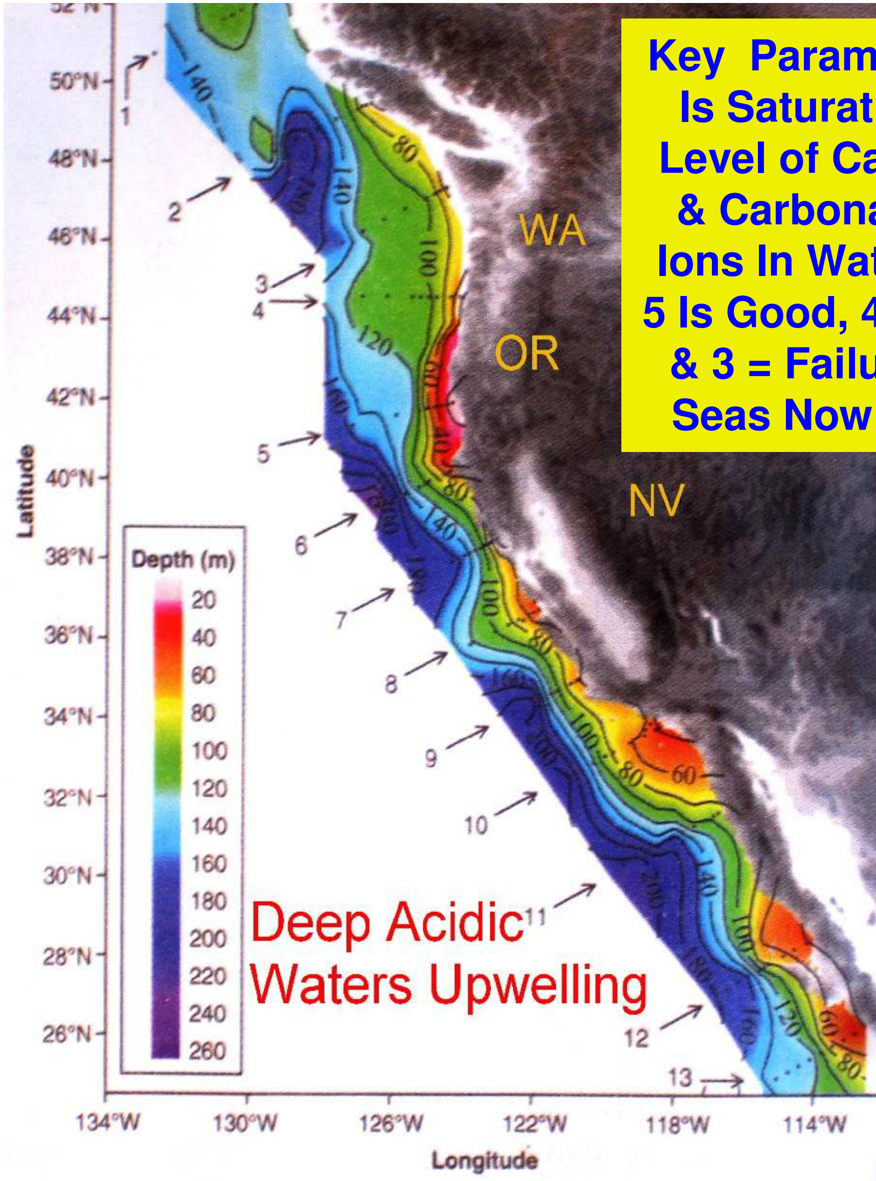
AAAS Science, Vol 344, 9 May 2014, p569

Oyster Stress, http://tinyurl.com/lqrj5v7
http://tinyurl.com/pfjc4ud

Deformed Animals

Also see April 2013 Scientific American

www.tos.org/oceanography/archive/22-4_kump.html



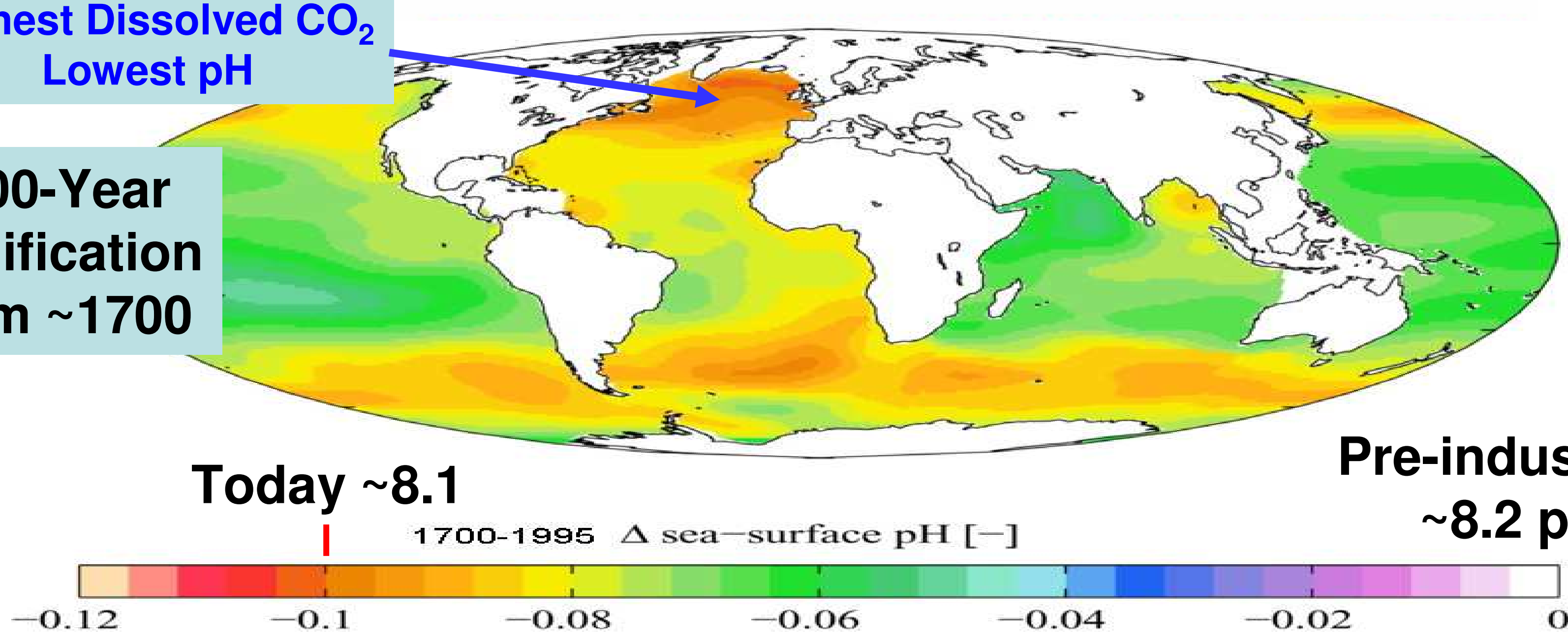
Key Parameter Is Saturation Level of Ca/Mg & Carbonate Ions In Water – 5 Is Good, 4 not, & 3 = Failure. Seas Now ~4.

Emissions Effects: Sea Chemistry

Oceans are Acidifying Fast **-- Ceasing All CO_2 Emissions Has Little Effect**

Highest Dissolved CO_2
Lowest pH

~300-Year Acidification From ~1700



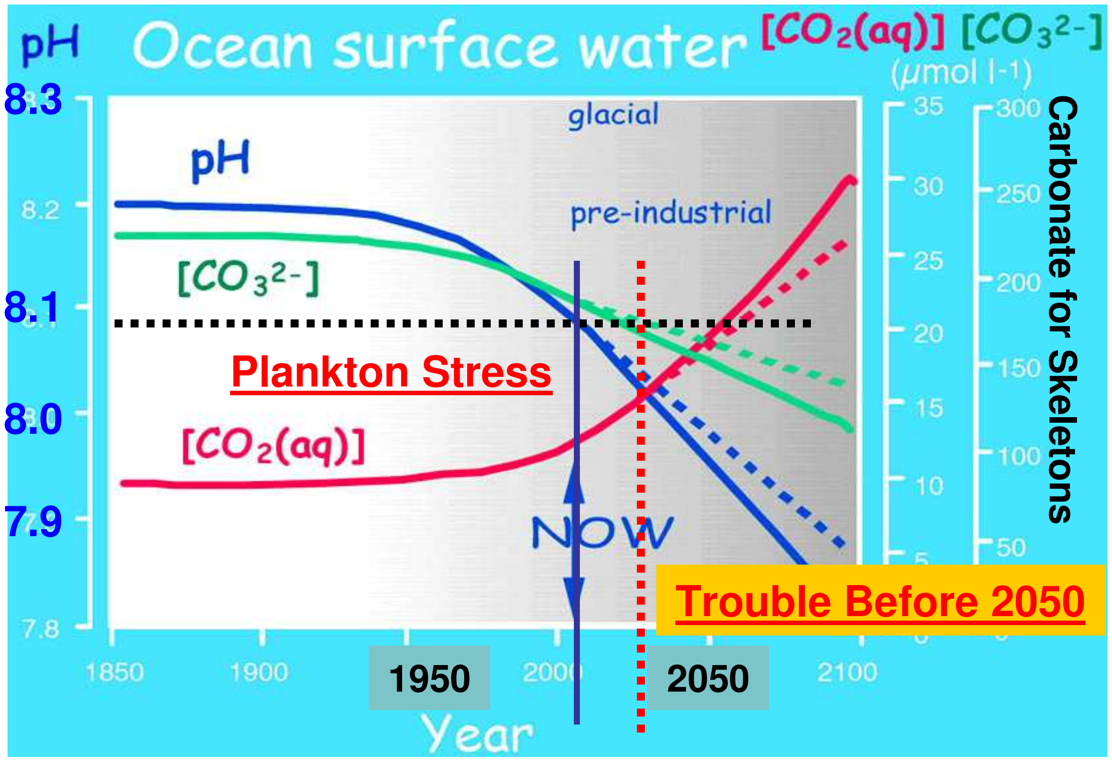
Today ~8.1

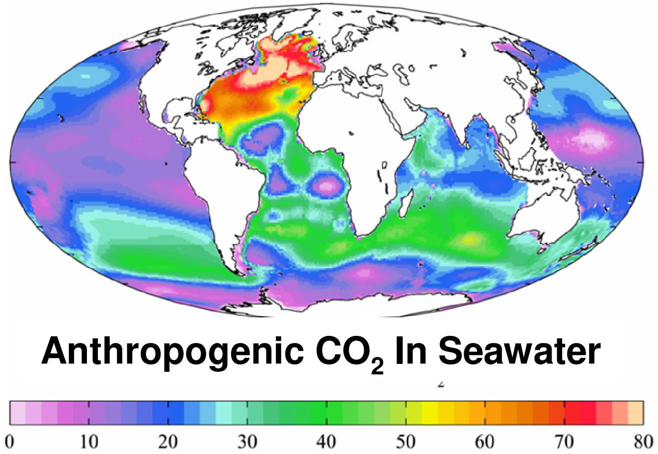
Pre-industrial ~8.2 pH

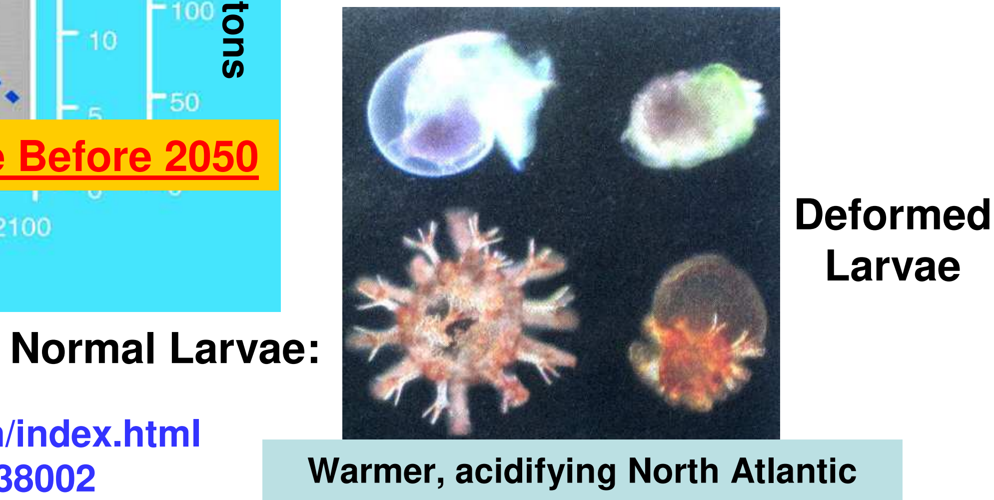
Acidification & Extinctions

<u>~30% of all ~1.5 trillion tons of CO_2 emissions are now in oceans</u> creating less alkaline seawater, affecting entire sea food chains -- <u>sea life provides ~20% of all human food protein</u> – "*The Sixth Extinction*" by Kolbert 2014

www.kqed.org/a/forum/R201405260900

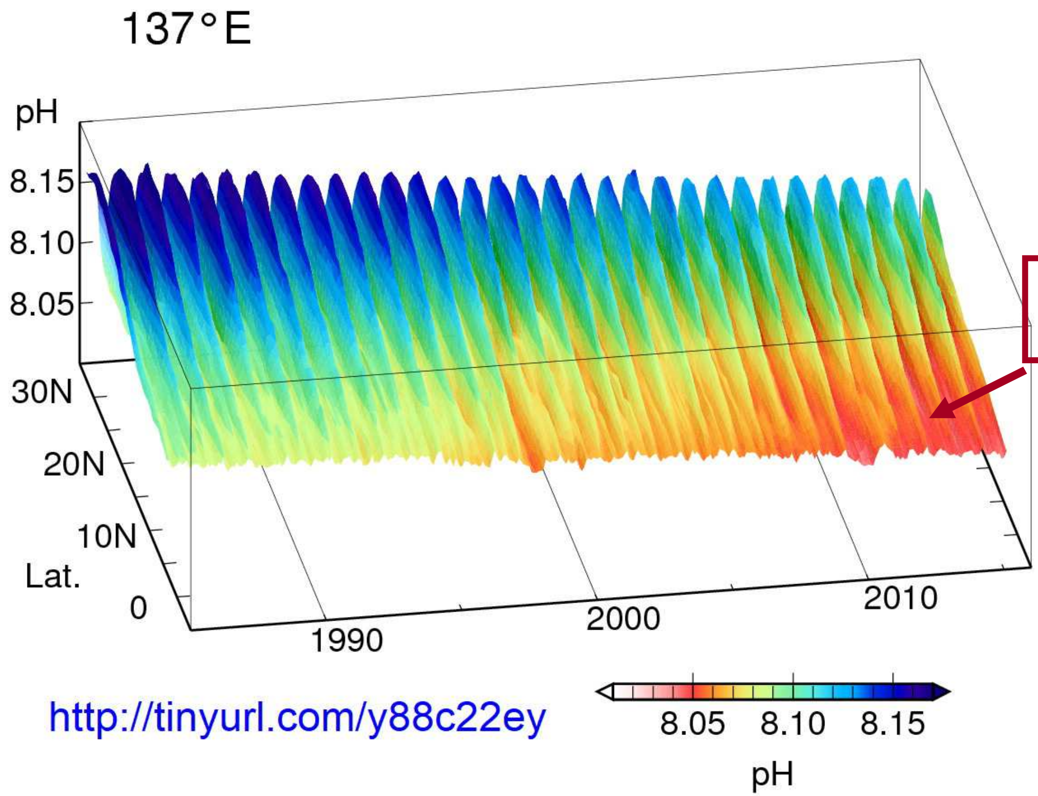






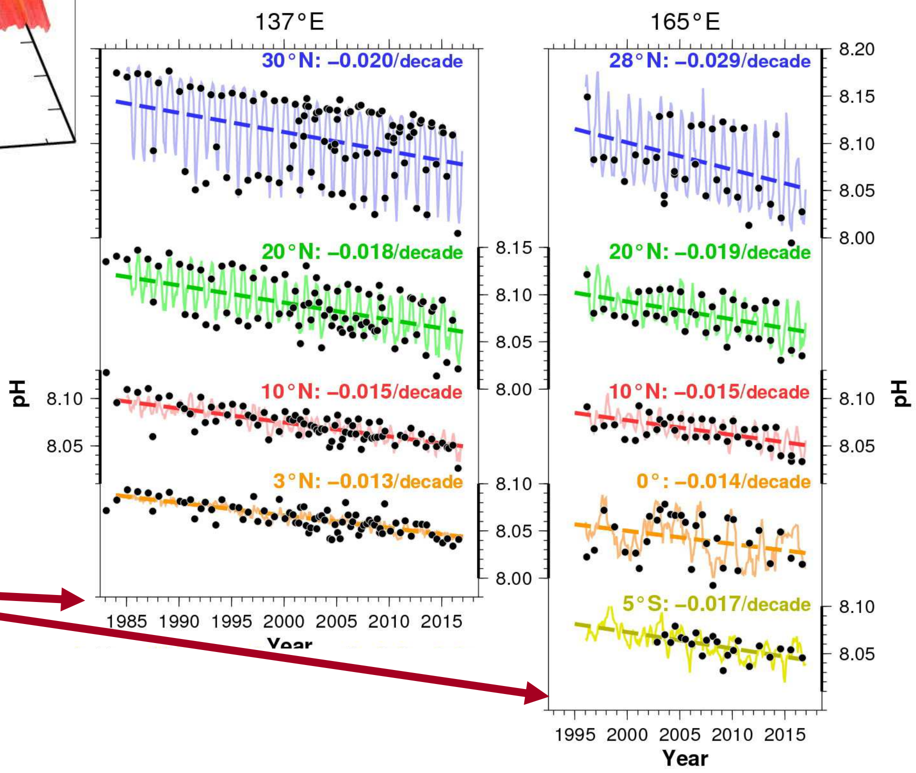
www.ocean-acidification.net/
http://tinyurl.com/6mtd8db
www.noaa.gov/video/administrator/acidification/index.html
www.bbc.co.uk/news/science-environment-18938002

Western Pacific pH 1986-2016



http://tinyurl.com/y88c22ey

Extinctions Below 8.0pH

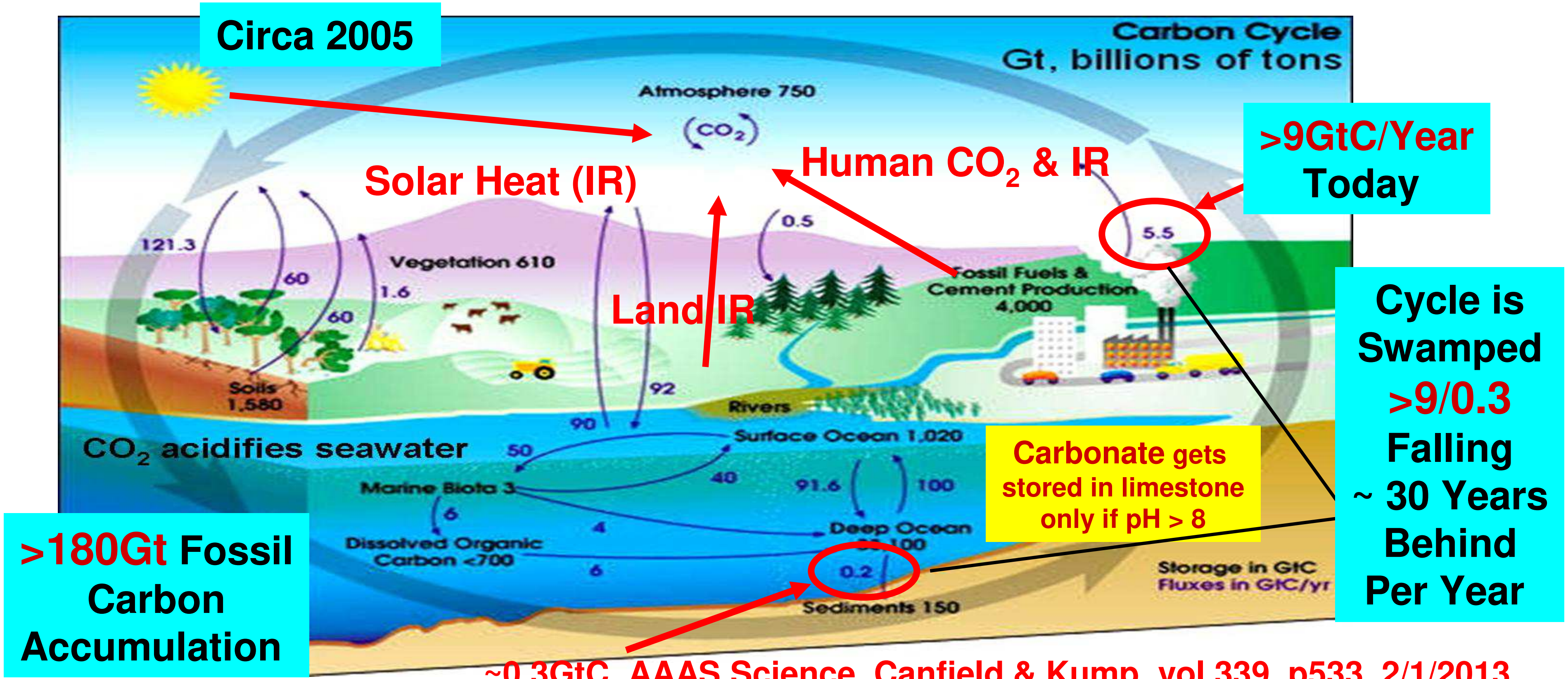


Extinctions Below 8.0pH

Acidification & Remediation (3 Numbers)

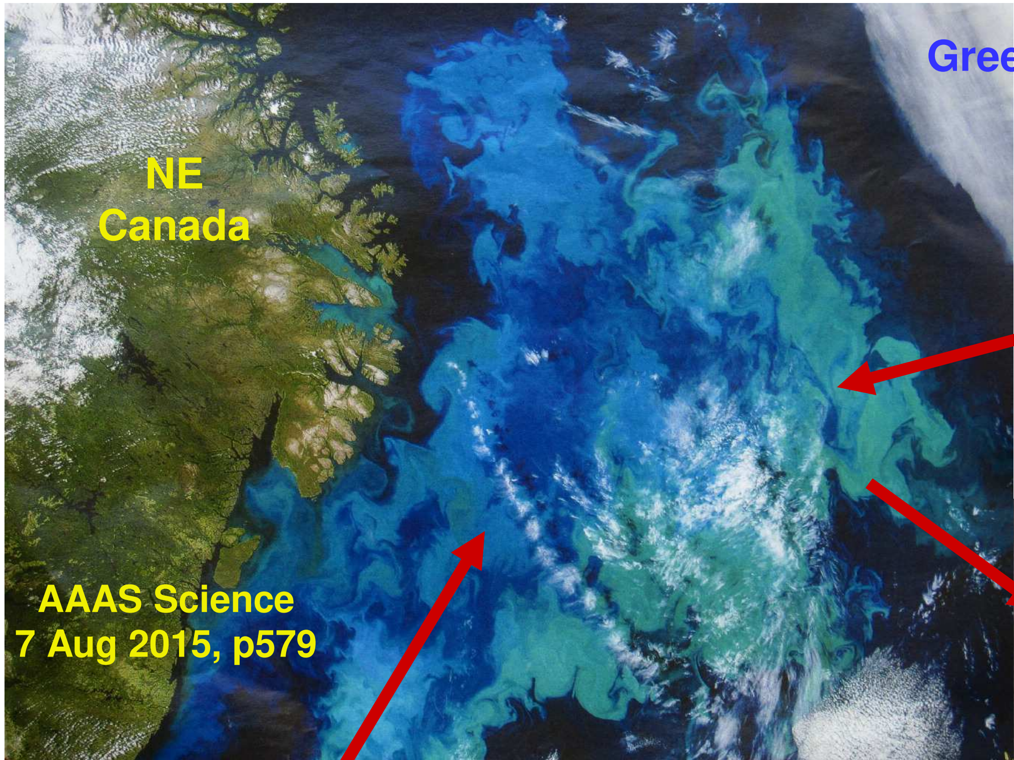
Cyanobacteria, plankton & algae produced most of the Oxygen we have to breathe & use, starting >2 billion years ago, with earliest photosynthesizing ocean life. Land plants later evolved & helped. All fossil fuels we dig up were made from plant decay. Carbon emissions today are **>9GtC** (>30Gt CO_2)

www.ocean-acidification.net
www.atmo.arizona.edu/courses/fall07/atmo551a/pdf/CarbonCycle.pdf
www.annualreviews.org/doi/abs/10.1146/annurev.earth.031208.100206?journalCode=earth

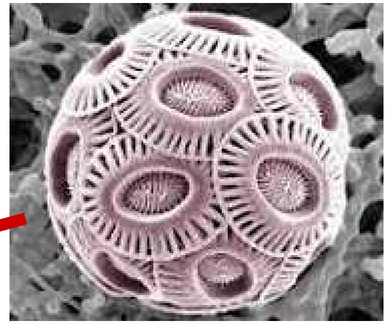


~0.3GtC, AAAS Science, Canfield & Kump, vol 339, p533, 2/1/2013

Emissions Effects: Algal Blooms



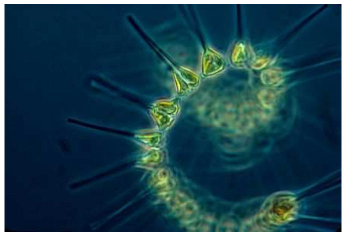
~0.000001 Meter

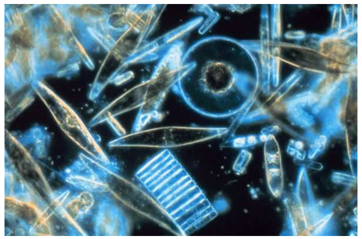


Coccolith: Calcite Shields Around Single Algal Cell of *Emiliania Huxleyi*

https://en.wikipedia.org/wiki/Coccolith

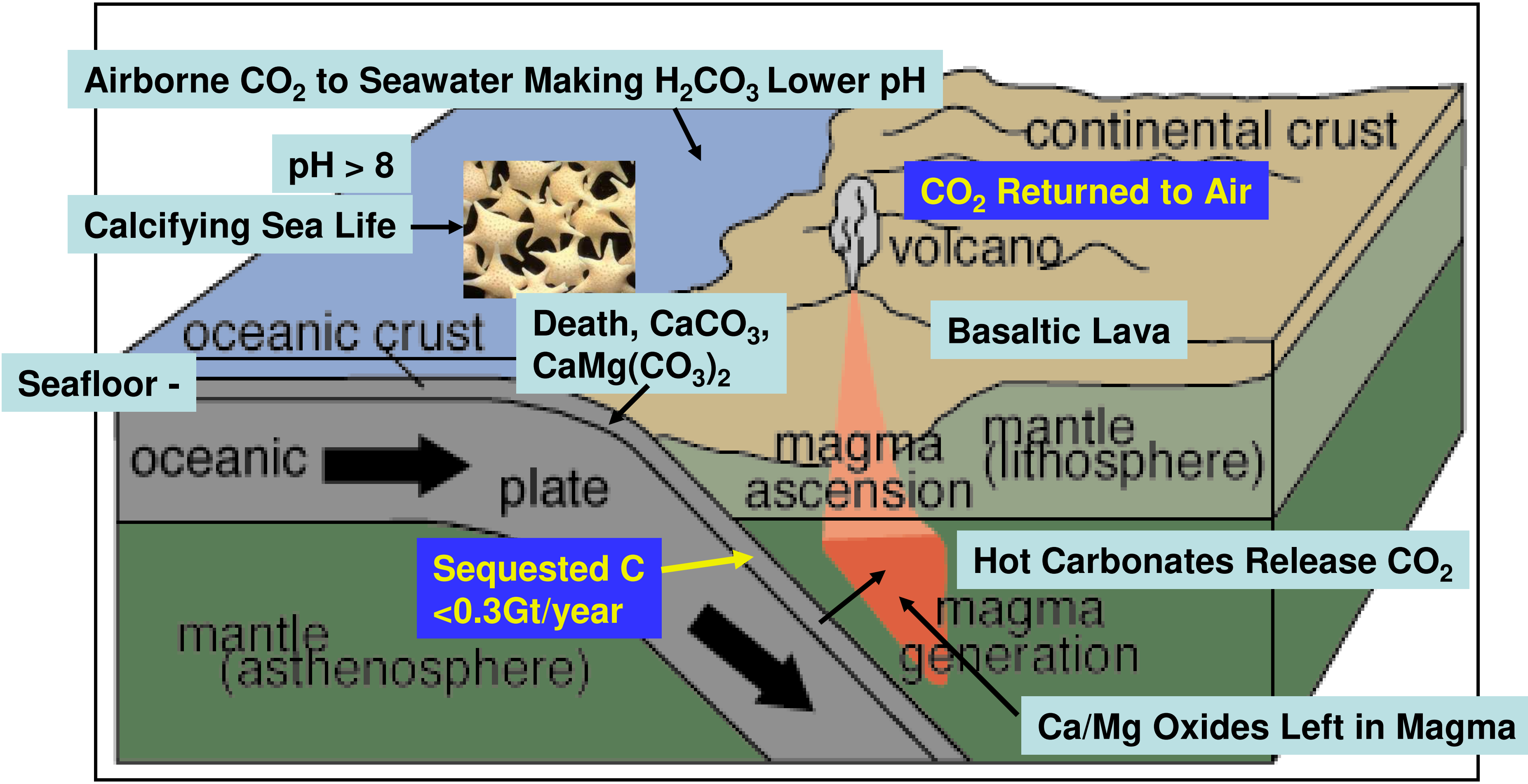
Arctic Algae Blooms 2015





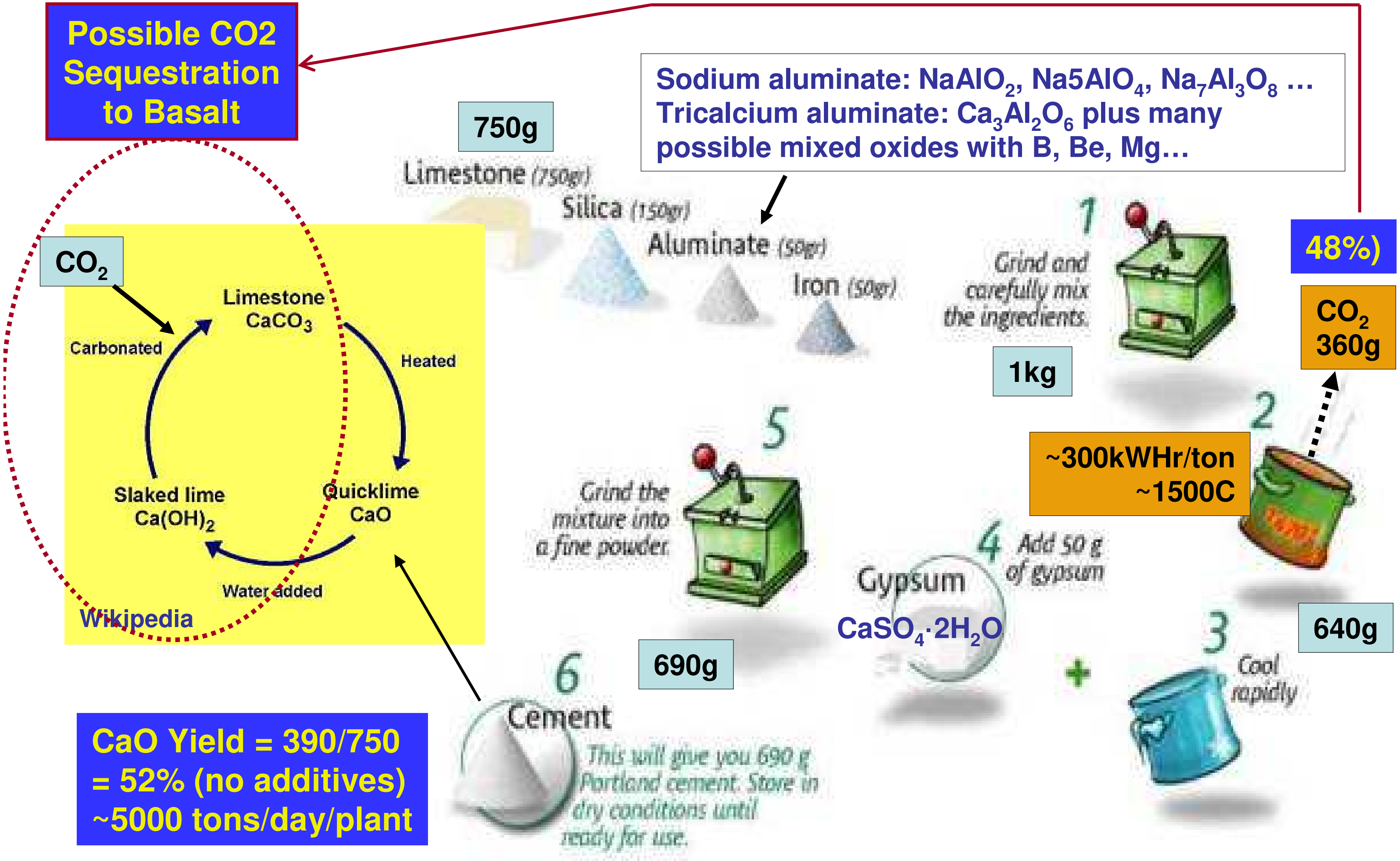
https://en.wikipedia.org/wiki/Phytoplankton

Seafloor C Sequestration/Subduction



Subduction Animation…
http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html

Lime Cycle & Cement Making

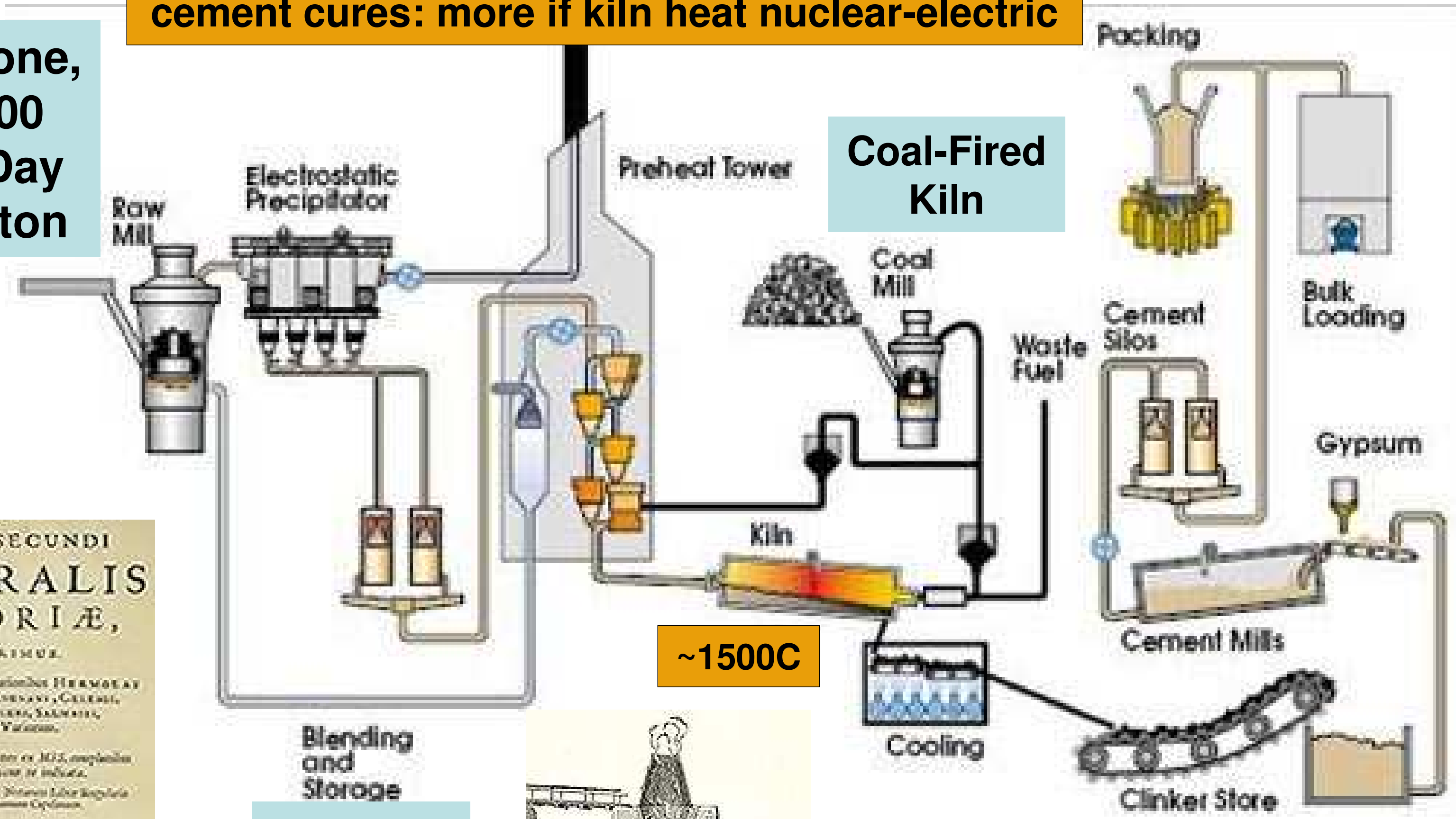


Cement Making

CO_2 exhaust, ~40% removed from air as cement cures: more if kiln heat nuclear-electric

Limestone, ~10,000 Tons/Day @1GJ/ton

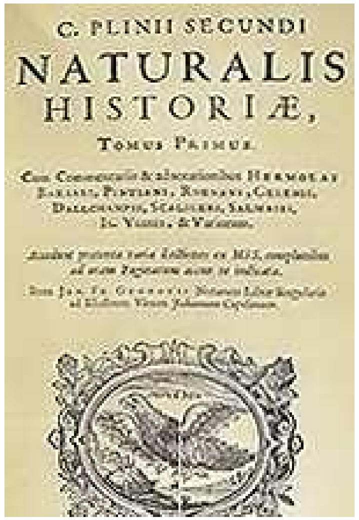
Coal-Fired Kiln



~1500C

Additives

Lime + Additives, ~5000 Tons/Day

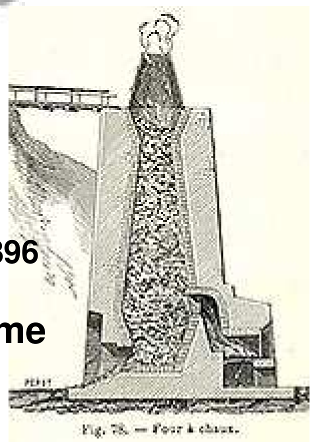


Pliny The Eklder ~50ce

Chatellier Kiln 1896

Wikipedia

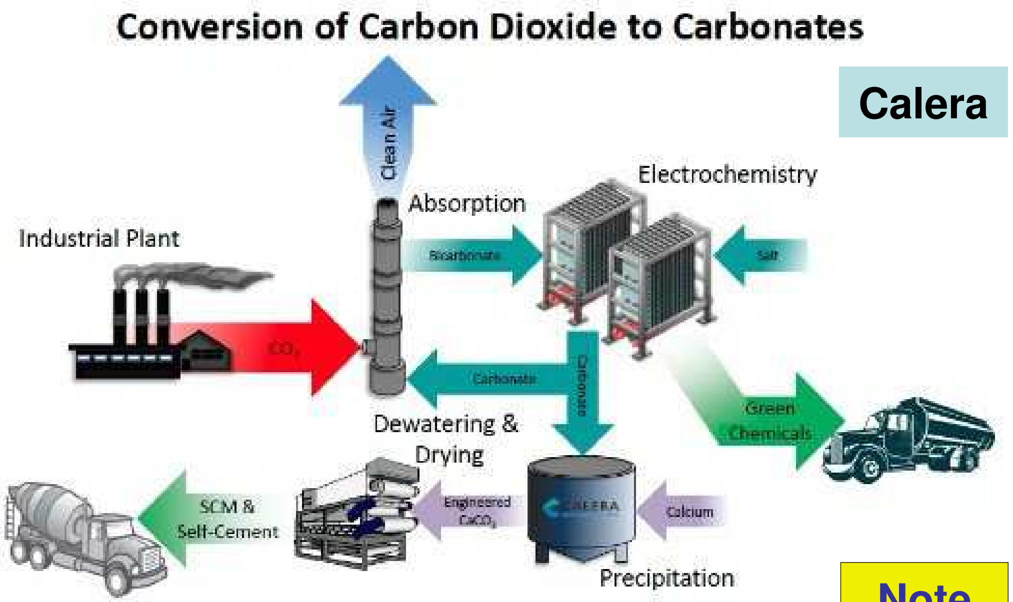
Lime



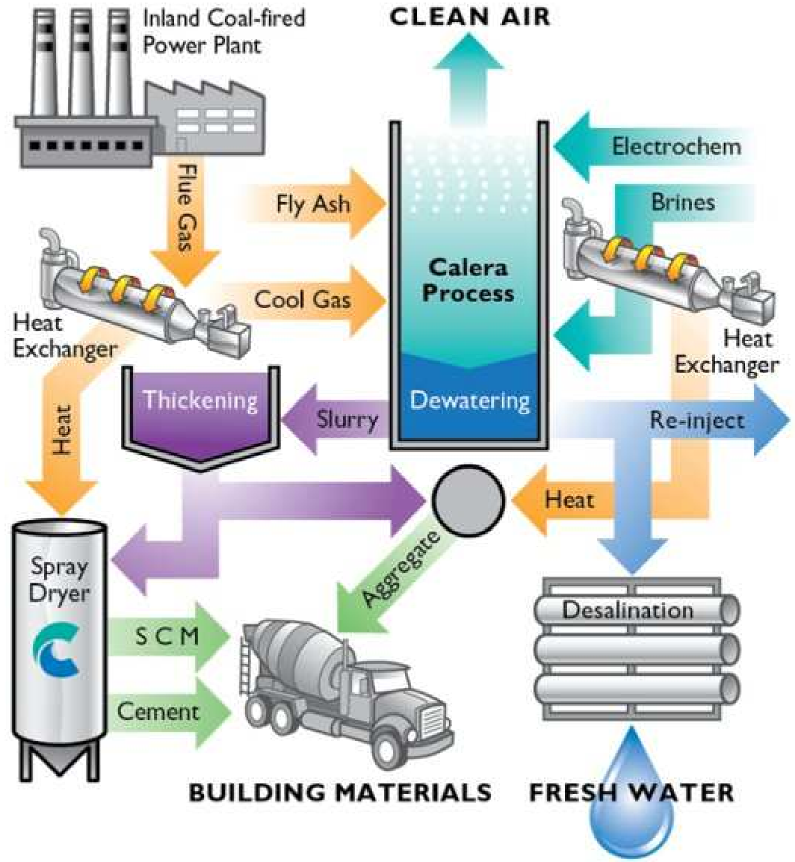
Fire

Reactions between Ca and Silicate compounds form the primary constituents of cement (calcium silicate). Material reaching the lower part of the kiln takes the shape of a clinker.

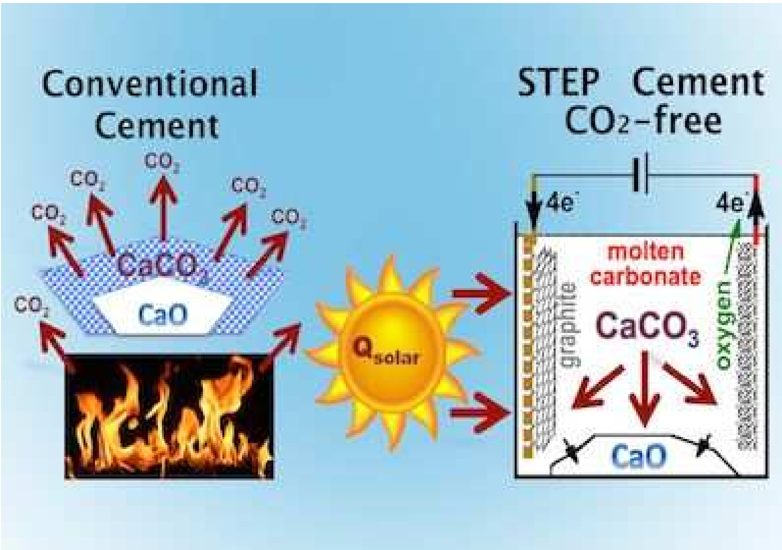
Alternative Cement Making



Calera



Note All Power Inputs



Electrolytic Carbon & Lime Precipitation T >600C

Calera Process Needs Additives for Strength But Yields Clean Water

Cement Making

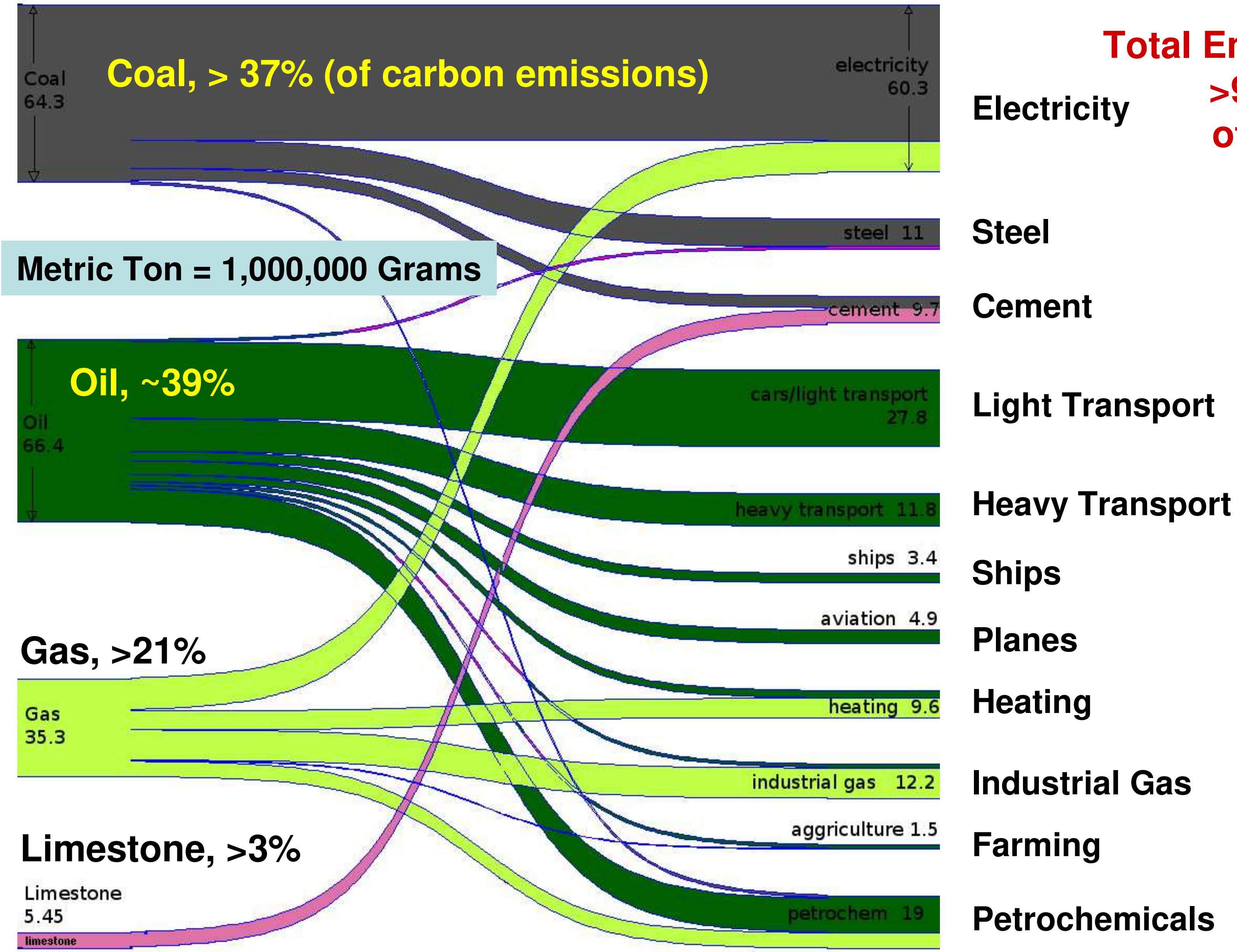
Typical Cement Plant

Flooded German Plant

Typical Kiln

Typical Kiln Is ~150ft Long & Several Feet in Diameter, Lined Inside With Refractory Brick. Final Lime Conversion Occurs in the Last (Lowest & Hottest) Several Feet.

Where Emitted C Comes From (2010)

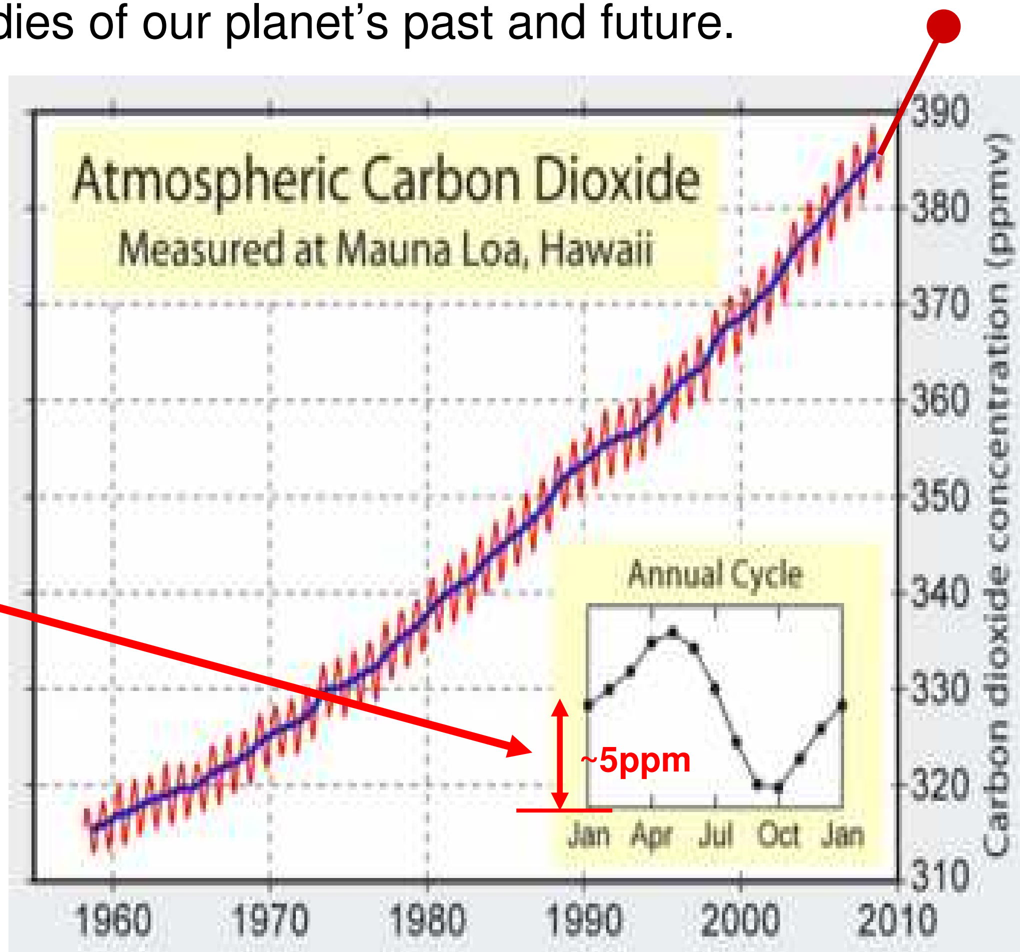


Total Emissions >9B Tons of Carbon per Year in >30B Tons of CO_2

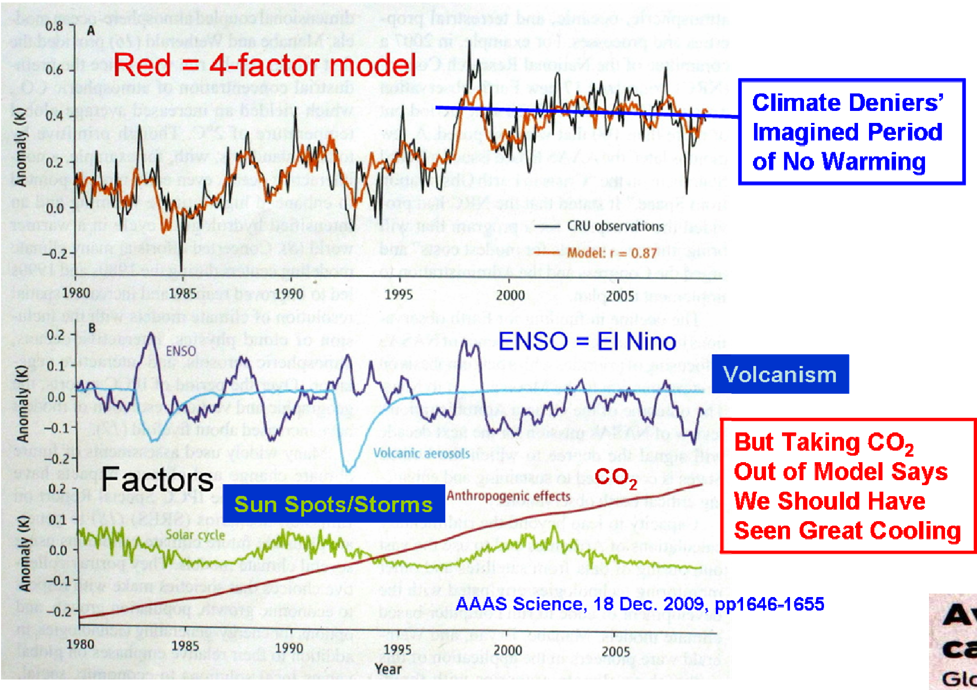
Recent CO_2 History

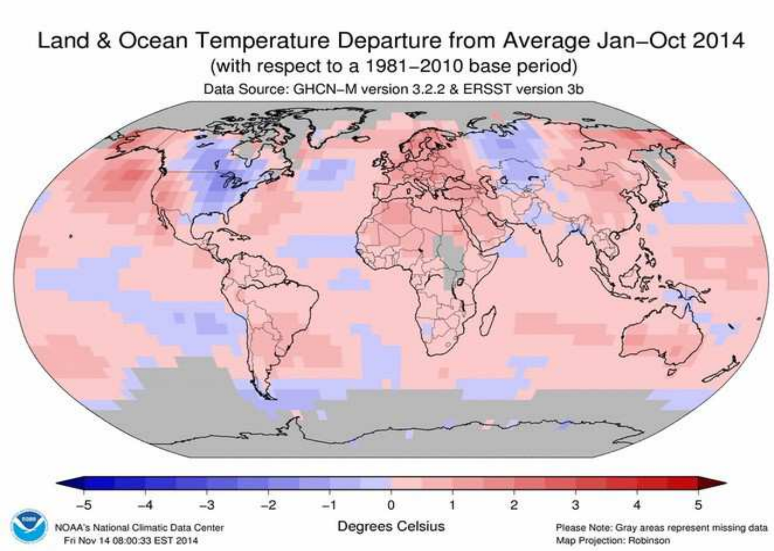
Our recent GHG awareness stems from the U. of Hawaii measurements of CO_2, beginning in 1957 – the first IGY (International Geophysical Year), when scientists worldwide began the intensive studies of our planet's past and future.

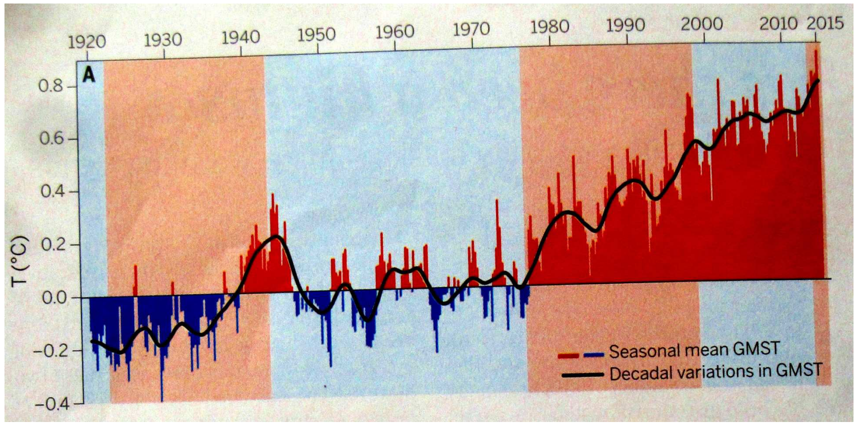
Note the important fact the ***Annual Cycle*** exposes -- it shows **what natural, sea & land photo-synthesizing organisms might do for us each year to reduce CO_2 levels -- about 4ppm/year, if no natural sources of CO_2 existed & we stopped all Hydrocarbon combustion -- (400-280)/4 = 30 years.**

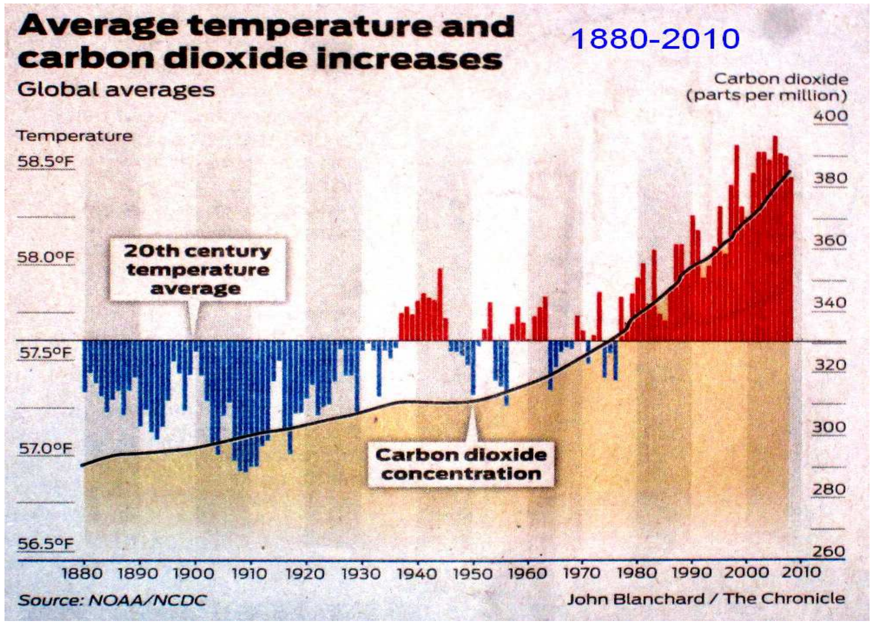


Temperature History

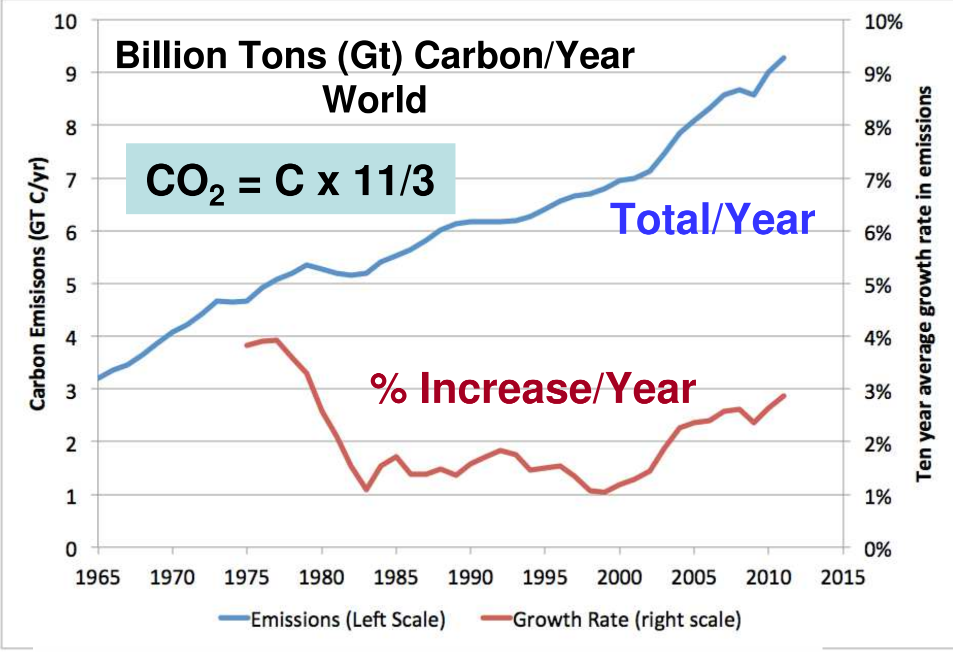


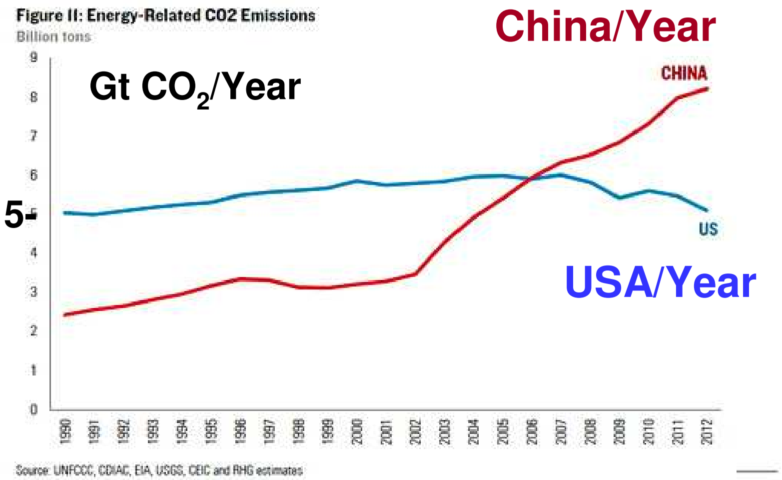


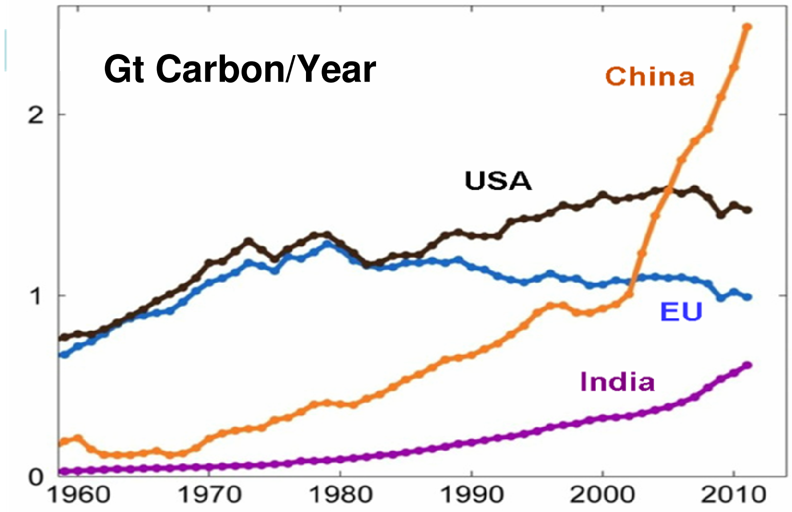


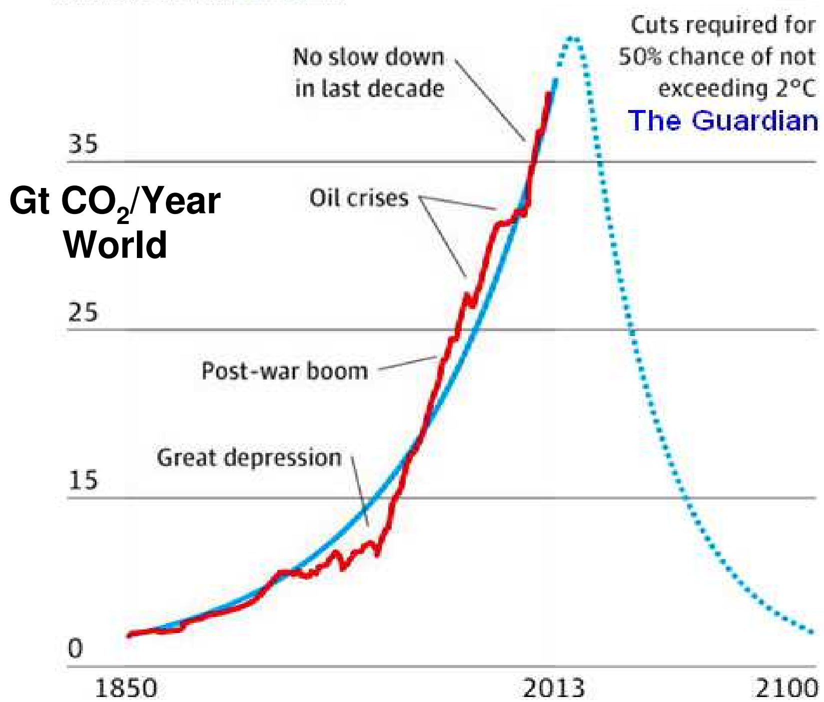


C & CO_2 Emissions (2013)









Acidification Remediation

Duplicate natural processes…

a) Reverse ancient seafloor carbonate formation via heating dolomite/limestone from land deposits, just as subduction & heating in magma accomplishes.

b) Capture freed CO_2.

c) Return residue of Ca/Mg oxides (lime) to oceans.

d) Sequester unusable CO_2 to geologic storage. Dissociate CO_2 and H_2O, releasing Oxygen to air and capturing C & H_2 for feedstocks.

e) Process C & H_2 into desired hydrocarbons for…

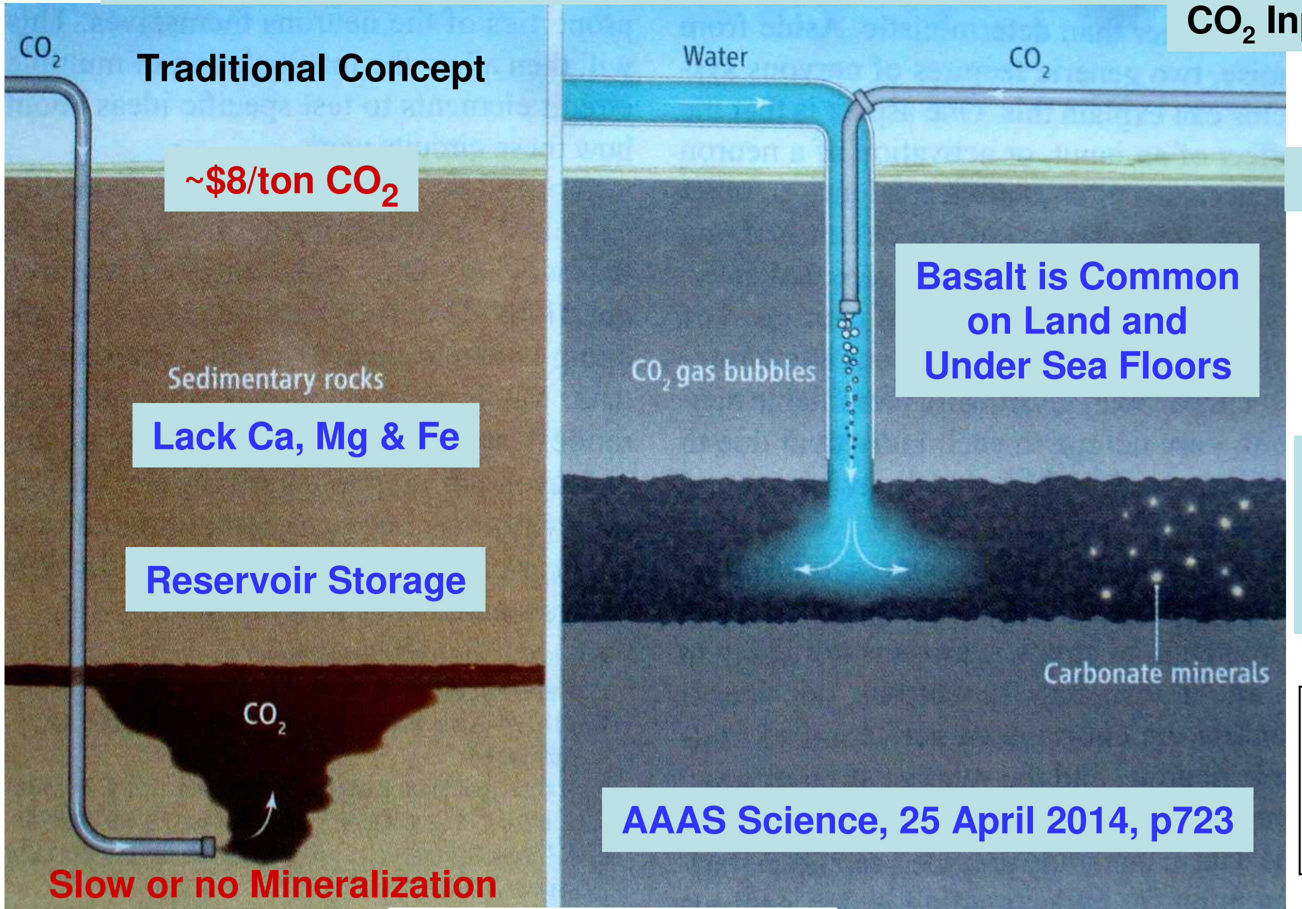
1) Carbon-neutral fuels;
2) Industrial feedstocks;
3) Benign C-H compounds for geologic storage – in old wells/mines, etc.

f) Store CO_2 permanently as carbonates in basalt.

CO_2 Sequestered to Basalt

CO_2 Capture from Emissions Sources ~$60-120/ton

CO_2 Input = 5% of H2O



Traditional Concept

~$8/ton CO_2

Lack Ca, Mg & Fe

Reservoir Storage

Slow or no Mineralization

~$17/ton CO_2

Basalt is Common on Land and Under Sea Floors

AAAS Science, 25 April 2014, p723

Present EU Carbon Trades at ~$7/ton

Porous Basalt Can Hold >50kg/m³ CO_2 as <u>Permanent Carbonates</u>

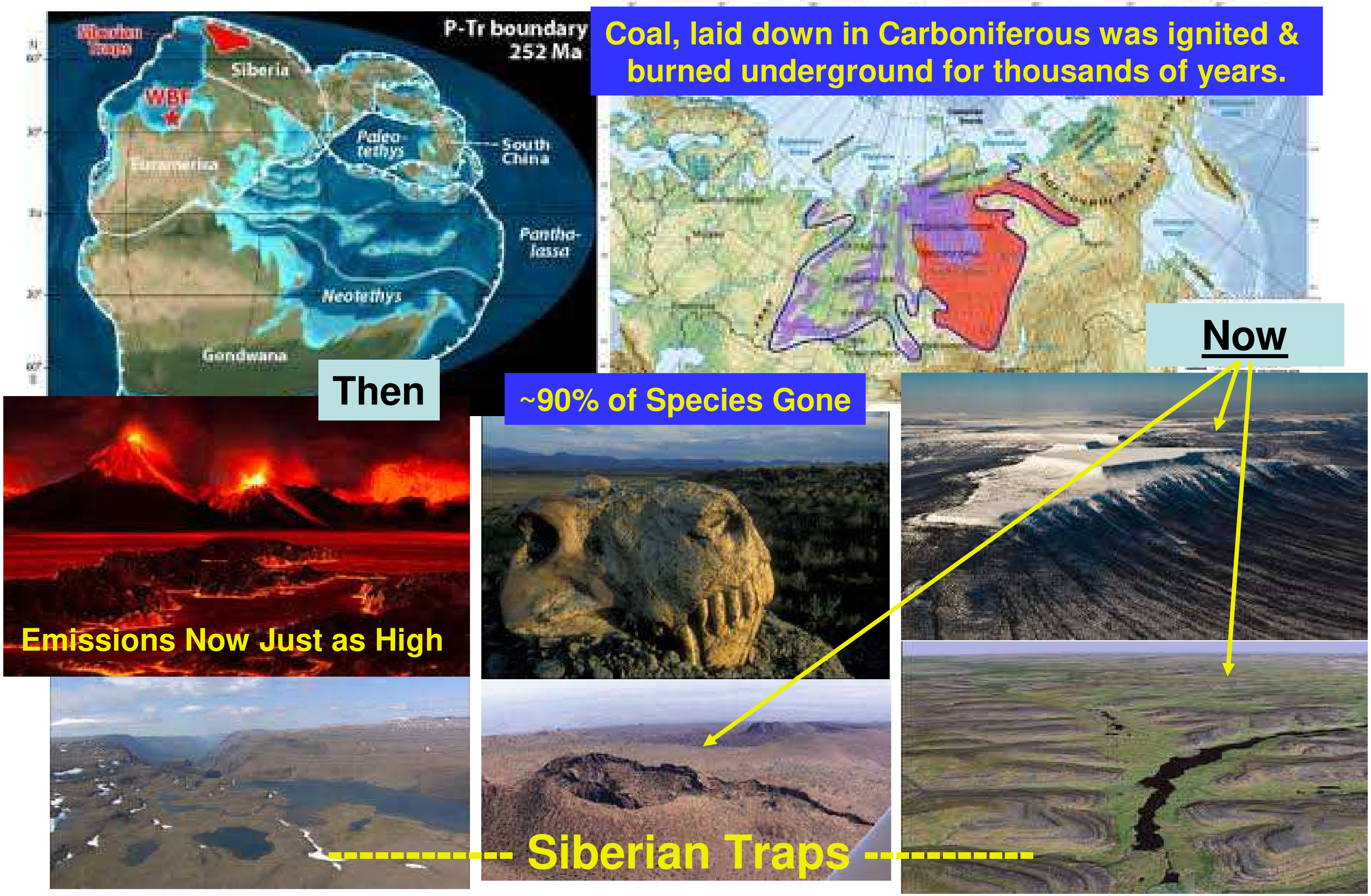
Example Reactions

$MgSiO_3 \longrightarrow MgO + SiO_2$
$MgO + CO_2 \longrightarrow MgCO_3$

Can also crush basalt with high alkali content and distribute in seas, If biologically safe.

Basalt is ~25% Ca, Mg & Fe Oxides.
Projects: Carbfix, 2012 in Iceland &
BSCP, 2013 in Wallula, Washington
http://tinyurl.com/hk6yxgv
Env. Sci. & Tech. Ltrs. 2016; 10.1021/acs.estlett.6b00387

CO_2 & 1,000,000 Sq. Miles of Basalt



Coal & Carbonate (Limestone)

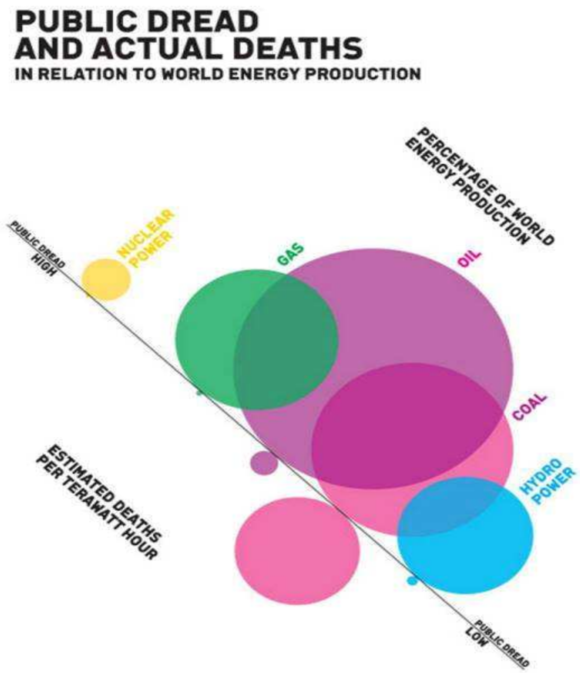
Alternating Swamps & Seas

Cretaceous Chalk/Limestone

Carboniferous Coal

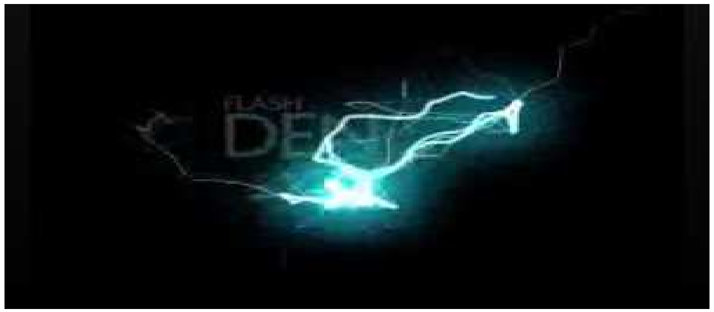
Remediation Power Choices

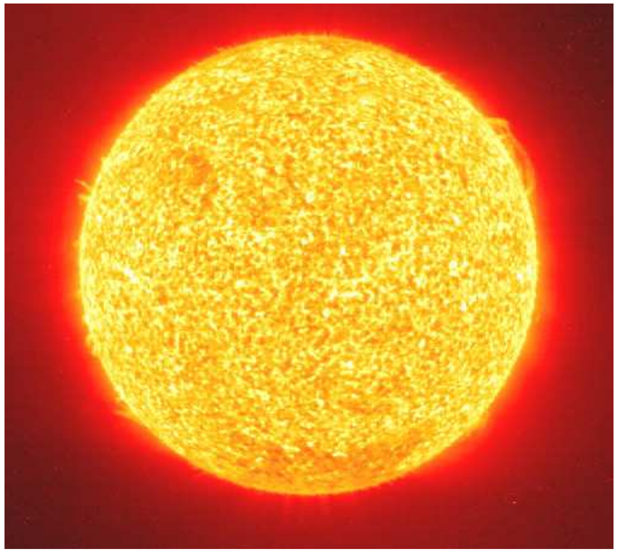
- ***Features*** – will not increase GHG emissions
- ***Power Density*** – resources needed to build & operate:
  - Processing limestone/dolomite to lime (~4**00kWHr/ton** -- mining, transport, process temperature >1400C)
  - Lime transport to ocean (kW)
  - CO_2 storage & cracking (kW + temp)
  - CO_2 sequestration (kW)
  - H_2O acquisition & cracking (temp + kW)
  - C-H compound reforming (temp):
    - Fuels (for critical uses – aircraft, etc.)
    - Feedstocks (petroleum/gas/coal substitutes)
    - For sequestration
- ***Reliability*** – on human time scale:
  - Longevity
  - Safety



Energy Rate & Density

- ***Rates*** are everything in nature (and banking).
- ***Power*** is the rate of doing work – moving mass-energy.
- ***Energy Density*** is the power available each second in a standard volume of some material.
  - Arrange these from highest to lowest energy density…





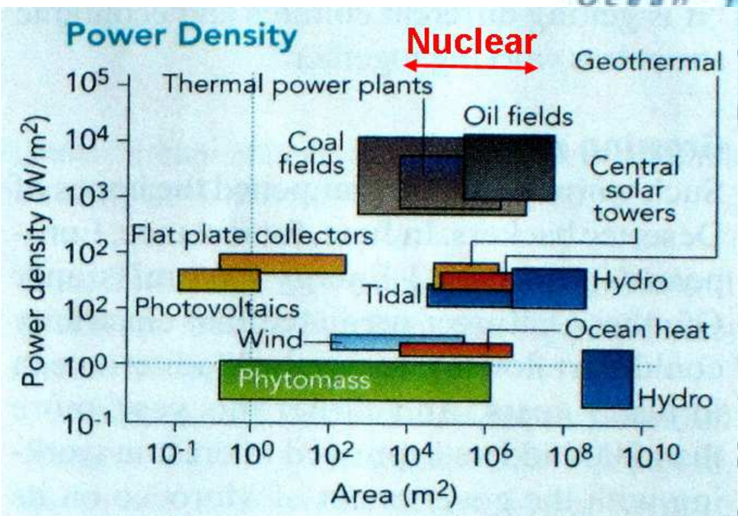
Areas Needed to Replace US Fossil Fuels

Area Needed for Nuclear*

Area Needed for Solar PV*
(Wind is much larger)

* All mining, construction, power & vehicular uses included in nuclear & solar.

It takes ~100 times more water to produce 1 gal of 'biofuel' than to produce 1 gal of diesel

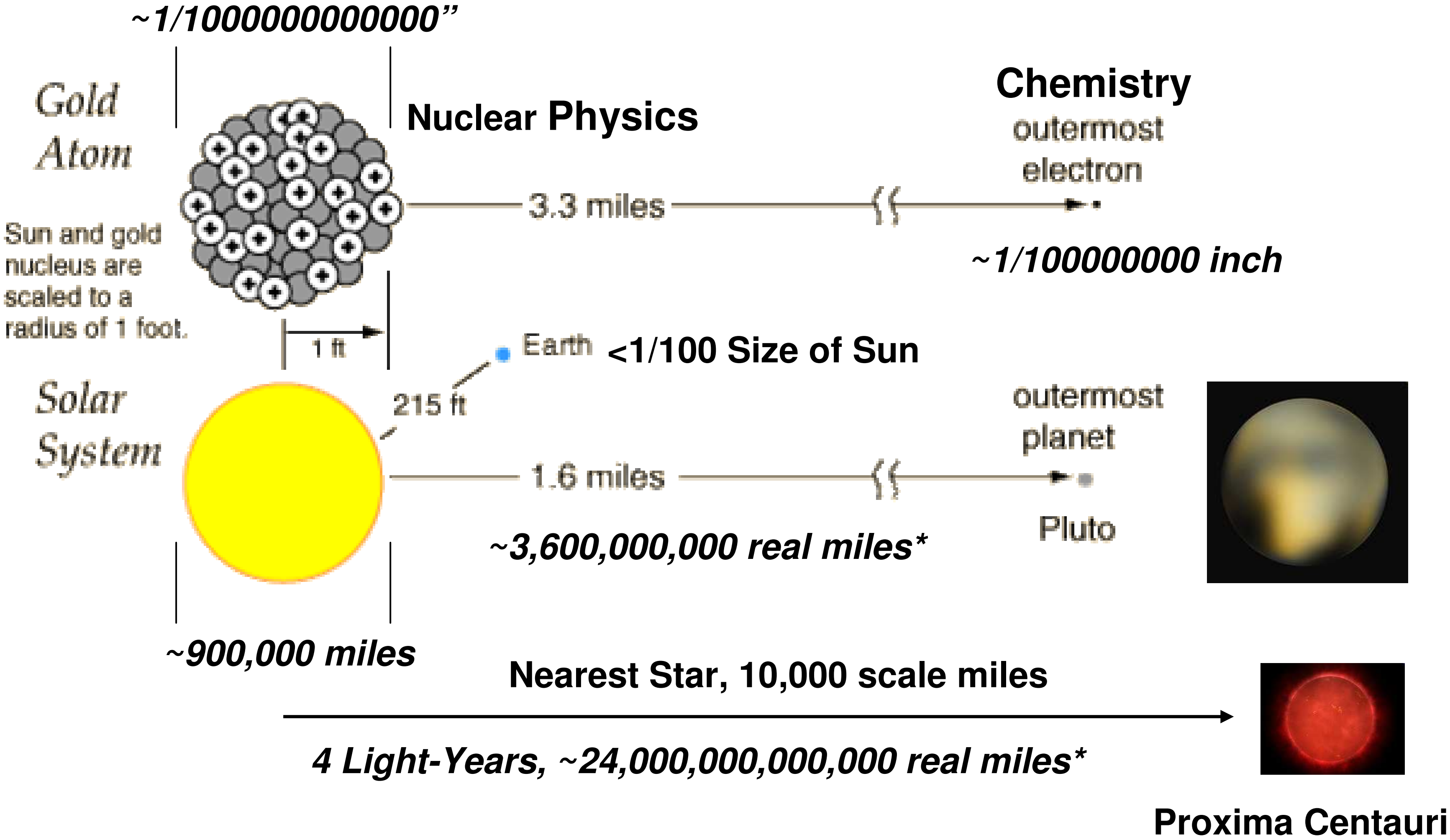


$>10^{13}$ J/kg

Combustion	Fission	Fusion

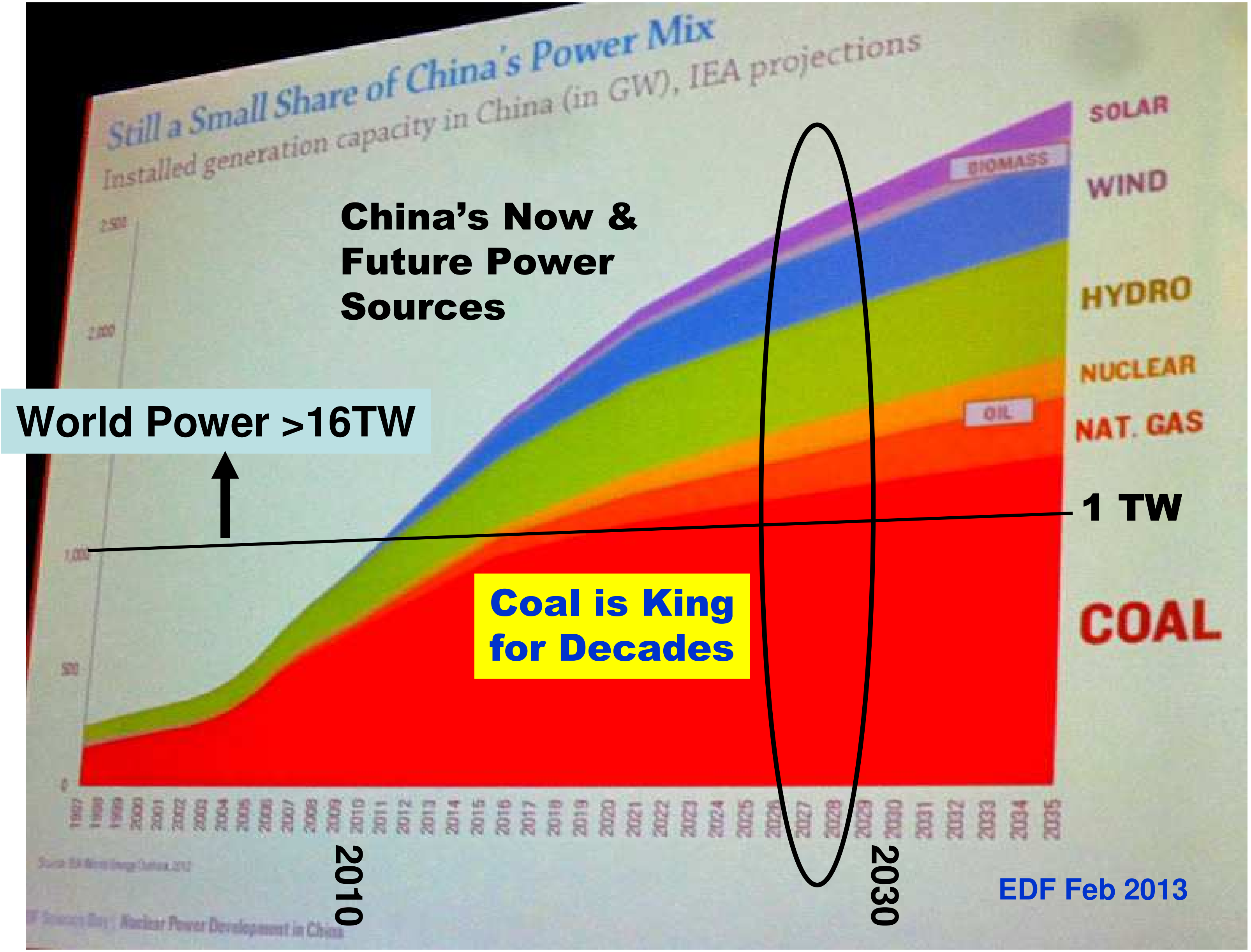
~10kWattHr/lb *x1,000,000* → ~3GWHr/lb *x100* → ~10^{11} WHr/lb

A Worldly Scale

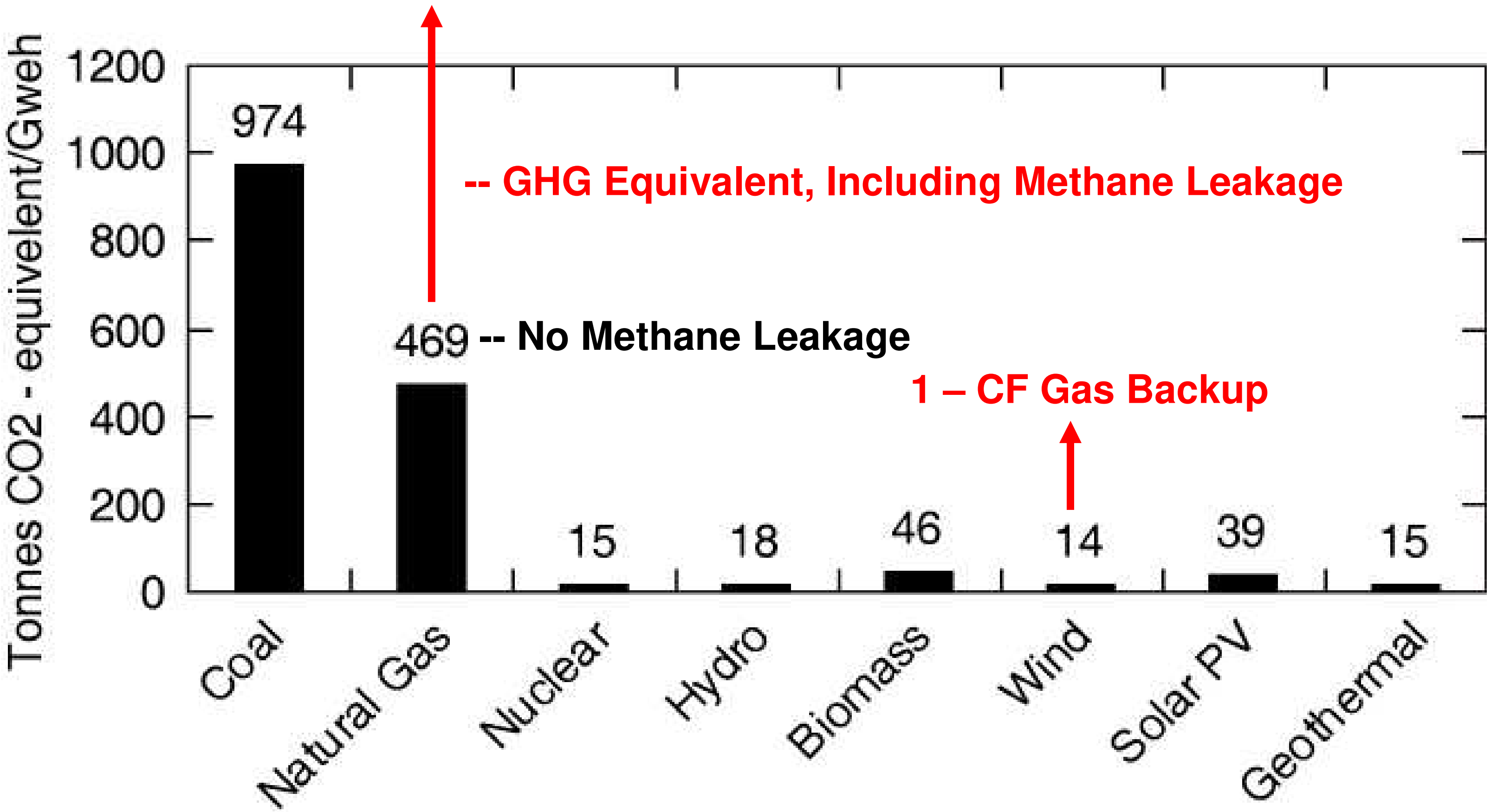


*** Actual distances are in italics***

Chinese Power 2010-2035

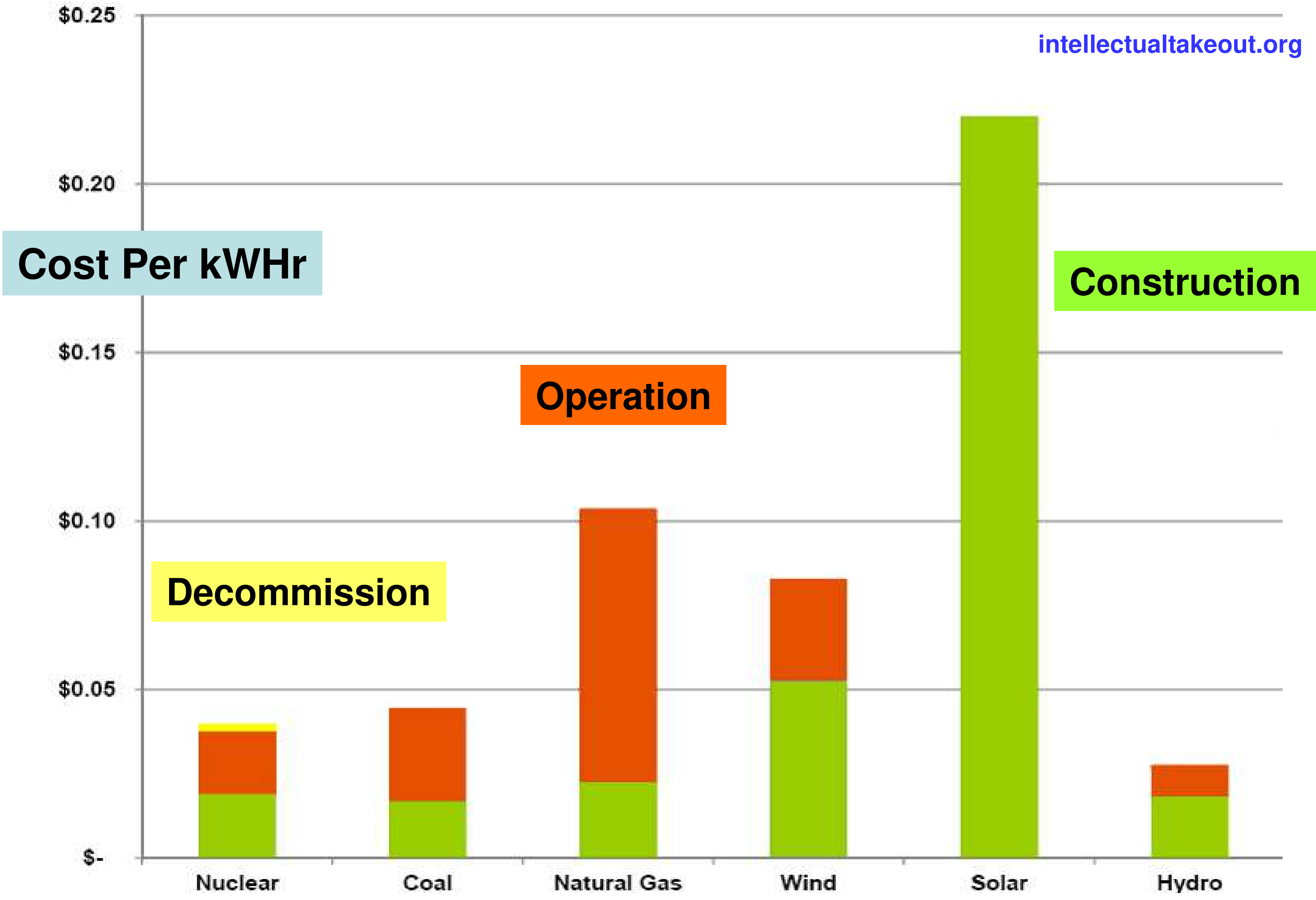


Lifecycle CO_2 Emissions

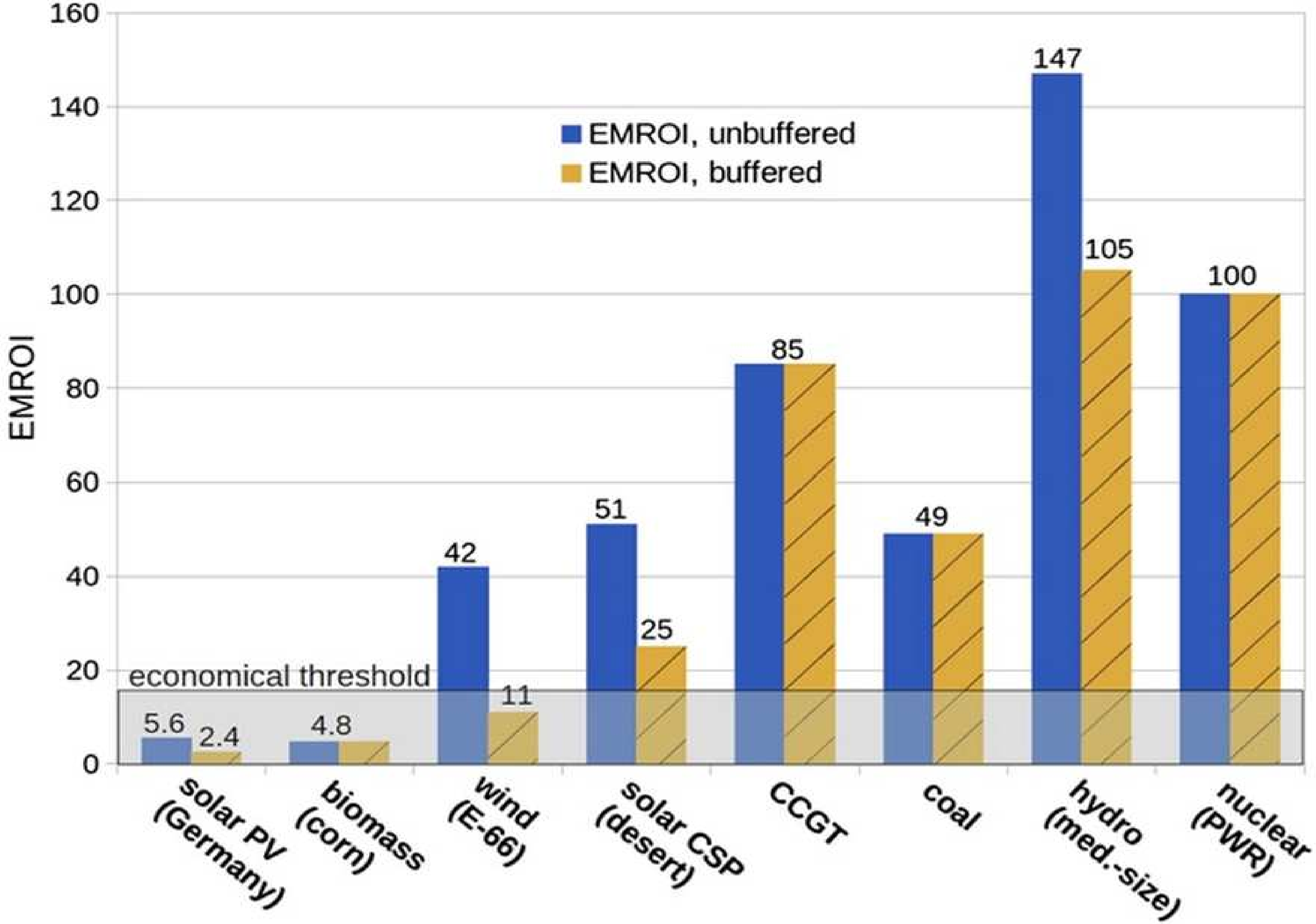


Courtesy Burton Richter -- *Comparison of Life Cycle Emissions in Metric Tonnes of CO_2e per GW-hour for various modes of Electricity Production;* P.J. Meier, *Life-Cycle Assessment of electricity Generation Systems with Applications for Climate Change Policy Analysis,*

Lifecycle Costs Per kWHr

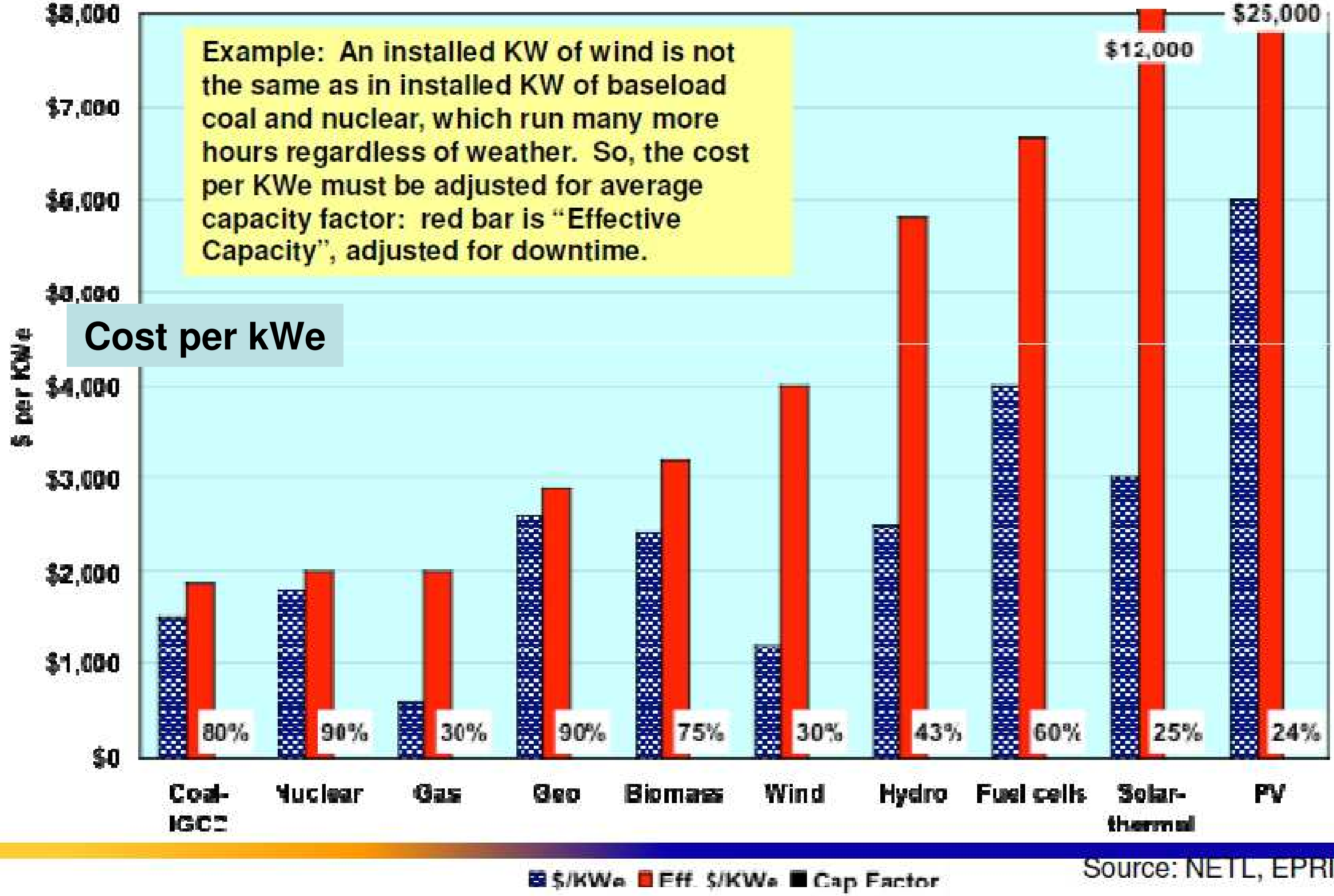


Lifecycle Return Per kWHr



Real Cost of Power Sources Affected by Capacity Factor (2006)

Fuel costs, weather affect downtime of some sources, which impacts investment.



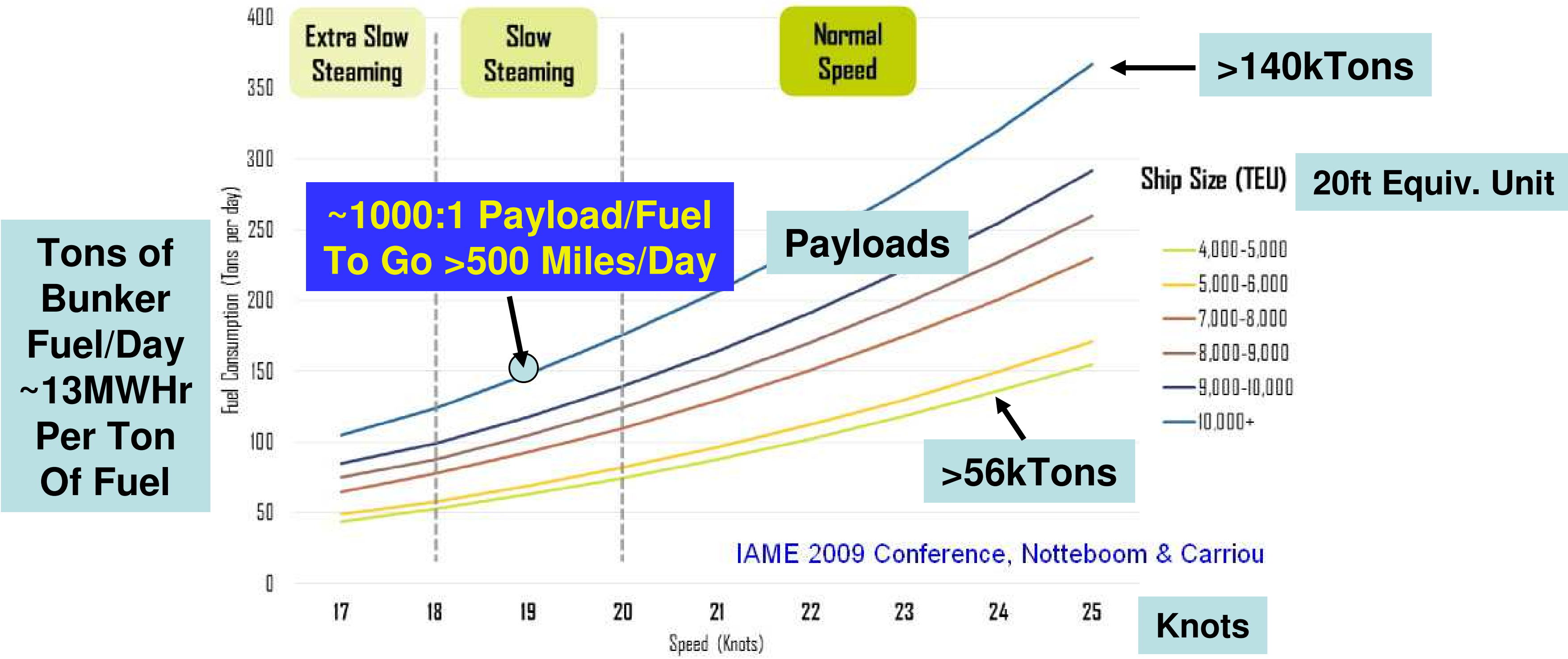
Source: NETL, EPRI

Remediation – The Numbers

- Processing limestone/dolomite to lime <u>~400kWHr/ton</u>
- Lime transport to ocean (rail 0.085kWHr/ton-mile + ship 4kWHr/ton-mile)
- CO_2 cracking (assume electrochemical reduction of at least 505 kJ/mole ~1.5GJ/ton ~420kWHr/ton)
- H_2O cracking -- @2000C, or electrolysis @850C 225 GJ/ton H_2 (64% efficient incl electricity gen)
- C-H compound reforming (use H_2O cracking heat)
  - Fuels (for critical uses – aircraft, etc.)
  - Feedstocks (petroleum/gas/coal substitutes)
  - For geologic sequestration (waxes – C_{25}+)
- <u>**Remediate 1/4 of yearly CO_2** emissions = **9Gt (dissolves)**</u>
  - $(9\text{x}10^9\ (1 + 1.5)\text{x}10^9\ )\ \text{x}\ 2.8\text{x}10^{-7}$ = 2100TWHrs + H_2O cracking
  - ***~400, 1GWe 0-emission powerplants* + H_2O cracking**

Remediation – Shipping

- Compounds for geologic sequestration
  - Rail: 400 ton-miles/gallon = 0.085kWHr/ton-mile
- Lime transport to ocean (~1 million yearly transits)
  - Rail: 0.085kWHr/ton-mile @1000mi/day
  - Ship: 14 tons/TEU,10k TEUs, ~4kWHr/ton-mile @500mi/day



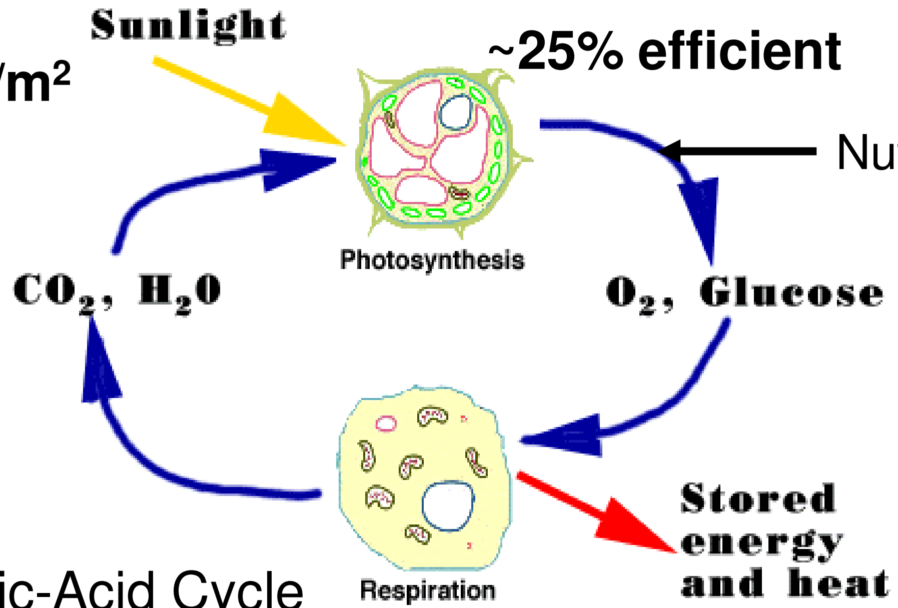
Photosynthesis – CO_2 Handling

Energy from Sun $+ 6CO_2 + 6H_2O \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6$ (glucose) $+ 6O_2$

www.johnkyrk.com/krebs.html

1kW/m²

~25% efficient



Nutrients, trace elements, water & climate

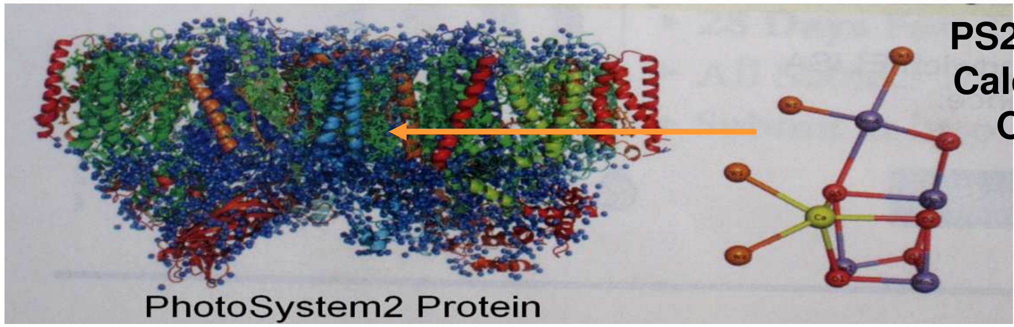
Plants did not evolve to supply humans' energy needs

~32% efficient

Photosynthesis net <7%

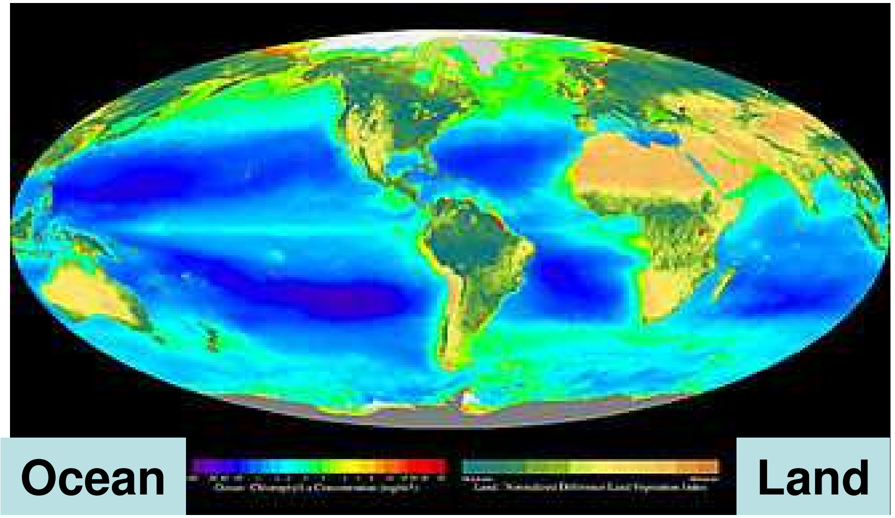
Krebs/Citric-Acid Cycle

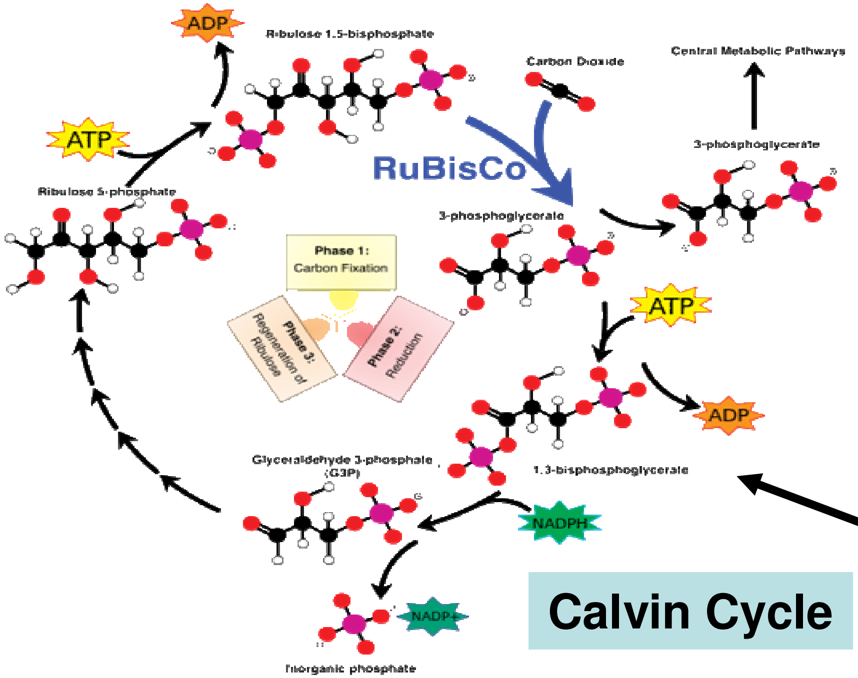
$C_6H_{12}O_6$ (glucose) $+ 6O_2 \xrightarrow{\text{Mitochondria}} 6CO_2 + 6H_2O +$ Stored Energy ← Plant & animal respiration energy released for metabolism & molecular catalysis

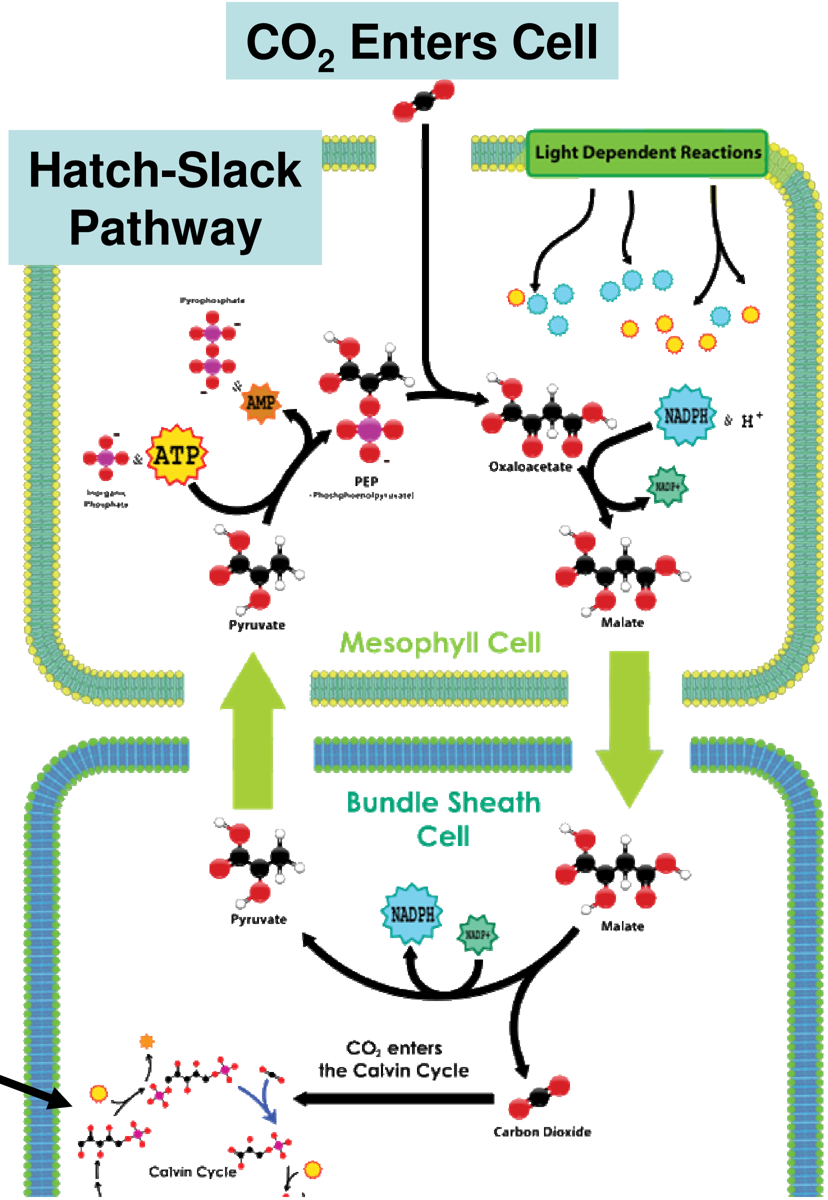


PS2 Protein Houses a Calcium, Manganese, Oxygen Catalyst To Split H_2O

Photosynthesis – CO_2 Handling







17 April 1970

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  - **Atlantic Ocean: http://tinyurl.com/n9t59et**
  - **Hansen & Lovelock: http://tinyurl.com/nh3bsh6**

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