Extracting CO_2 from seawater: Climate change mitigation and renewable liquid fuel

Matthew Eisaman

Sustainable Energy Technologies Department

Brookhaven National Laboratory

Outline

- Context: CO_2 emissions and their impact
- Technology: Extracting CO_2 from seawater
- Application: Renewable liquid fuel

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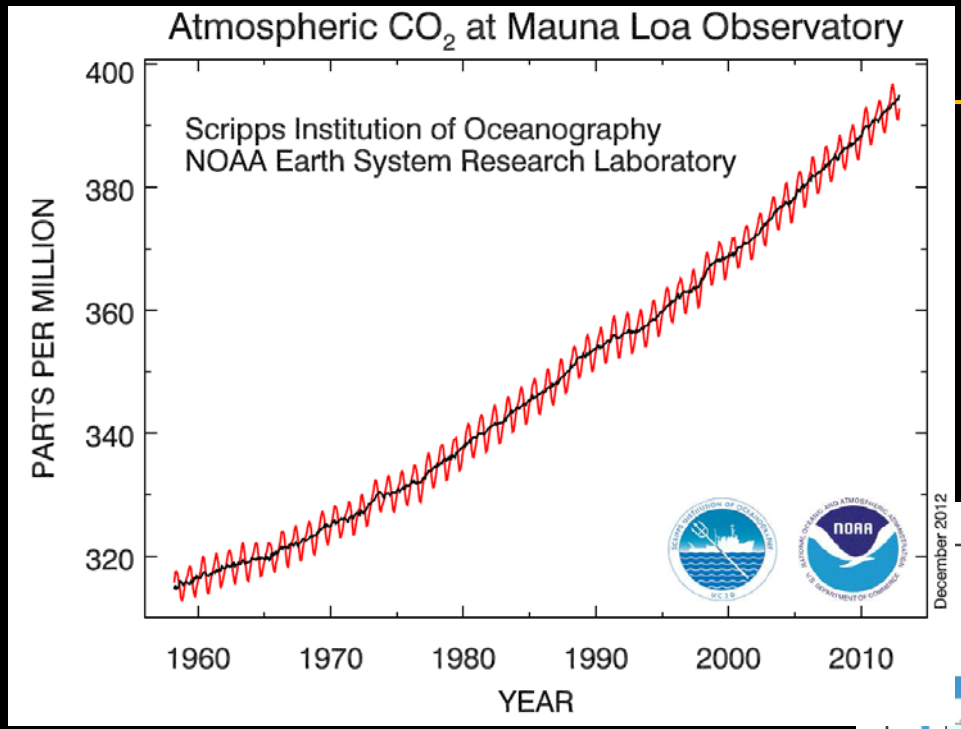
The data on atmospheric CO_2

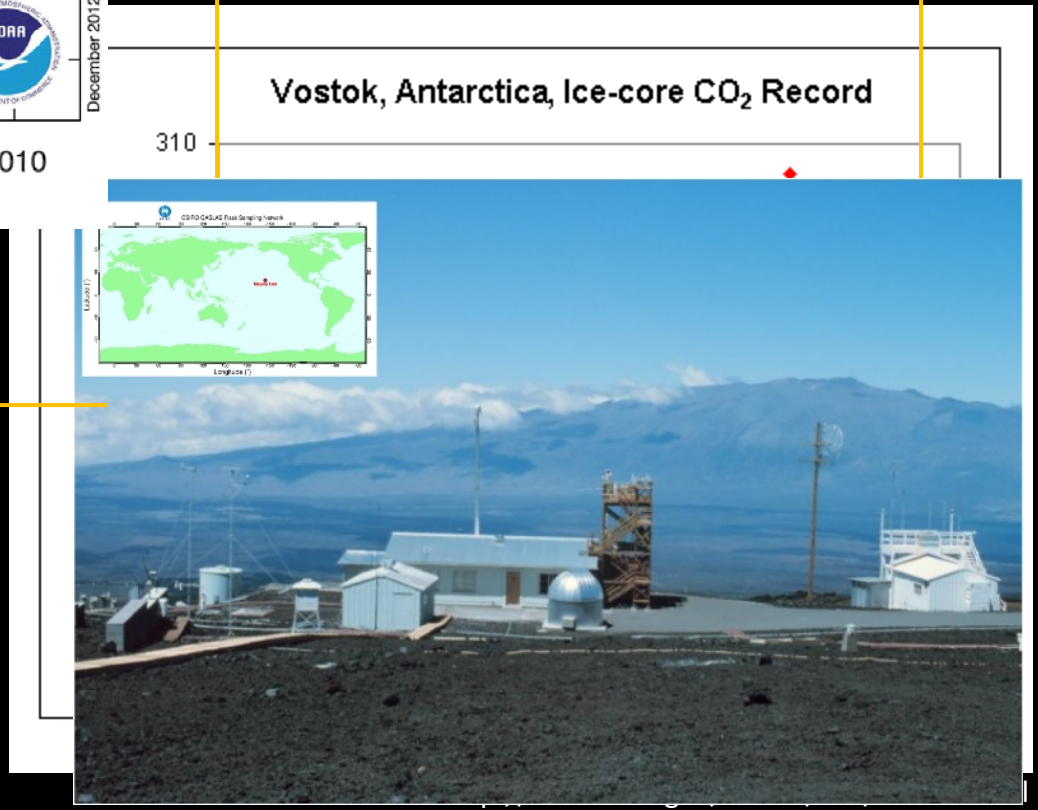


http://www.esrl.noaa.gov/gmd/ccgg/trends/

> 390 ppm now

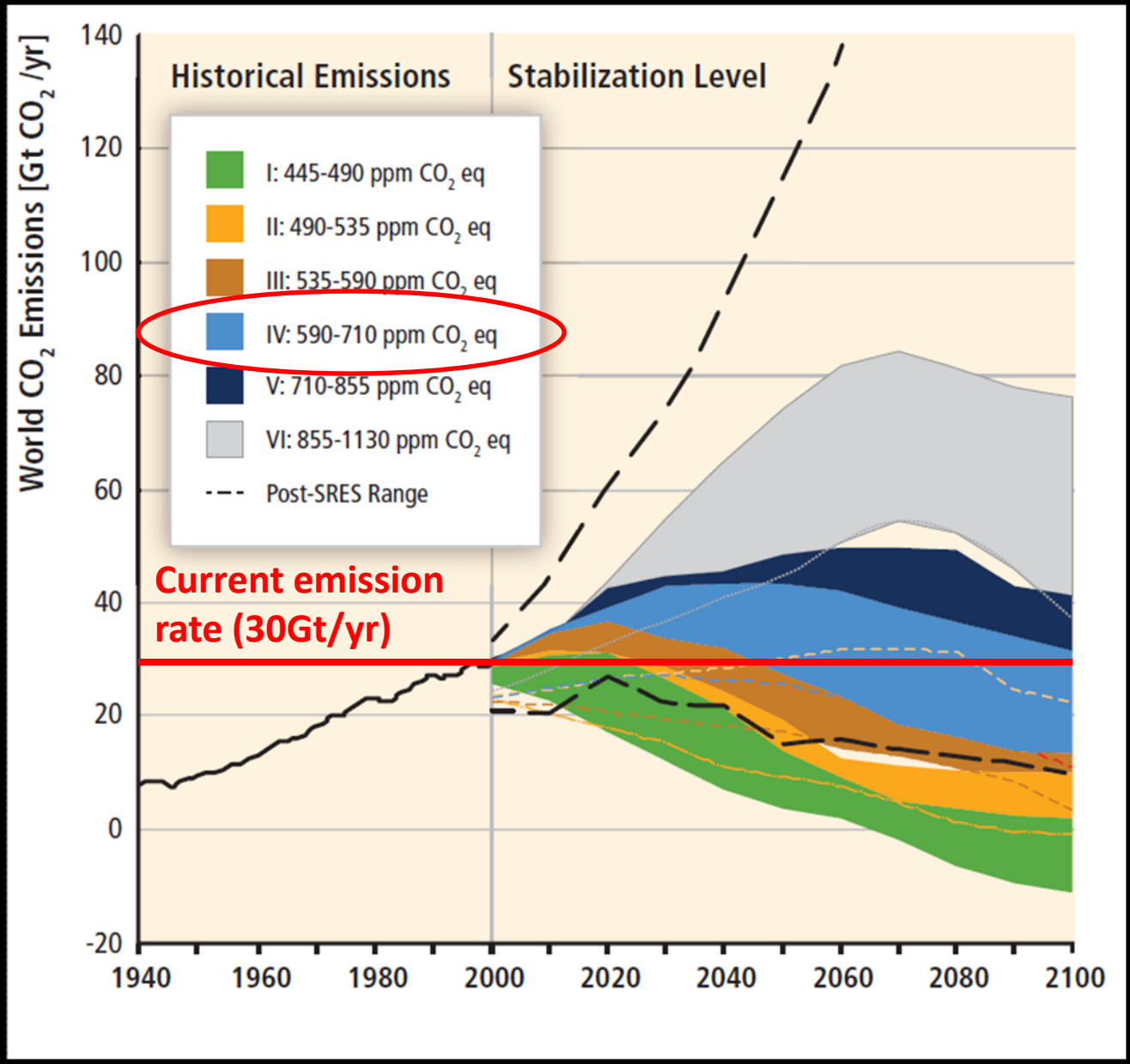
2000 years ago

400,000 years ago



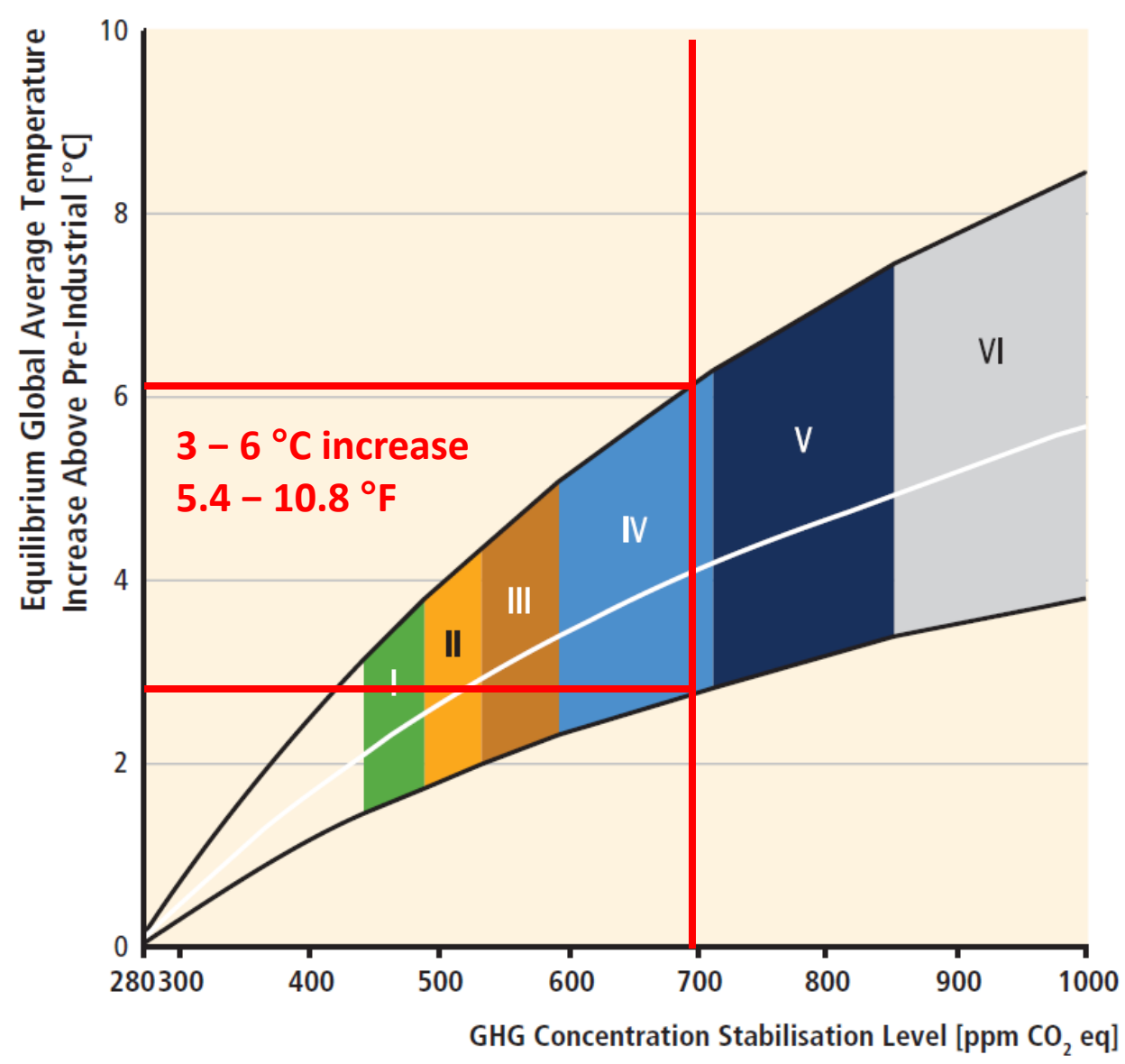
190-290 ppm historically

Projected CO_2 concentrations



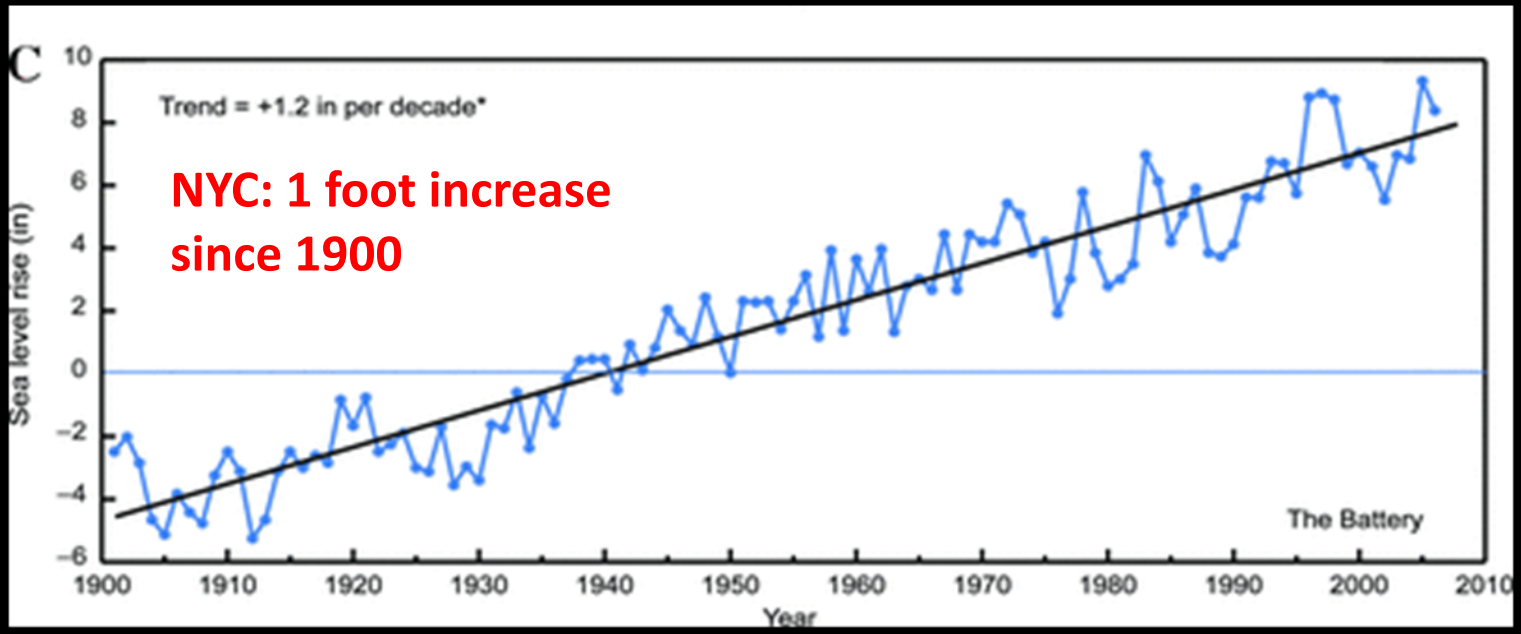
IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

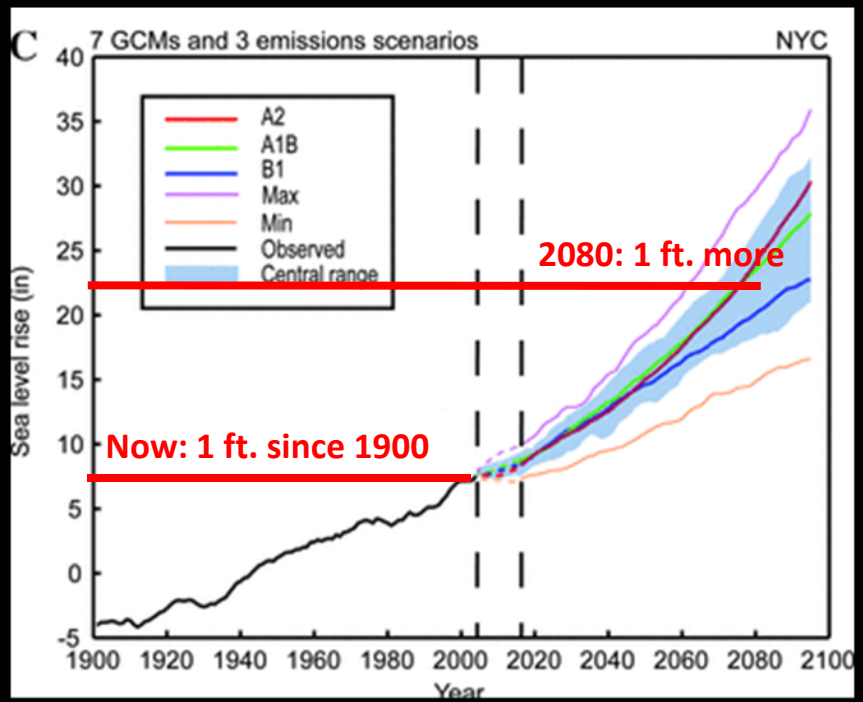
Projected Temperature Increase



IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

The effect on our oceans: sea level rise

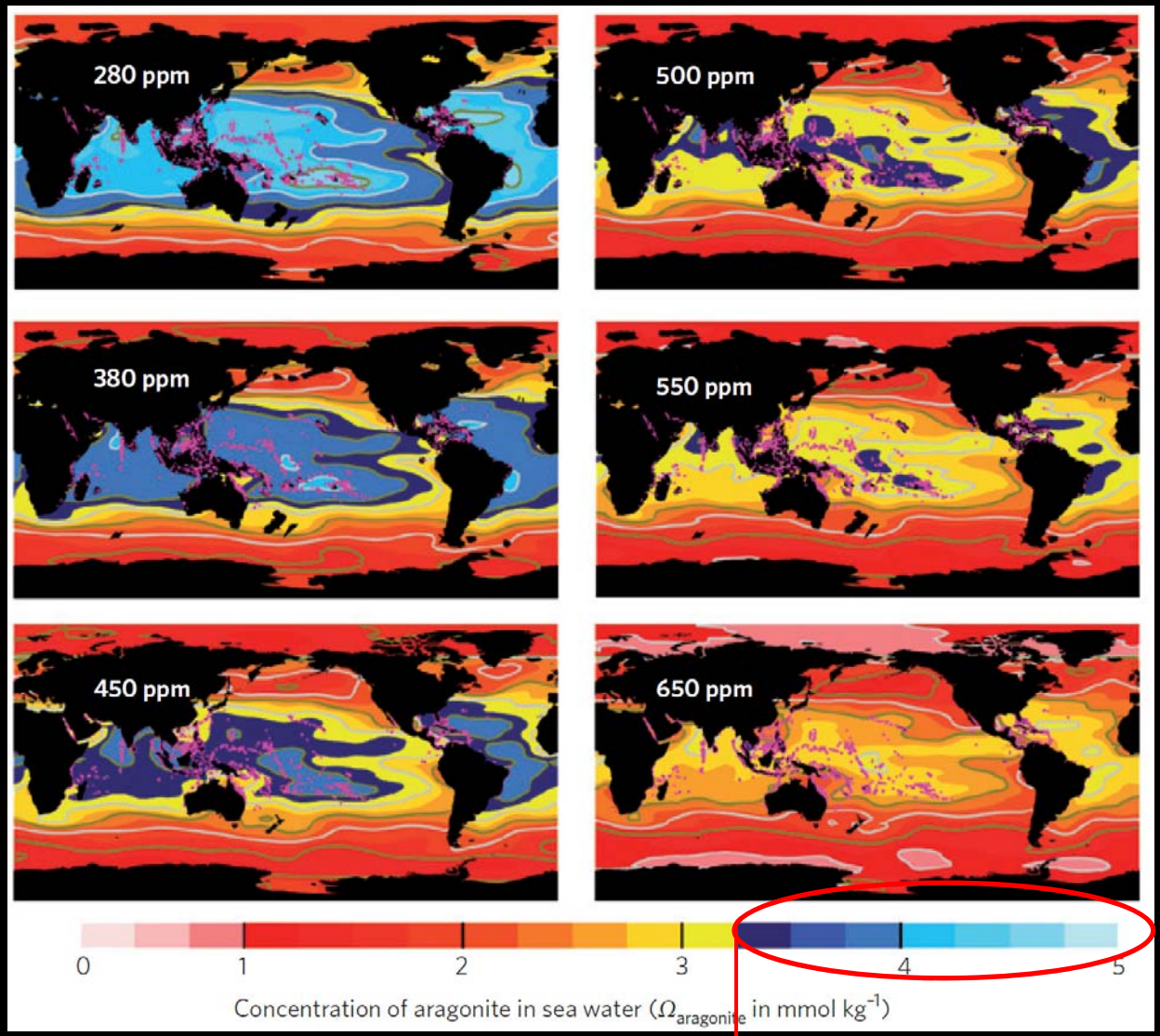




- Once in 10 year flood will occur once every 1-3 years by 2080

Annals of the NY Academy of Sciences, *Climate Change in NYC*, **1196**, 41-62 (2010)

The effect on our oceans: acidification

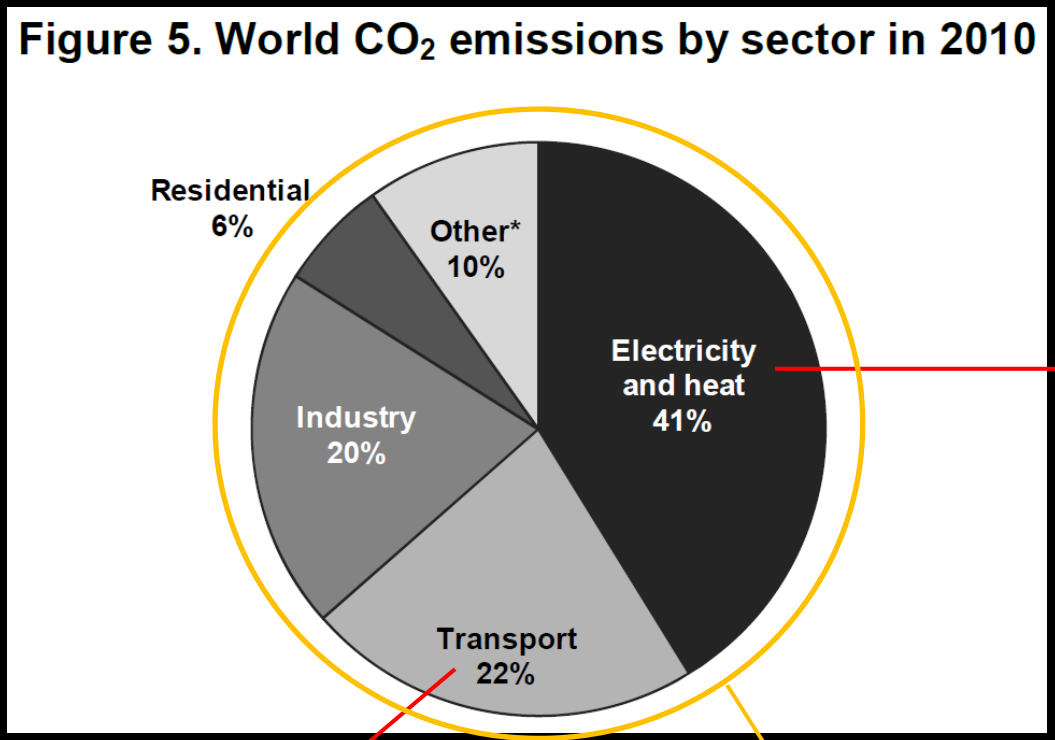


Reefs can survive

Min. for coral reefs

Nature Climate Change, **1**, 339 (2011).

Reducing CO_2 emissions from all sectors



IEA, 2012; CO_2 emissions from fuel combustion: Highlights.

- Solar
- Wind
- CO_2 capture and sequestration from power plants

- Battery electric
- Fuel cell (H_2)

CO_2 capture from air and/or seawater

- CO_2 capture and sequestration
- Renewable fuels

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Possibilities for CO_2 capture

Industrial

- 10% CO_2 by volume
- Fixed location only
- Requires fossil fuels

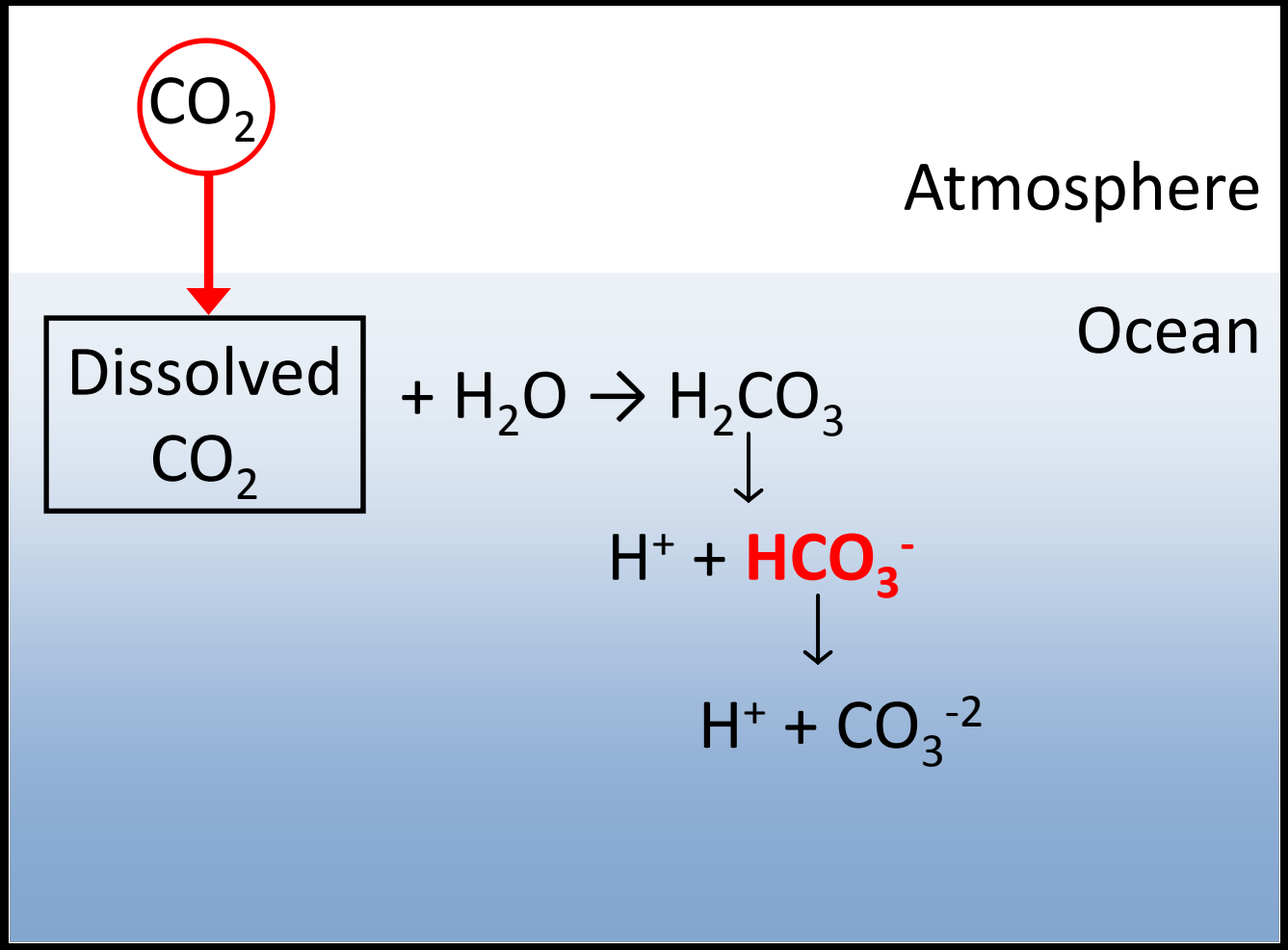
Atmosphere

- 0.04% CO_2 by volume
- Large physical size
- Unproven at this scale

Seawater

- 5.6% CO_2 by volume
- Small footprint
- Mobile
- Combine with desalination
- Can use proven commercial technology

CO_2 from seawater



CO_2 from seawater

Capture (natural equilibrium)

CO_2 [~ 400 ppm in air]

$[CO_2]_{dissolved} = K_H P_{CO2}$ Atmosphere

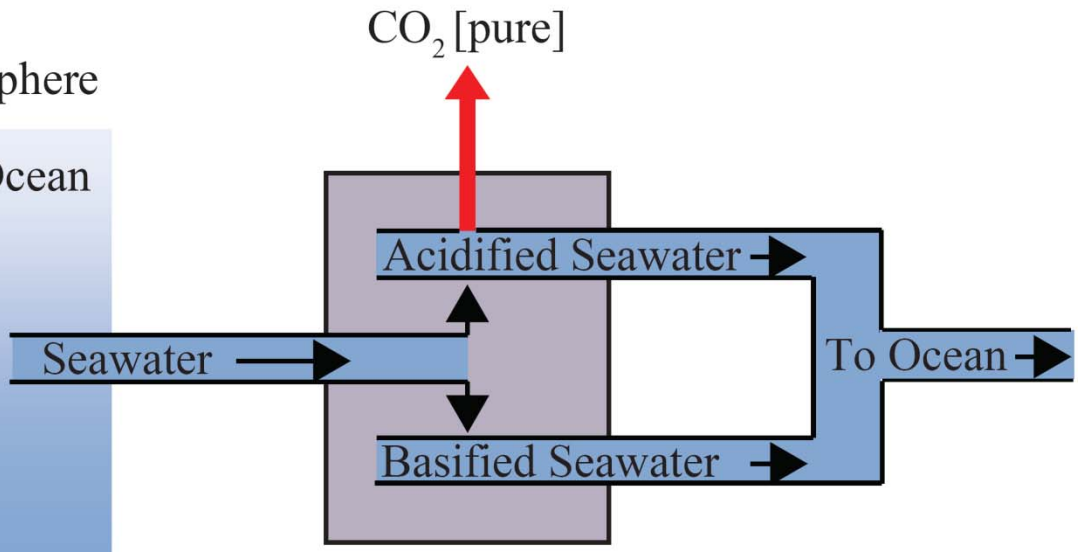
Ocean

Dissolved CO_2 $+ H_2O \rightarrow H_2CO_3$

$H^+ + HCO_3^-$

$H^+ + CO_3^{2-}$

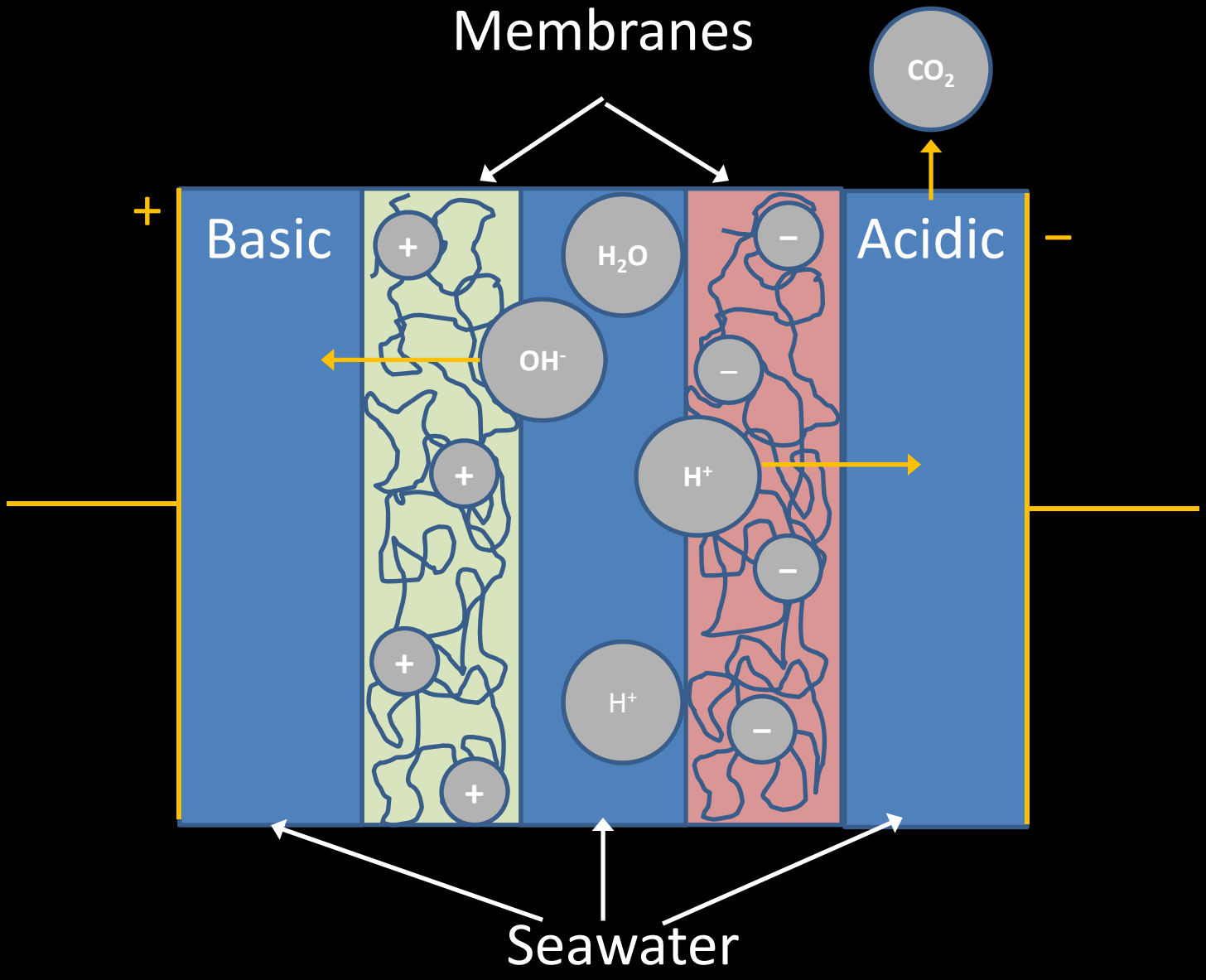
Regeneration



Electrodialysis – Scalable, commercial technology

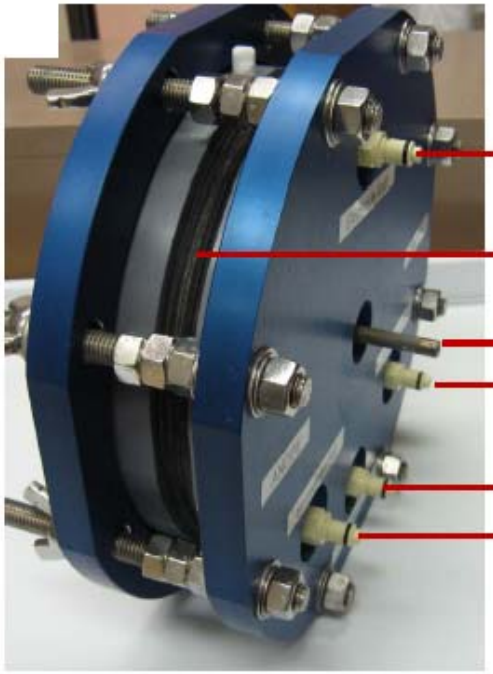
Eisaman et al., US patent application 13177421 and Energy Environ. Sci., **5**, 7346-7352 (2012).

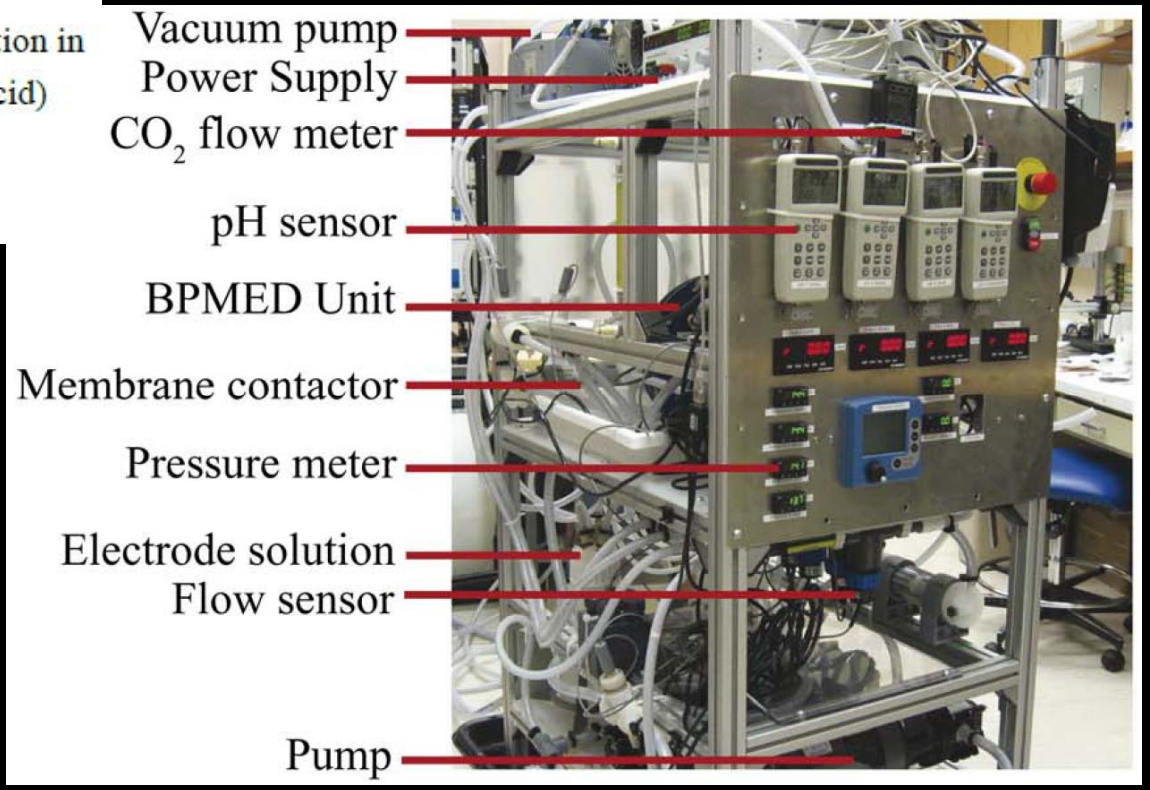
CO_2 extraction from seawater: How it works



Eisaman et al., US patent application 13177421 and Energy Environ. Sci., **5**, 7346-7352 (2012).

Prototype unit





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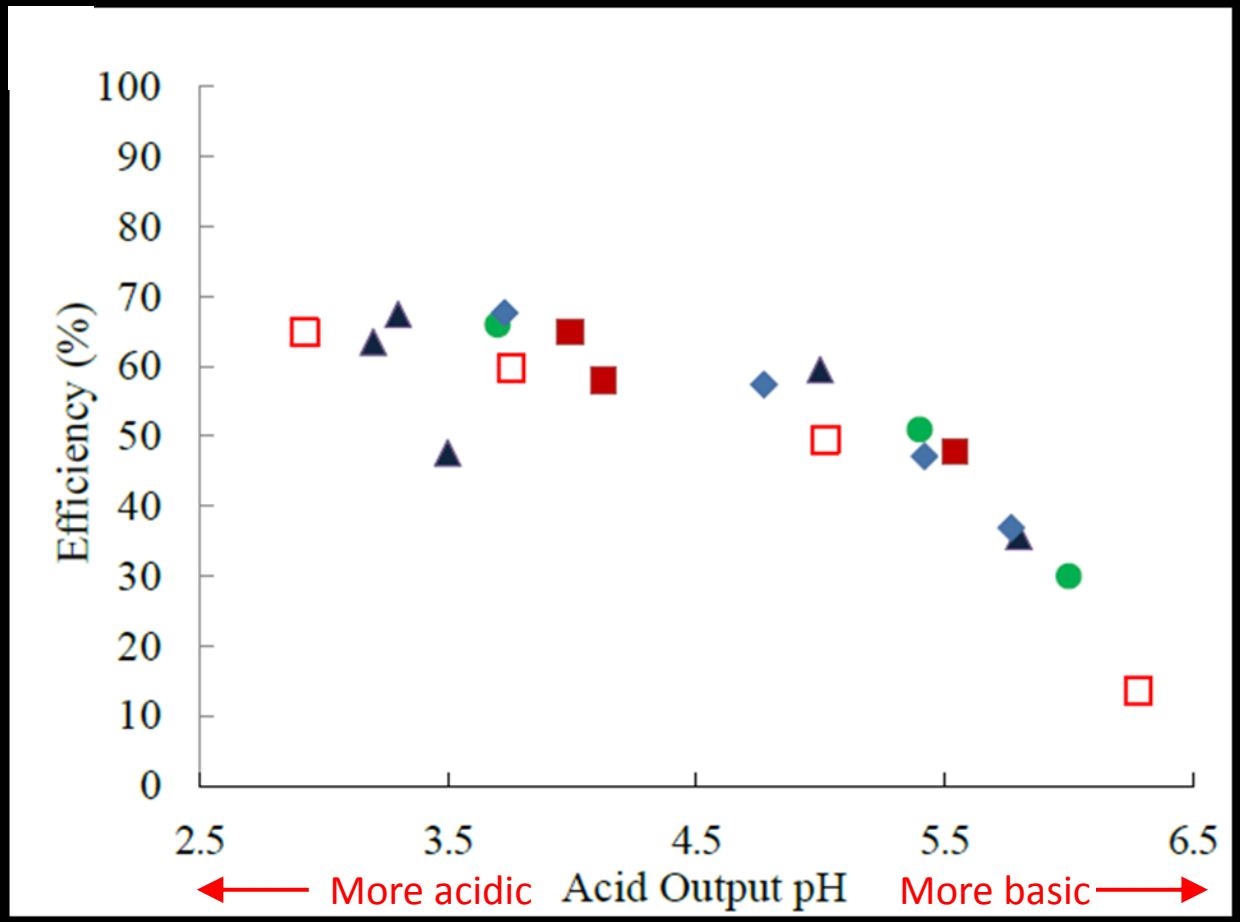
Efficiency of CO_2 extraction



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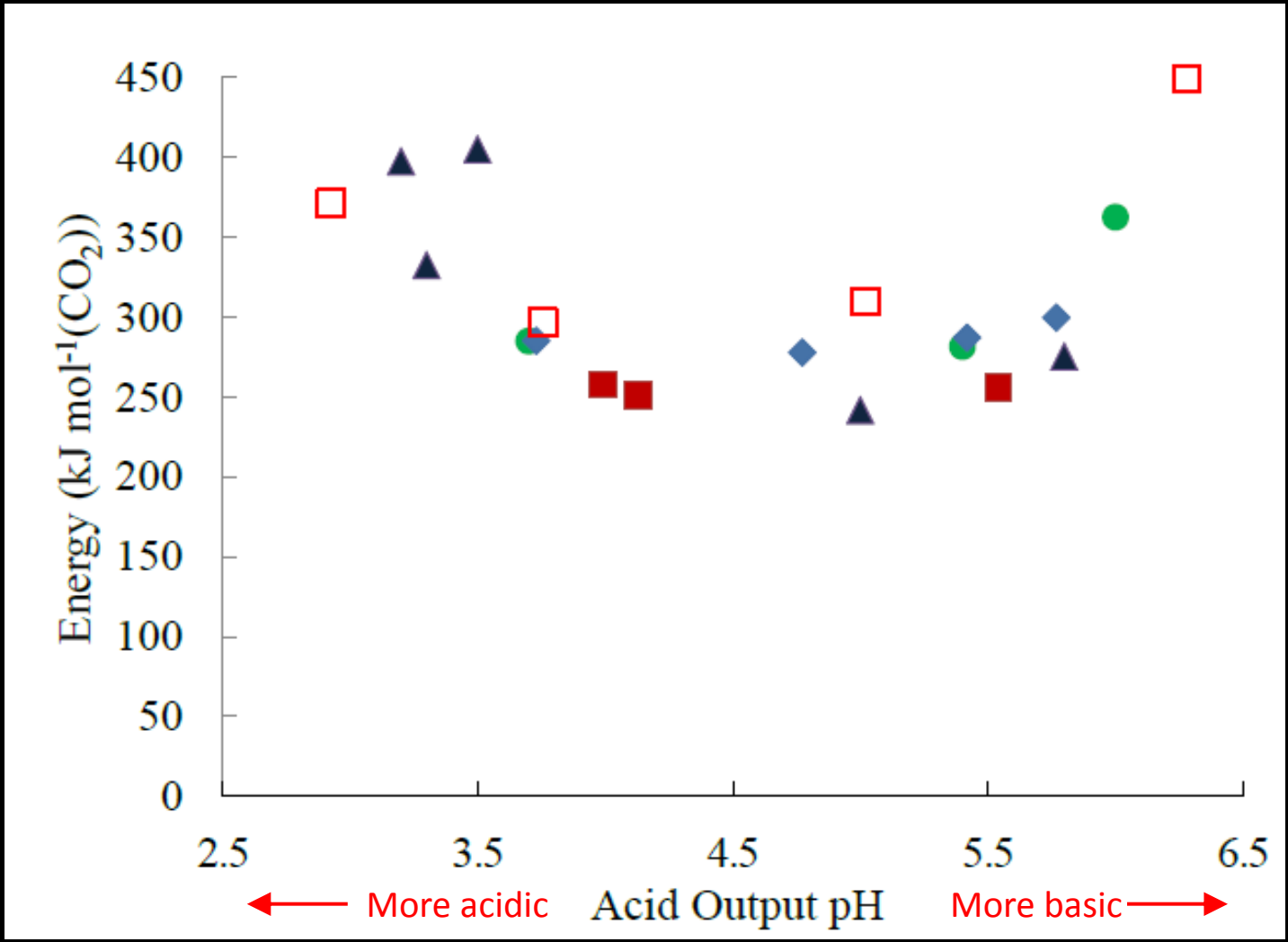
Energy of CO_2 extraction



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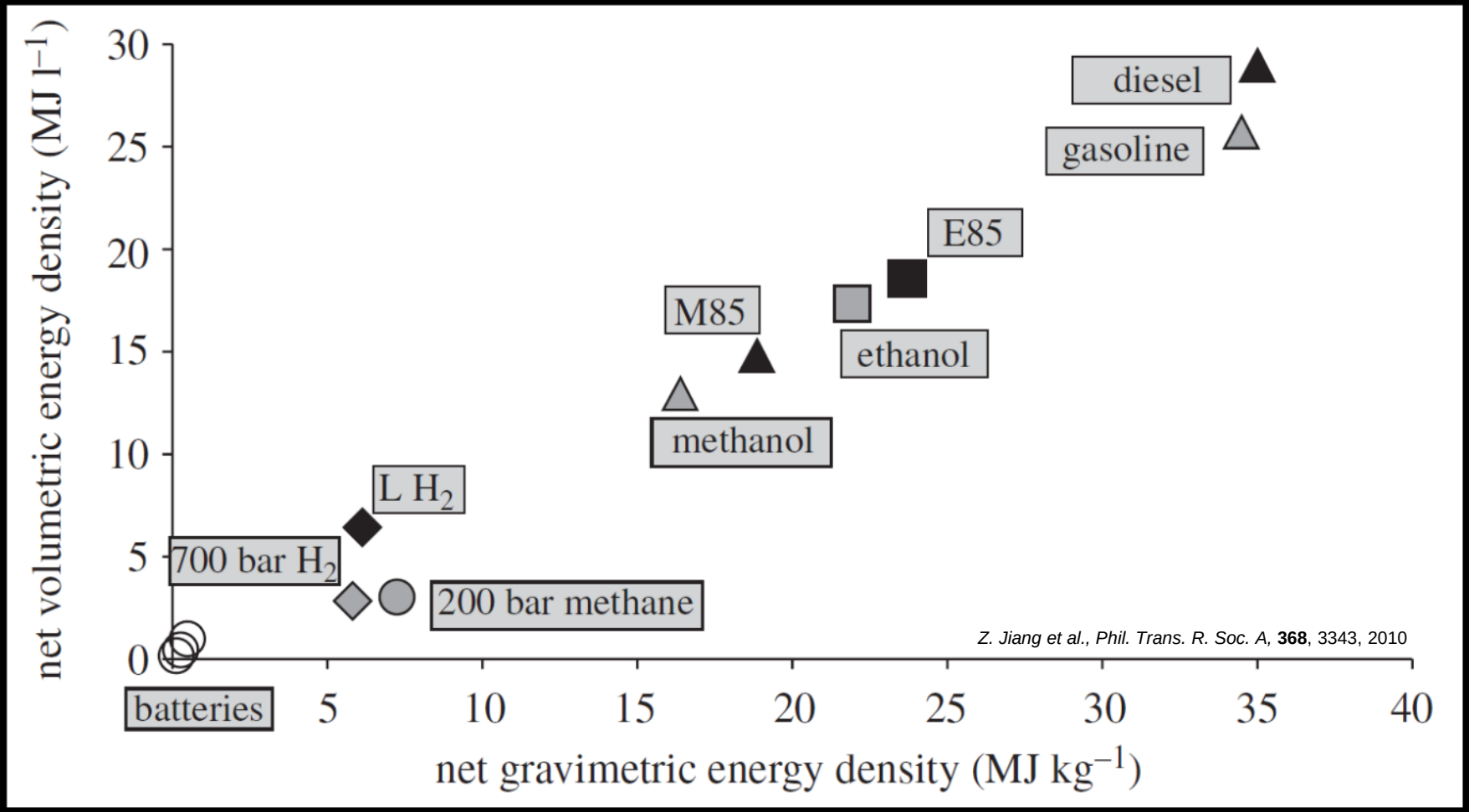
Liquid fuels offer unmatched performance



- Gasoline is energy dense and no new infrastructure needed
- Power delivered by gas pump (20MW) equivalent to 125 acres of solar

Biological renewable liquid fuel

Combustion

CO_2 in air

Photosynthesis

Water

Biomass

Fuel synthesis

Renewable liquid fuel

Industrial renewable liquid fuel

Combustion

CO_2 in air

CO_2 in flue gas

CO_2 separation

CO_2

Fuel synthesis

Renewable liquid fuel

H_2

Electrolysis

Water

Advantages of the industrial route

Biological

Industrial

1. Land area: % NY land area needed for gasoline consumption (5.8B gal/yr) – 22% is currently under cultivation

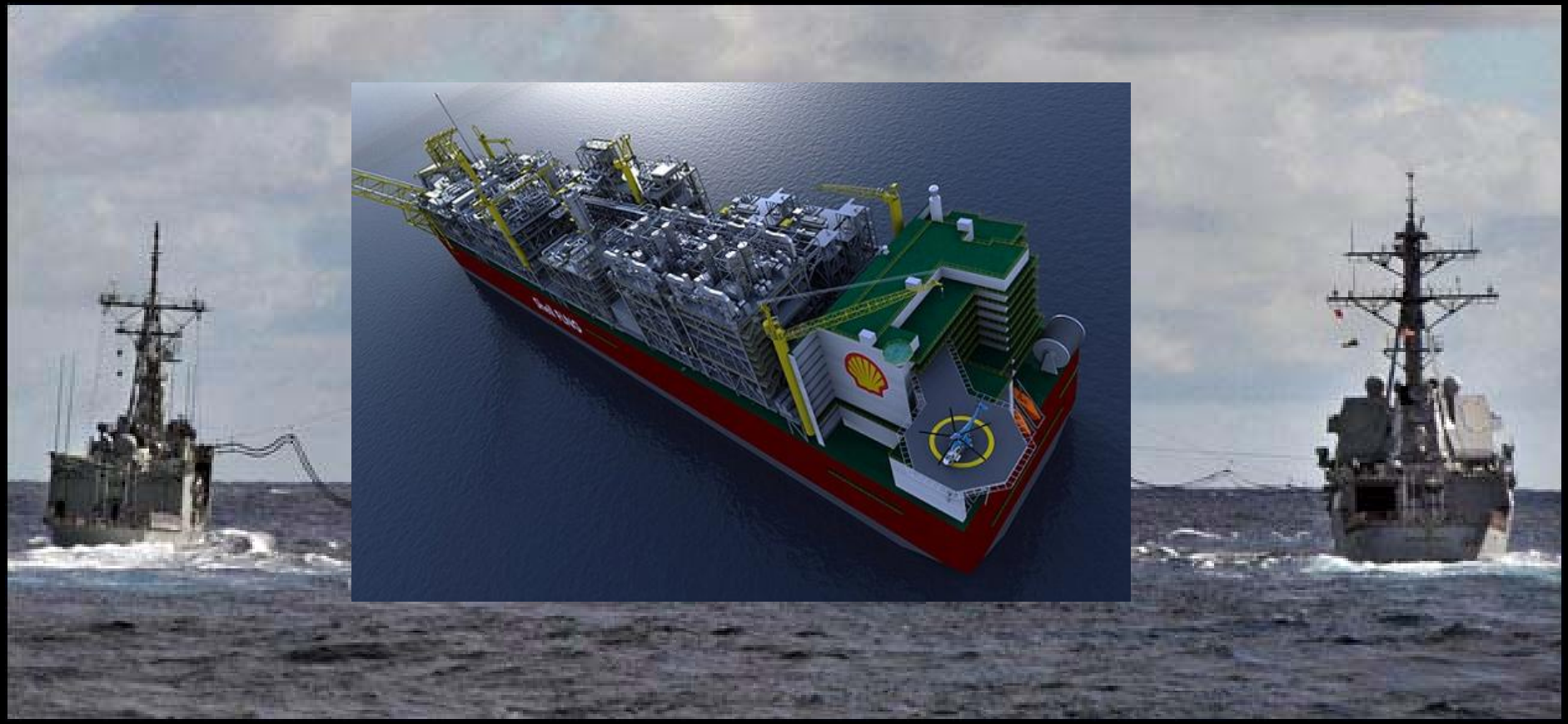
- Algae: 4.3%
- Other (e.g., corn ethanol): 17%
- Nuclear: 0.1%
- Solar: 0.8%

2. Mobility: Especially important for military applications

- Immobile and location constrained
- Mobile

Shell Prelude

U.S. Navy: Fuels at Sea



U.S. Navy photo by Bryan Reckard

A sense of scale

Military

Diesel for 1 assault ship: 50,000 gal/day

- 100MW yields 34,000 gal/day
  - 600 acre solar farm
  - Shipboard nuclear reactor
- Requires 2.8e6 m^3(seawater)/day
- Large desalination plant ~ 1-2e6m^3/day

Commercial

NY: 16M gallons gasoline/day

- 46GW yields 16M gal/day
  - 1160 km^2 solar (1450 BNL arrays)
  - Six 1000-acre nuclear plants
- 320 large desal. plants

Summary

- CO_2 extraction from seawater can play an important role (among many other technologies) in CO_2 mitigation strategies

- Scale-up will require interdisciplinary team of scientists and engineers

Thank you for your attention

Funding: DARPA