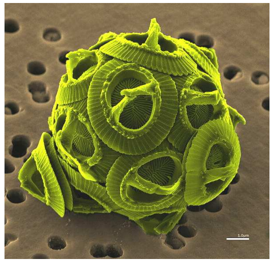
# Climate/Energy: Acidification

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

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

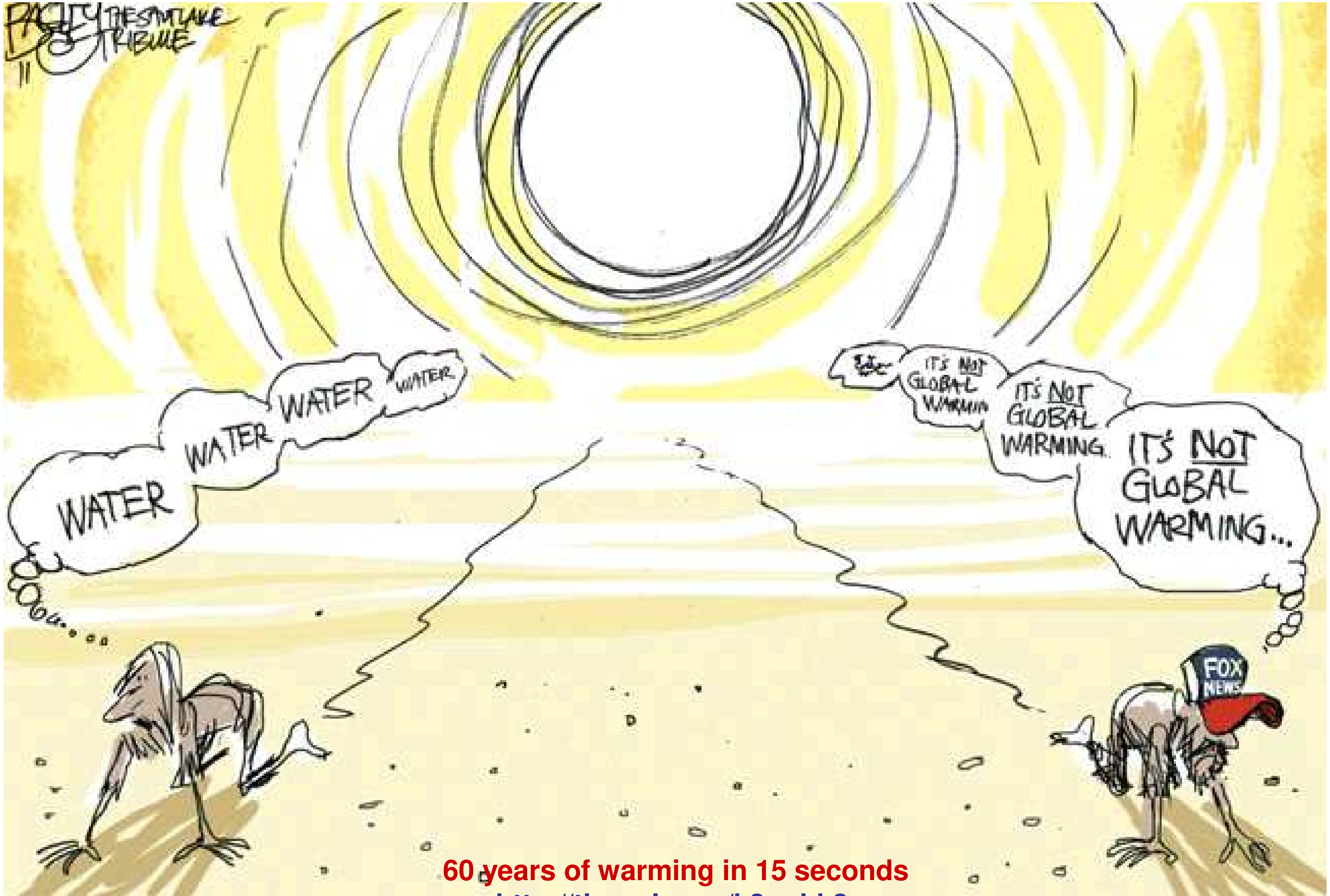


**"Let's work the problem.**
**Let's not make things worse by guessing."**


***Eugene Kranz,***
***Apollo 13***
***Flight Director,***
***April 1970.***


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

# Why Energy From Fire Must Go

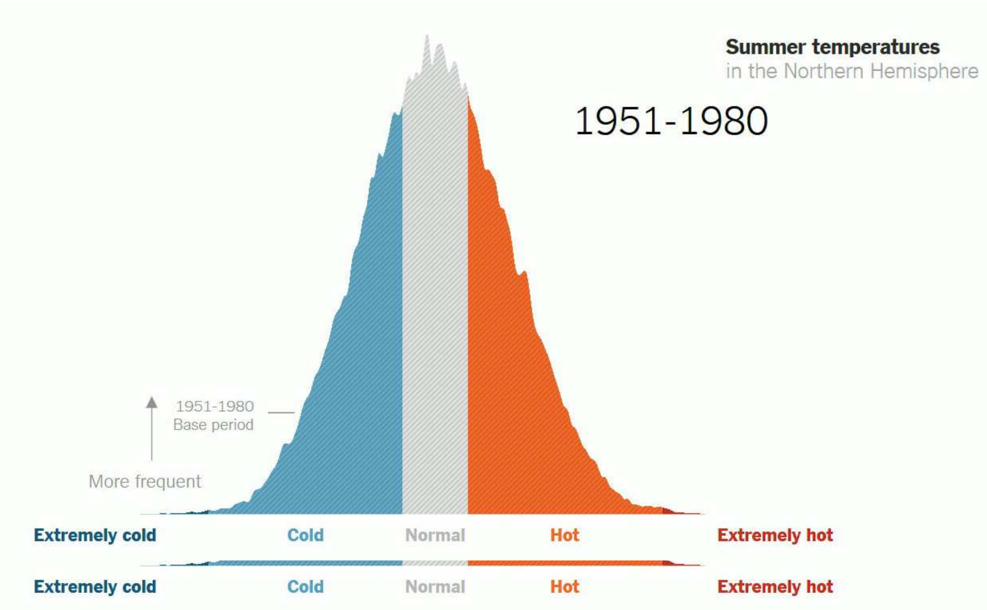


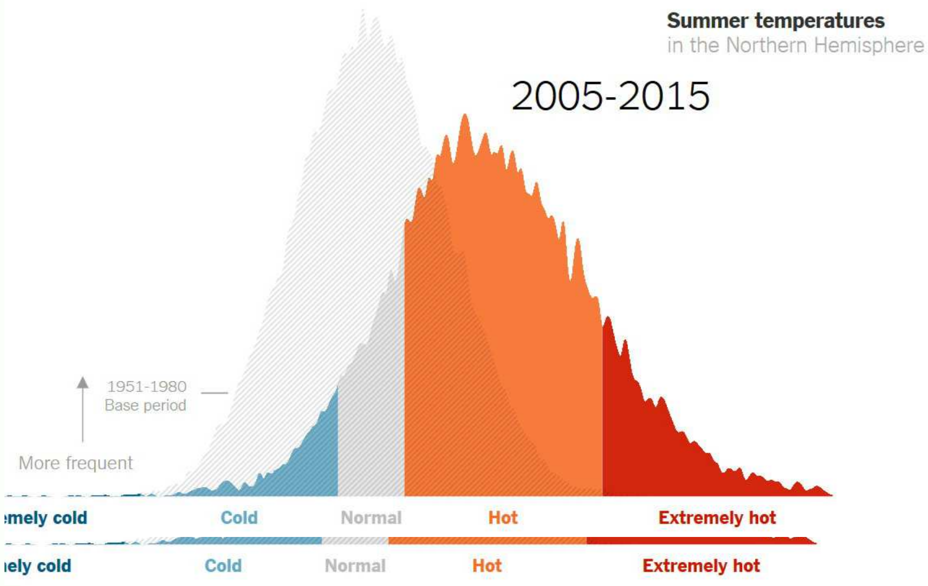

60 years of warming in 15 seconds
http://tinyurl.com/k3guhk2

# Warming (1951-2015)

**http://tinyurl.com/yaaewjkm**

(note animation)

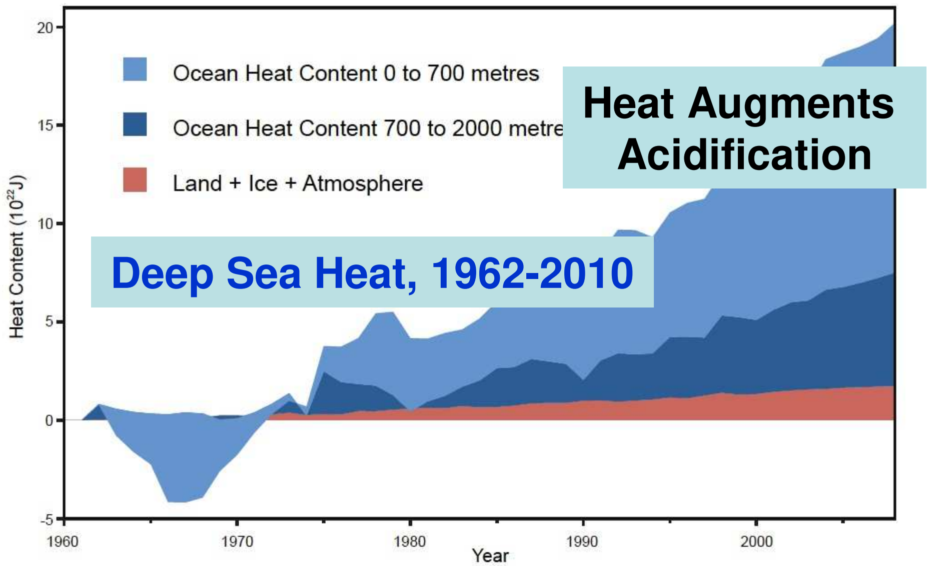


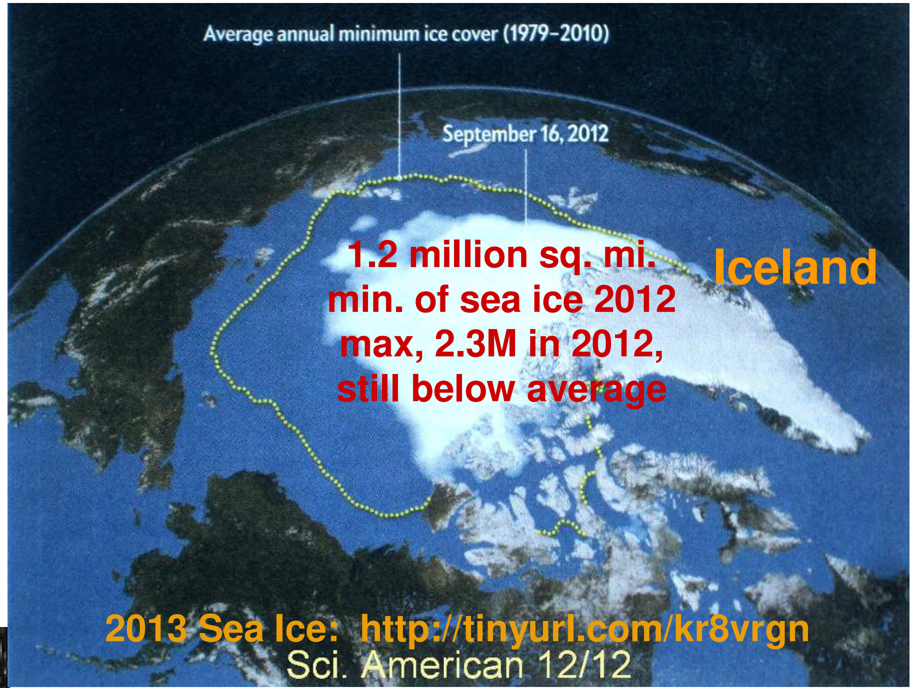




**Extraordinarily hot summers (red), that were virtually unheard-of in the 1950s, have become commonplace.**

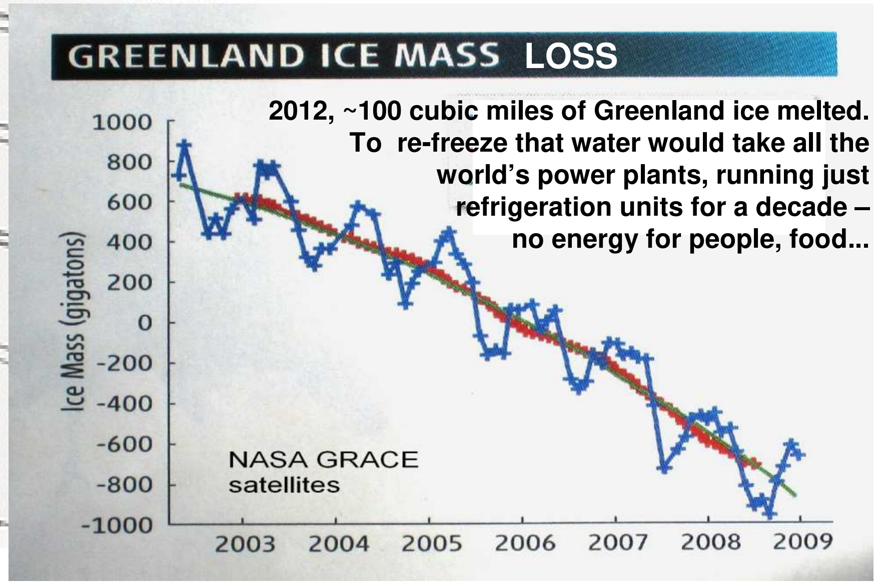
Northern Hemisphere

# Emissions Effects: Sea Warming

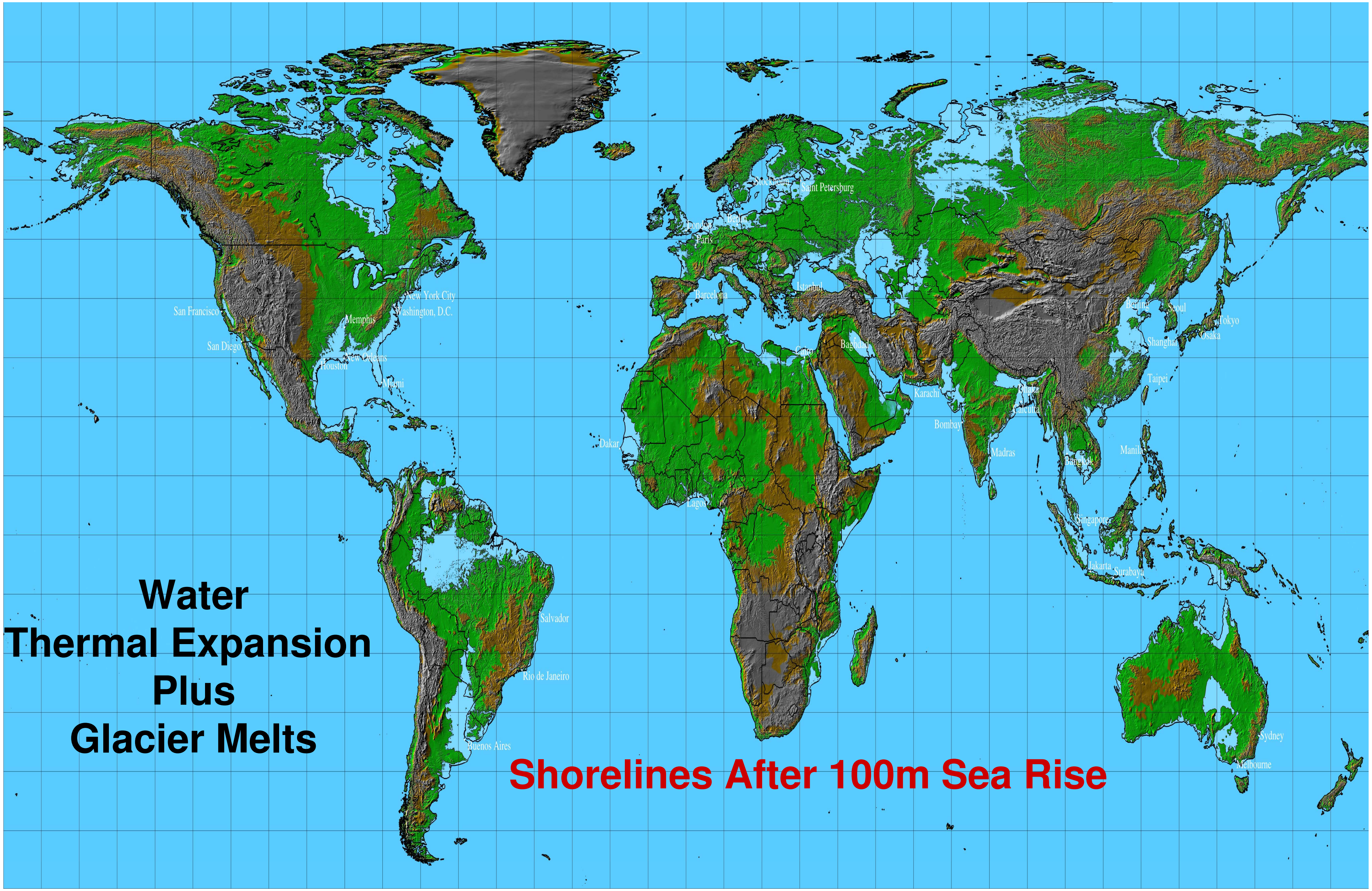




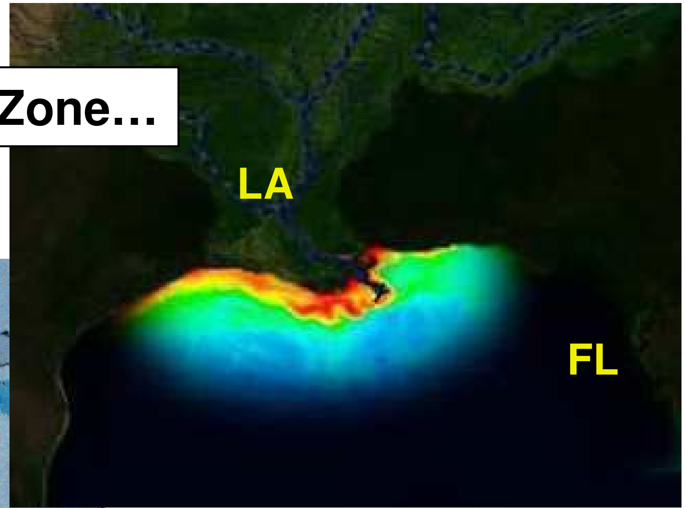


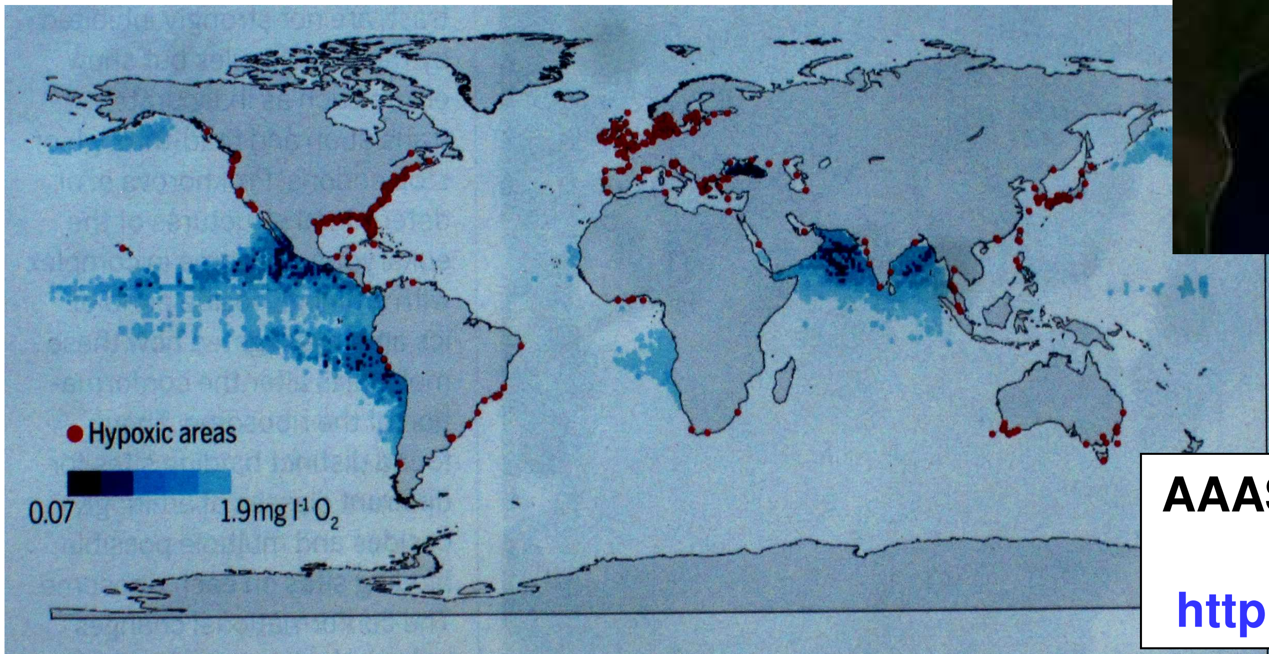
# Warming => Sea Rise



# Oceanic Oxygen Loss & Extinctions

**Gulf of Mexico & Mississippi Dead Zone…**

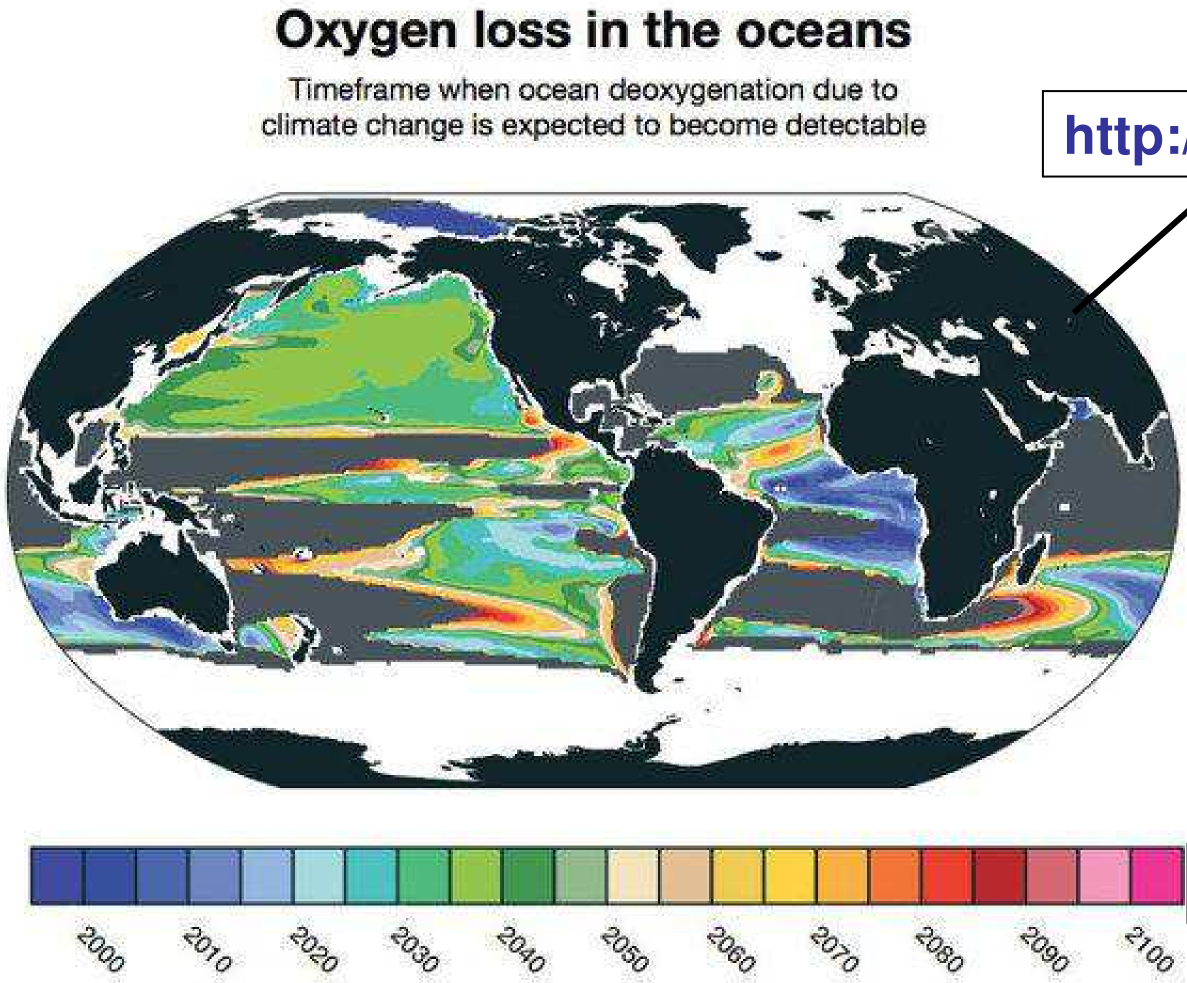



**Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security.** The global map indicates coastal sites where anthropogenic nutrients have exacerbated or caused $O_2$ declines to <2 mg liter$^{-1}$ (<63 µmol liter$^{-1}$) (red dots), 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

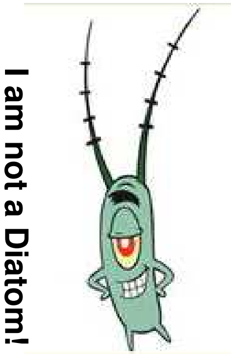
**Fluvial chemical threats:** http://tinyurl.com/yd6mkoec **and...**
**"A short history of ocean acidification science in the 20th century: a chemist's view", P. Brewer, 2013,** www.biogeosciences.net/10/7411/2013/

# 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**




*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 *.

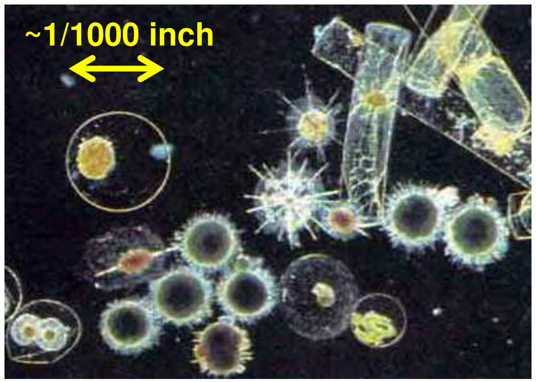
I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

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.**

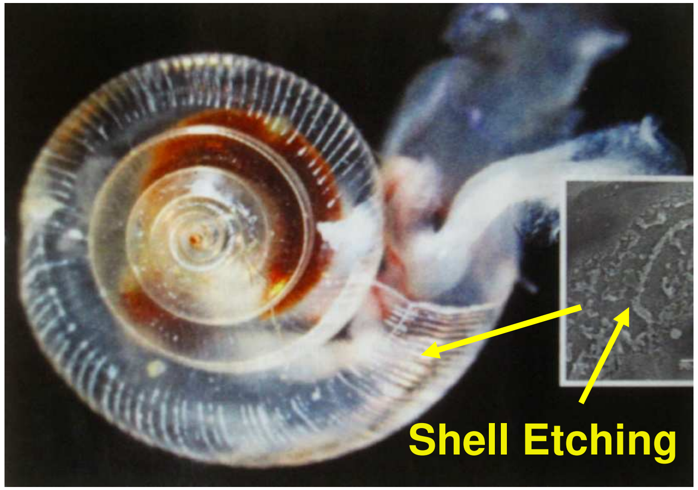
**Since seas dissolve $CO_2$ well, they become more acidic every year we overload the natural Carbon Cycle (among plants, air, water & land ) by burning fossil Carbon compounds made millions of years ago by plants, especially ocean Plankton…**

**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



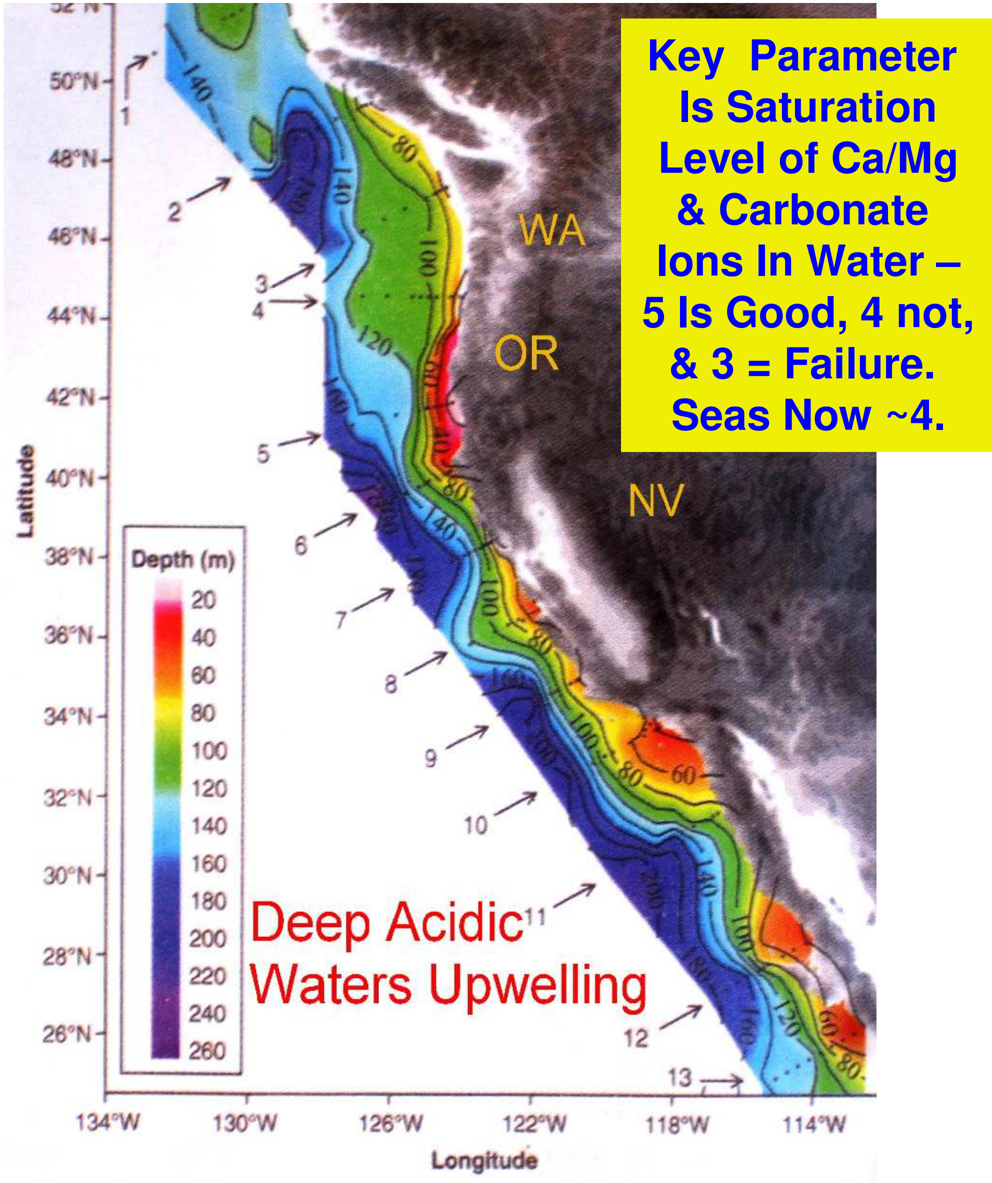

AAAS Science, Vol 344, 9 May 2014, p569

**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

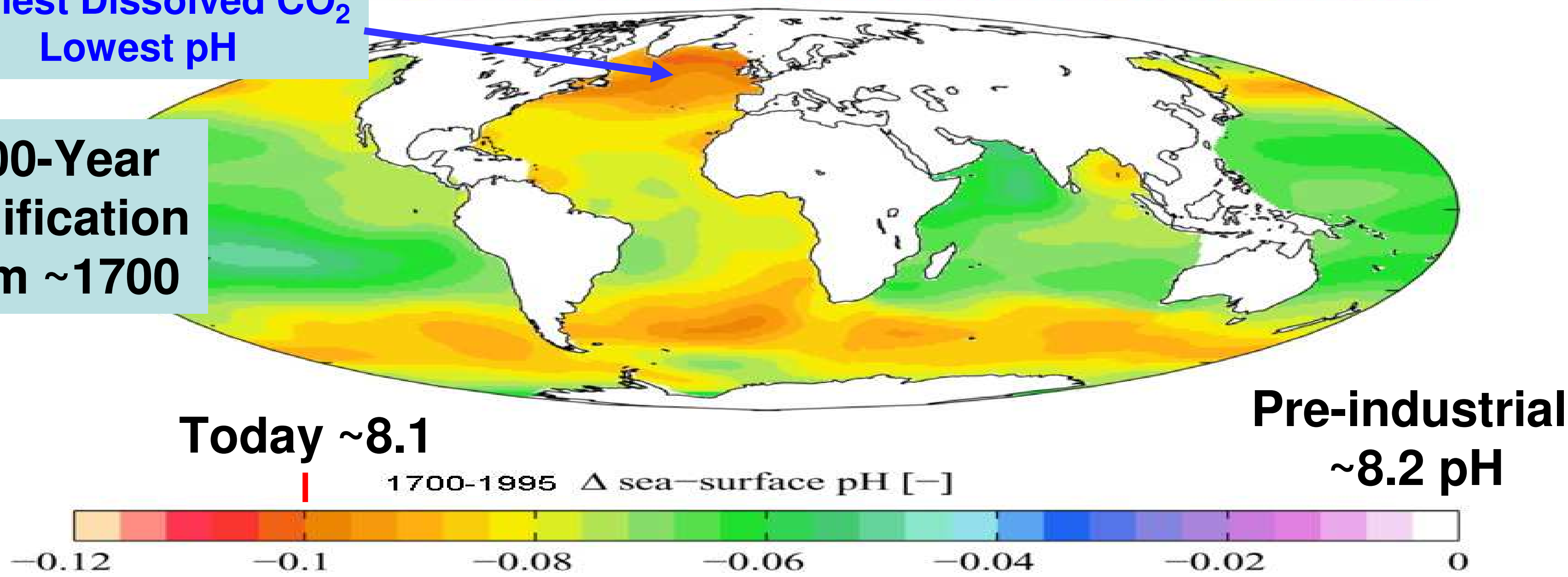


# Emissions Effects: Sea Chemistry

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


**Highest Dissolved $CO_2$ Lowest pH**

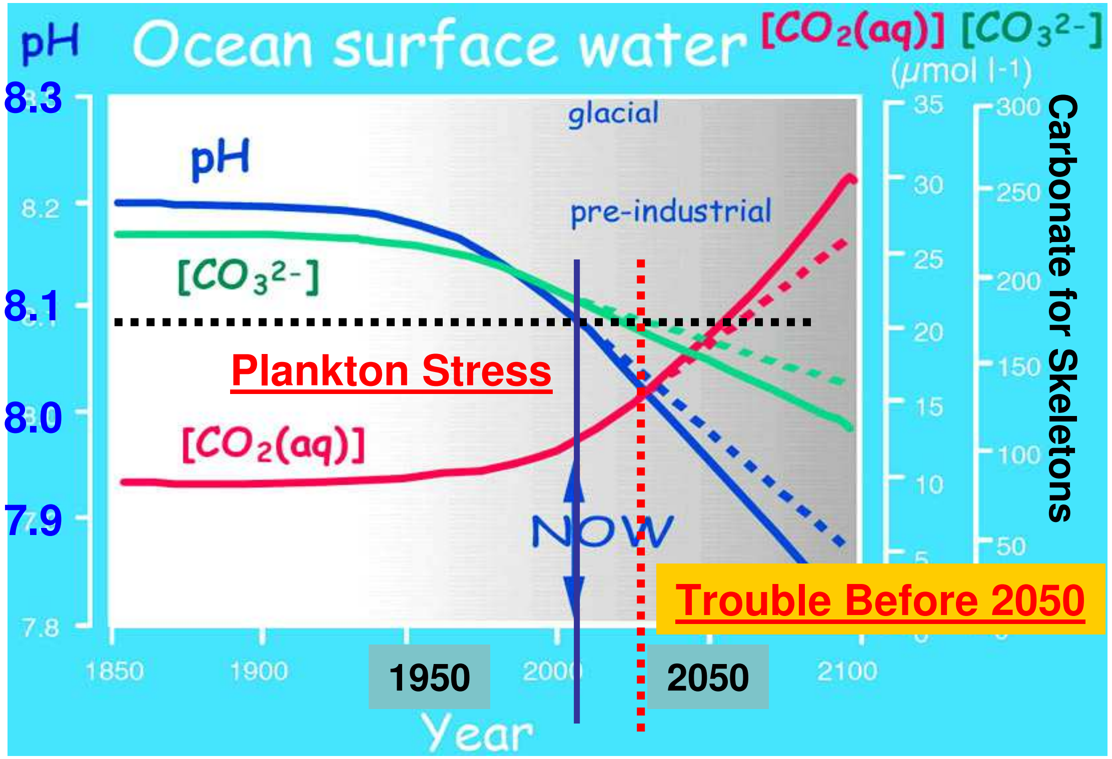
**~300-Year Acidification From ~1700**

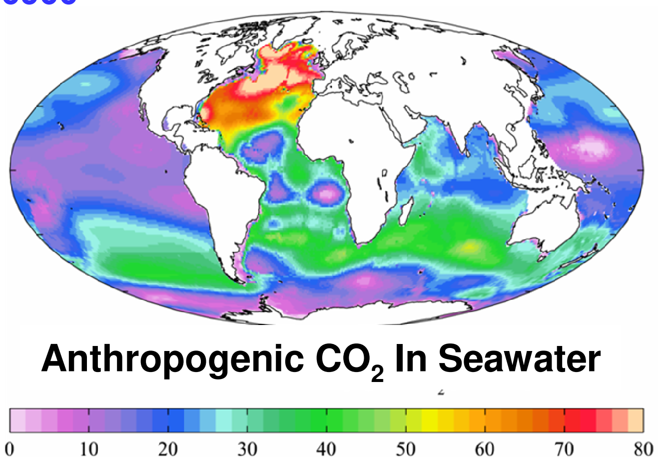


# Acidification & Extinctions

**<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**



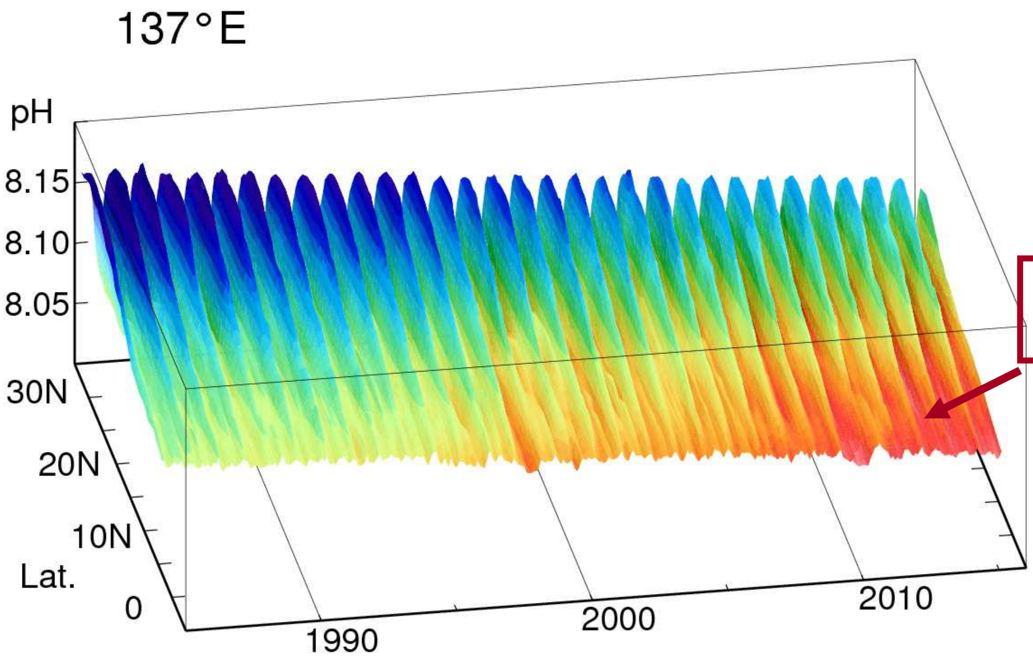

**Normal Larvae:**

**Deformed Larvae**

**Warmer, acidifying North Atlantic**

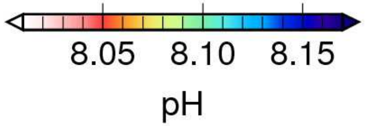
**www.ocean-acidification.net/**
**http://tinyurl.com/6mtd8db**
**www.noaa.gov/video/administrator/acidification/index.html**
**www.bbc.co.uk/news/science-environment-18938002**

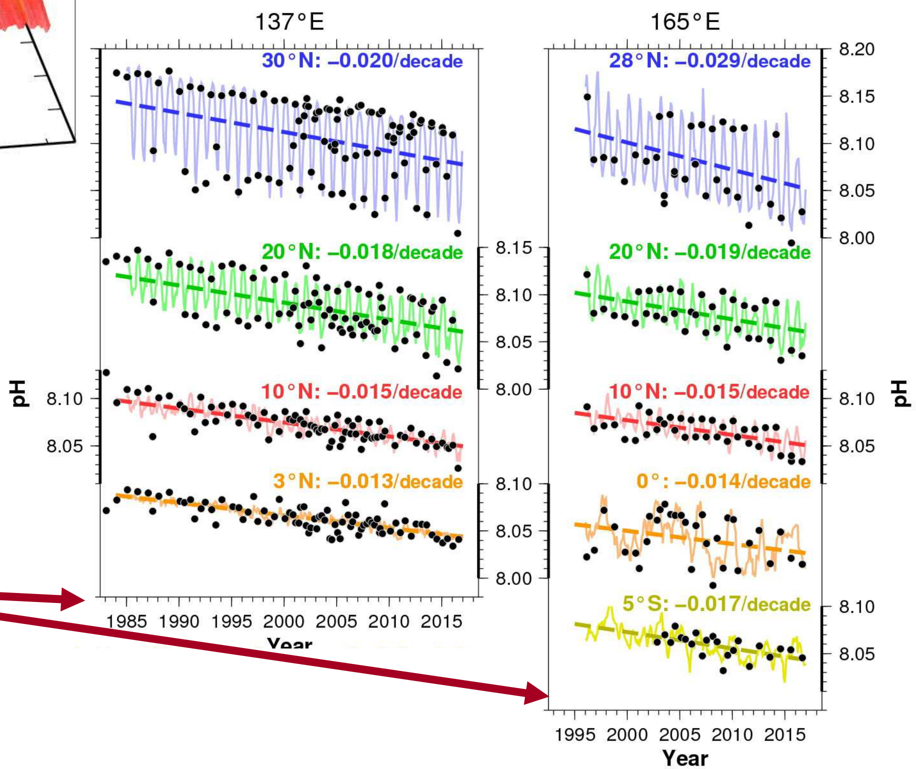
# Western Pacific pH 1986-2016




**Extinctions Below 8.0pH**

http://tinyurl.com/y88c22ey



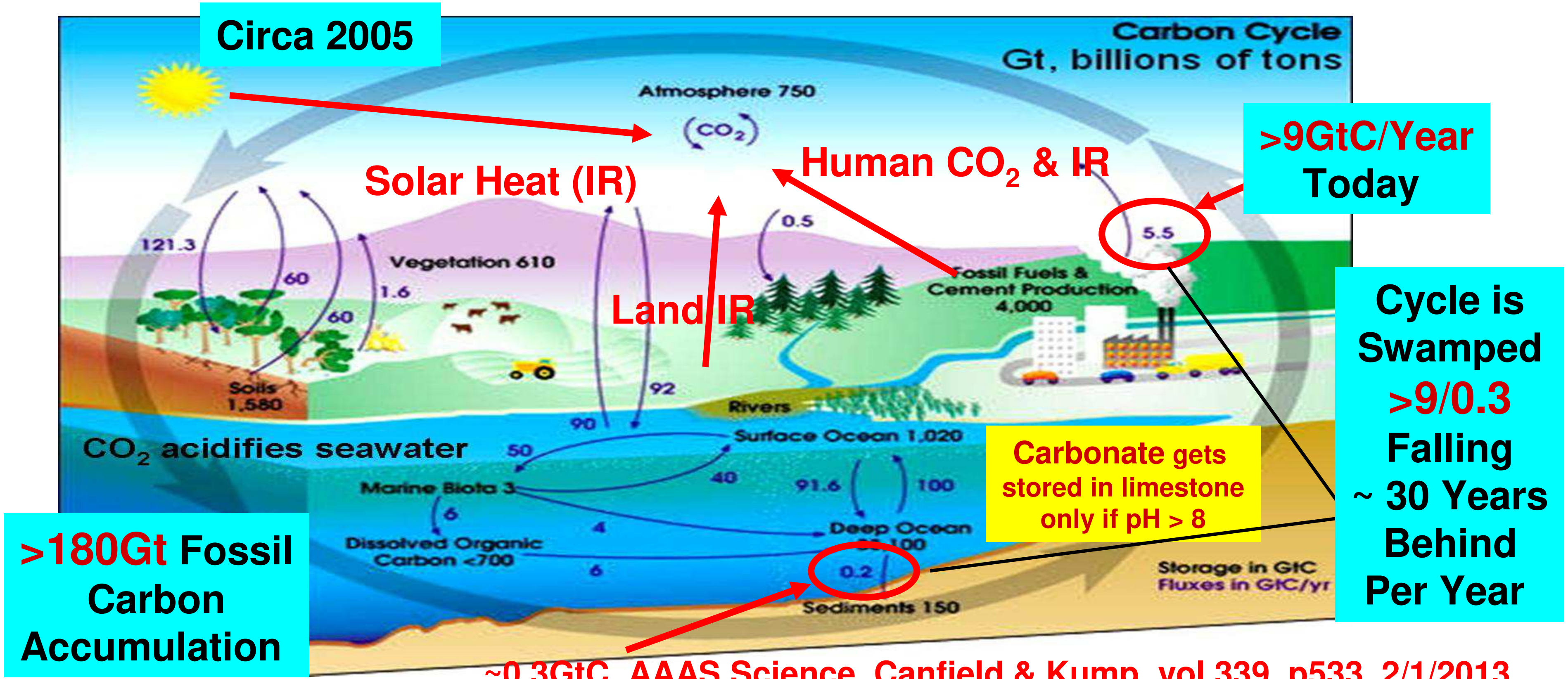




**Extinctions Below 8.0pH**

# Acidification & Remediation (**3 Numbers**)

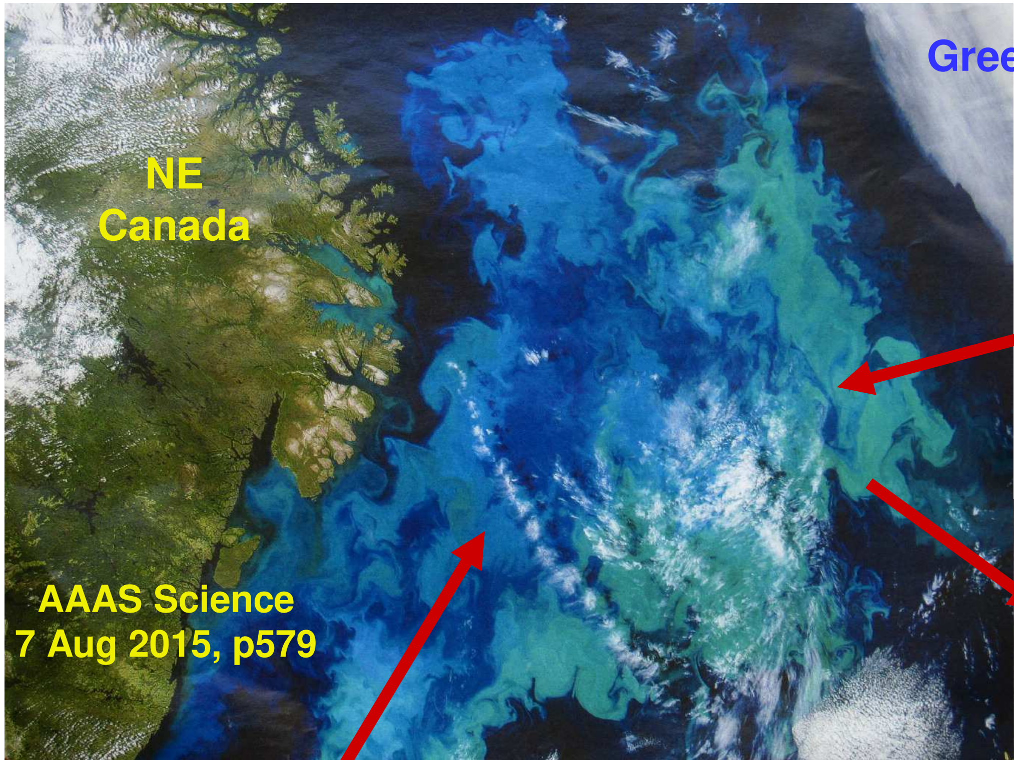
**Cyanobacteria, plankton & algae produced most of the Oxygen we have to breathe & use, starting >2 billion years ago,** with earliest photosynthesizing ocean life. Land plants later evolved & helped. <u>All fossil fuels we dig up were made from plant decay</u>. Carbon emissions today are **>9GtC** (>30Gt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

**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**

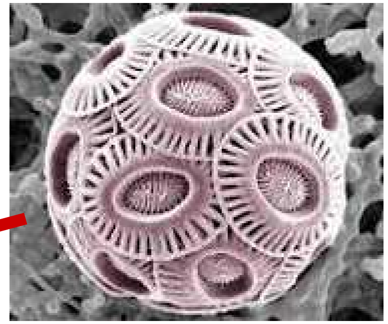



~0.3GtC, AAAS Science, Canfield & Kump, vol 339, p533, 2/1/2013

# Emissions Effects: Algal Blooms



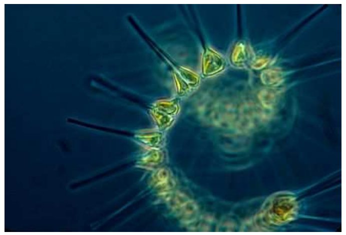

~0.000001 Meter

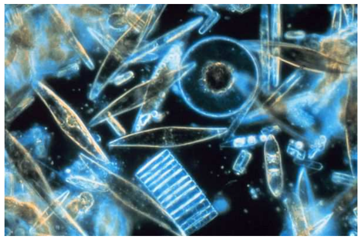


**Coccolith: Calcite Shields Around Single Algal Cell of *Emiliania Huxleyi***

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

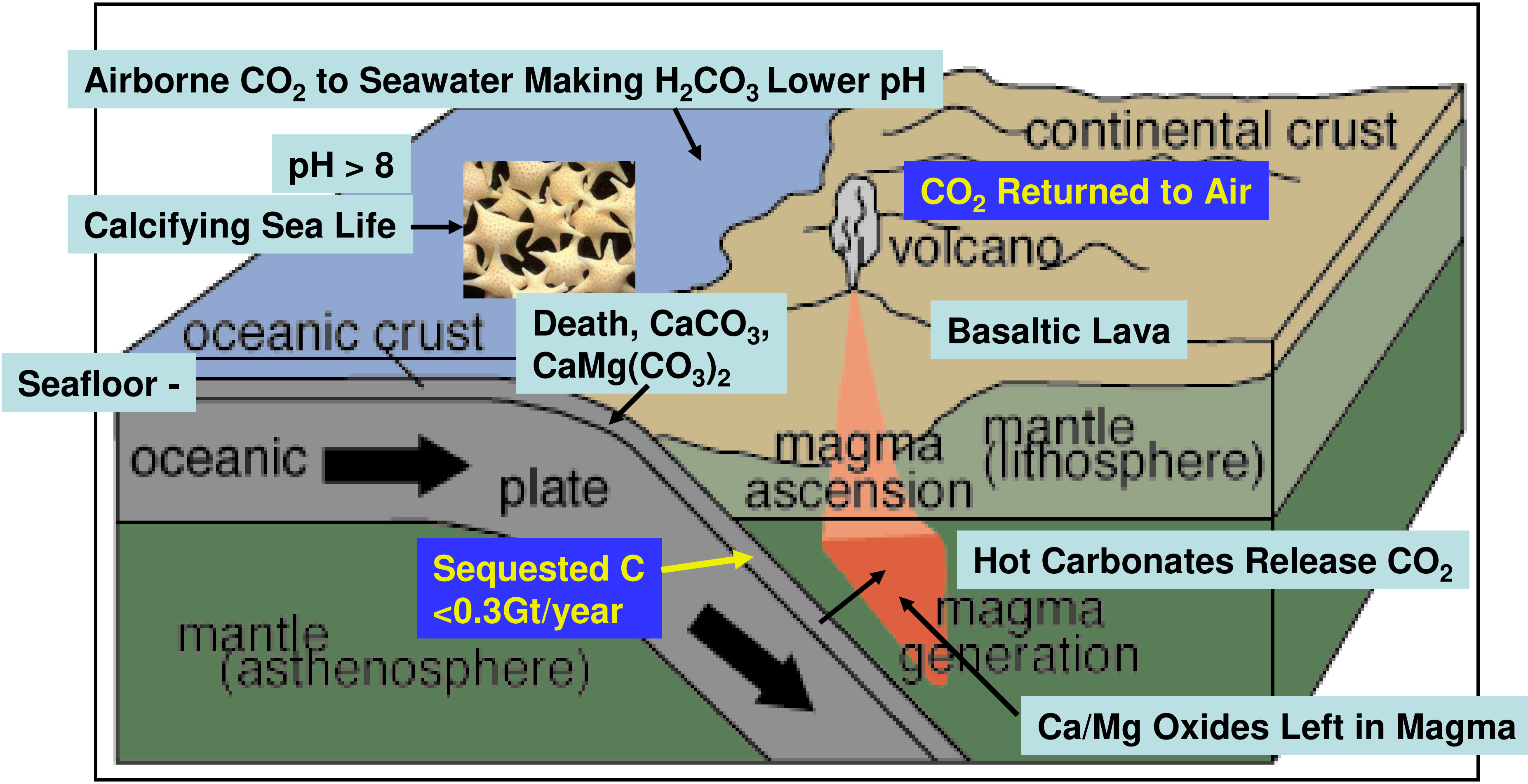

**Arctic Algae Blooms 2015**





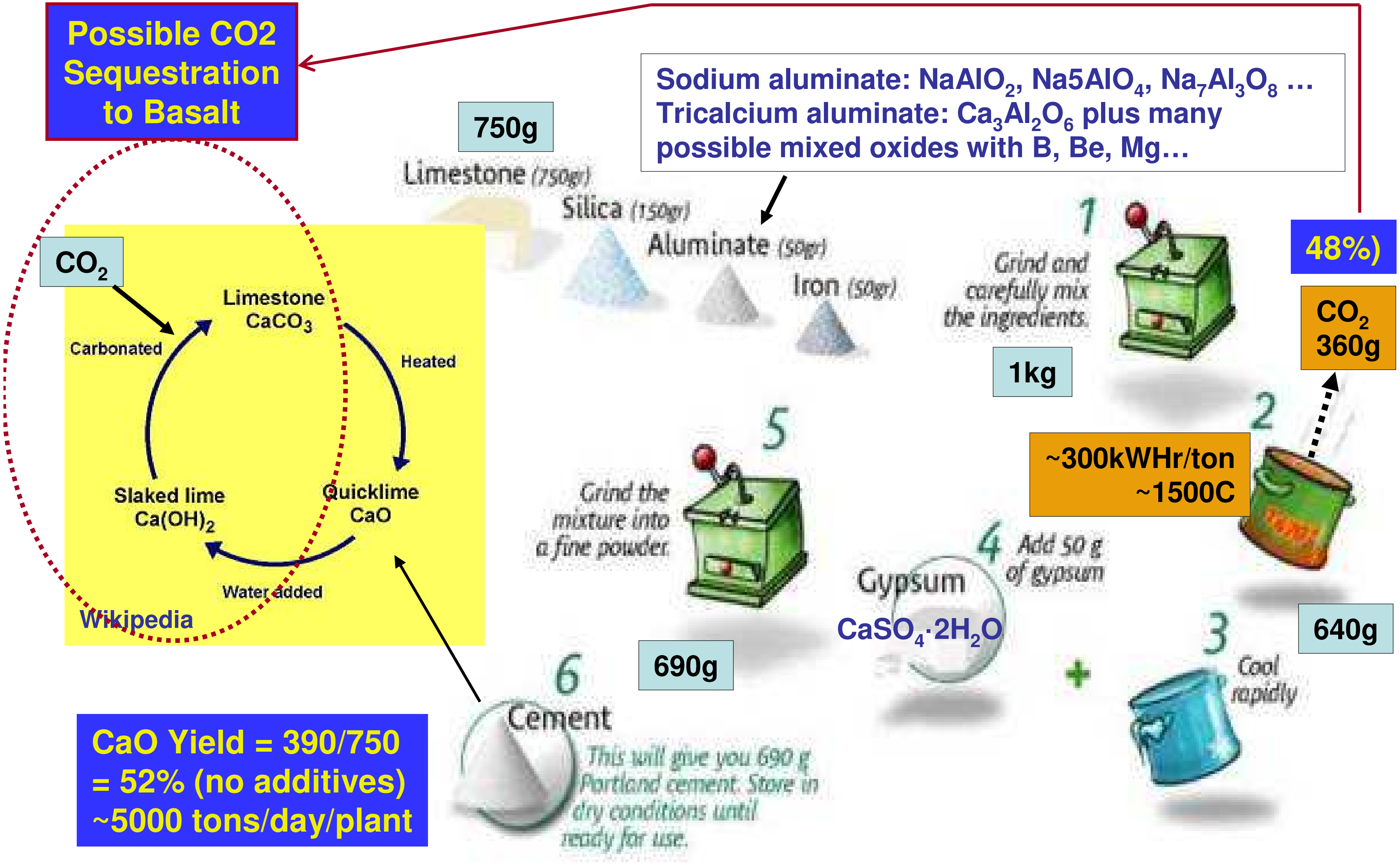
https://en.wikipedia.org/wiki/Phytoplankton

# Seafloor C Sequestration/Subduction




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

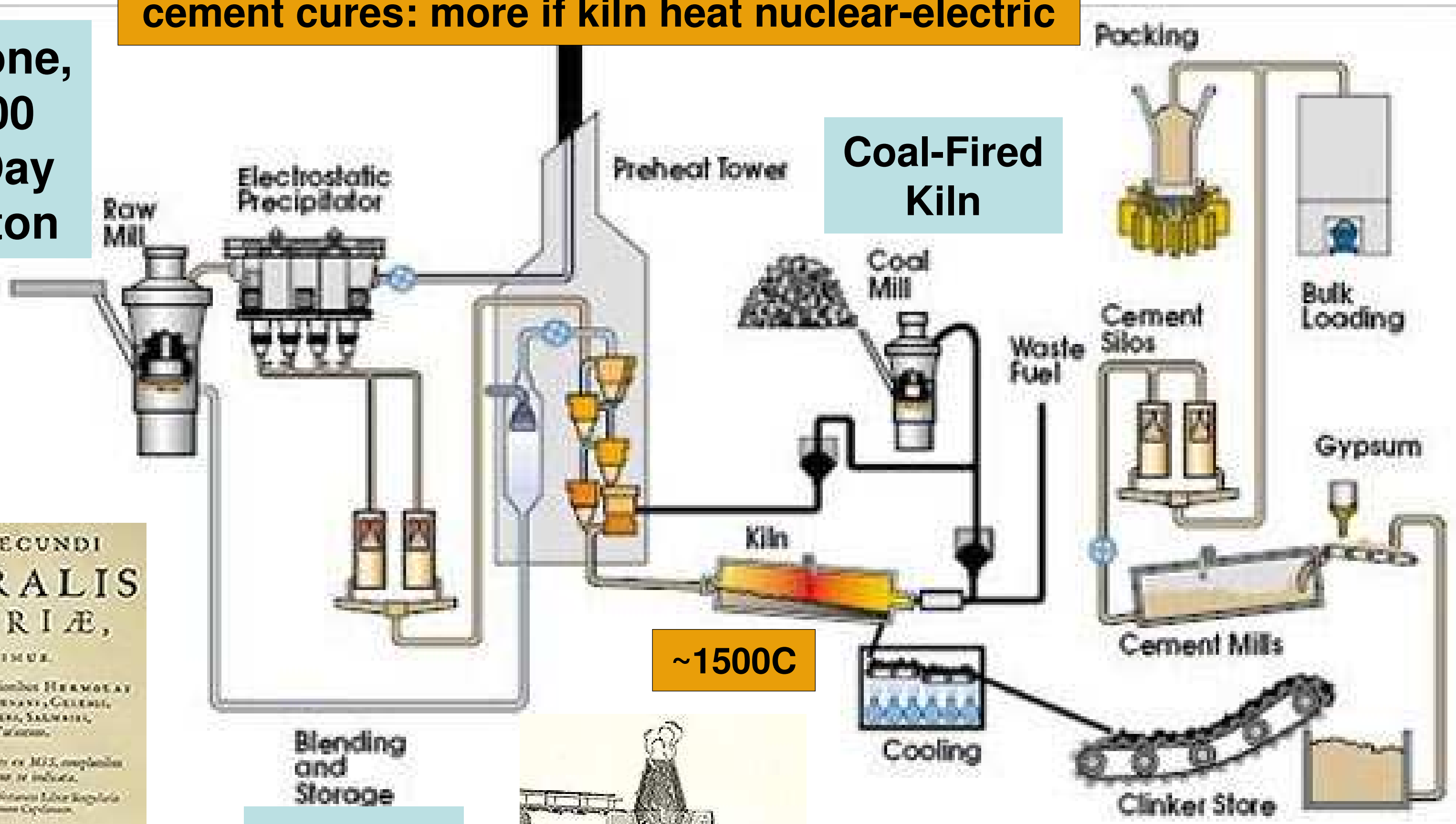
# Lime Cycle & Cement Making



# 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**

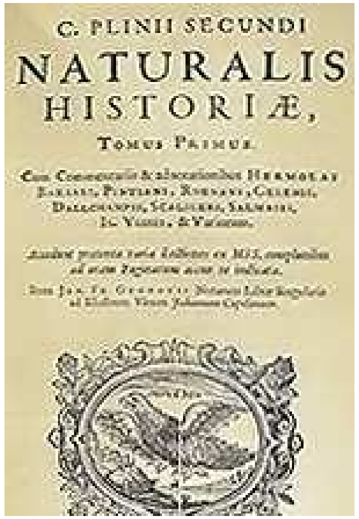



**Coal-Fired Kiln**

**~1500C**

**Additives**

**Lime + Additives, ~5000 Tons/Day**

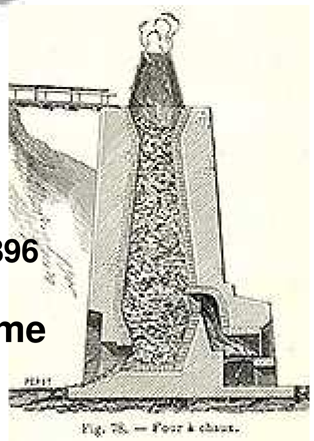



**Pliny The Eklder ~50ce**

**Chatellier Kiln 1896**

**Wikipedia**

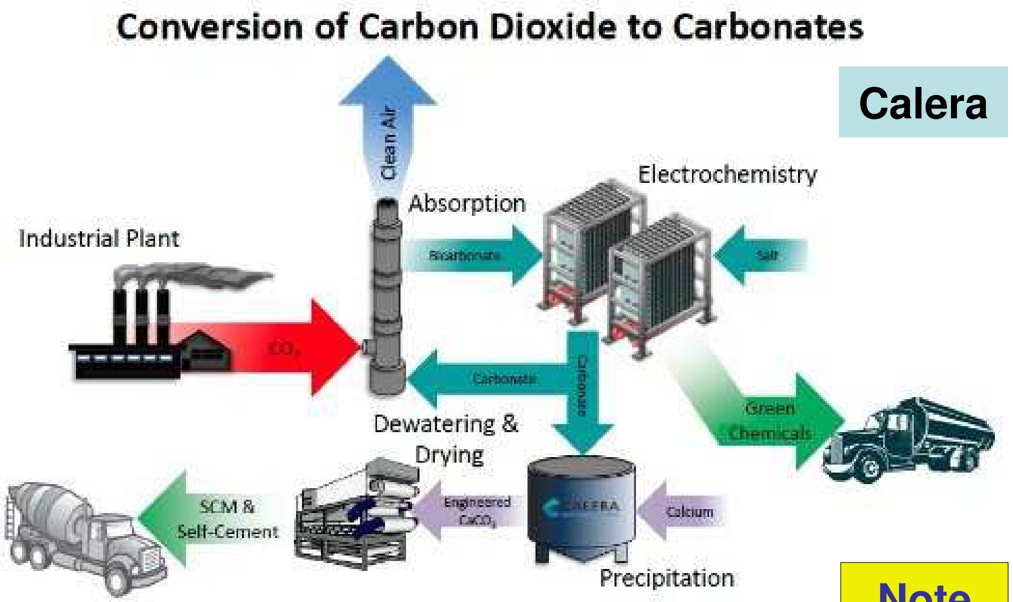
**Lime**



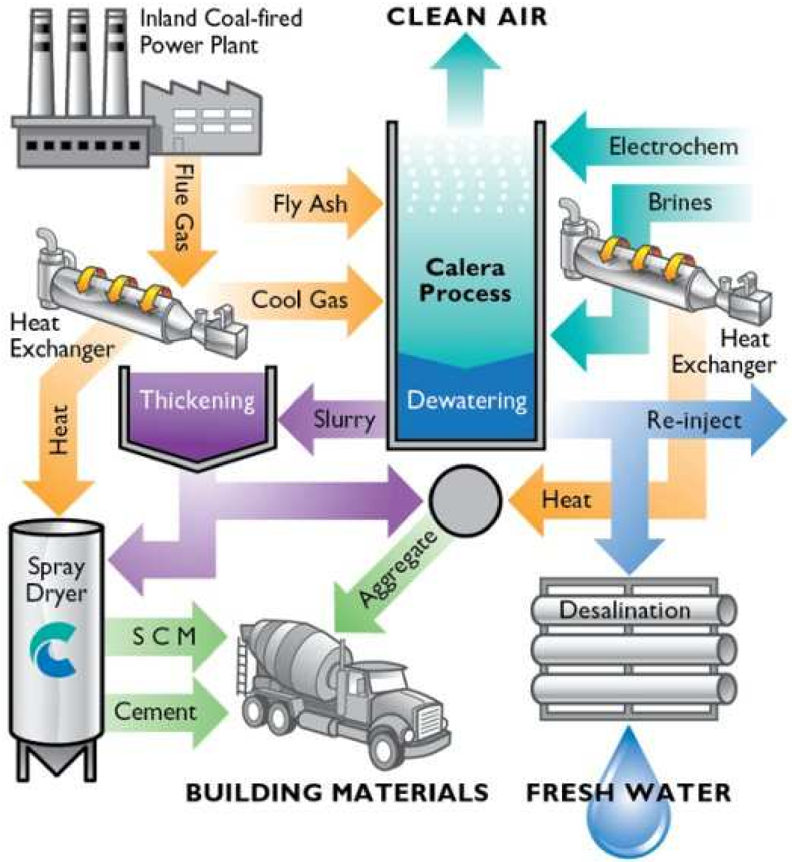

**Fire**

**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.**

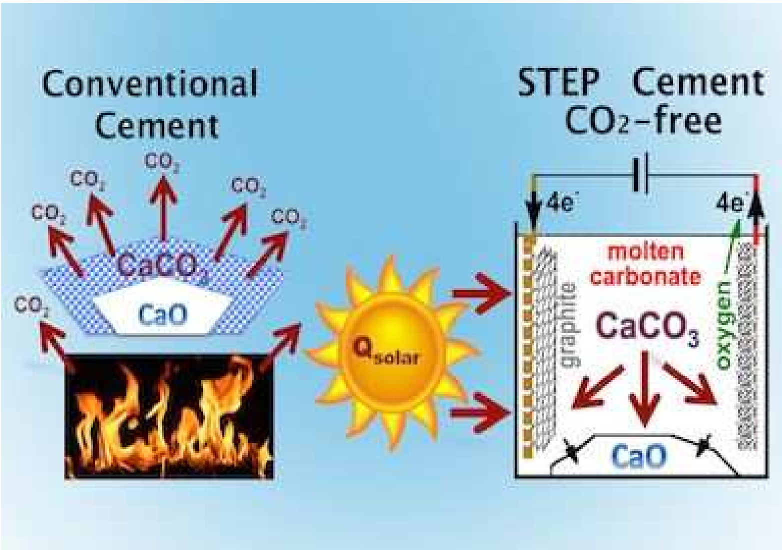
# Alternative Cement Making




**Calera**




**Note All Power Inputs**




**Electrolytic Carbon & Lime Precipitation T >600C**

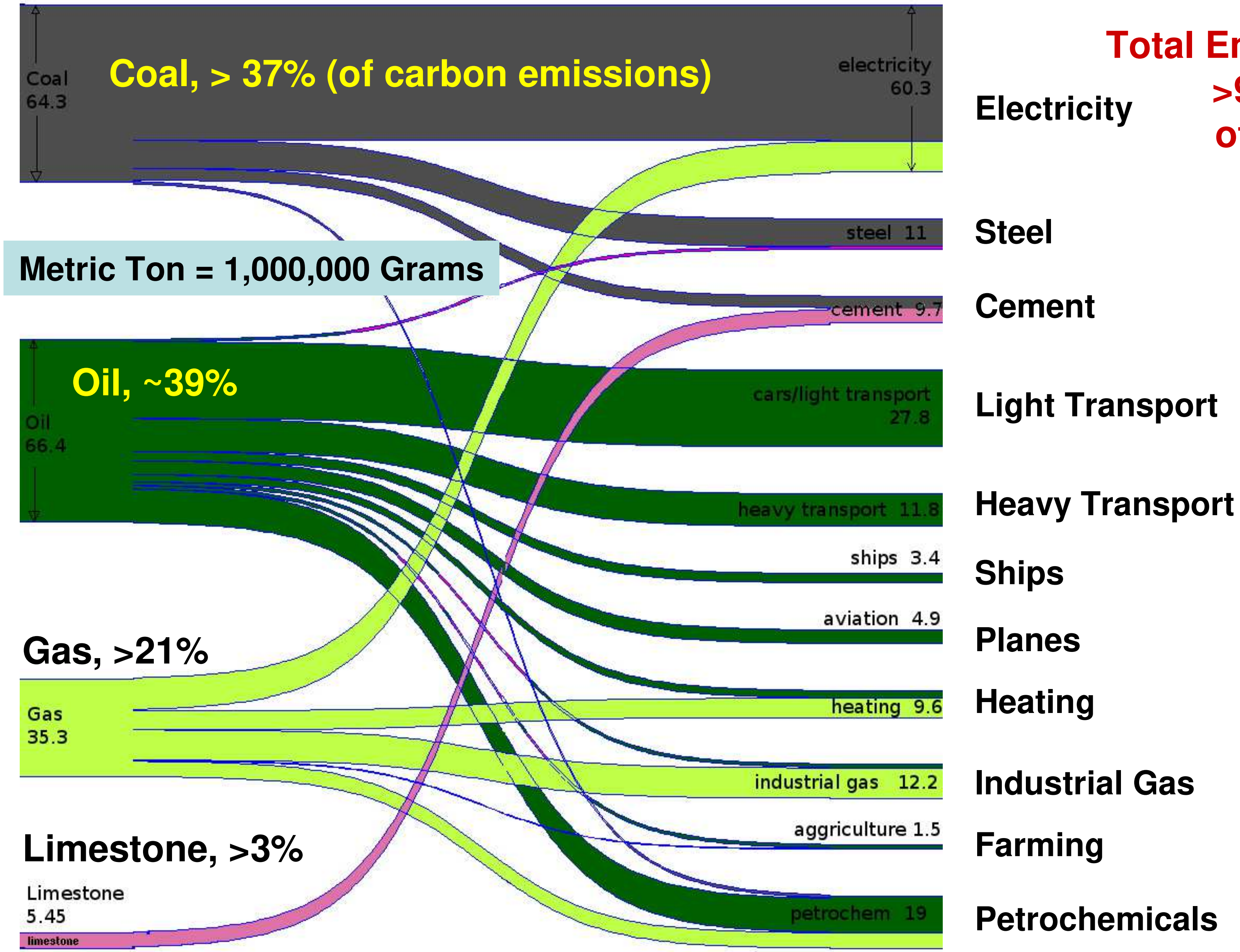
**Calera Process Needs Additives for Strength But Yields Clean Water**

# Cement Making


Flooded German Plant


**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)

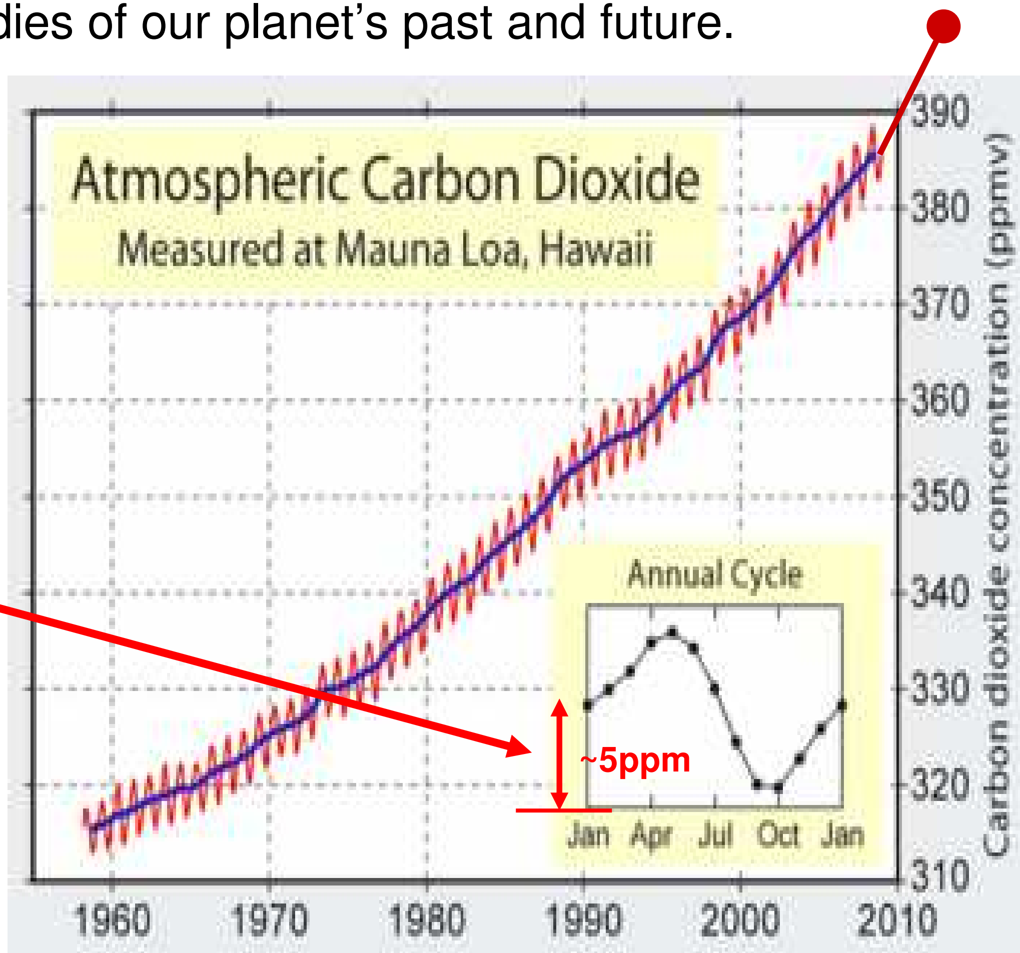



**Total Emissions >9B Tons of Carbon per Year in >30B Tons of $CO_2$**

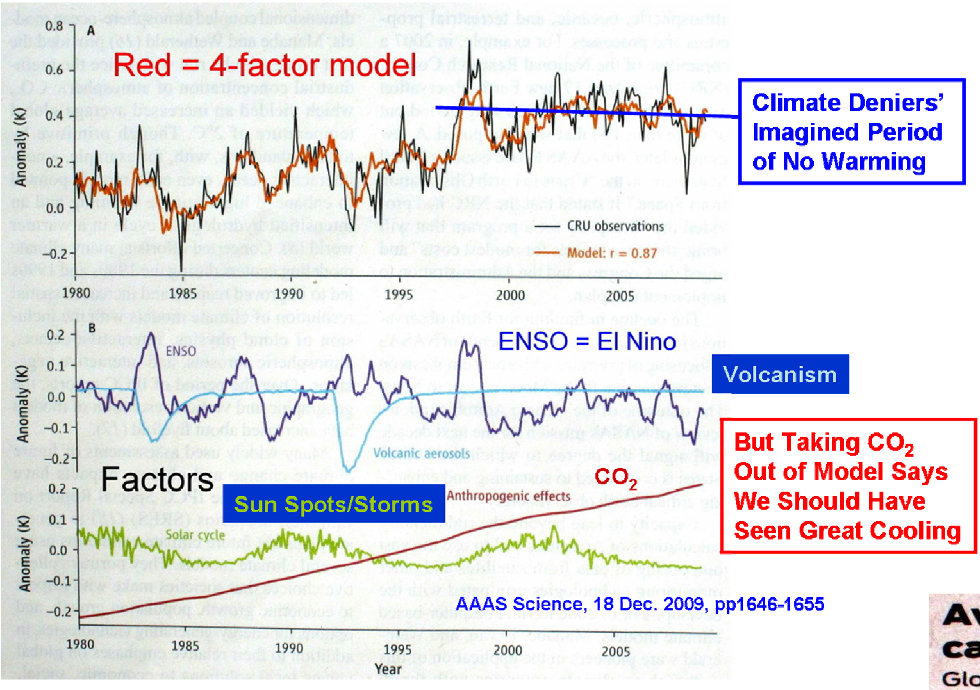
# Recent $CO_2$ History

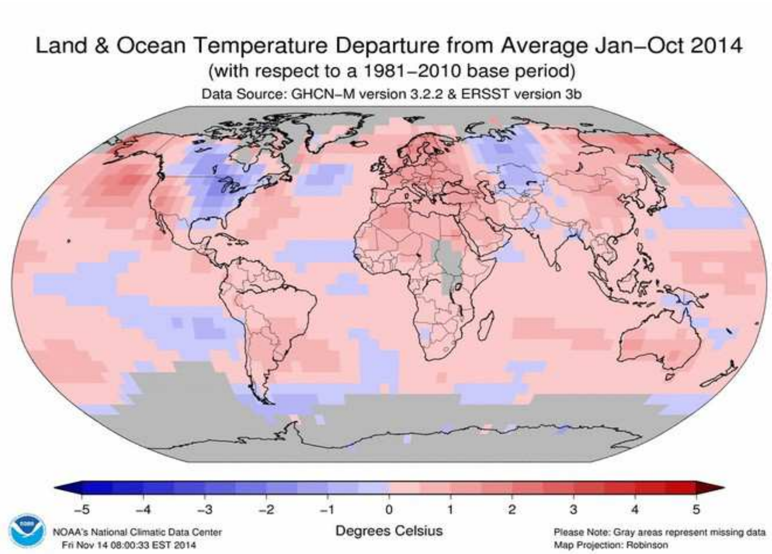
Our recent GHG awareness stems from the U. of Hawaii measurements of $CO_2$, beginning in 1957 – the first IGY (International Geophysical Year), when scientists worldwide began the intensive studies of our planet's past and future.

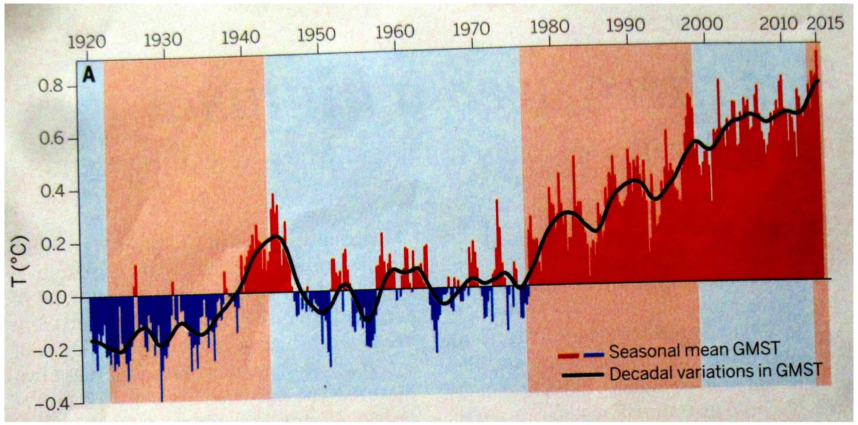
Note the important fact the ***<u>Annual Cycle</u>*** exposes -- it shows **what natural, sea & land photo-synthesizing organisms might do for us each year to reduce $CO_2$ levels -- about 4ppm/year, if no natural sources of $CO_2$ existed & we stopped all Hydrocarbon combustion -- (400-280)/4 = 30 years.**

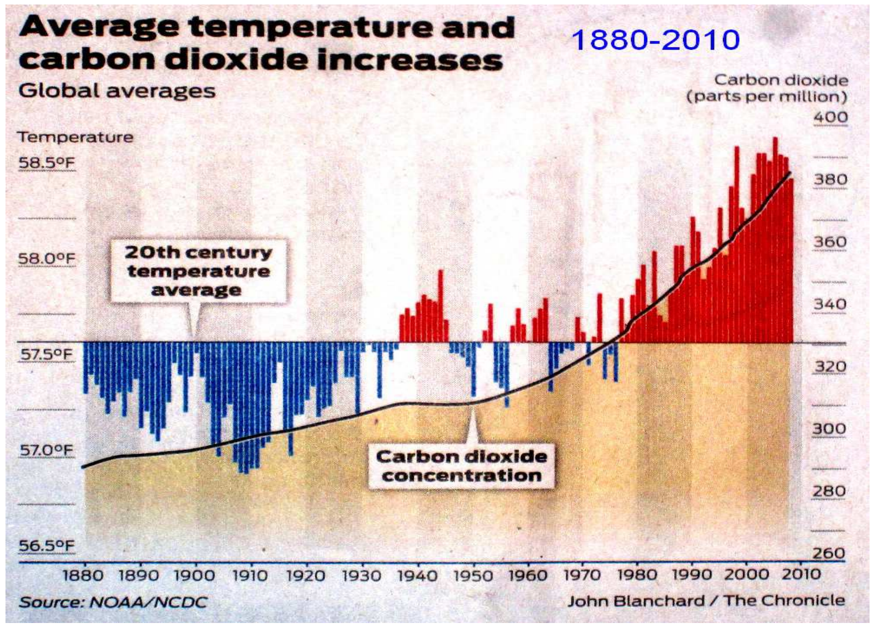


# Temperature History

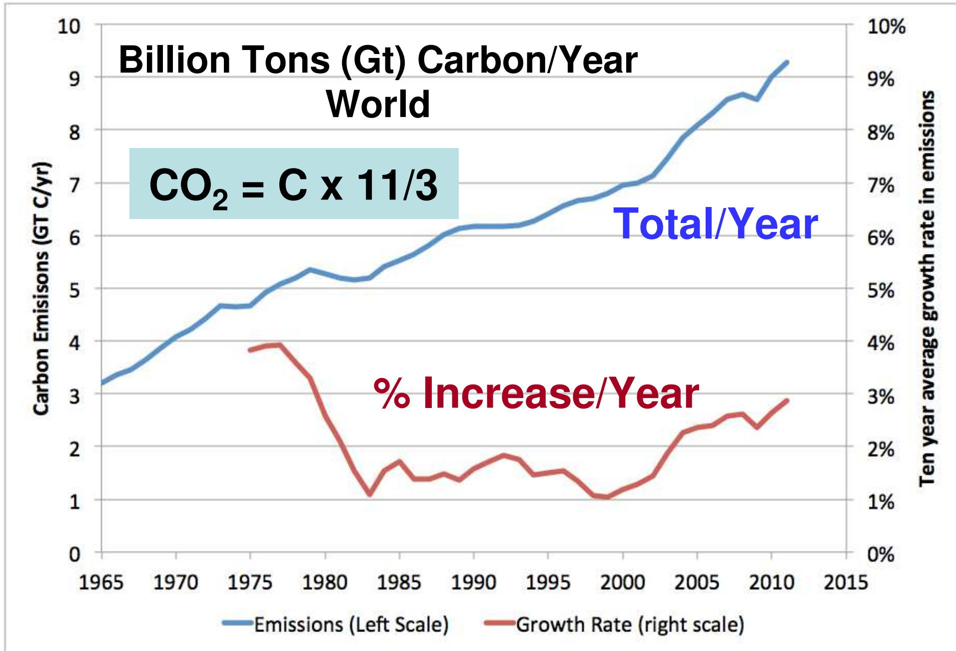


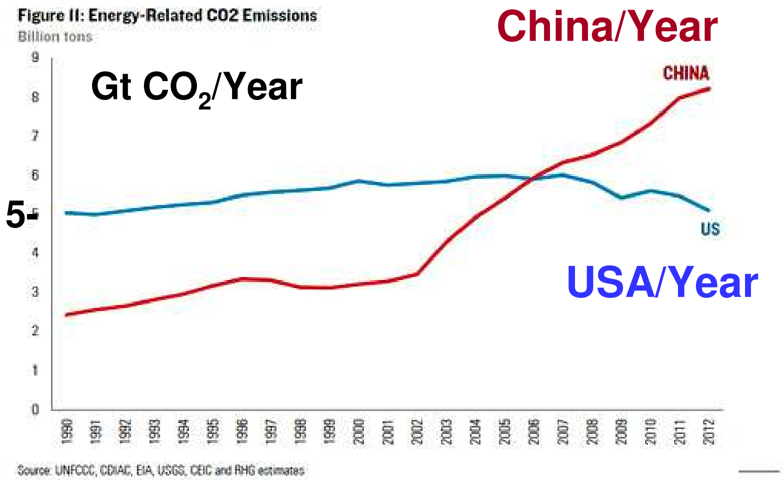



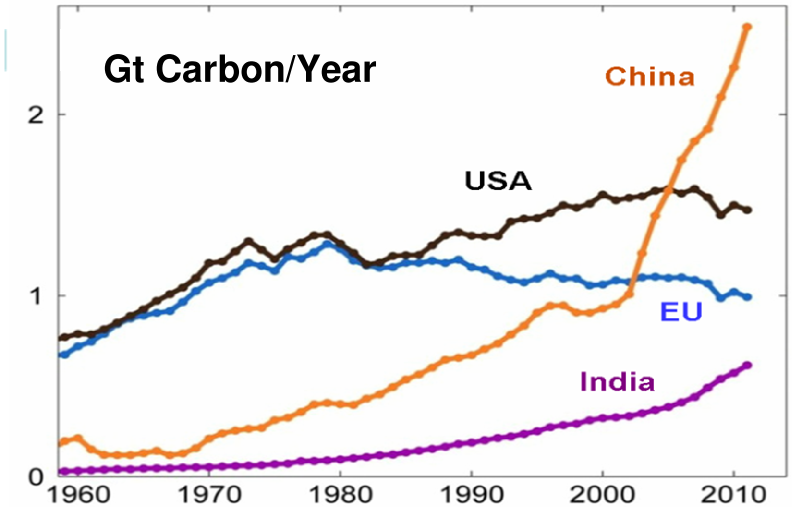



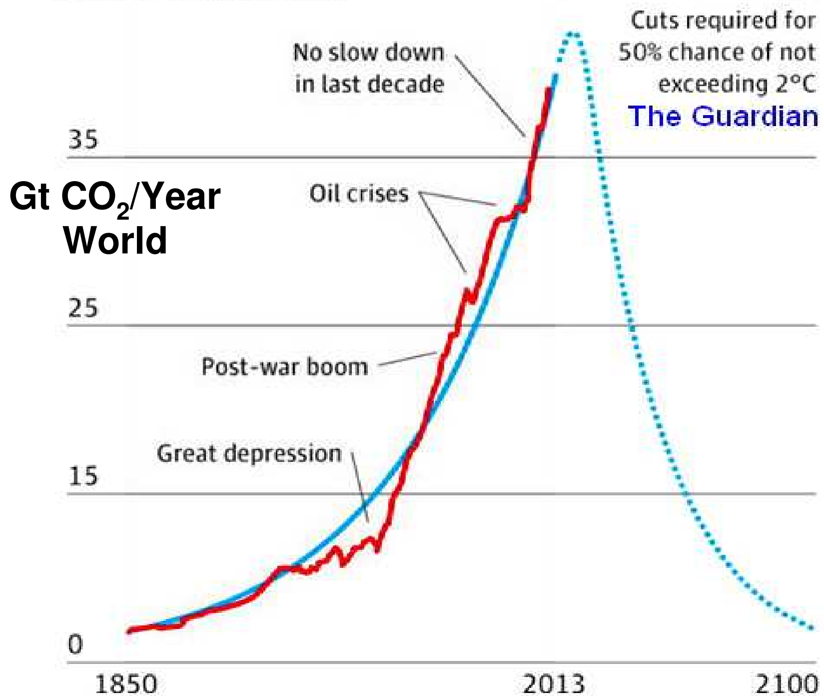



# C & $CO_2$ Emissions (2013)



# 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…

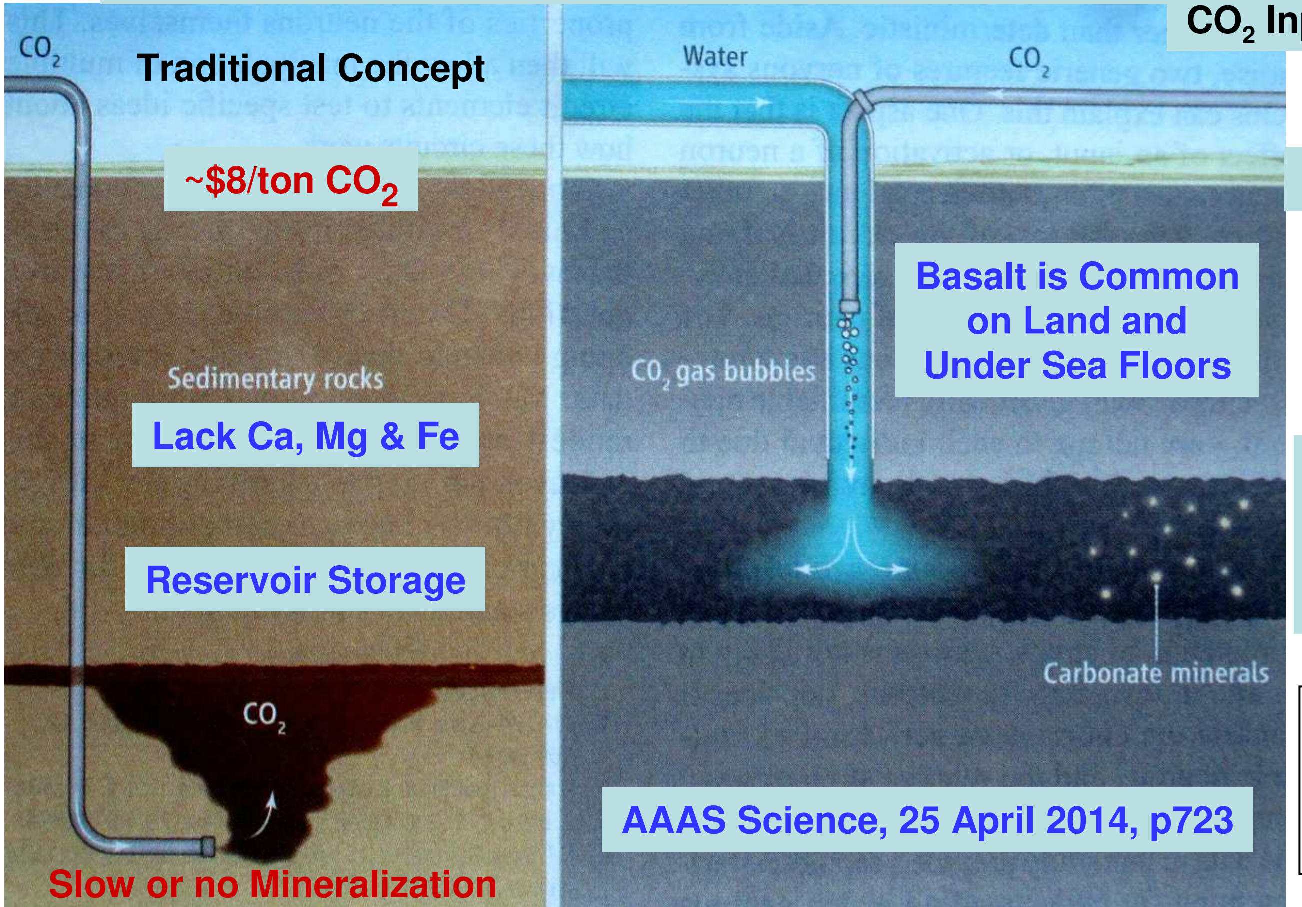
1) Carbon-neutral fuels;
2) Industrial feedstocks;
3) Benign C-H compounds for geologic storage – in old wells/mines, etc.

**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>

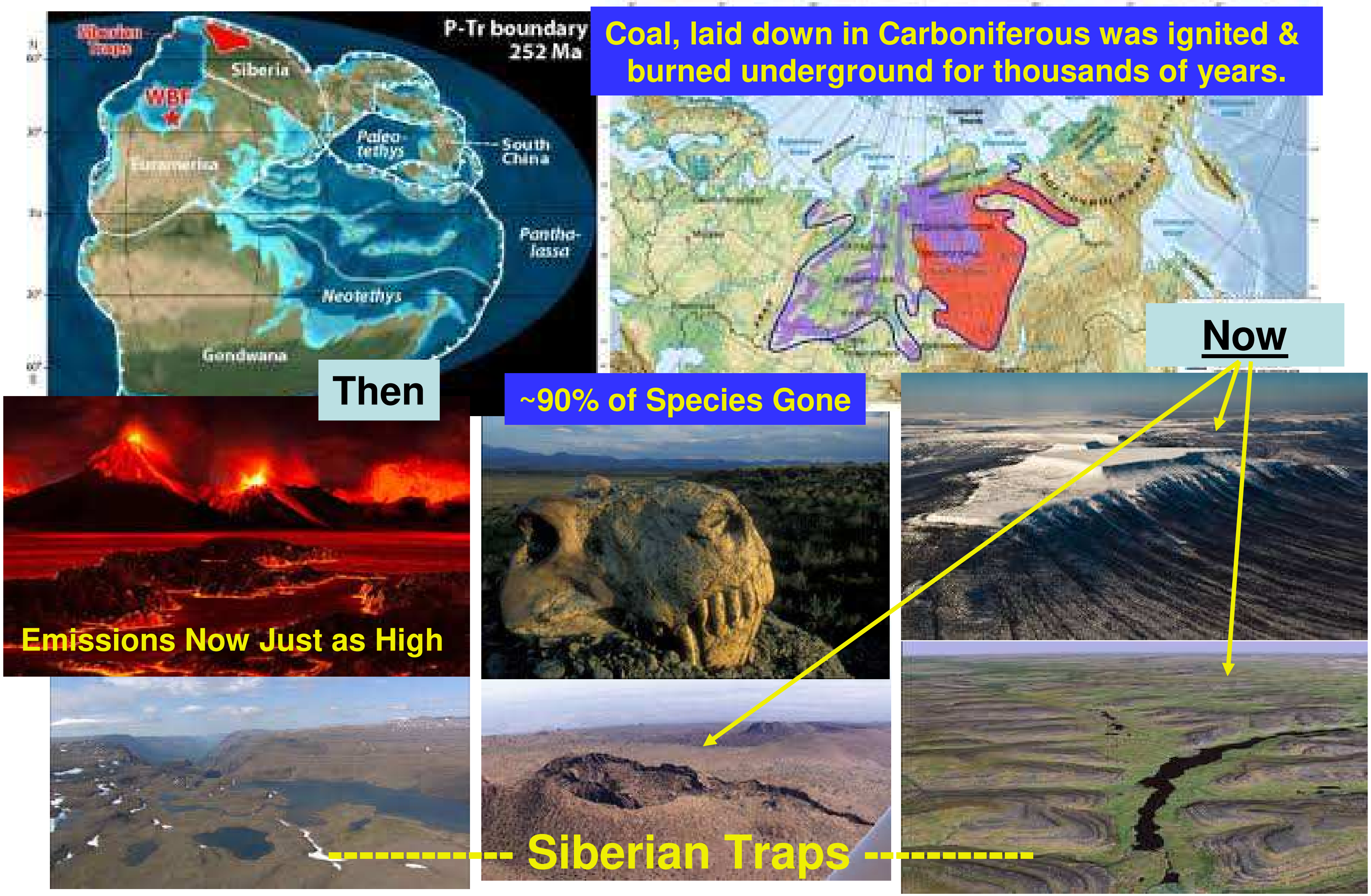
**Example Reactions**

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

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)

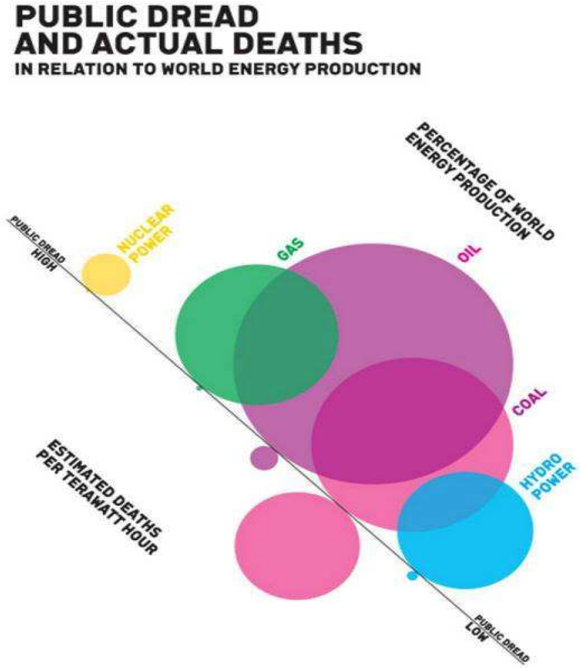
***Alternating Swamps & Seas***

**Cretaceous Chalk/Limestone**


**Carboniferous Coal**

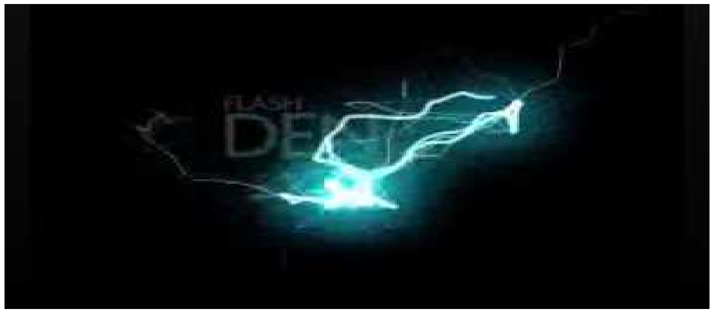
# Remediation Power Choices

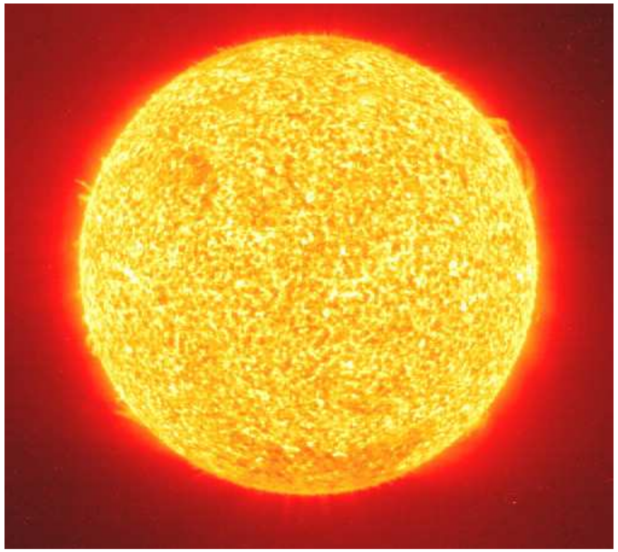
- ***Features*** – will not increase GHG emissions
- ***Power Density*** – resources needed to build & operate:
  - Processing limestone/dolomite to lime (~4**00kWHr/ton** -- mining, transport, process temperature >1400C)
  - Lime transport to ocean (kW)
  - $CO_2$ storage & cracking (kW + temp)
  - $CO_2$ 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…



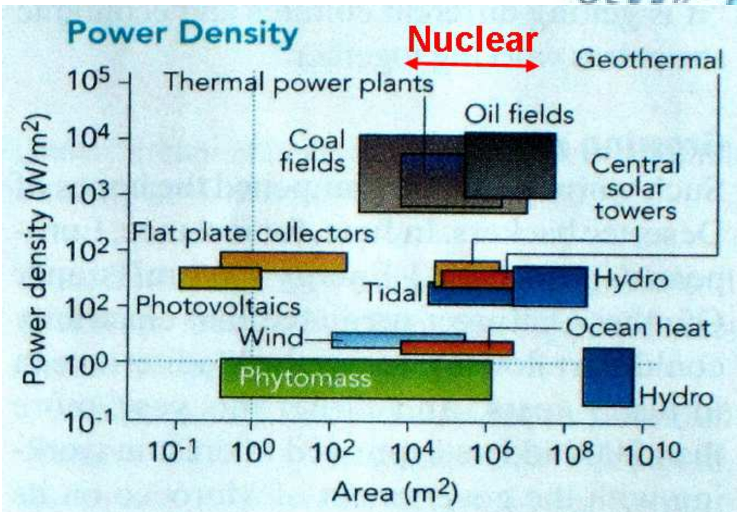


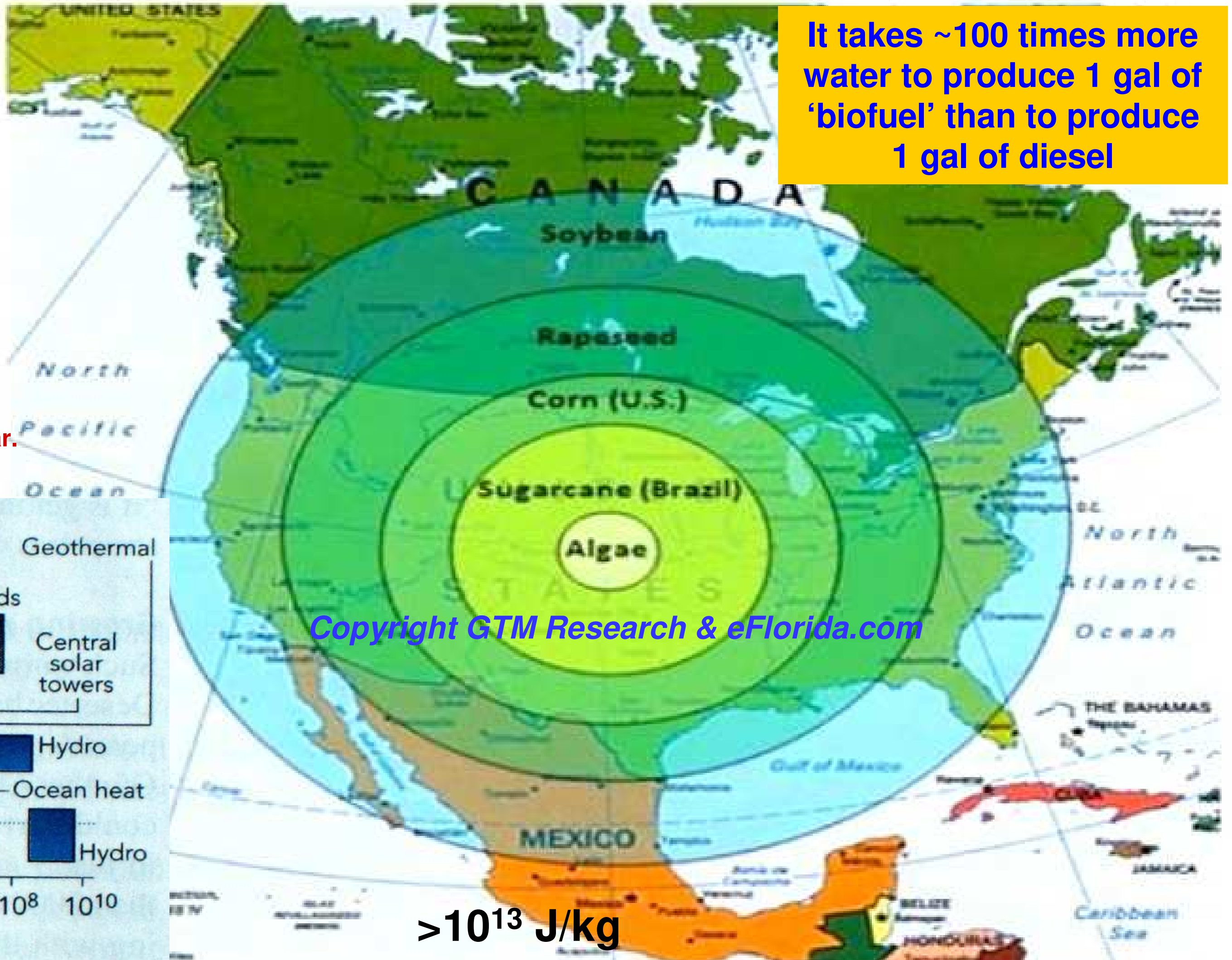
# Areas Needed to Replace US Fossil Fuels

**Area Needed for Nuclear***

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

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



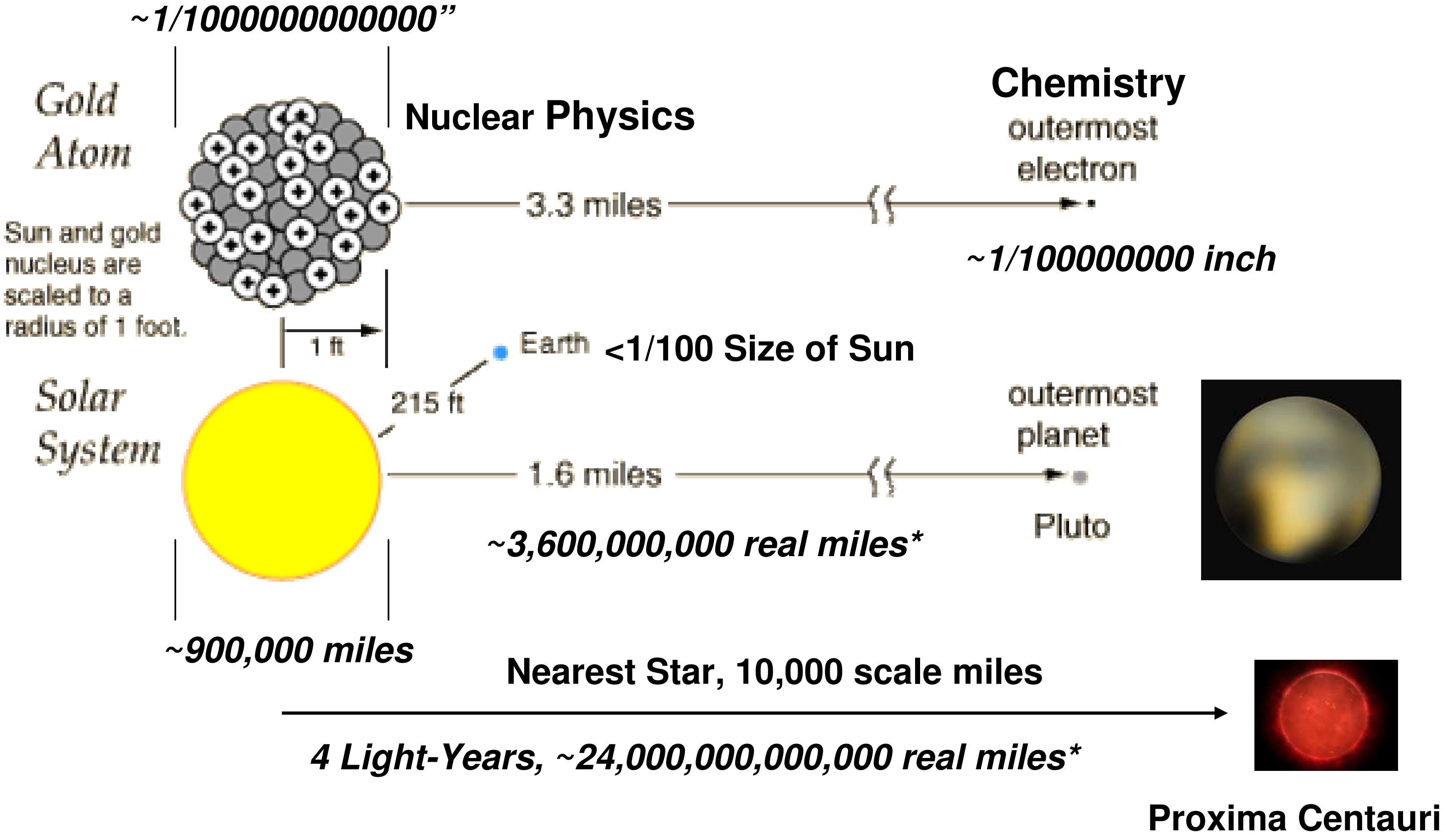

**It takes ~100 times more water to produce 1 gal of 'biofuel' than to produce 1 gal of diesel**

**$>10^{13}$ J/kg**

| Combustion | Fission | Fusion |
|---|---|---|
| ~10kWattHr/lb | ~3GWHr/lb | ~$10^{11}$ WHr/lb |

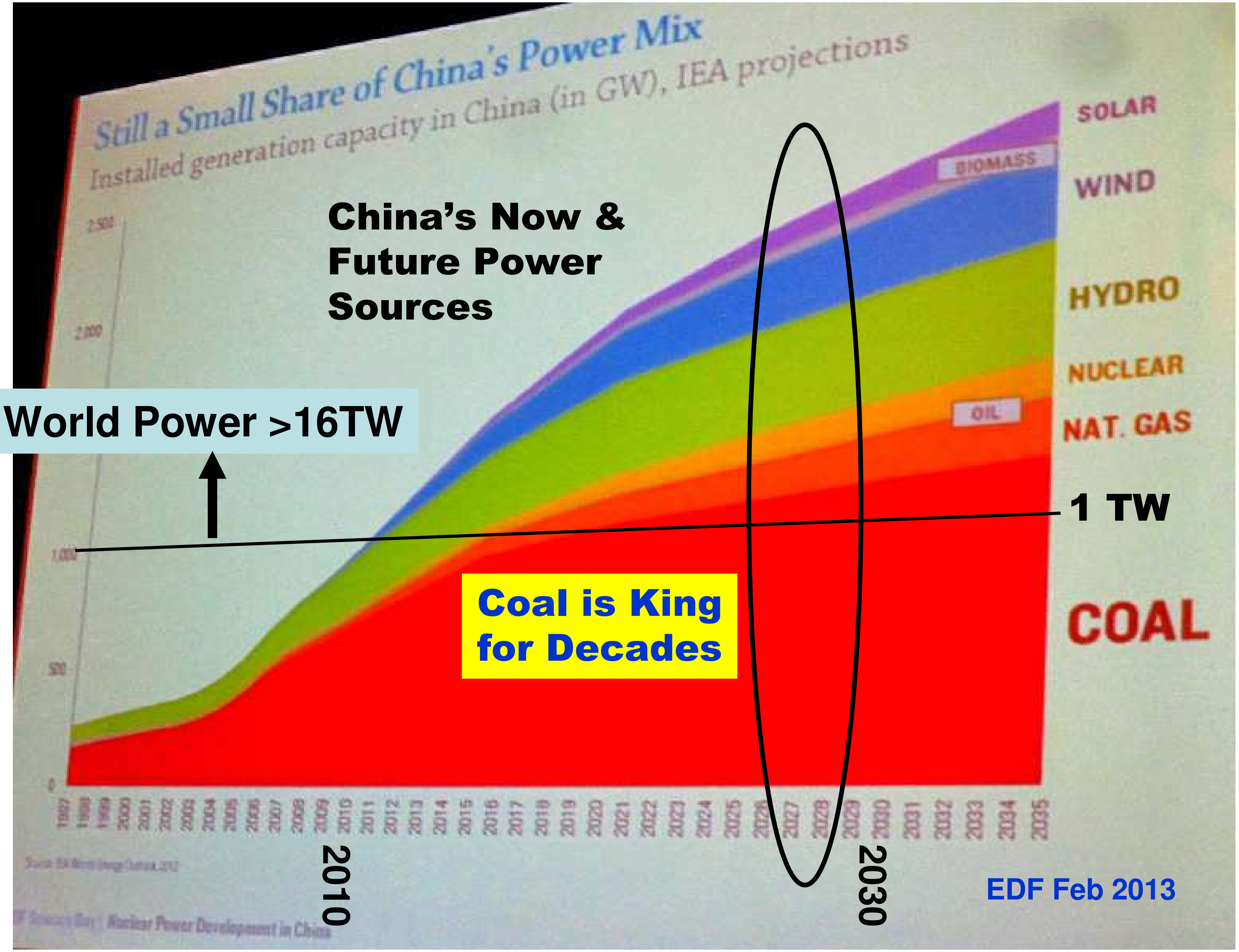
**~10kWattHr/lb** ***x1,000,000*** → **~3GWHr/lb** ***x100*** → **~$10^{11}$ WHr/lb**

# A Worldly Scale

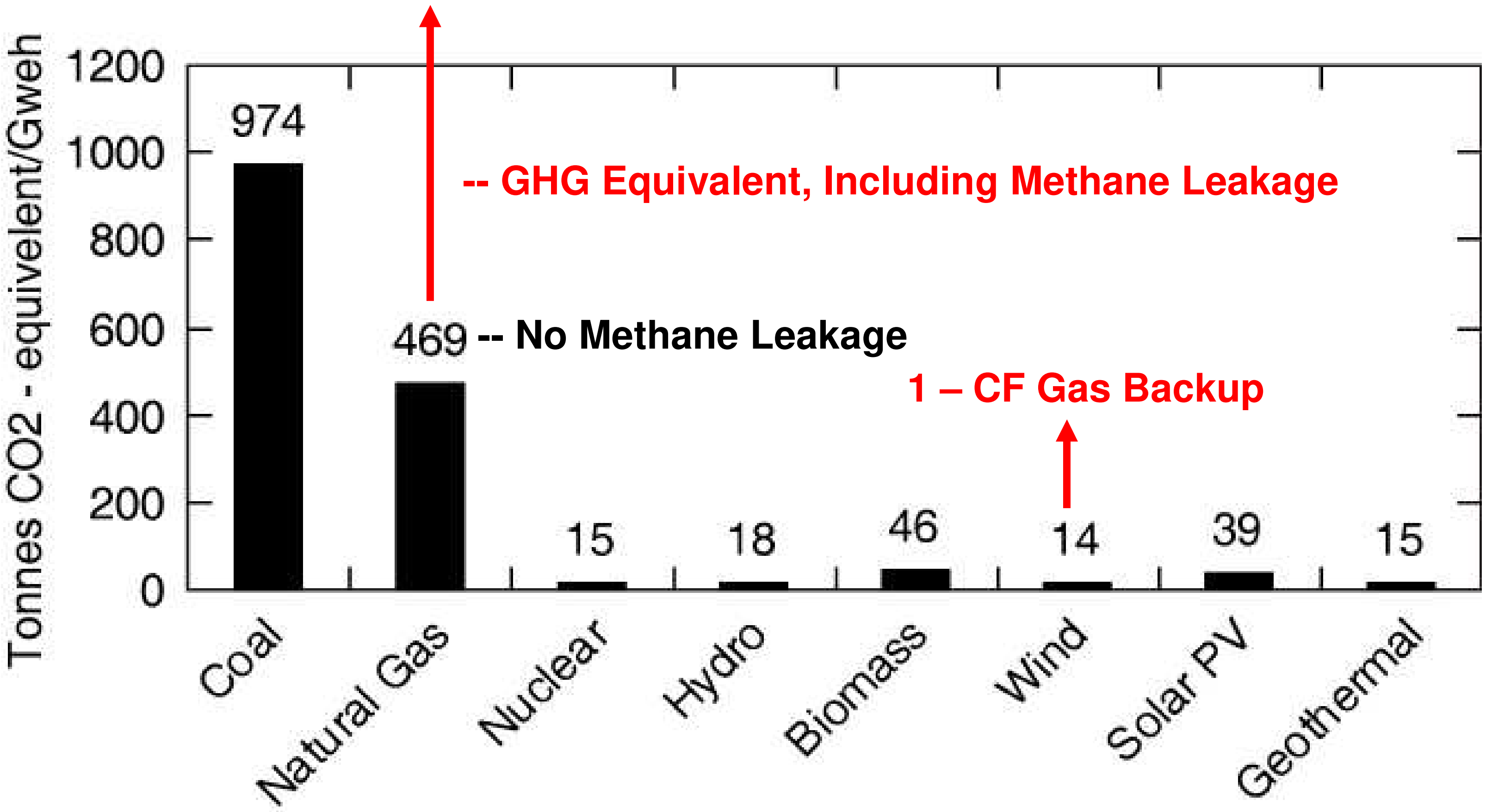



* Actual distances are in italics

# Chinese Power 2010-2035

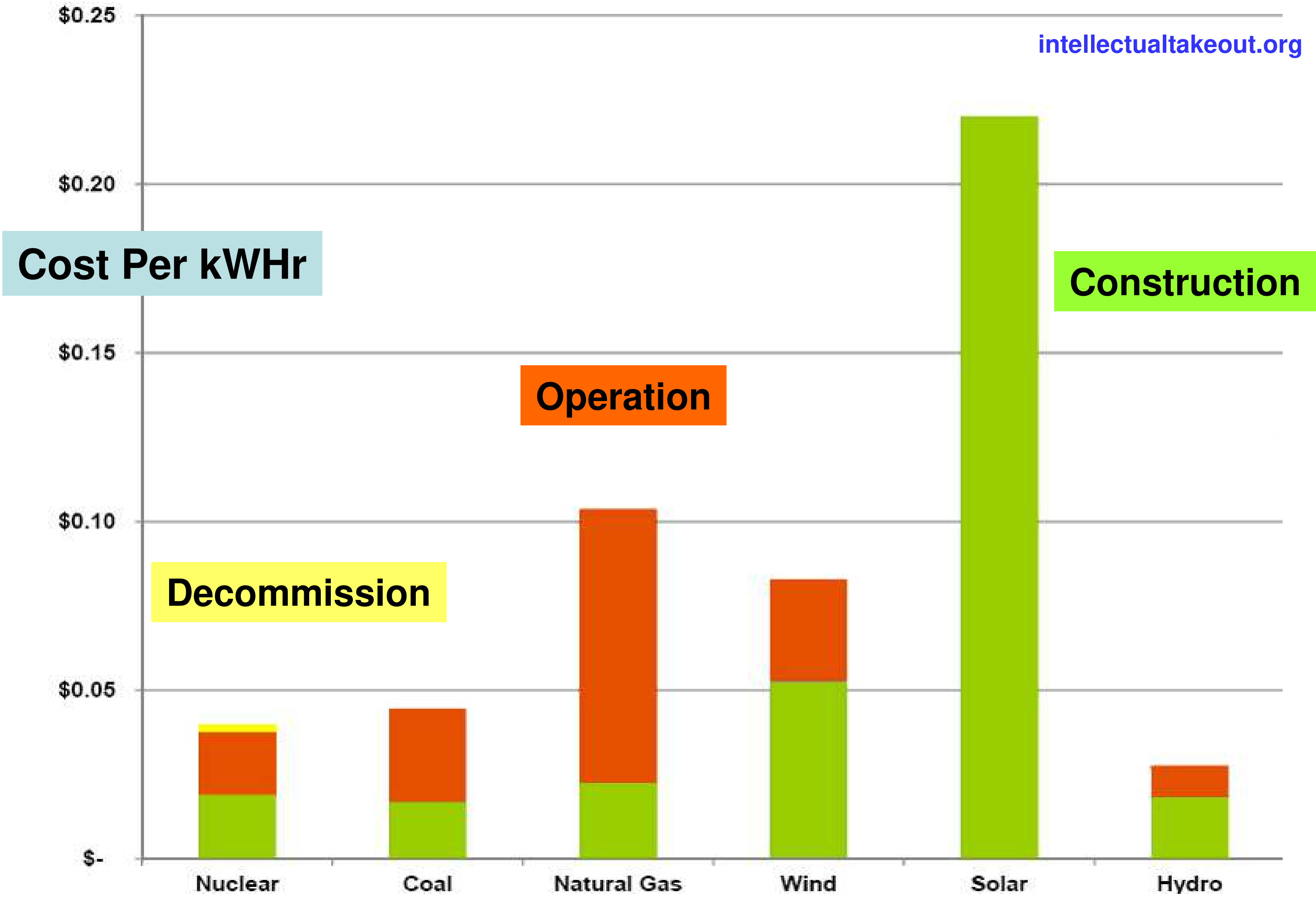


# Lifecycle $CO_2$ Emissions

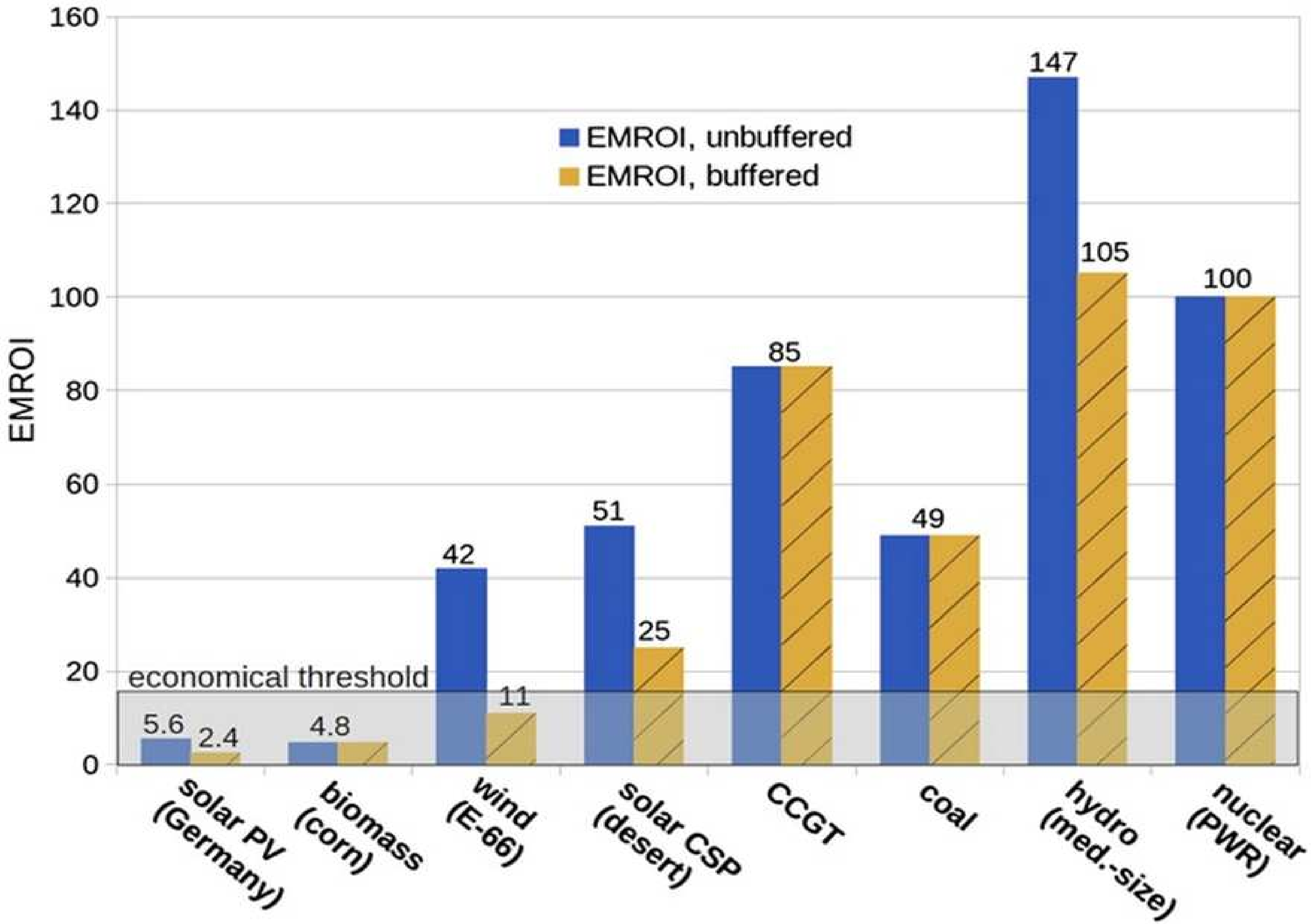



**Courtesy Burton Richter --** *Comparison of Life Cycle Emissions in Metric Tonnes of $CO_2$e per GW-hour for various modes of Electricity Production;* P.J. Meier, *Life-Cycle Assessment of electricity Generation Systems with Applications for Climate Change Policy Analysis,*

# Lifecycle Costs Per kWHr

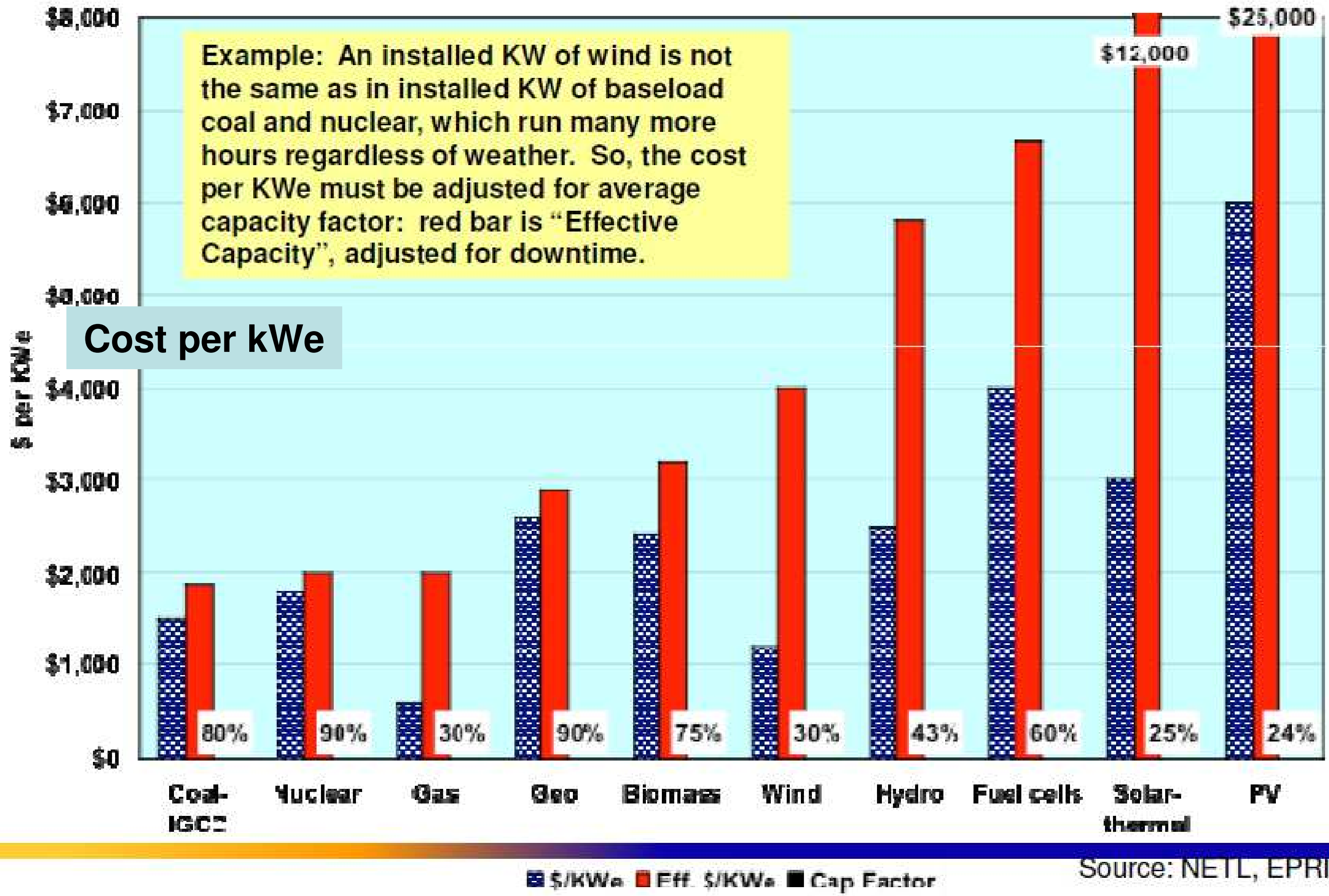


# Lifecycle Return Per kWHr



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

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



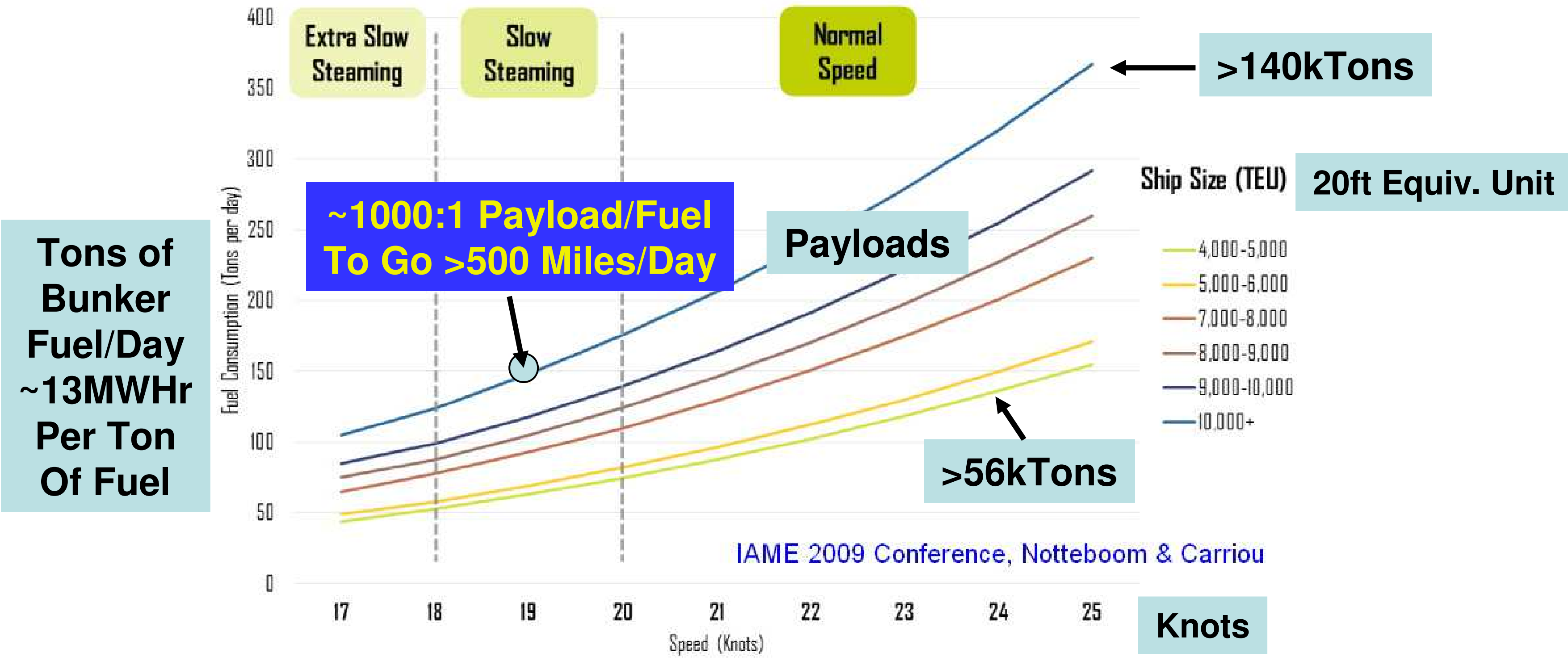

Source: NETL, EPRI

# 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



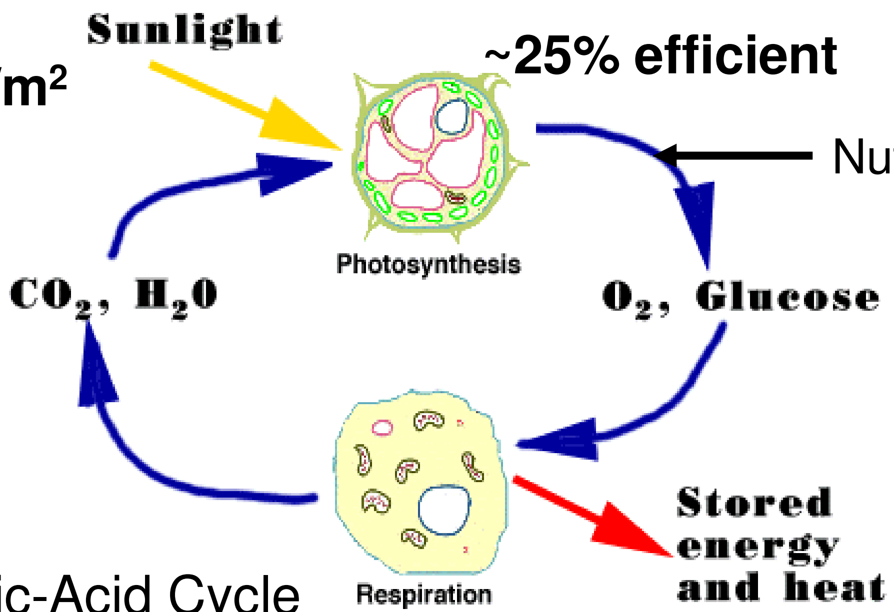
# Photosynthesis – $CO_2$ Handling

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

www.johnkyrk.com/krebs.html

1kW/m²

***Plants did not evolve to supply humans' energy needs***




~25% efficient

Nutrients, trace elements, water & climate

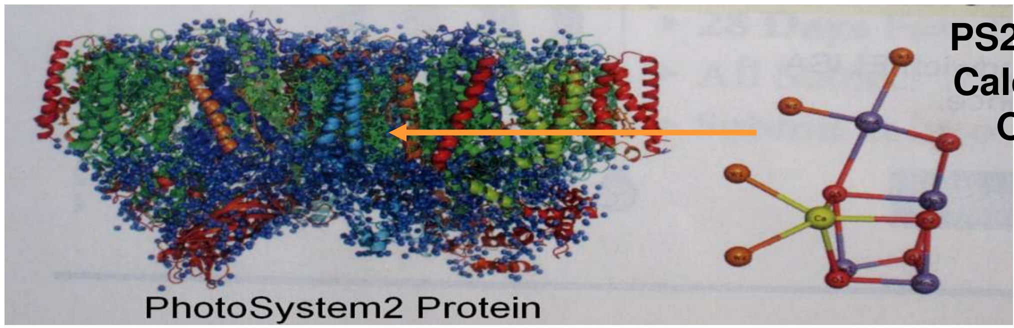
~32% efficient

**Photosynthesis net <7%**

Krebs/Citric-Acid Cycle

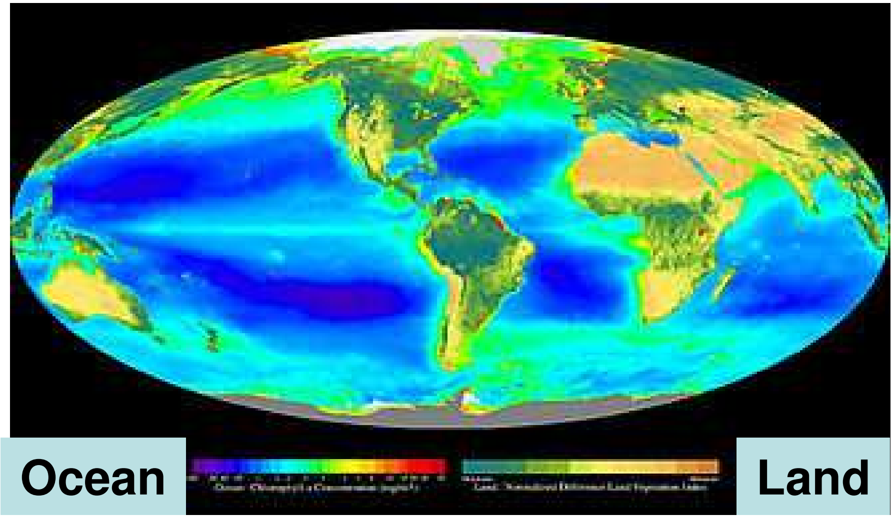
$$C_6H_{12}O_6\ (\text{glucose}) + 6O_2 \xrightarrow[\text{Mitochondria}]{} 6CO_2 + 6H_2O + \text{Stored Energy}$$

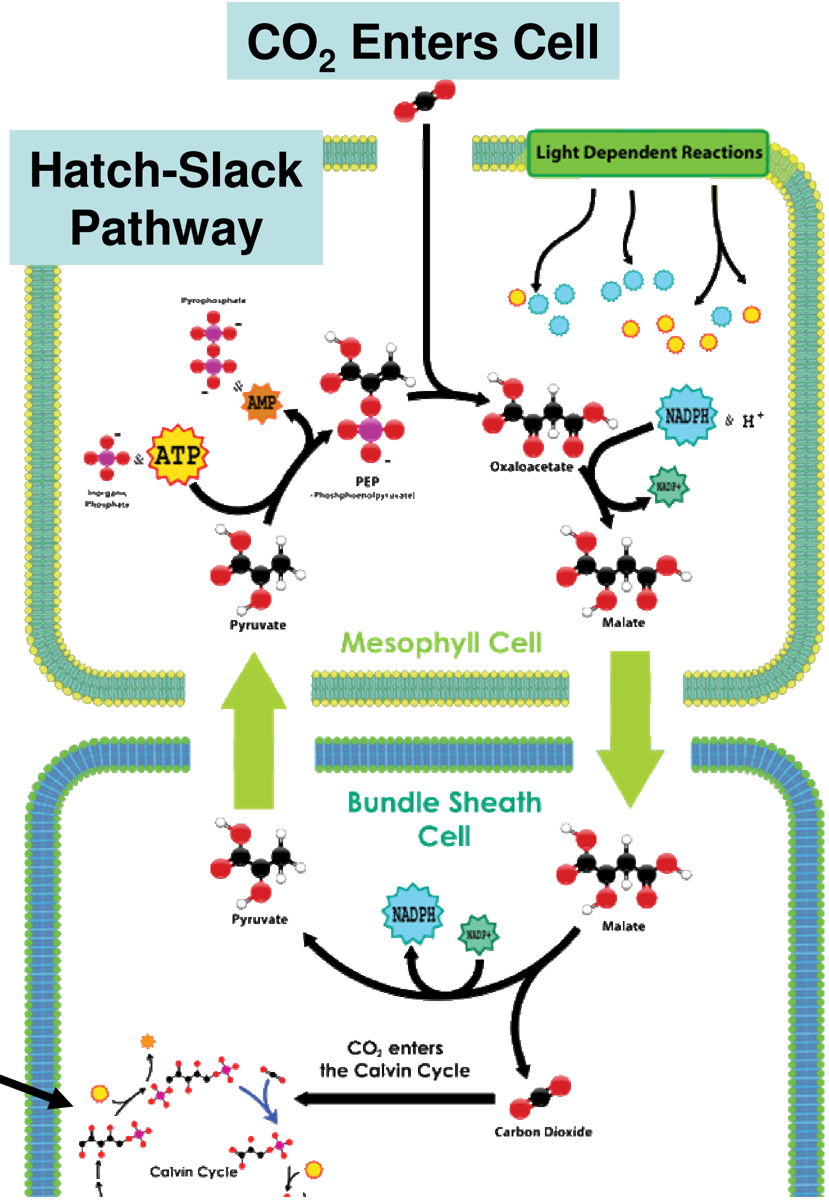
← Plant & animal respiration energy released for metabolism & molecular catalysis

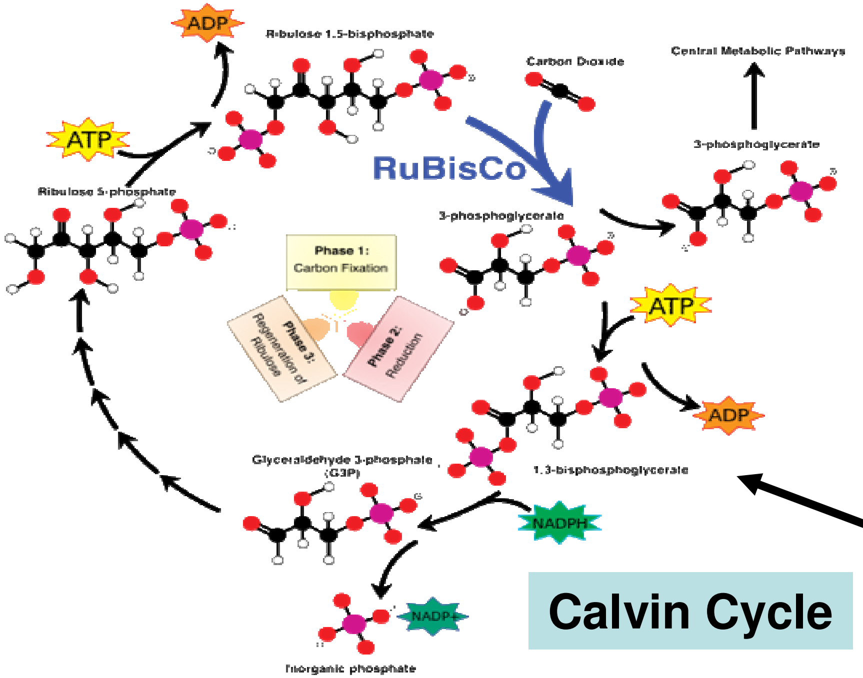



**PS2 Protein Houses a Calcium, Manganese, Oxygen Catalyst To Split $H_2O$**

# Photosynthesis – $CO_2$ Handling



# 17 April 1970

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  - **Permafrost carbon: http://tinyurl.com/kr9ctqr**
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    - **http://tinyurl.com/lsj75vv**
  - **Kerry Emanuel talk, 2014: https://www.youtube.com/watch?v=7so8GRCWA1k**
  - **Southern Ocean: http://tinyurl.com/p8srvng**
  - **Atlantic Ocean: http://tinyurl.com/n9t59et**
  - **Hansen & Lovelock: http://tinyurl.com/nh3bsh6**

    **https://www.youtube.com/watch?v=mYP22Kfl8lw&feature=youtu.be**