The Possibility & Difficulty of Engineering the Ocean & the Atmosphere

Kurt Zenz House

Engineering the Earth

May 10th, 2008

Agenda

- Our current geoengineering *success (failure?)*
- The various approaches to engineer the Earth more thoughtfully
- The Earth's thermostat
- Can we adjust the Earth's thermostat?

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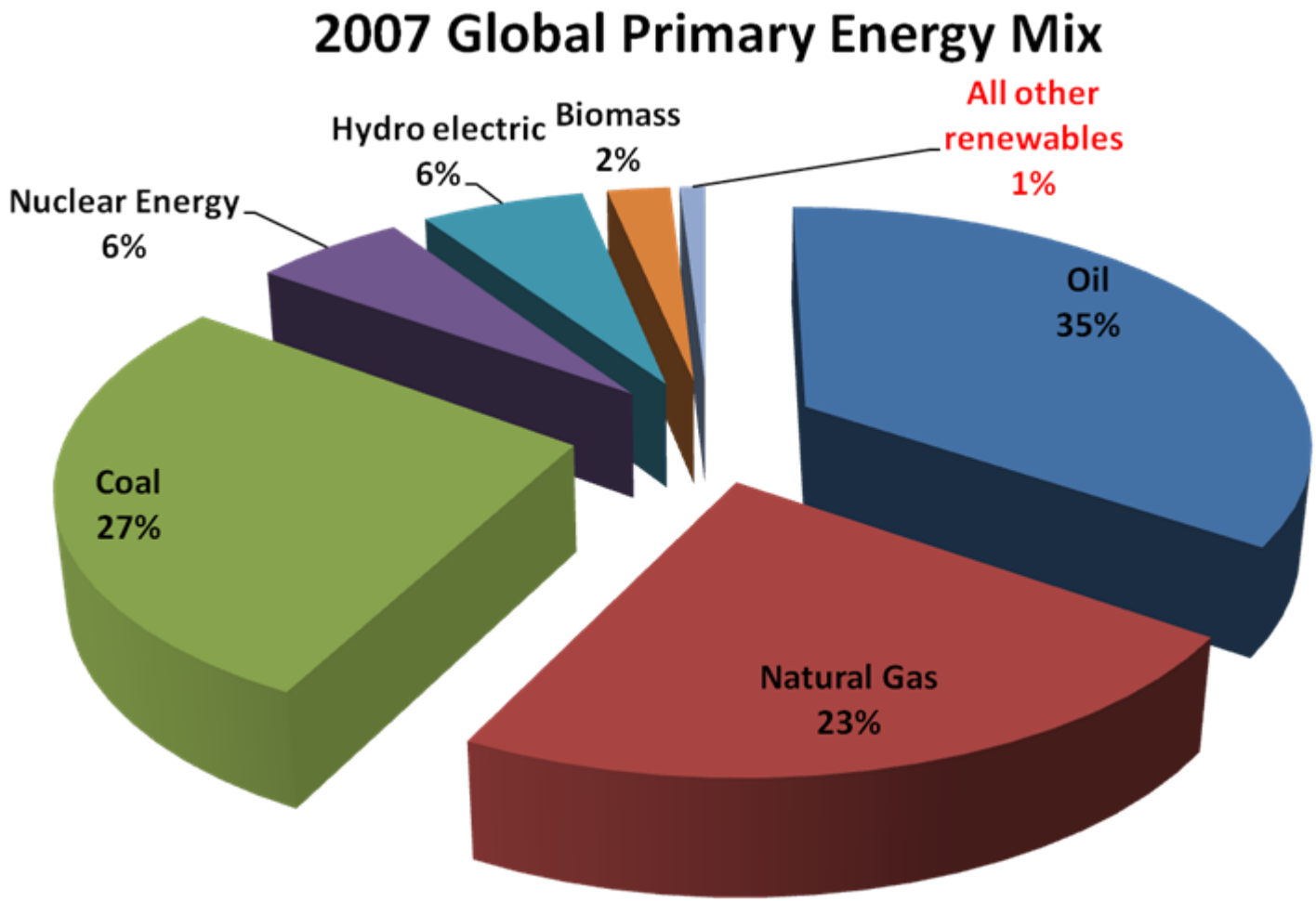
We live in the fossil hydrocarbon age



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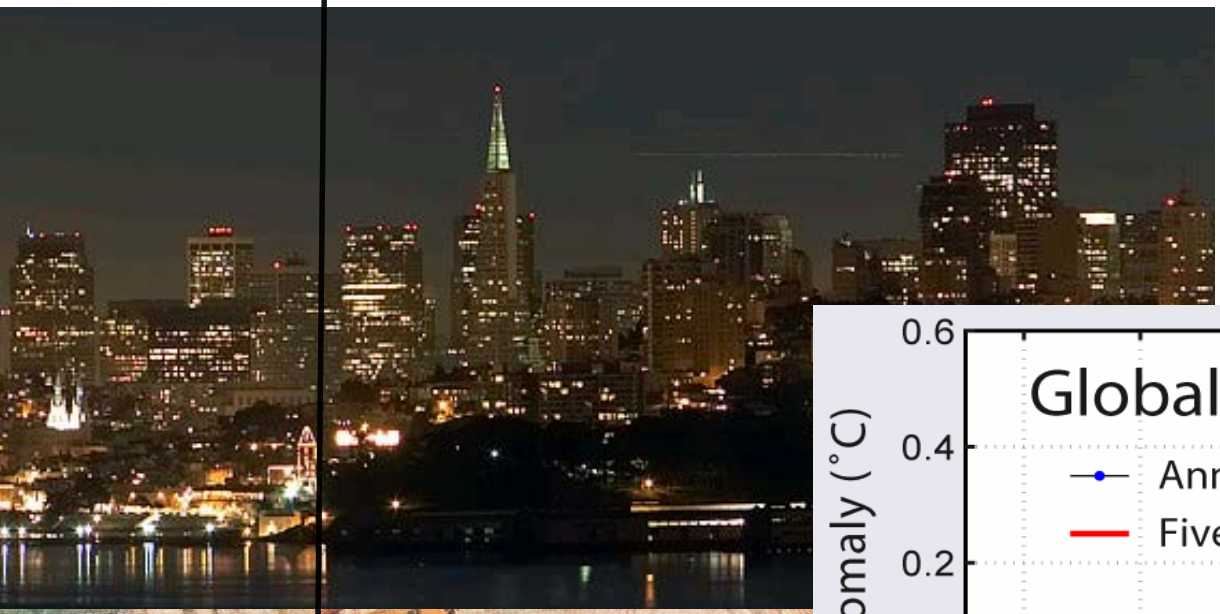
The global economy is based on making CO_2 from fossil carbon

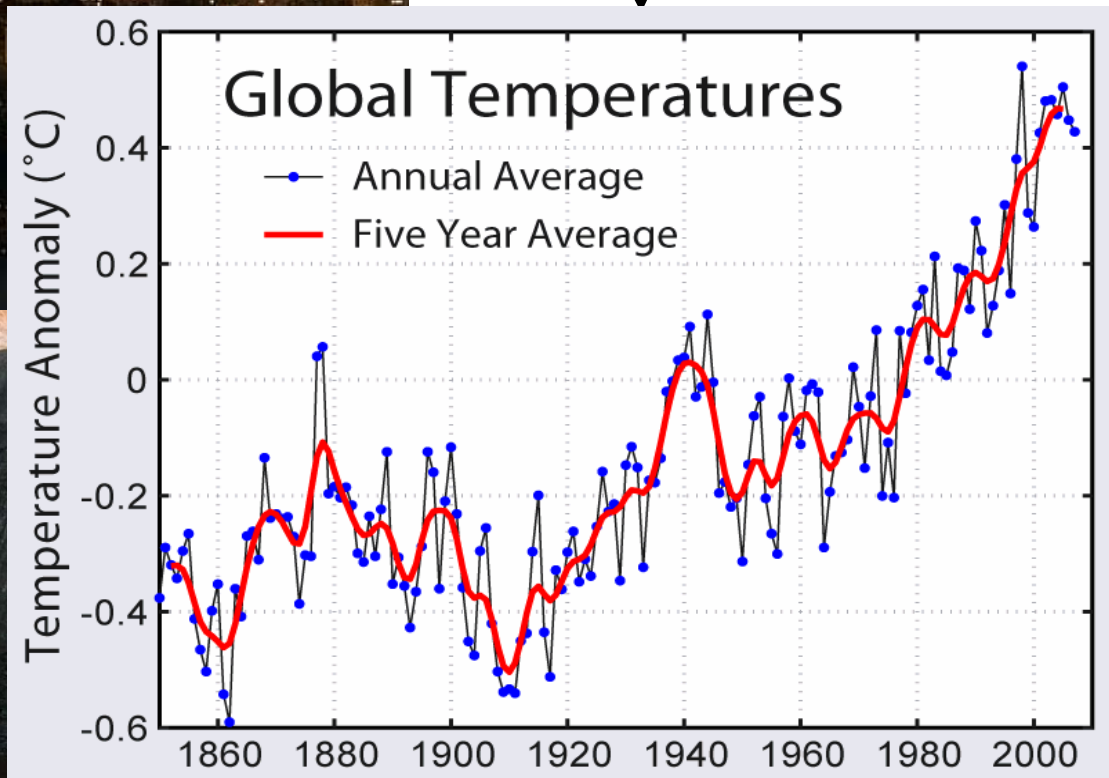
Coal (C)

$C + O_2 \rightarrow CO_2 + Energy$

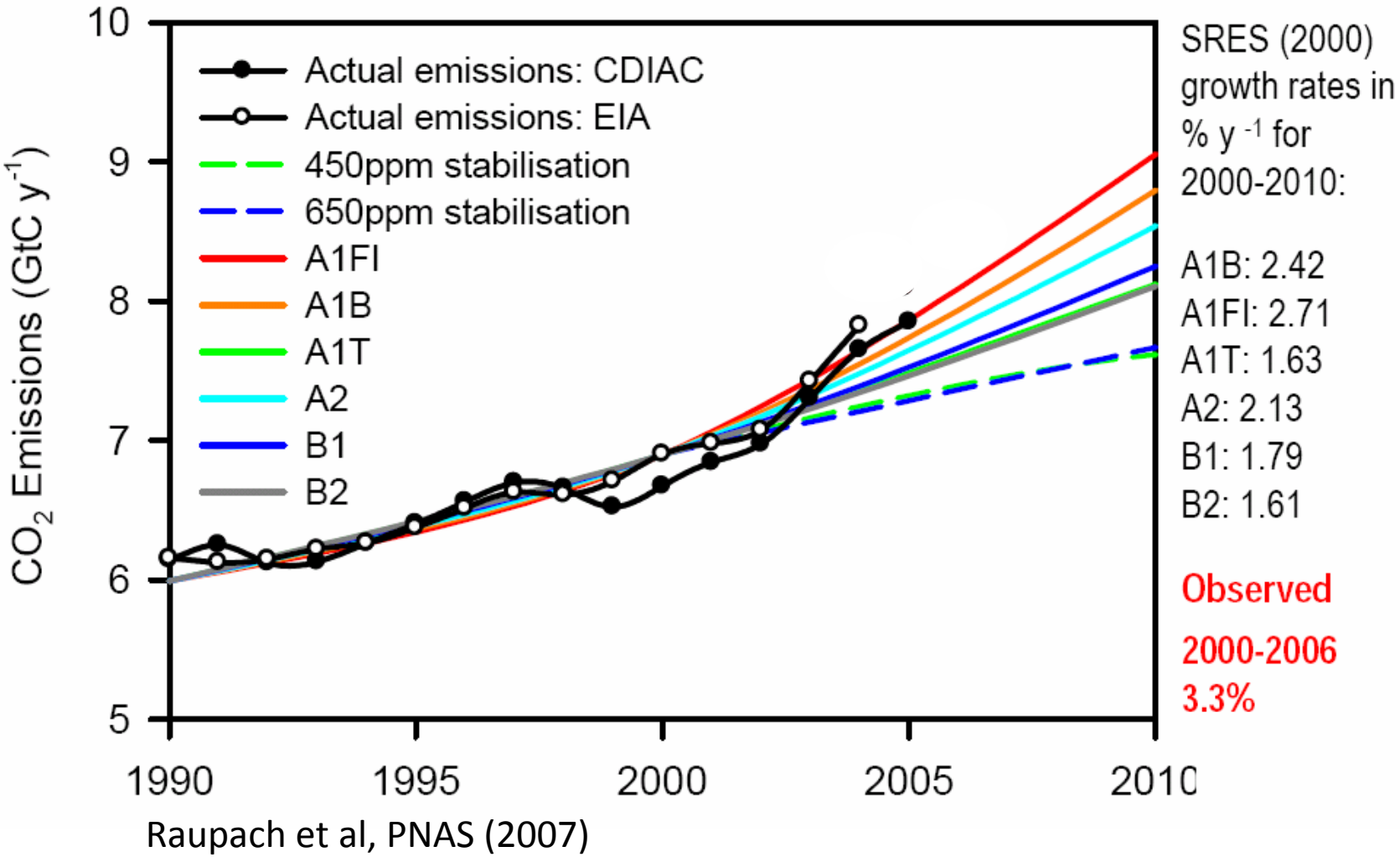
Energy

CO_2





"The emissions growth rate since 2000 was greater than for the most fossil-fuel intensive of the IPCC emissions scenarios developed in the late 1990s"
- Raupach et al, PNAS (2007)



Raupach et al, PNAS (2007)

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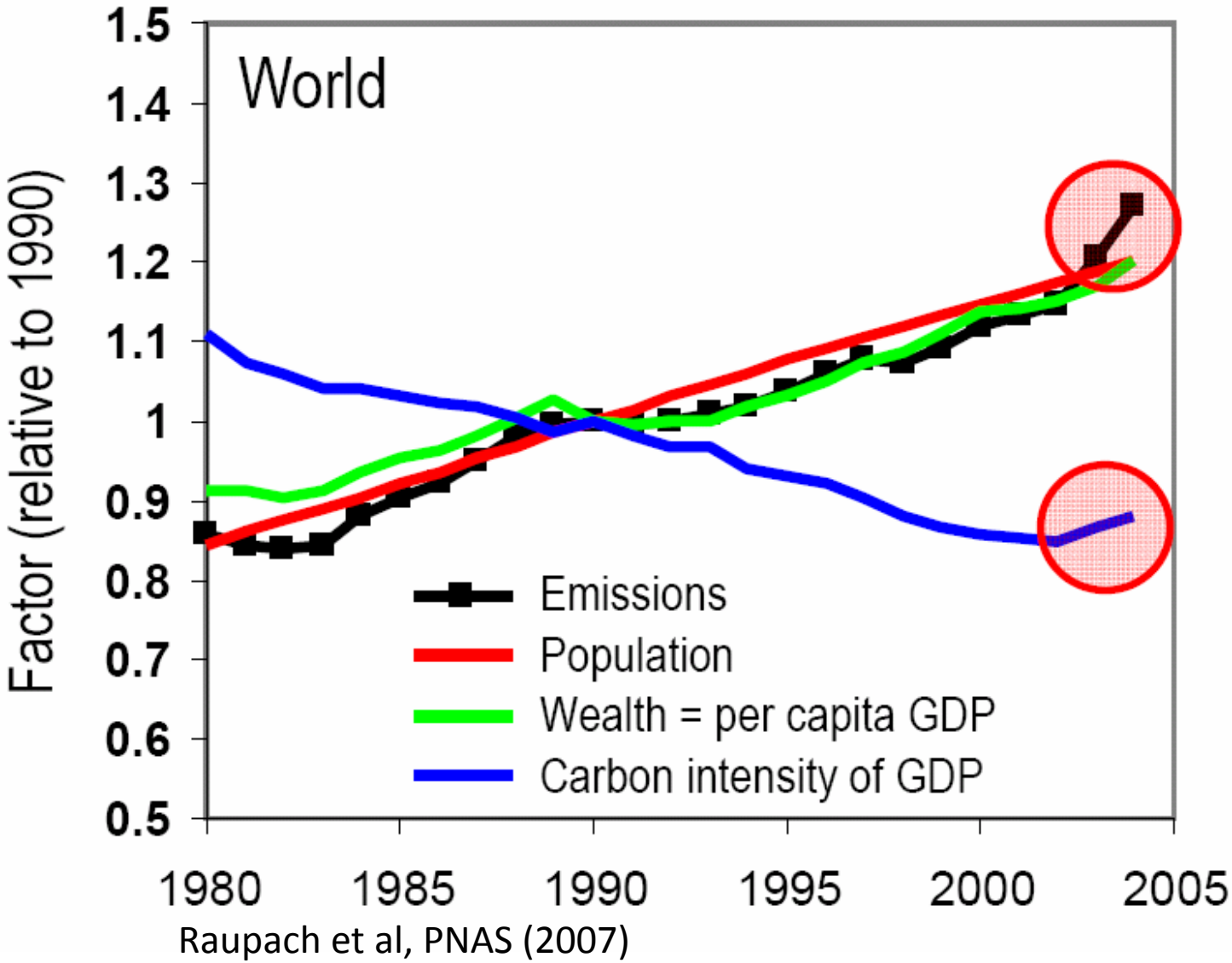
The biggest surprise has been a reversal of the long-time trend in carbon intensity (kgC/$GDP)



Raupach et al, PNAS (2007)

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The oil supply curve suggests that oil supply is have trouble keeping up with demand indicating a potential increase in coal combustion

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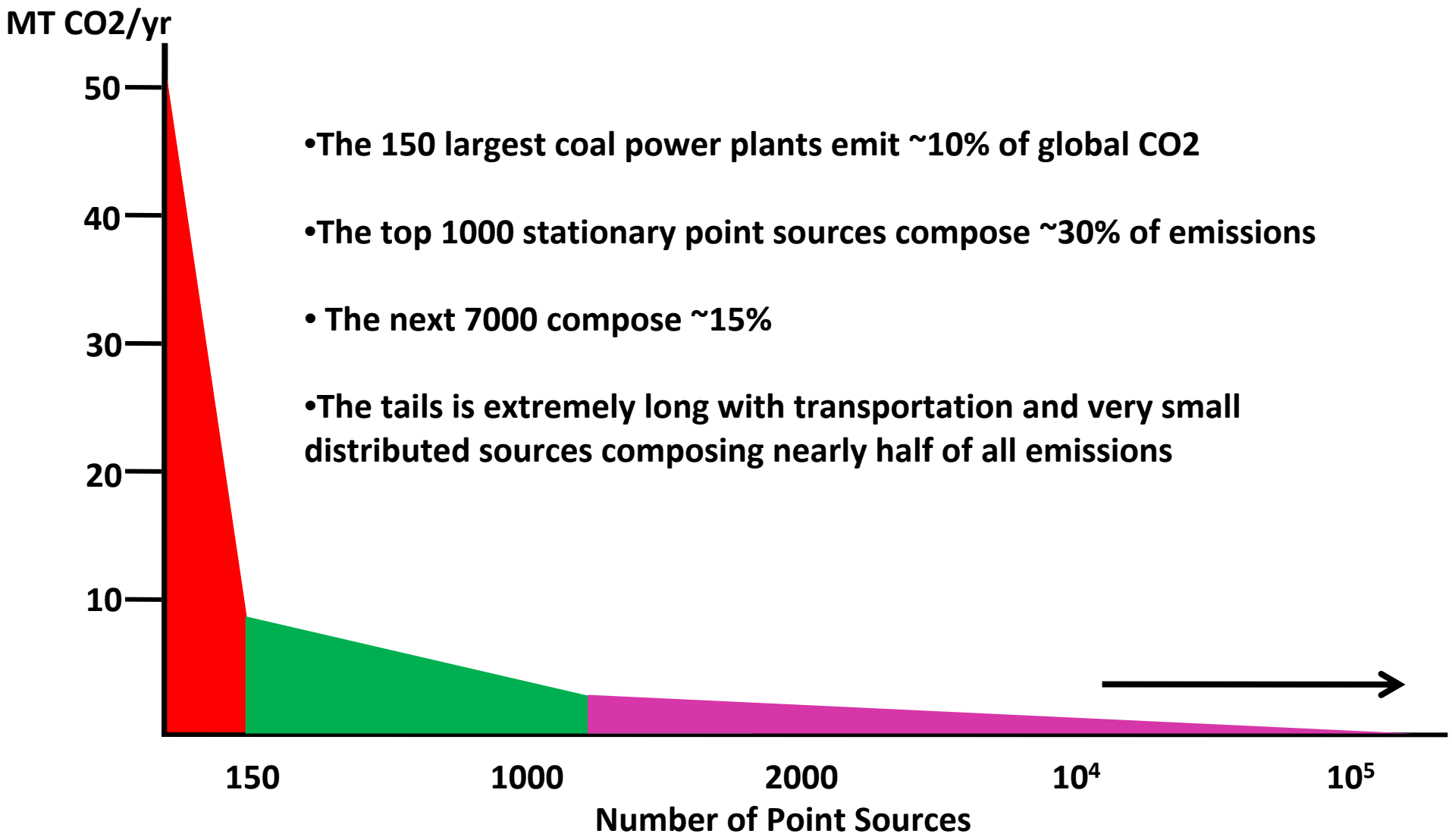
The extremely skewed distribution of point sources indicates the potential need for multiple strategies



Source: Alliance Bernstein

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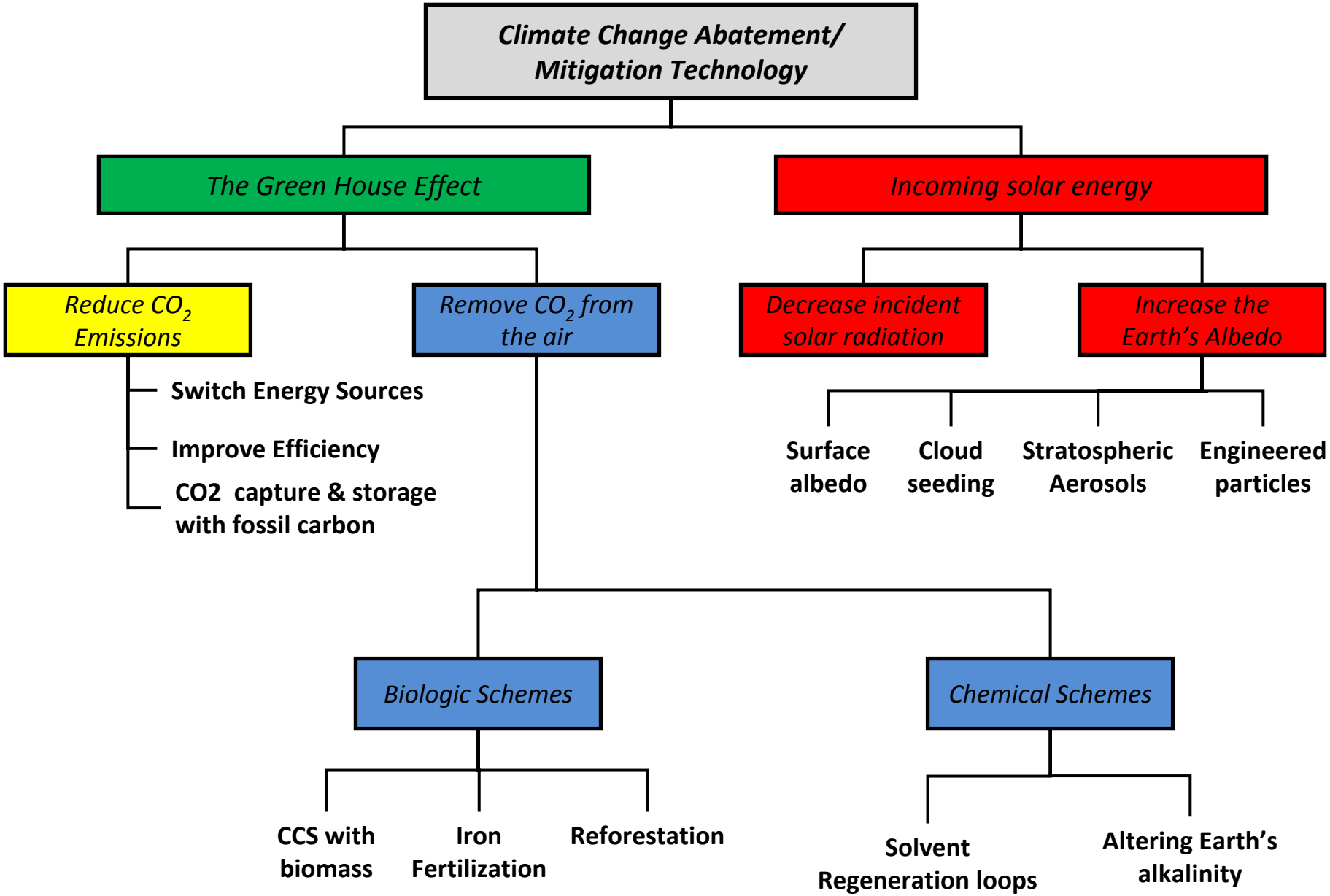

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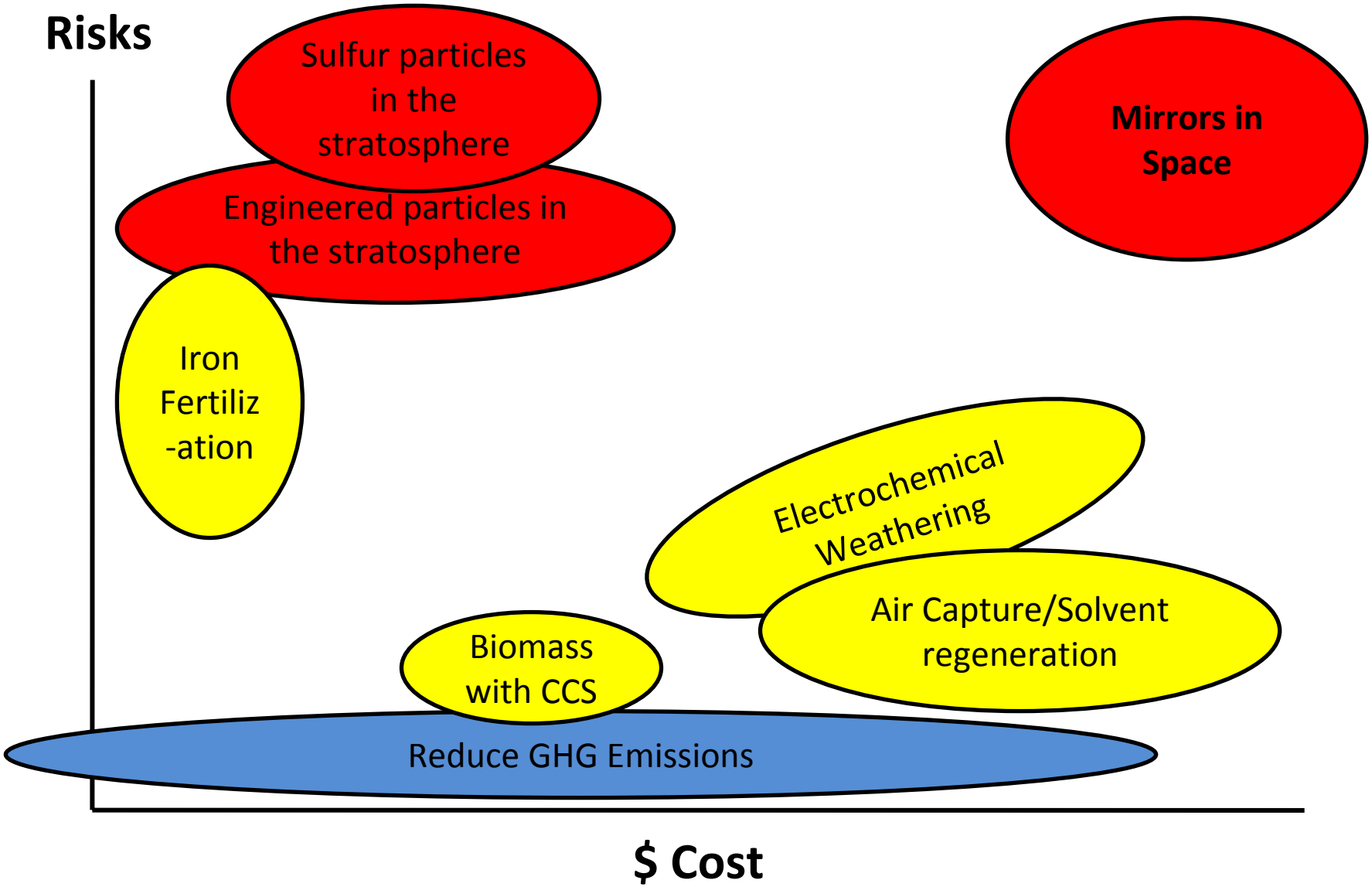
The sensibility of these various schemes can be visualized in risk-cost space



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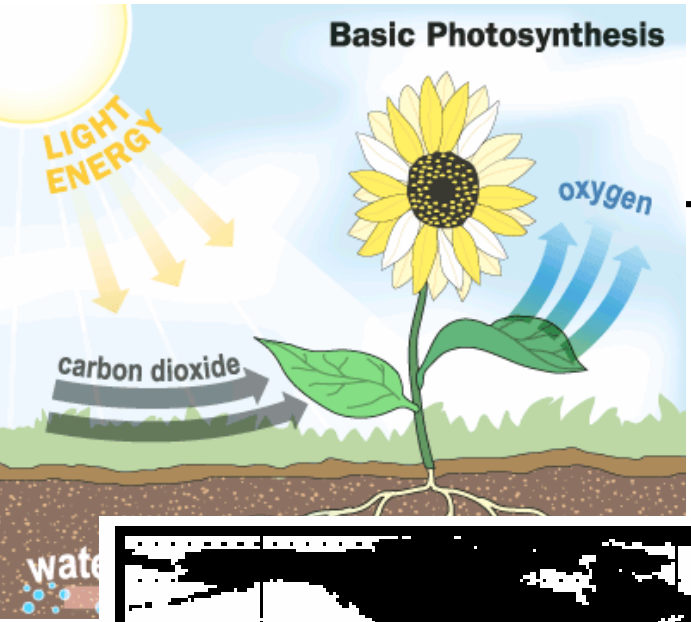
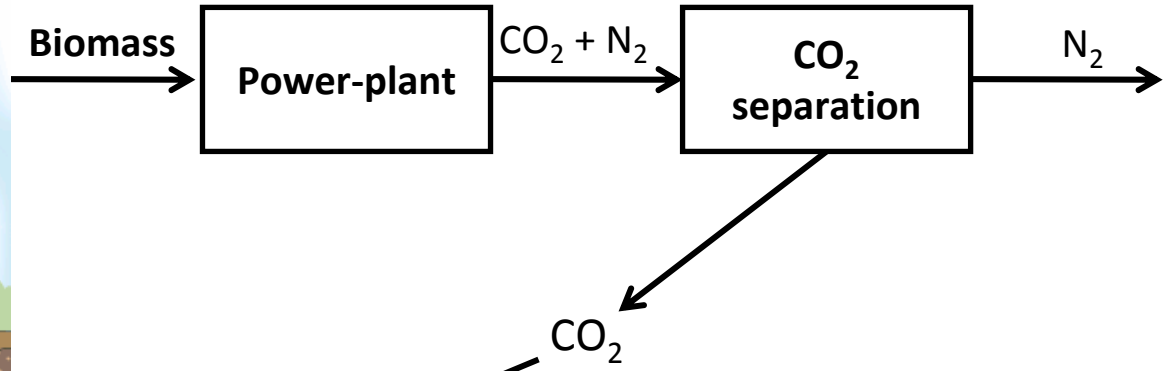
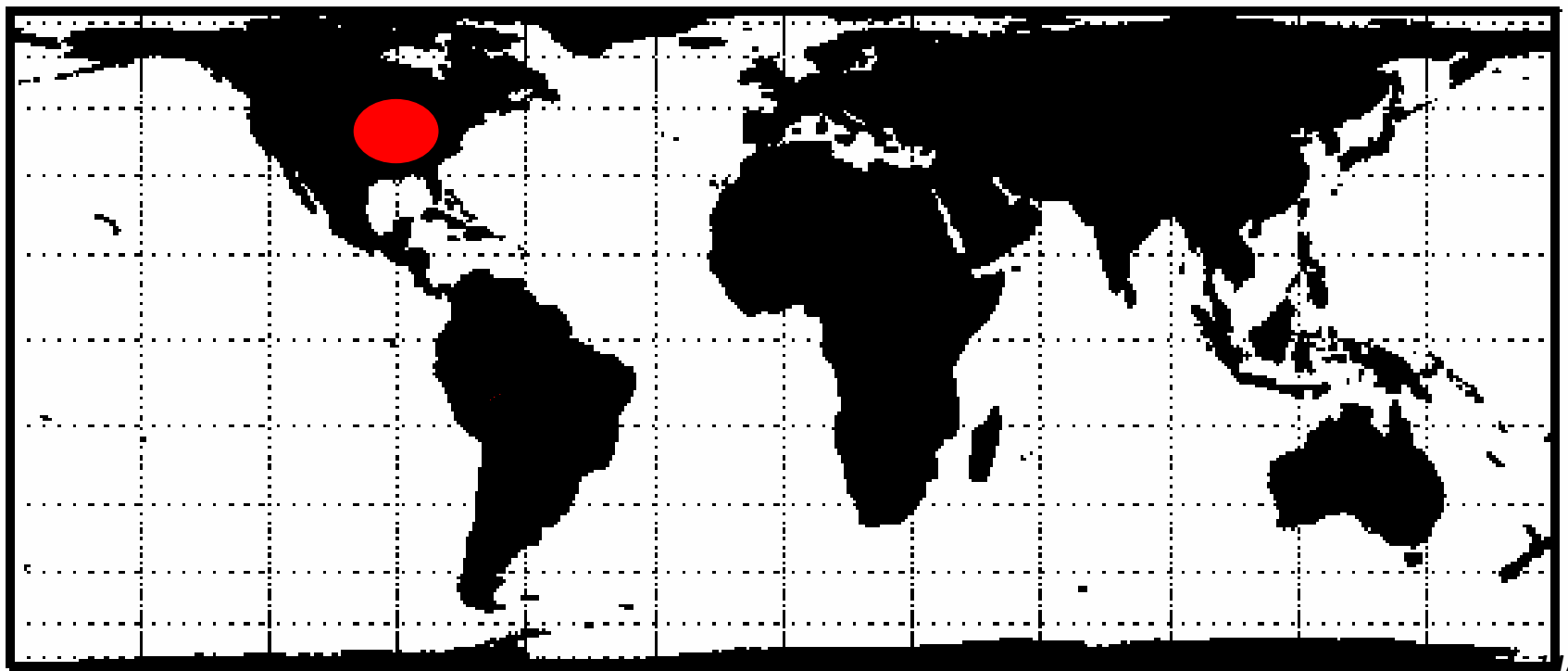
The cheapest way to remove CO2 from the air is to combust appropriately harvested biomass and capture and store the CO_2







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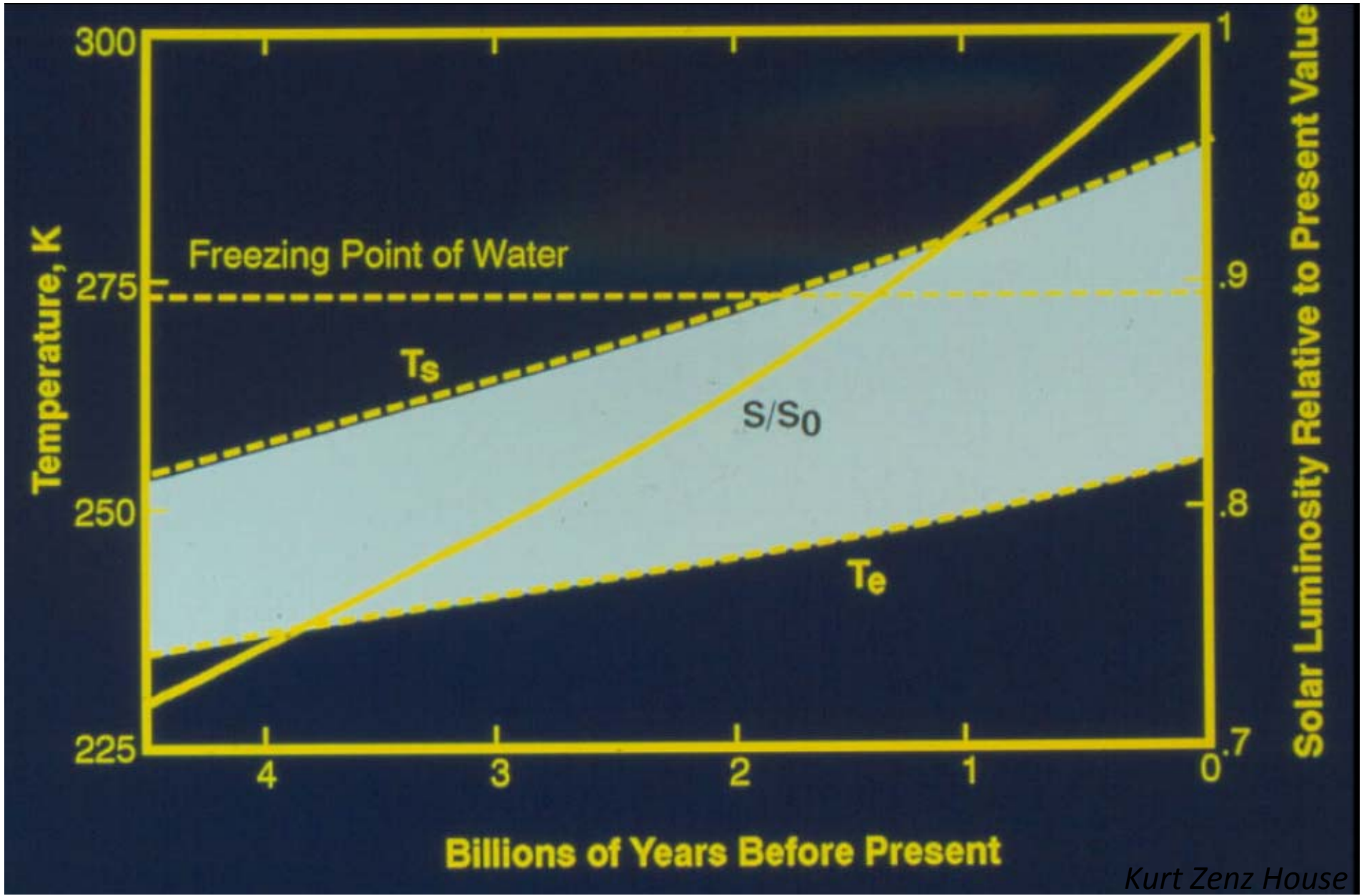
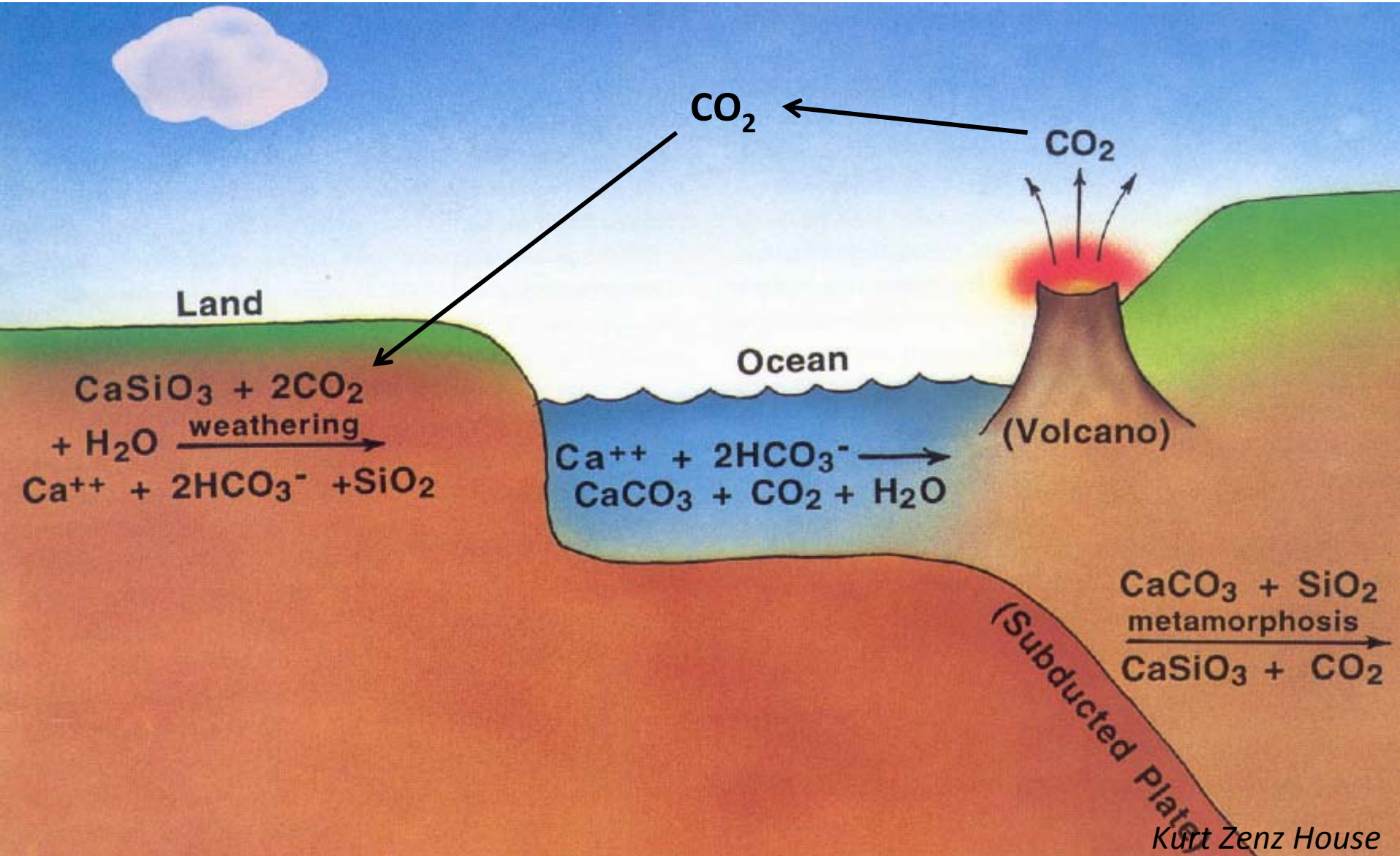
The Earth's atmosphere has acted as a thermostat for the past 4 billion years



…the thermostat works through changing the rates as which CO_2 reacts with rocks…the silicate weathering reactions



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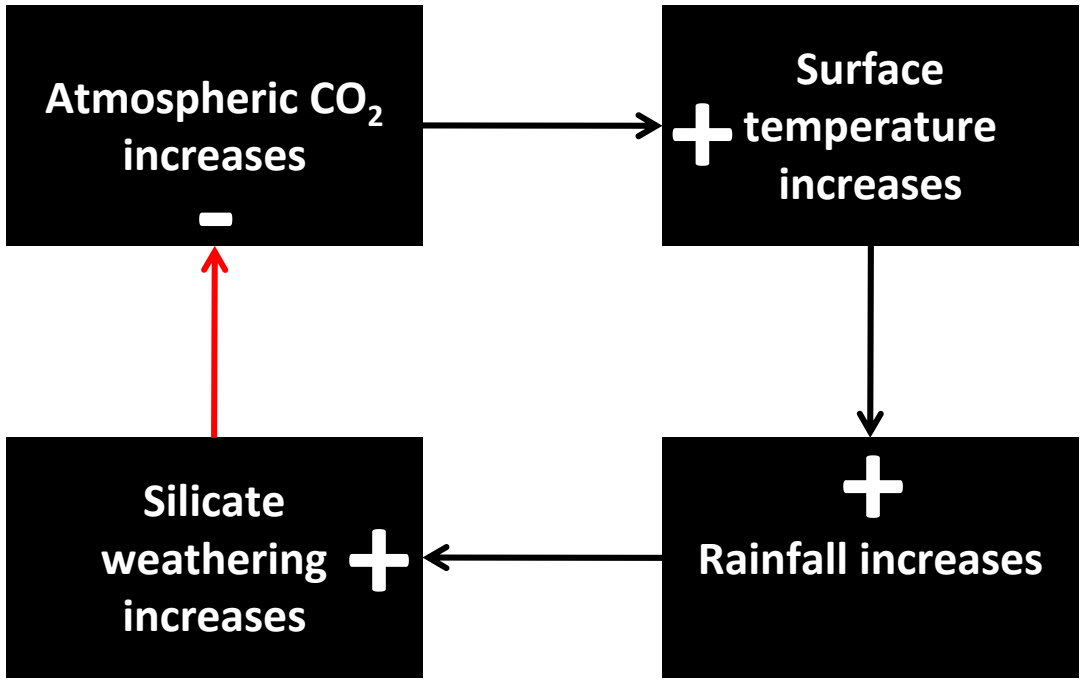
The silicate weathering system can be thought of as a negative feedback loop for the Earth's climate



$$CaSiO_3 + CO_2 \longrightarrow CaCO_3 + SiO_2$$

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

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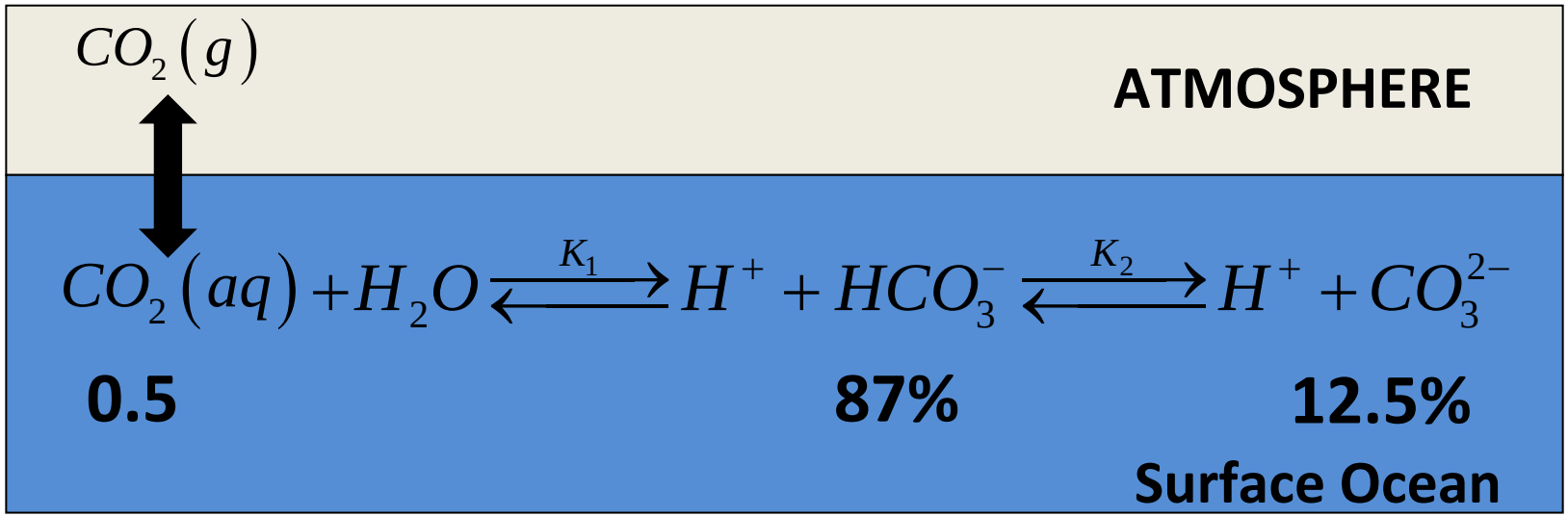
The partitioning of carbon between the atmosphere and the oceans is controlled in part by the ocean's alkalinity



The ocean has a surplus of conservative positive charge

$$Alkalinity = \left[Na^+\right] + 2\left[Mg^{2+}\right] + 2\left[Ca^{2+}\right] + \left[K^+\right] + \ldots - \left[Cl^-\right] - 2\left[SO_4^{2-}\right] - \ldots$$

…which is primarily balanced by the carbonate system

$$Alkalinity = \left[HCO_3^-\right] + 2\left[CO_3^{2-}\right] + \ldots$$

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If alkalinity can be added to the ocean at industrial rates, then the ocean will take up atmospheric CO_2

$$Alkalinity = \left[Na^+\right] + 2\left[Mg^{2+}\right] + 2\left[Ca^{2+}\right] + \left[K^+\right] + \ldots - \left[Cl^-\right] - 2\left[SO_4^{2-}\right] - \ldots$$

Various scholars have considered ways to increase the ocean's alkalinity by dissolving carbonates into the ocean (e.g., Broecker, Caldeira)

So I thought, perhaps we can remove *conservative* negative charge in order to increase the ocean's alkalinity

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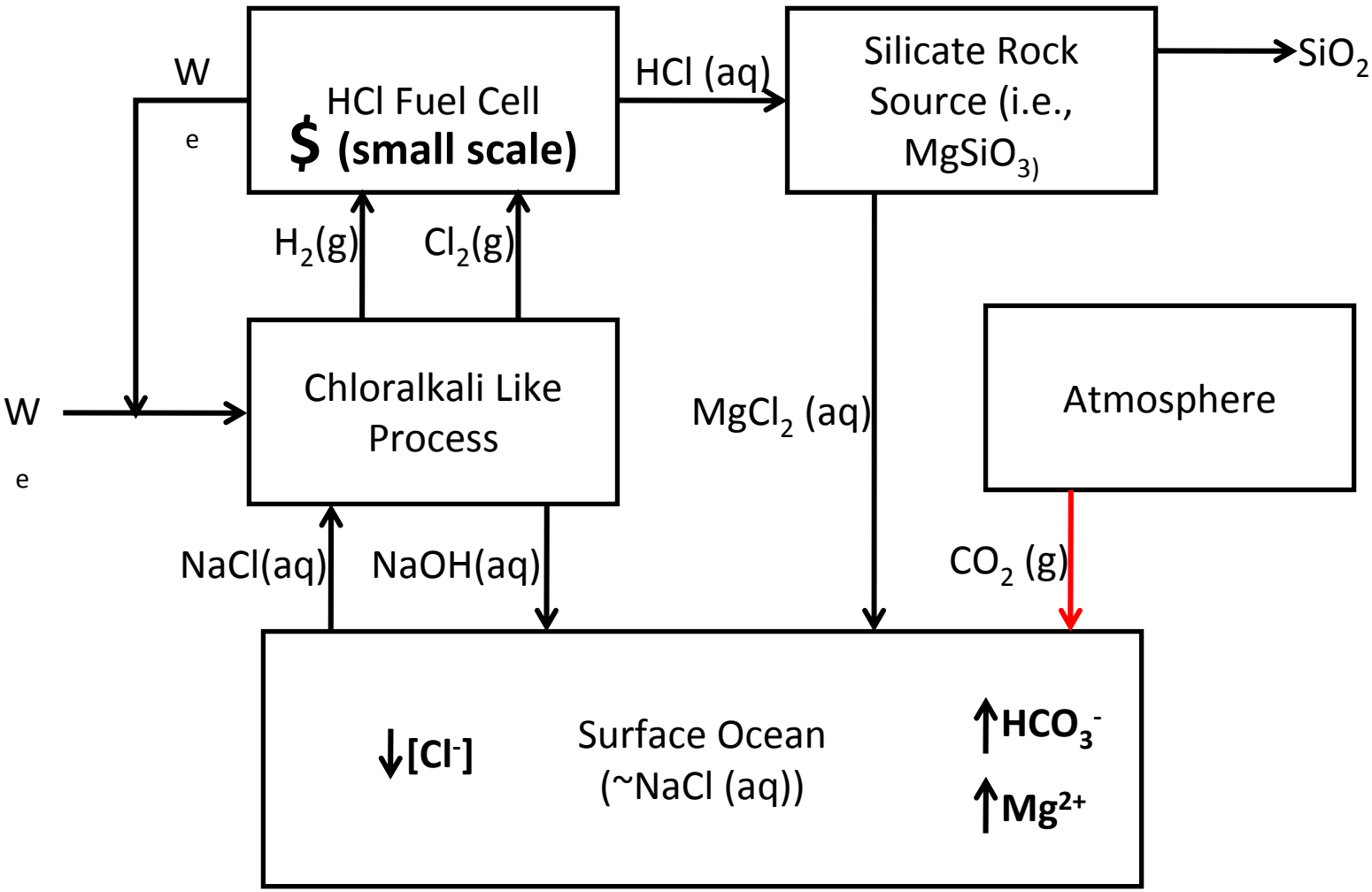
More detailed block diagram (version 1)



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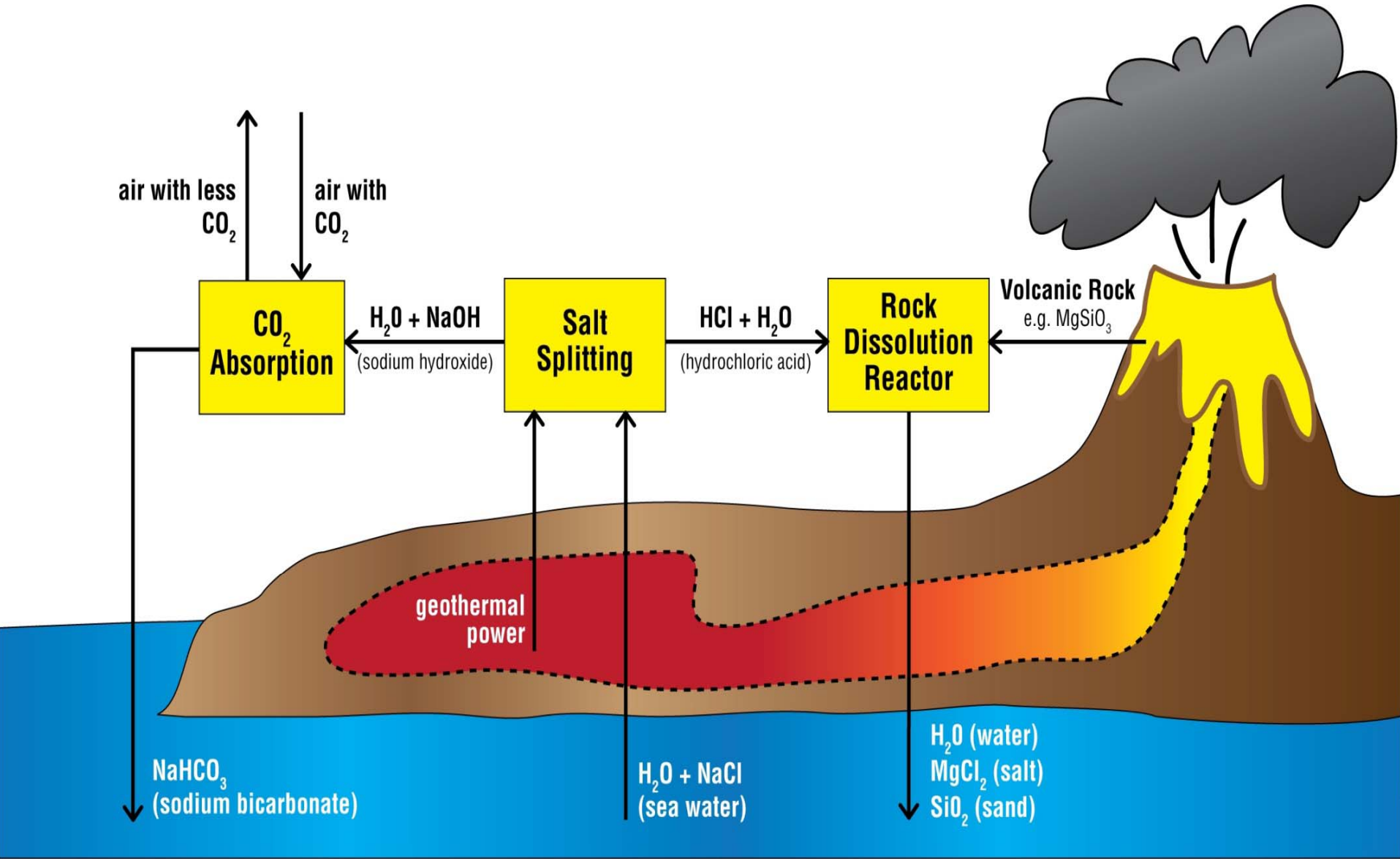
The entire electrochemical weathering process



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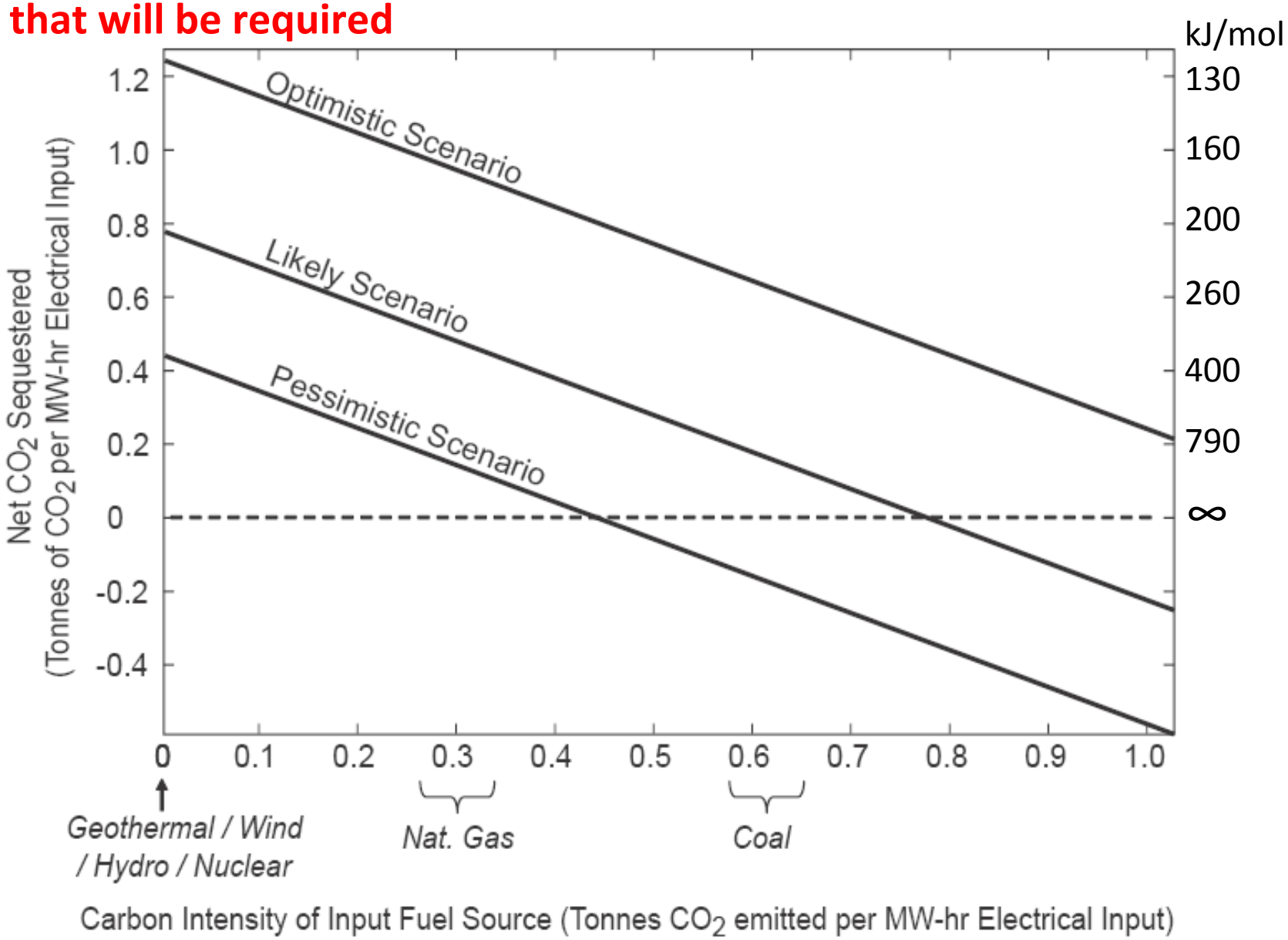
The net reaction is spontaneous, but a range of scenarios bounds the work that will be required



House et al, ES&T (2007)

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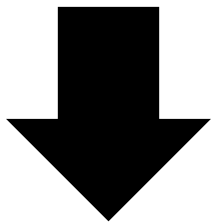
Enhanced $CaCO_3$ precipitation is the ultimate fate of the additional alkalinity and carbon

$$MgSiO_3(s) + H_2O(l) + 2CO_2(g) \longrightarrow Mg^{2+} + SiO_2(s) + 2HCO_3^-$$

$$2HCO_3^- + Ca^{2+} \longrightarrow CaCO_3 + CO_2 + H_2O$$



If the dissolution products are returned to the ocean, $CaCO_3$ is certain to precipitate quickly due to the increase in local alkalinity

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Another way to think about this the creation of artificial soda-lakes

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Offsetting 1 GtC/yr with electrochemical weathering is a serious task

- To offset 1 GtC, ~10^{14} moles of HCl would have to be produced and neutralized each year
    i. Volumetric flow rate of seawater equal to 6000 m^3/sec
    ii. Volumetric flow rate of artificial brine from mined halite of 600 m^3/s

- If basalt were used for neutralization, then 10 Gt would be required annually

- Our kinetic experiments indicate the rock dissolution would require ~10^7 m^3 of reaction volume (1500 Olympic swimming pools)

- The global weathering rate would be ~x5

- Local alkalinity hot spots would form and likely damage local marine ecosystems

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Benefits of electrochemical weathering

- Permanency of storage to do thermodynamics and kinetics of marine chemistry
- Simultaneously manage the oceans and the atmosphere→ particularly ocean pH
- Could be run off stranded power
- 1 large plant (~50 m^3/sec) would offset ~5,000,000 cars

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Conclusions

•Humanity has succeeded in engineering the Earth by transferring ~200 billion tonnes of carbon from the lithosphere to the atmosphere

•The recent growth in CO_2 emissions has outpaced our most pessimistic forecast

•A wide variety of schemes—other than decreasing CO_2 emissions—have been proposed to deal with climate change

•Biomass combustion with CO2 capture and storage will work, but it is limited to in scale

•We can accelerate weathering with electrochemistry, but it will be expensive and the rock requirements will severely limit its scale

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