CO_2 capture and biofuel production by microalgae

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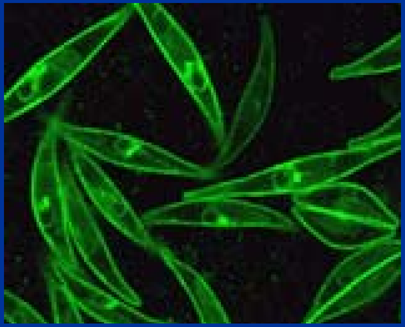

Outline

1. Microalgae-mediated CO_2 sequestration in oceans
    - Ocean fertilization and its potential
    - Requirements
    - Costs
    - Possible impacts

2. Energy options from algae

3. Summary and conclusions

CO_2 capture by nutrient fertilization of oceans

The process concept

Nutrient poor ocean

Nutrients (Fe, N, P, Si)

→

Algal bloom

CO_2 in atmosphere → Carbon in biomass

How much CO_2 can be sequestered?

What is possible in a constructed culture system?

Raceway ponds

Typical biomass productivity

$0.025\ \text{kg m}^{-2}\ \text{day}^{-1}$ (~91 tons $\text{ha}^{-1}\ \text{year}^{-1}$)

Culture conditions

- CO_2 supplemented culture
- Equatorial location, clear skies
- Nutrient sufficiency (N, P, Fe)
- 0.25 m deep pond

CO_2 sequestration in the ocean…

Best case scenario – Case A

Ocean biomass productivity same as in raceways

0.025 kg m^{-2} day^{-1} (~91 tons ha^{-1} $year^{-1}$)

~171.4 tons of CO_2 ha^{-1} $year^{-1}$

Minimal case scenario – Case B

Ocean biomass productivity is 5% of raceways

1.25×10^{-3} kg m^{-2} day^{-1} (~4.6 tons ha^{-1} $year^{-1}$)

~8.7 tons of CO_2 ha^{-1} $year^{-1}$

Stoichiometric data

- 1 ton dry algal biomass ≡ 1.883 tons CO_2 captured

How much ocean surface do we need?

Complete absorption of global CO_2 emissions

- Emissions from fossil fuels (2006) = 27.4×10^9 tons

Best case scenario – Case A

Ocean surface area needed = 159.4×10^6 ha

- 0.4 % of total ocean surface
- 17.4% of United States area

Minimal case scenario – Case B

Ocean surface area needed = 3.19×10^9 ha

- 8.8% of total ocean surface
- 3.5 times the United States area

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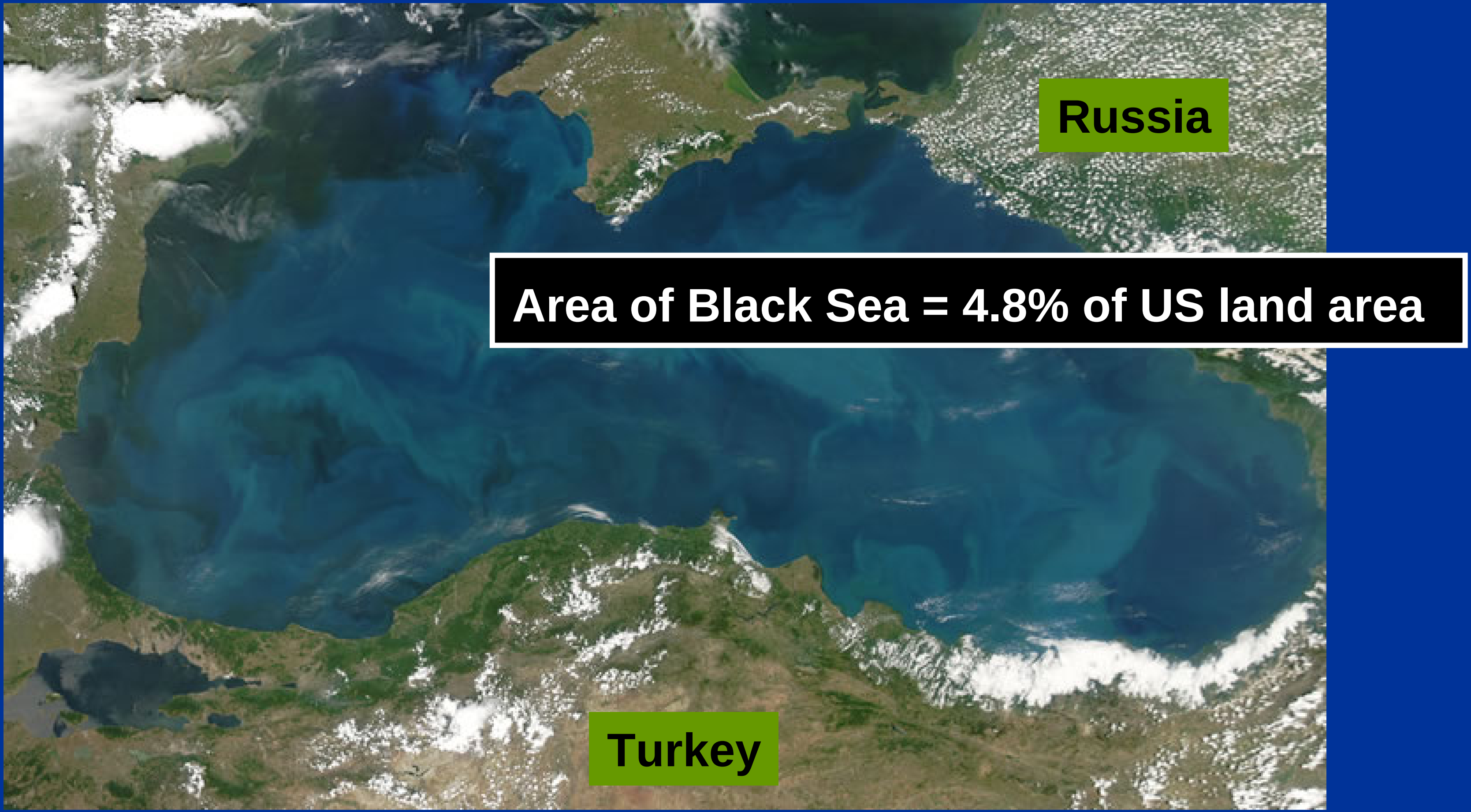
Natural algal blooms

Atlantic Ocean (June 2, 2006)

Satellite image by NASA

Natural algal blooms…



Area of Black Sea = 4.8% of US land area

Black Sea (June 20, 2006)

Satellite image by NASA

How much and what nutrients do we need?

For <u>total absorption</u> of 2006 global CO_2 emissions

Molecular formula of microalgae

$CH_{1.83}O_{0.48}N_{0.11}P_{0.01}Fe_{9.4\times10^{-6}}$

For both Case A and Case B

Nutrient	Quantity (tons)	Cost ($, 2007)[a]
$FeSO_4 \cdot 7H_2O$	16.3×10^5	378.3×10^6

[a] Including transport

<u>Assumptions</u>

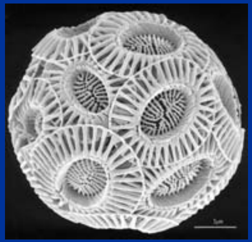
- Only Fe is needed
- N-fixing algae are grown
- Complete absorption of Fe
- Fe supplied as $FeSO_4 \cdot 7H_2O$

How feasible is the proposed CO_2 capture?

How realistic is raceway-like productivity in the oceans?

- Typical doubling time (industrial algae) ≈ 24 h
- Doubling time (22 °C) of *Emiliana huxleyi* ≈ 22 h

(~50% of ocean surface is at >22 °C)



Emiliana huxleyi
Professor Y. Shiraiwa
Tsukuba University, Japan

Do we have the ocean surface?

- Yes

Do we have the technology?

- Yes

How feasible is the proposed CO_2 capture?

Other impacts?

- <9% of ocean surface used (worst case)
- Sequester for next 100 years (2006 CO_2 emission rates)
    - Total sequestered <0.004% of 2.1×10^{16} tons dissolved inorganic carbon already in oceans

Economics?

- \$4 billion (~ 0.1% of 2009 US Federal Budget)
    - assuming the total cost is ~10-fold the cost of iron nutrient
- Could be much cheaper

A natural fertilization event…

Mount Pinatubo, the Philippines (June 12, 1991)

Image by D.H. Harlow, USGS

18 km high plume

- 40,000 tons of iron-rich dust dumped in oceans
- Algal blooms
- Observable global decline in atmospheric CO_2

An ongoing natural fertilization…

Amazon River discharge

Norman Kuring, NASA

Discharge = 80,000–250,000 $m^3 s^{-1}$

Area of outflow plume = 1.3×10^6 km^2

(~0.4% of world ocean surface area)

Nutrient inputs (non anthropogenic)

- Nitrate = 8,626 tons day^{-1} (minimum)
- Phosphate = 460 tons day^{-1} (minimum)

What will happen to algal biomass?

- Natural blooms in oceans last generally for less than ~120 days
- >50% of the biomass is eaten (zooplanktons and the supported food chain)

Thomas P. Peschak
National Geographic

- Rest sinks (up 30% degraded by bacteria → CO_2 release)
- 20–30% sinks to below ~150 m (cold ocean) ⇒ trapped for 100s or 1000s of years

Is this really carbon sequestration?

- Forests sequester carbon for tens of years
- Biomass carbon that sinks to below ~150 m is removed for 1000s of years

Energy options from algae

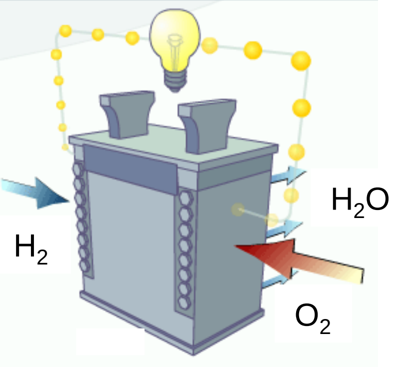
Microalgae

Biogas – methane
- Anaerobic digestion

Bioethanol
- Fermentation

Biodiesel – microalgal oils
- Liquid hydrocarbon fuels
- Jet fuel

Biohydrogen
- H_2 fuel cells



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Summary and conclusions

1. Ocean sequestration of CO_2
    - What is it?
    - What does it require?
    - How realistic is it?

2. Ocean sequestration is technically/economically feasible

3. Environmental impact is comparable to some natural events'

4. Options for energy from algae