OMEGA for the future of biofuels

OMEGA for the future

OMEGA

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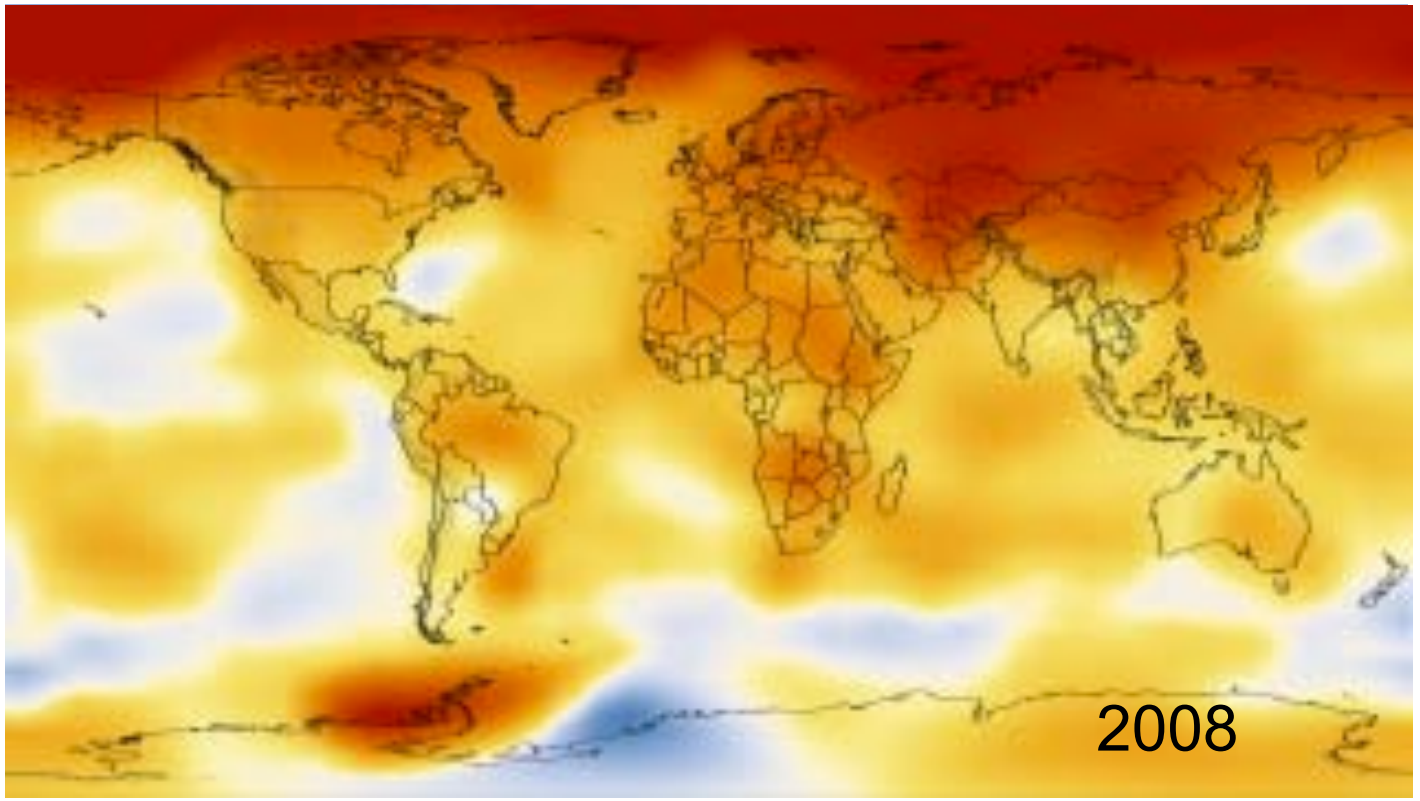
NASA Ames Research Center
Jonathan.d.trent@nasa.gov

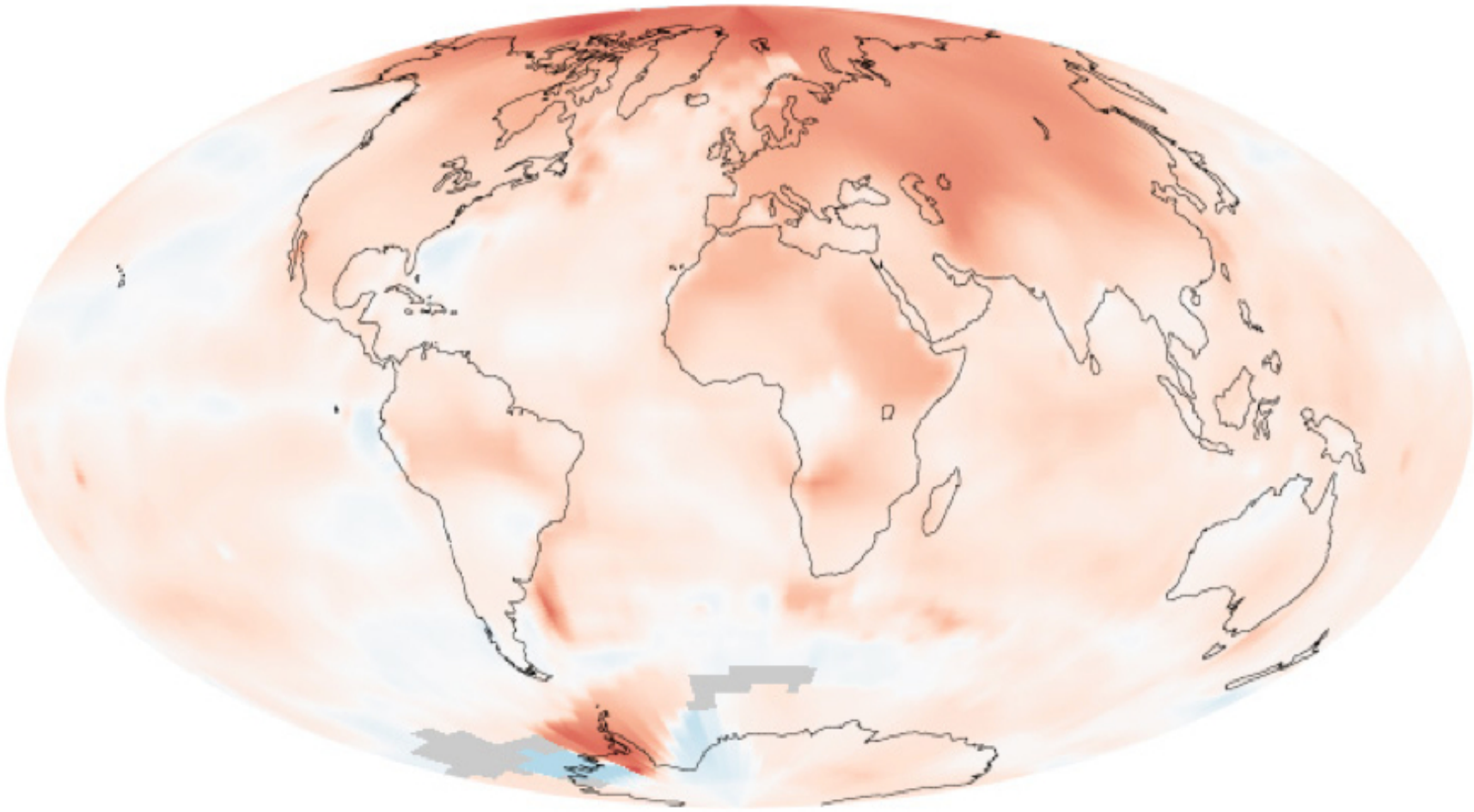
NOAA
17 March 2010


Google Project
Jonathan Trent
Deborah Bazar
Mel Averner
John Hogan
Robert Baertsch
Richard Mogford
Global
Research into
Energy and the
Environment at
NASA



Data from NASA/Goddard Space Flight Center
James Hansen, Goddard Institute of Space Studies
Robert B. Schmunk, Scientific Visualization Studio

The warmest decade on record…



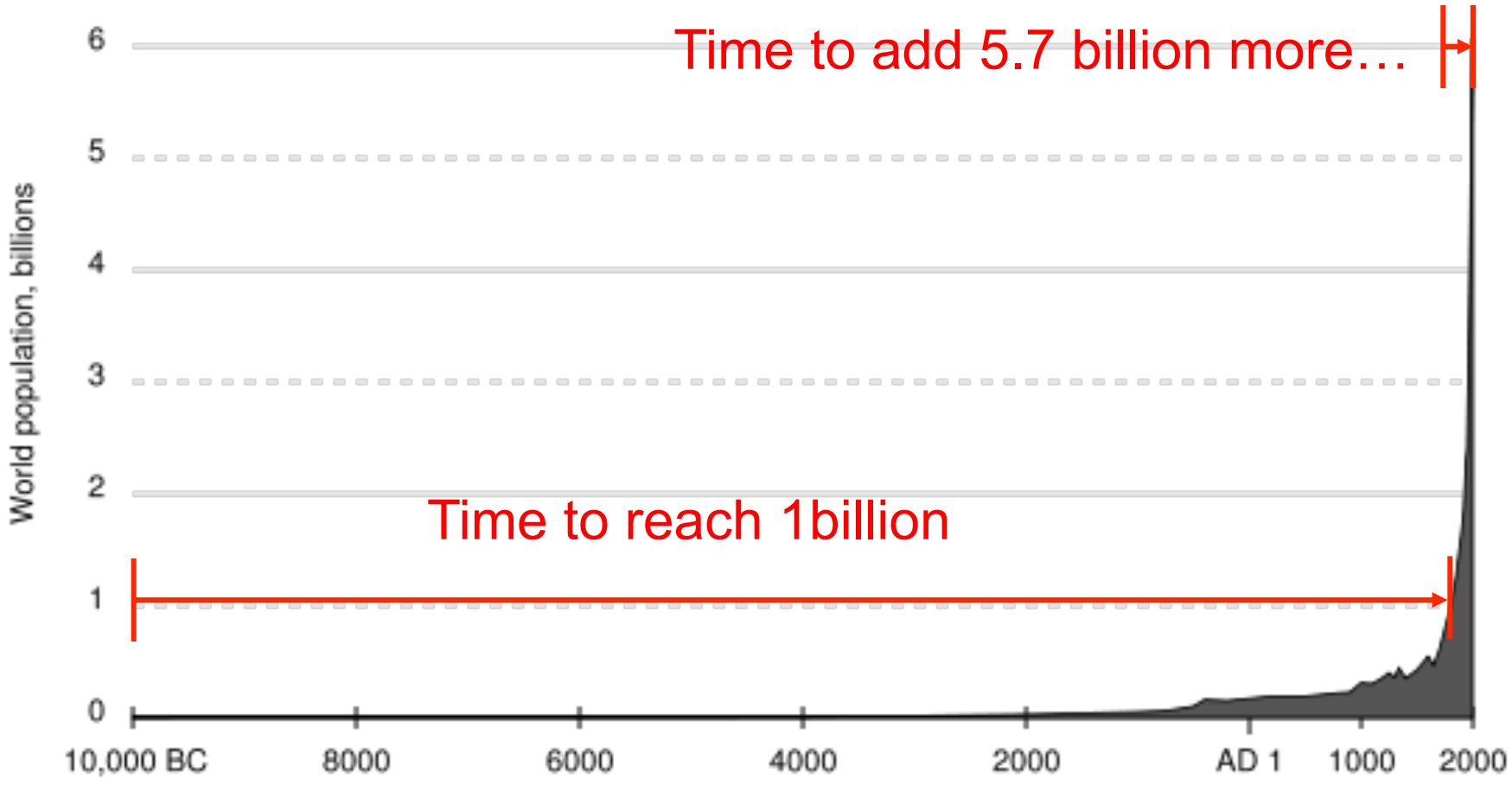
Temperature Anomaly °C

-2.5 -1.5 -0.5 0 +0.5 +1.5 +2.5

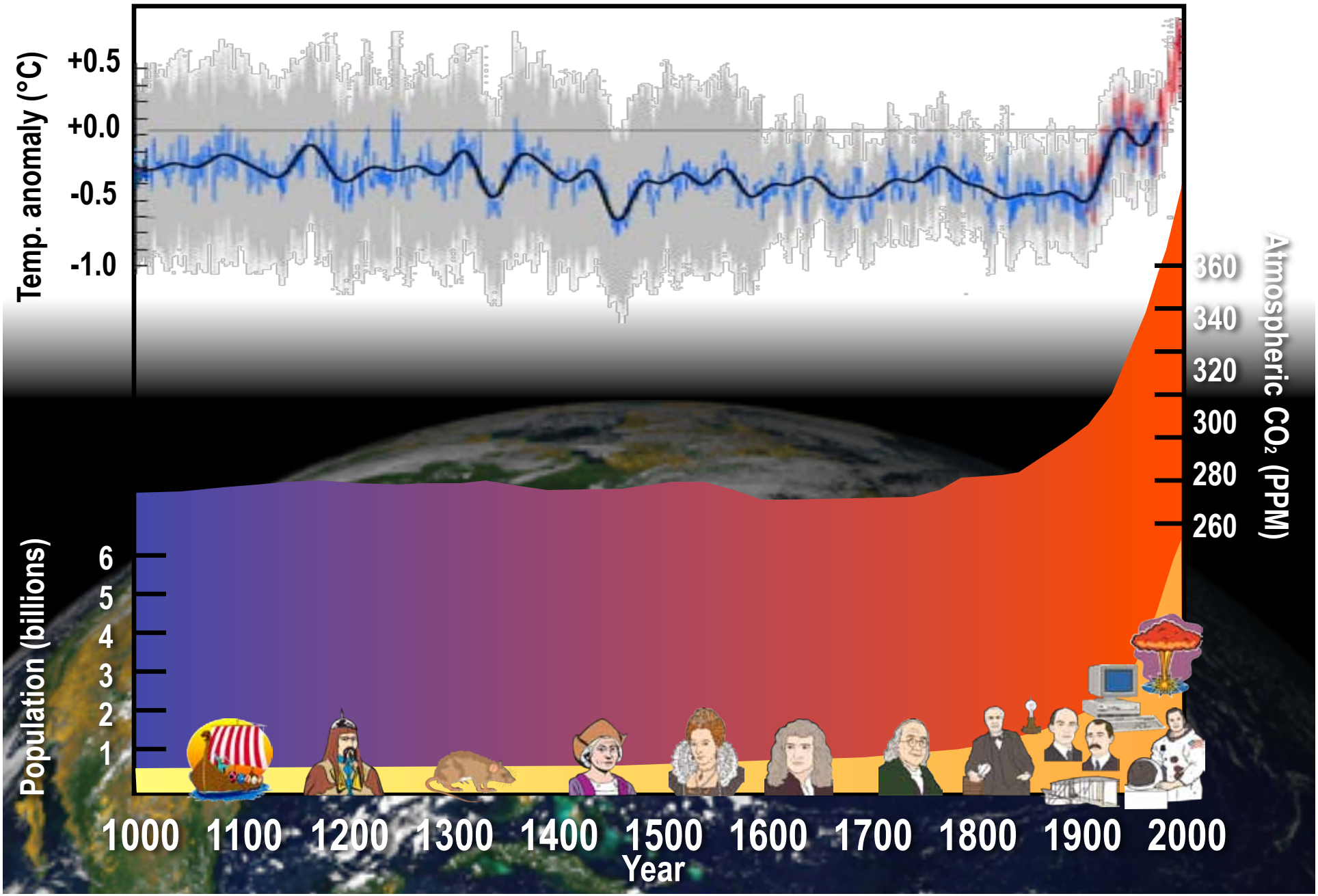
DATA from GISS

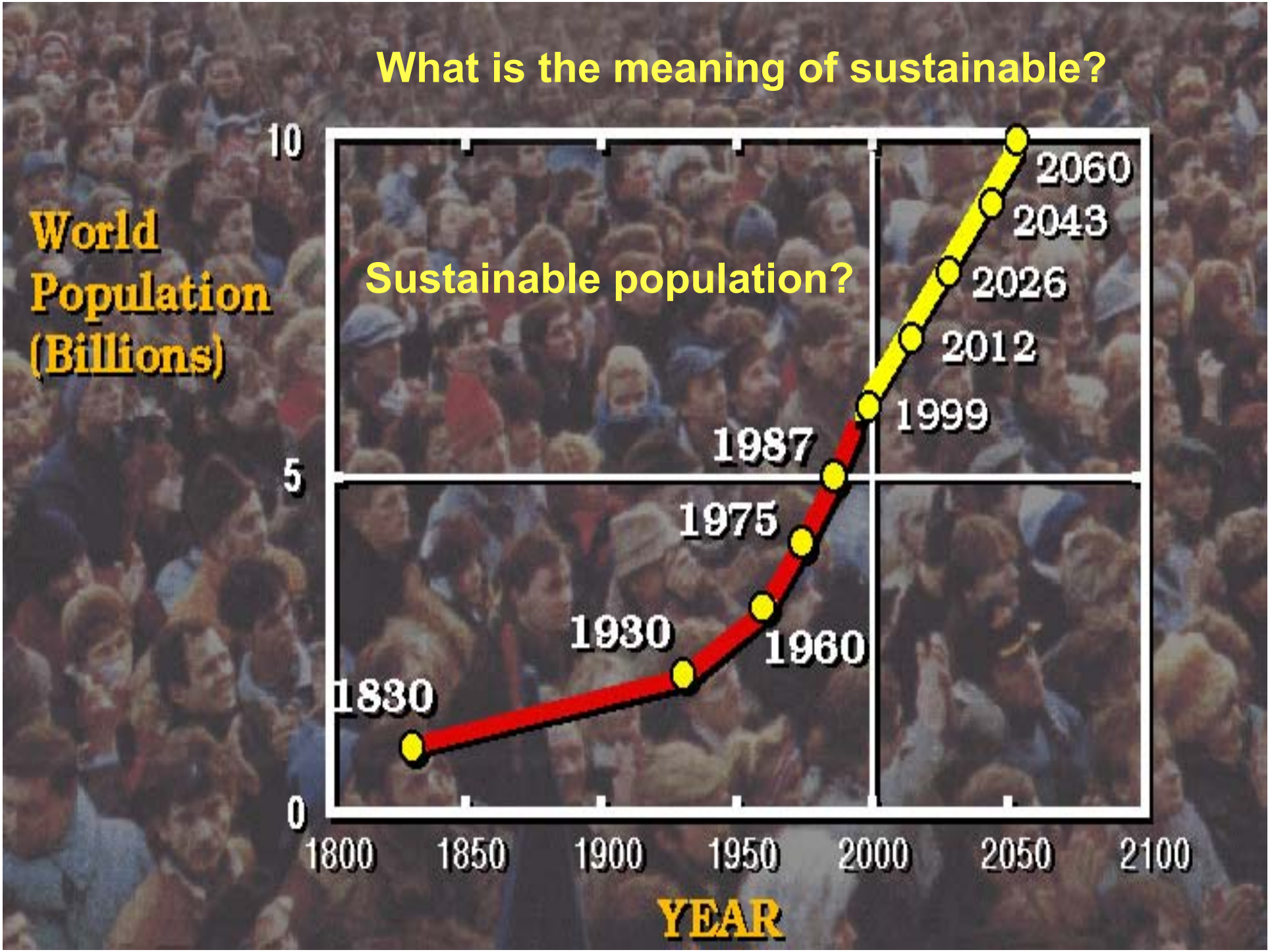
Avg: 2000-2009
1951-1980

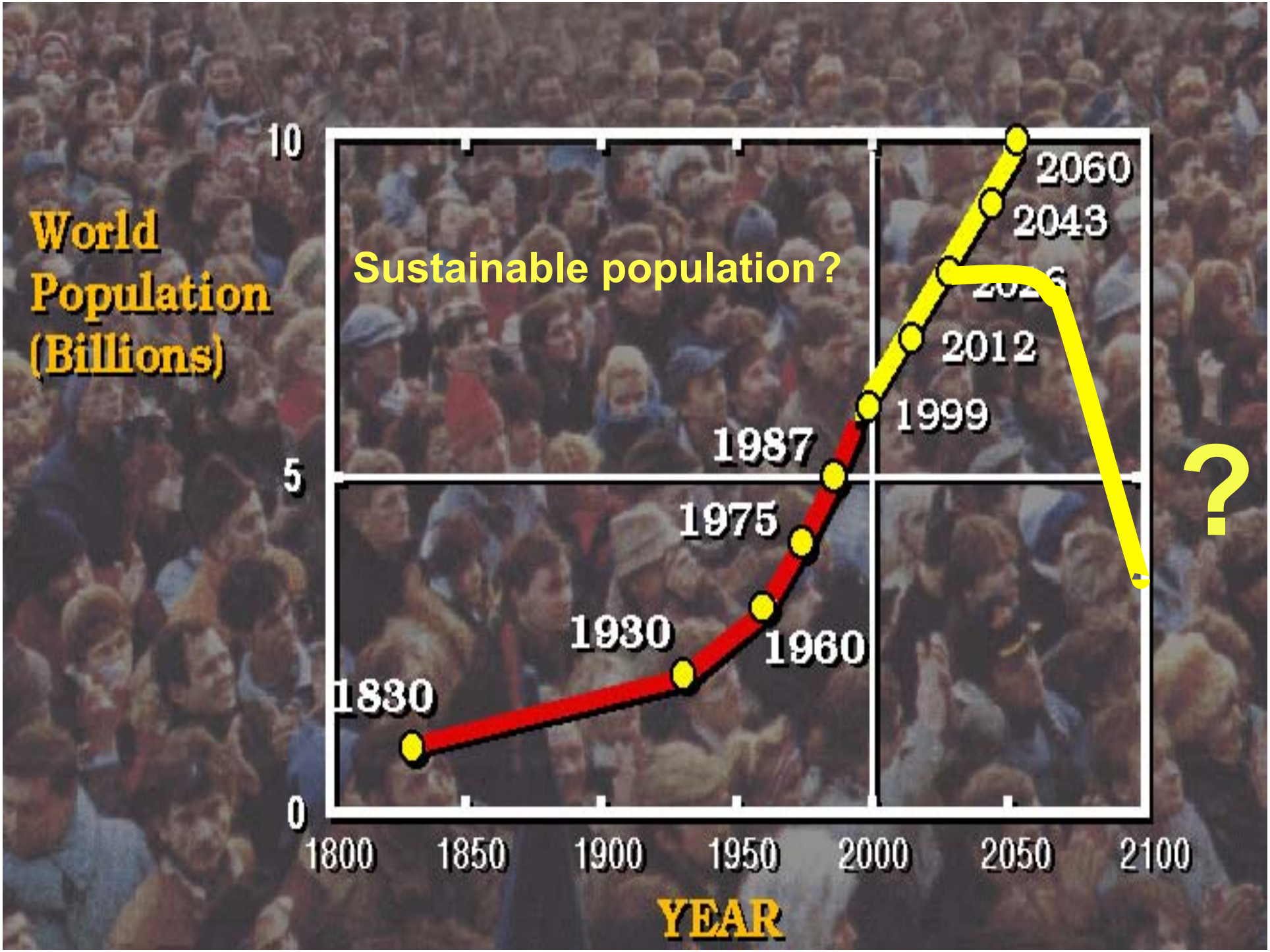
Limits to growth?




1000 A.D.
Viking Conquests


Temp. anomaly (°C)
+0.5
+0.0
-0.5
-1.0
Atmospheric CO₂ (PPM)
360
340
320
300
280
260
Population (billions)
6
5
4
3
2
1
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year


What is the meaning of sustainable?
Sustainable population?
World Population (Billions)
10
5
0
1800
1850
1900
1950
2000
2050
2100
YEAR
1830
1930
1960
1975
1987
1999
2012
2026
2043
2060


World Population (Billions)
Sustainable population?
10
5
0
1800
1850
1900
1950
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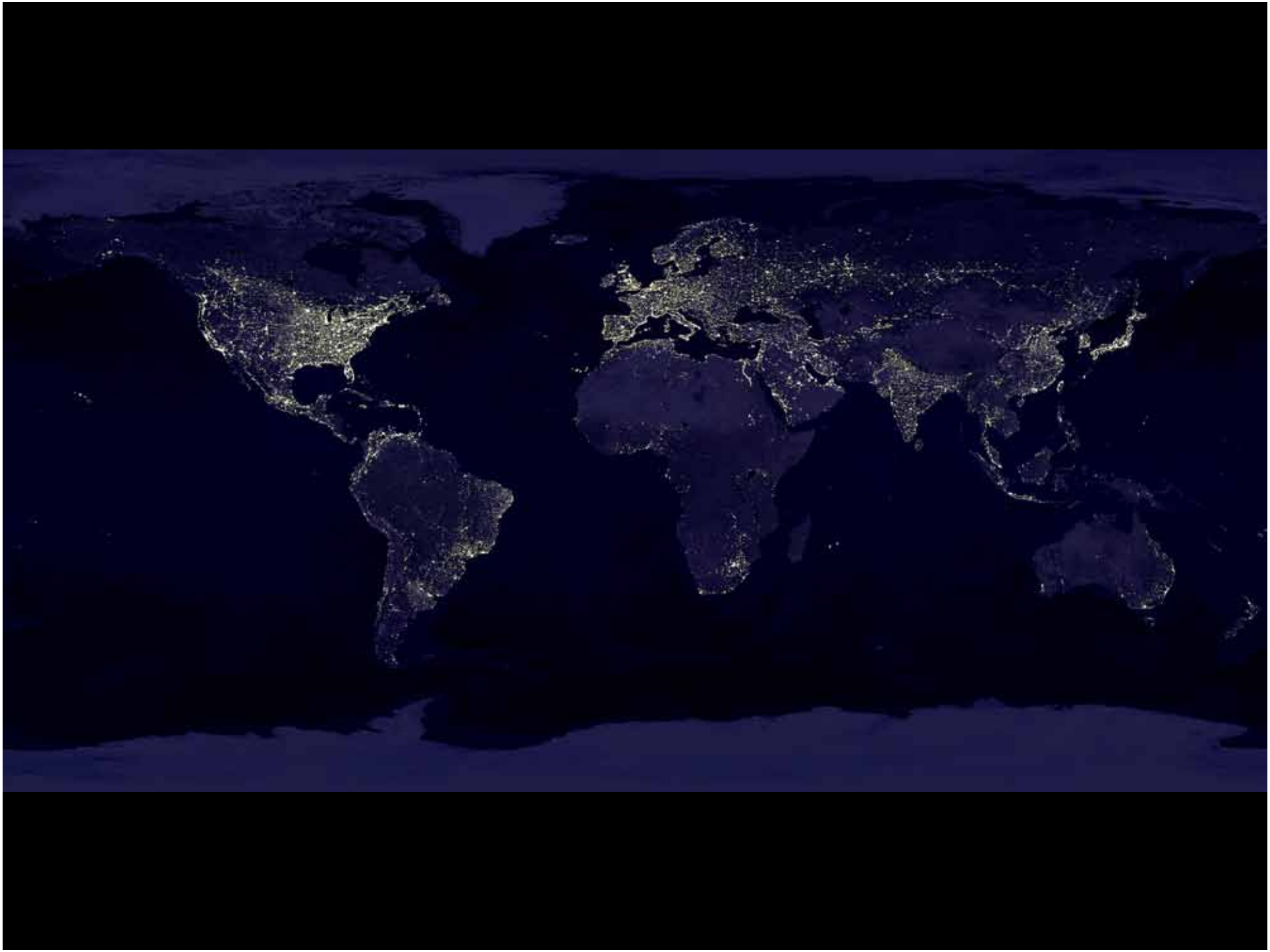
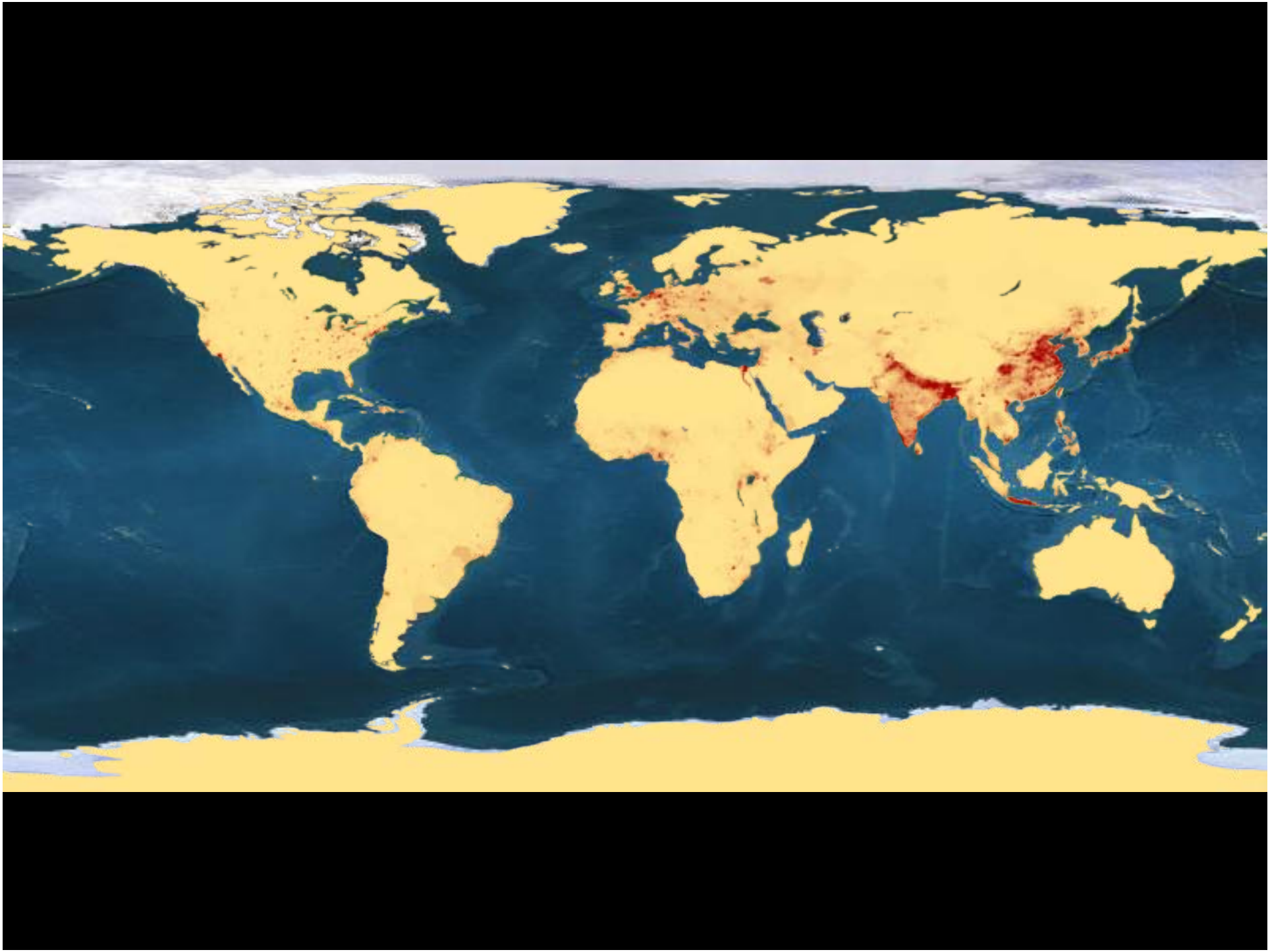
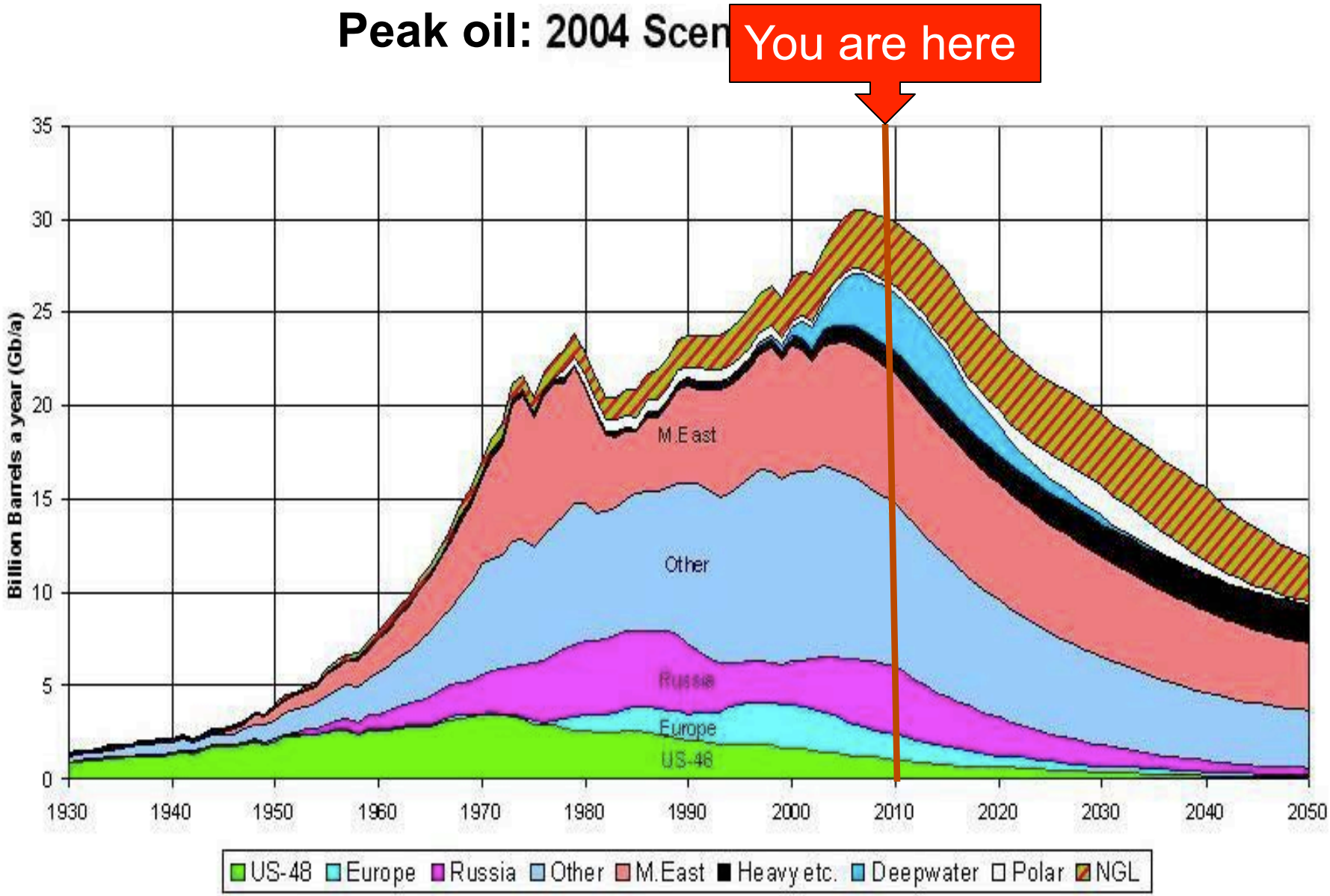
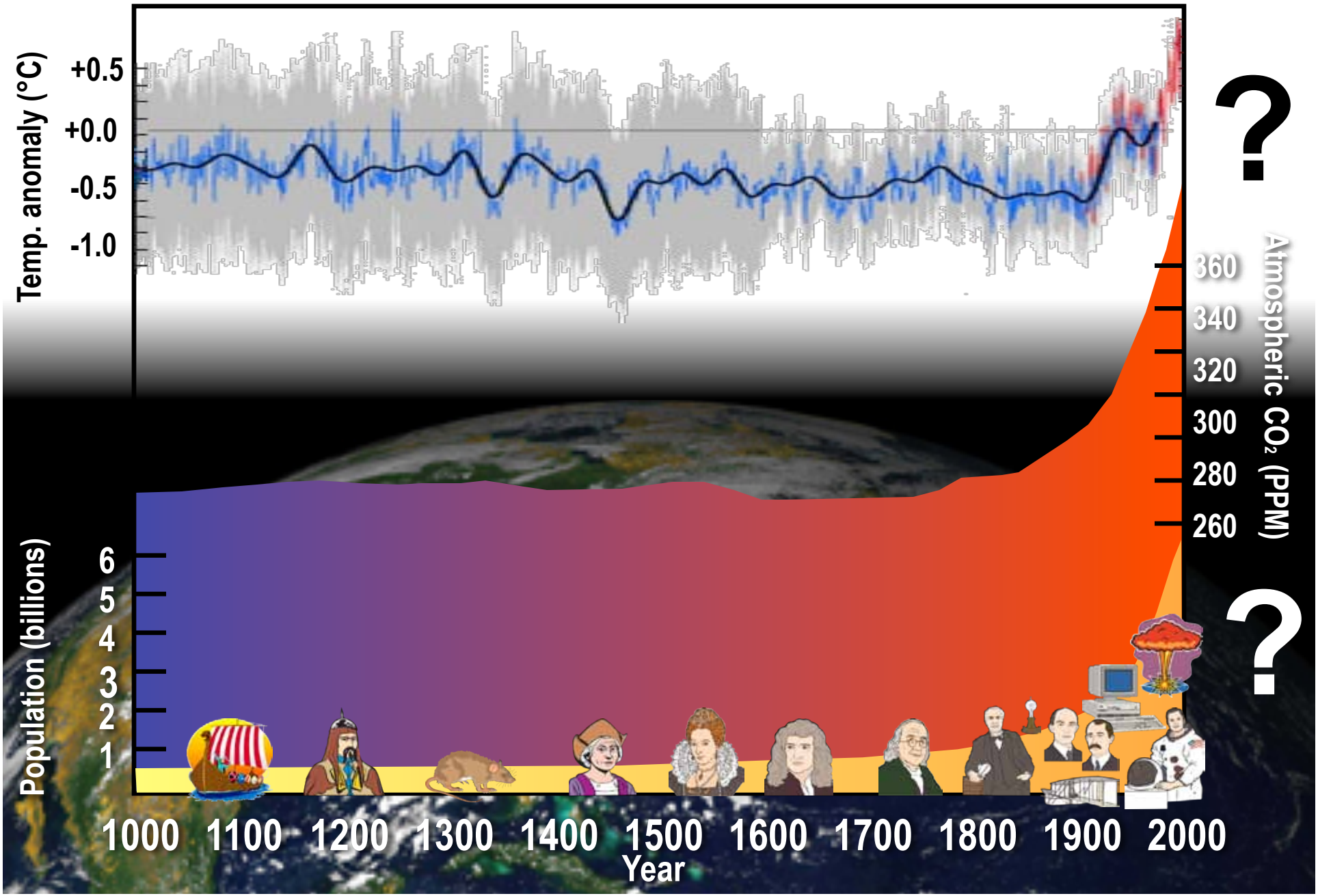
1830
1930
1960
1975
1987
1999
2012
2043
2060
?

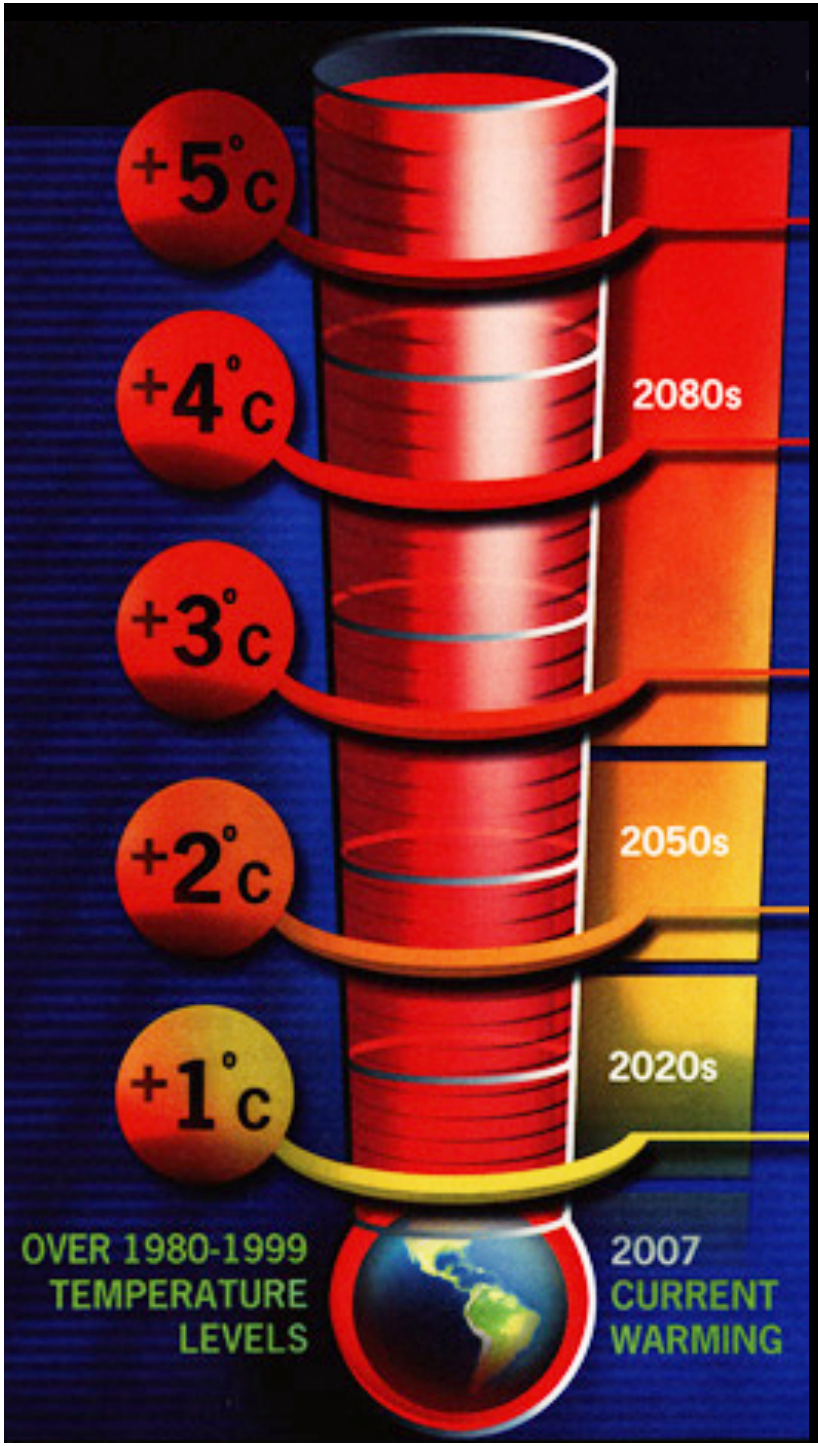




Peak oil: 2004 Scen




Temp. anomaly (°C)
+0.5
+0.0
-0.5
-1.0
Atmospheric CO₂ (PPM)
360
340
320
300
280
260
?
?
Population (billions)
6
5
4
3
2
1
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year



IPCC predictions www.net.org

Mass extinction (>40% known spp),
Sea level rise…

Food?

~30% wetlands flooded,
freshwater, Islands

Food?

Stress on ecosystems
(Population 9 billion)

Food?

Extinctions (20-30% known spp),
ocean acidification

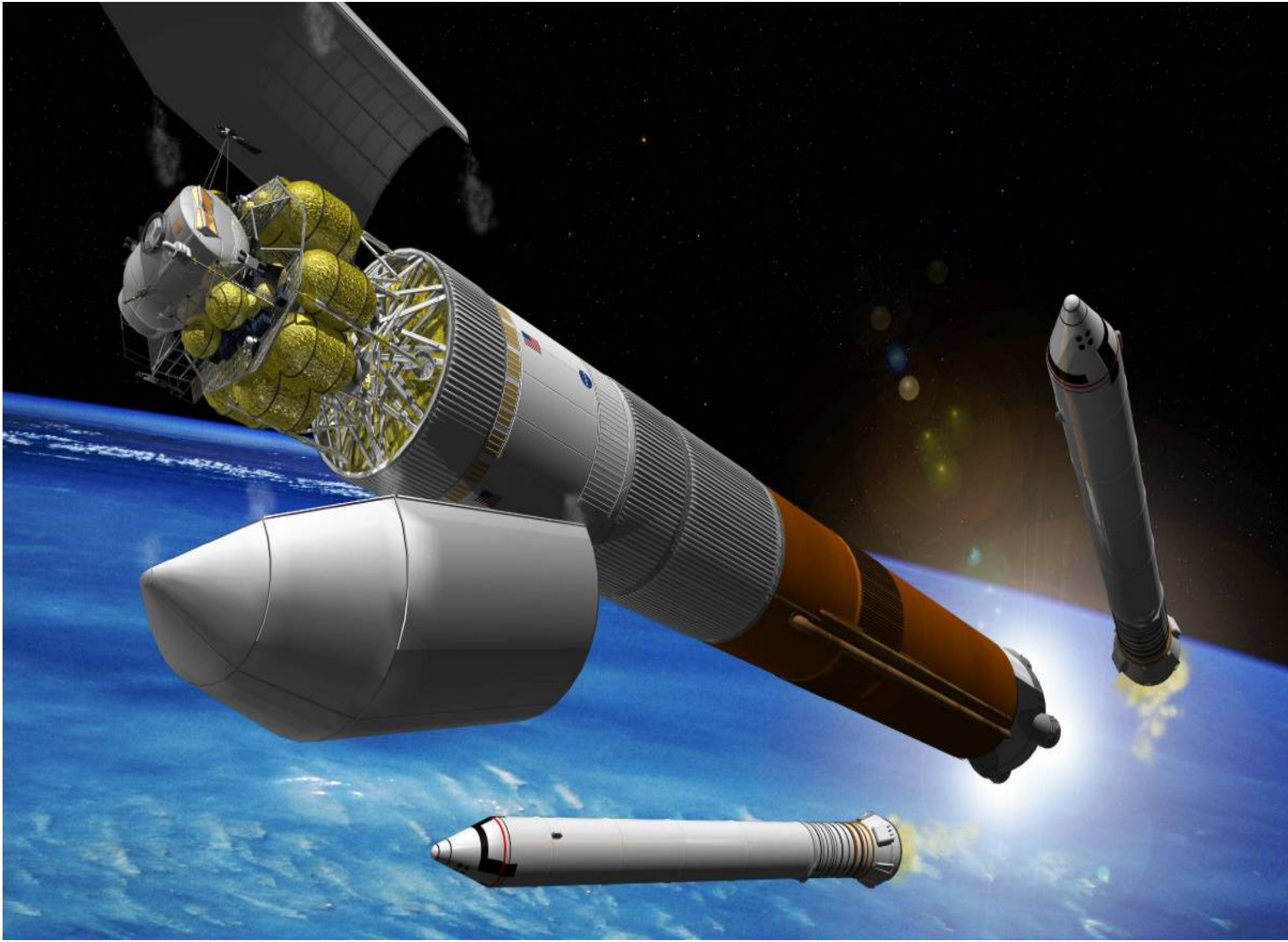
Food?

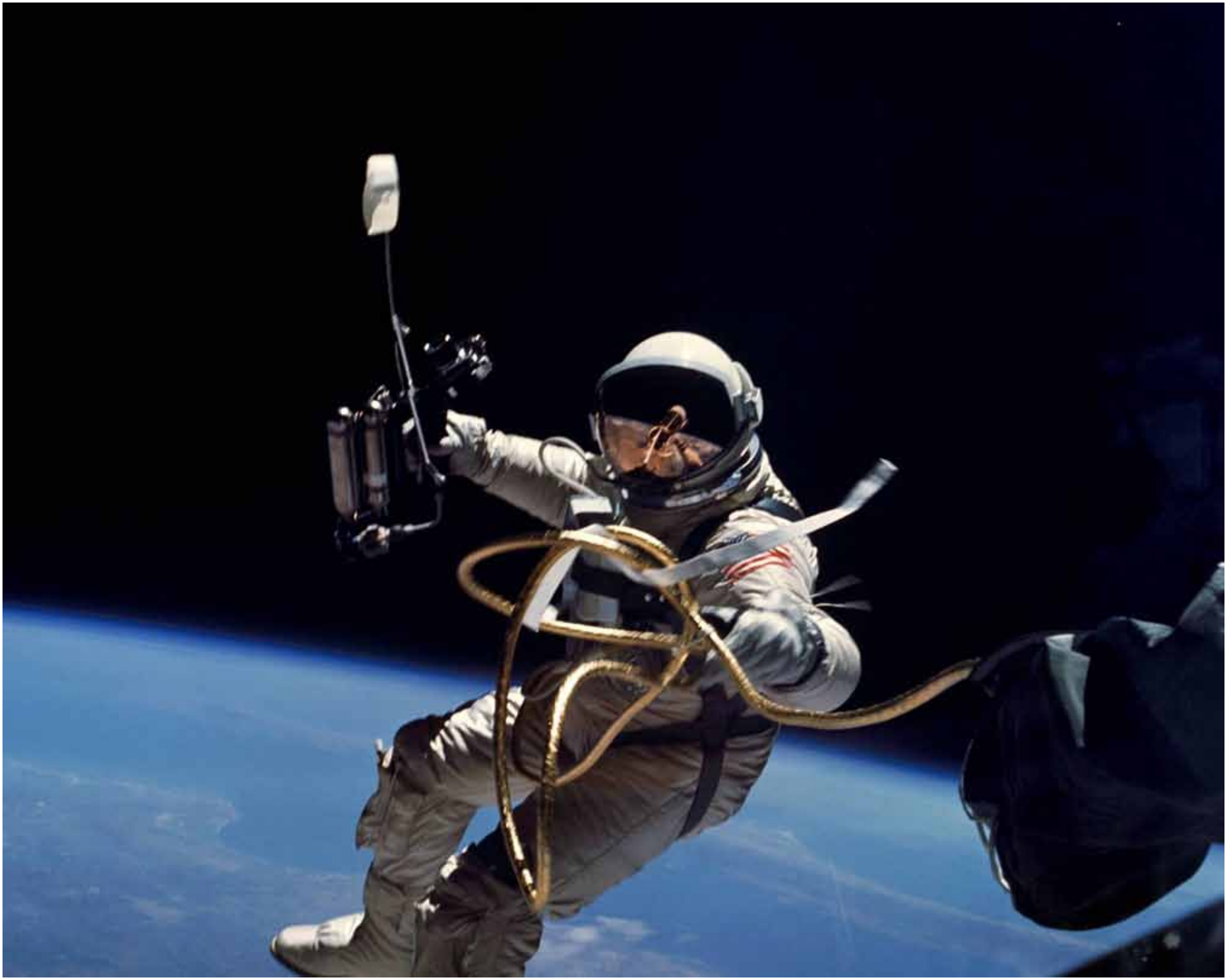
} Temp rise 0.7°C
Weather patterns, wildfires,
floods/droughts

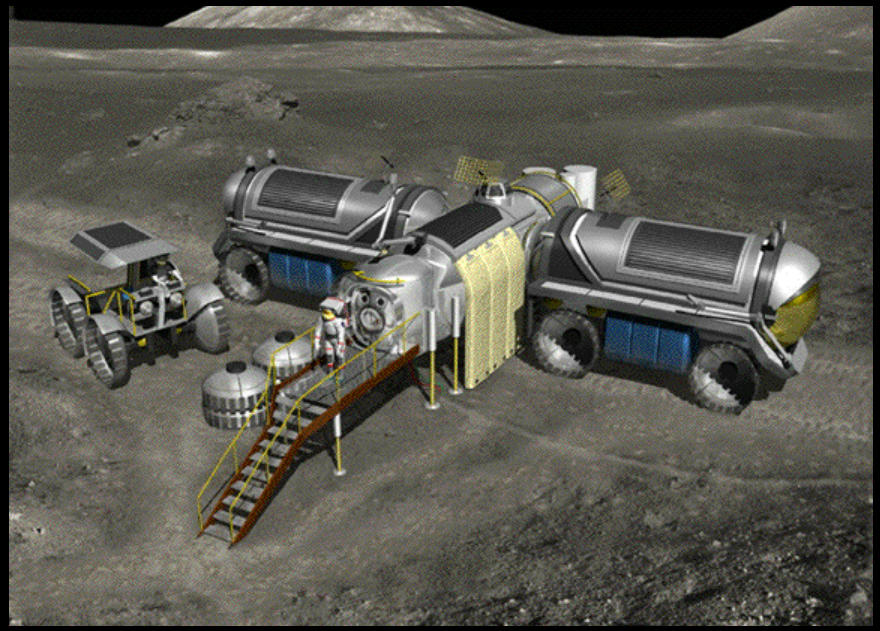
Food?

T. Root, Stanford


Sustainability?
Population?
Affluence?
Species diversity?
Technology?







First flight test with sustainable biofuels for commercial aviation

NASA

First sustainable biofuel flight test in Asia

Scheduled 2009

First North American sustainable biofuel flight test

Scheduled 2009

Biofuels fly airplanes…

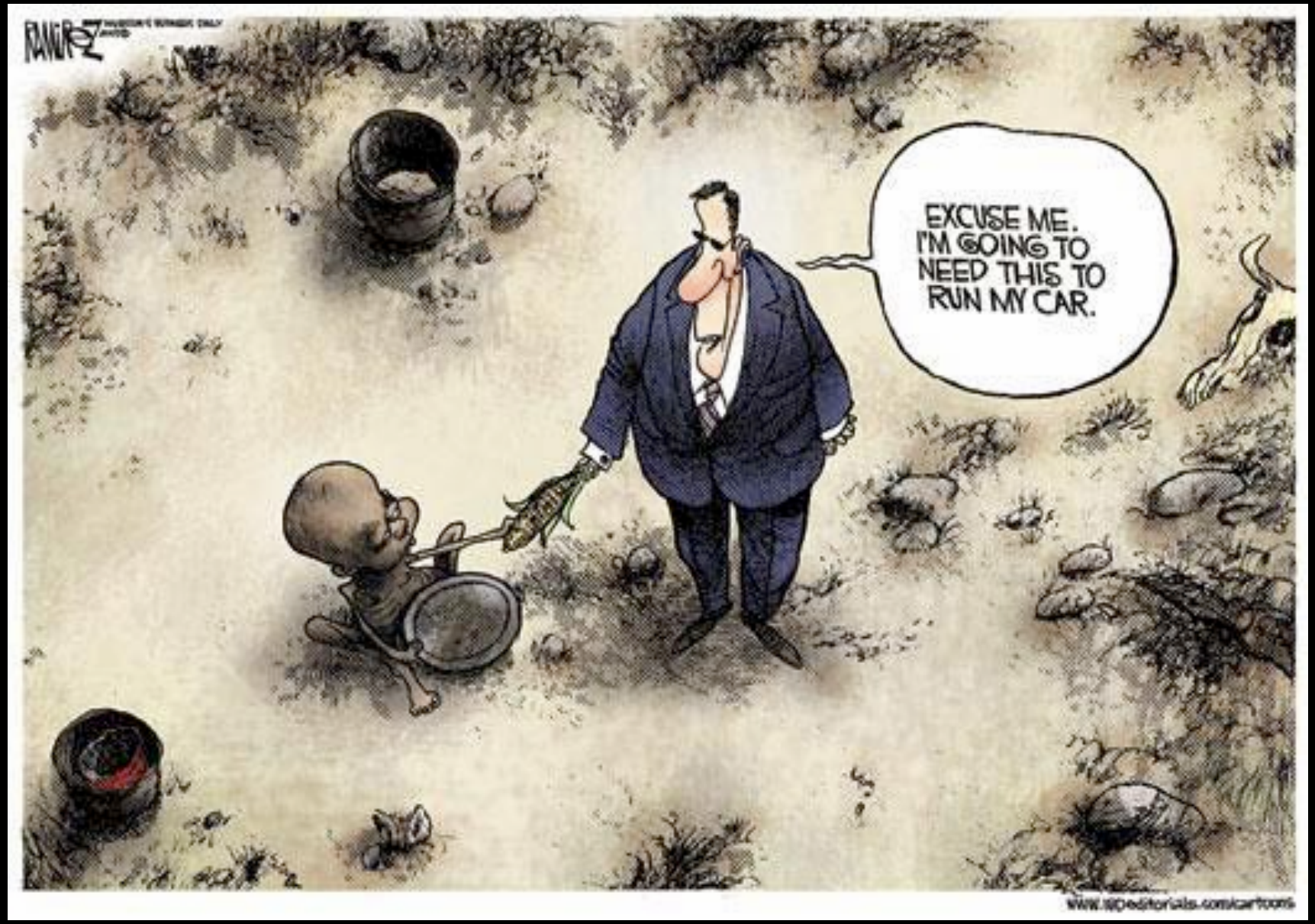
What about Biofuels?

Not use agricultural land

Not use freshwater or fertilizers

Feasible, affordable, scalable, sustainable…

NOW!

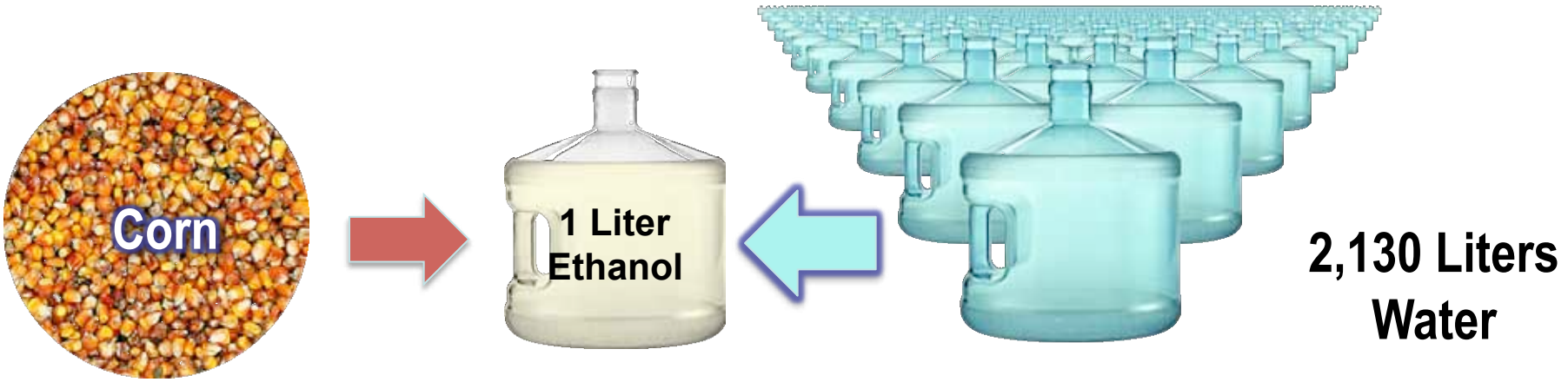

RAMIREZ
EXCUSE ME. I'M GOING TO NEED THIS TO RUN MY CAR.

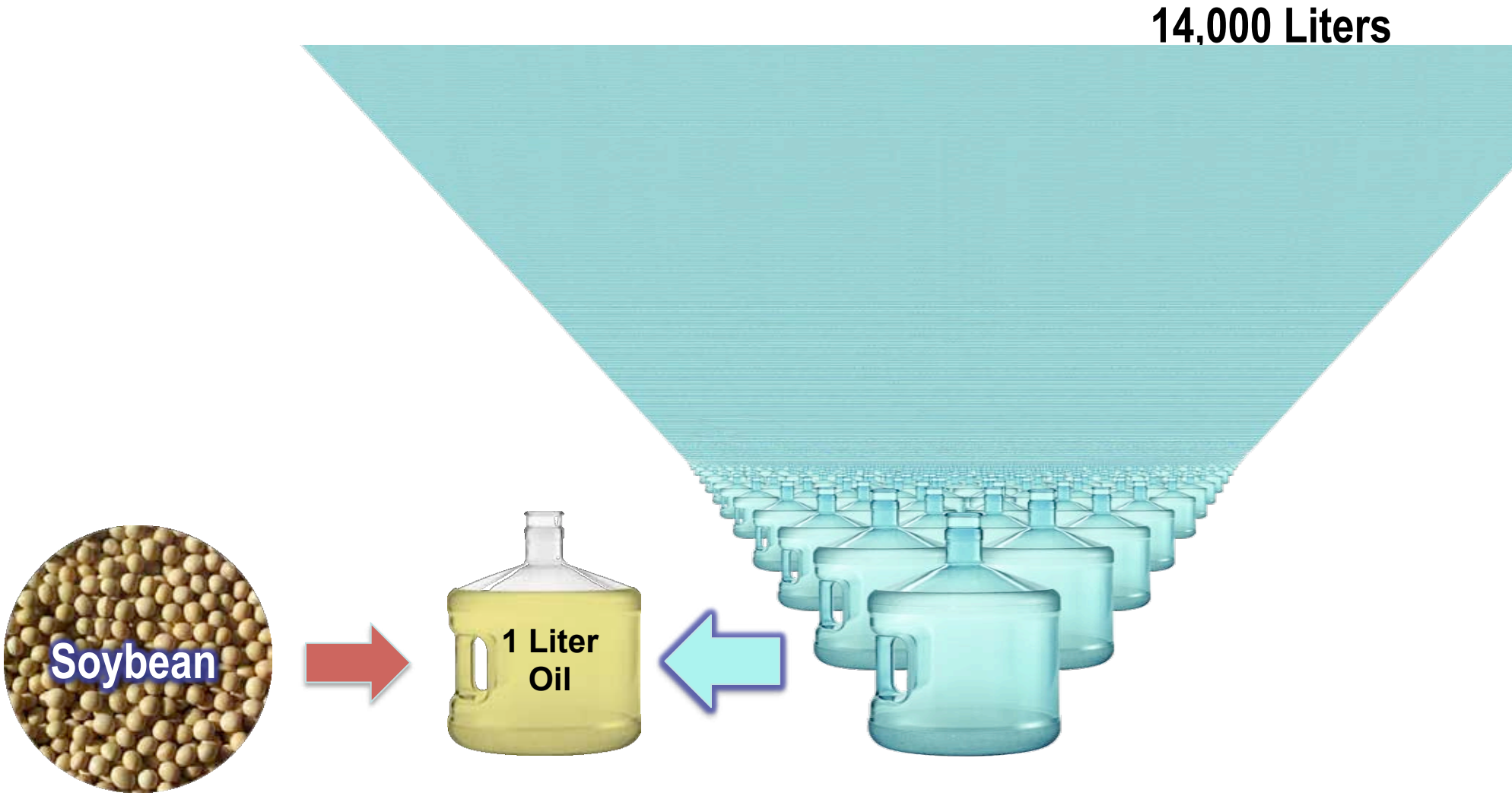
How **green** are biofuels?

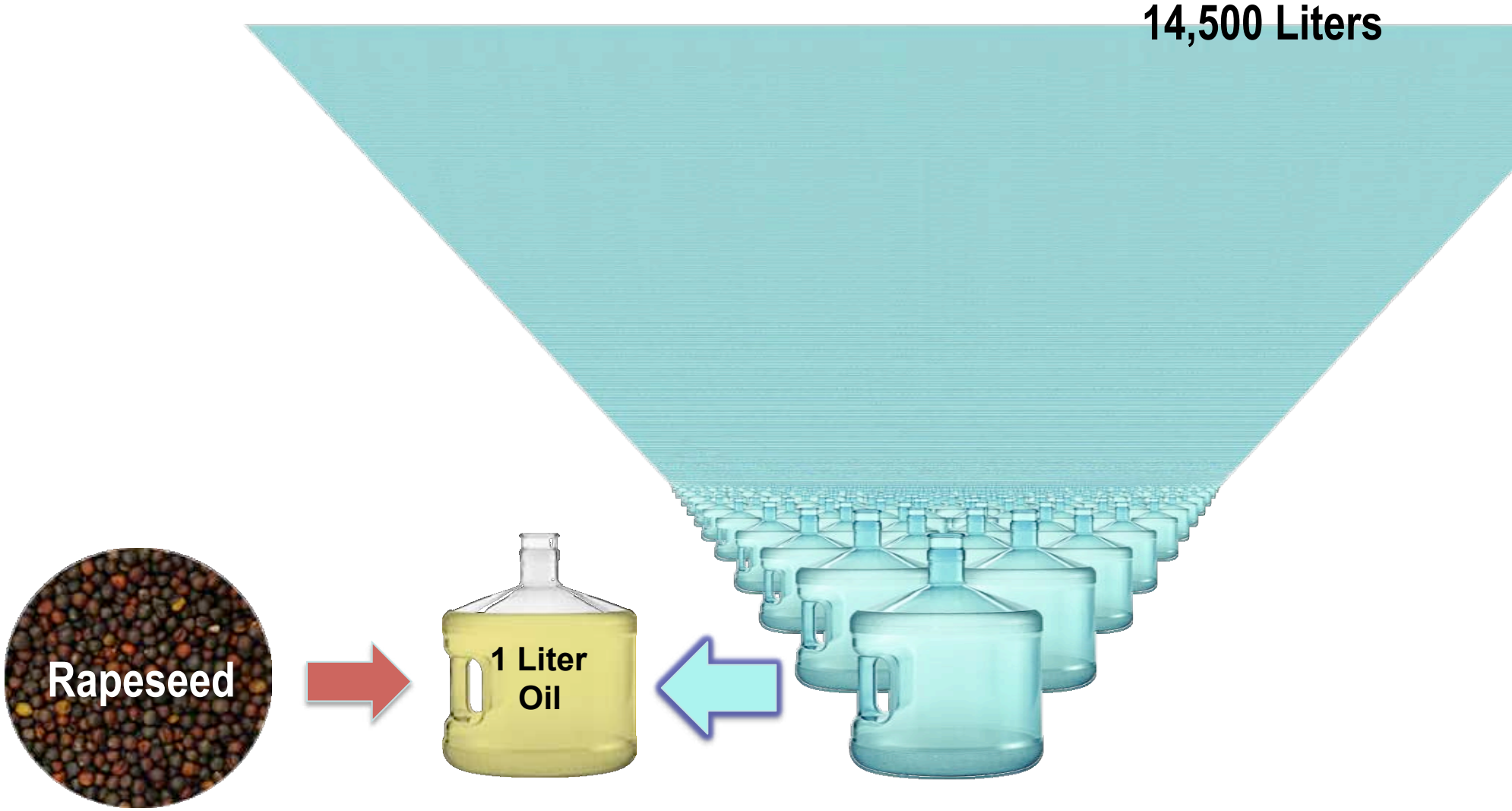
	Corn	Sugar Cane	Switch Grass
Product			
GHG output*			
Water			
Fertilizer			
Pesticide			
Energy			
US crop land/ half demand			

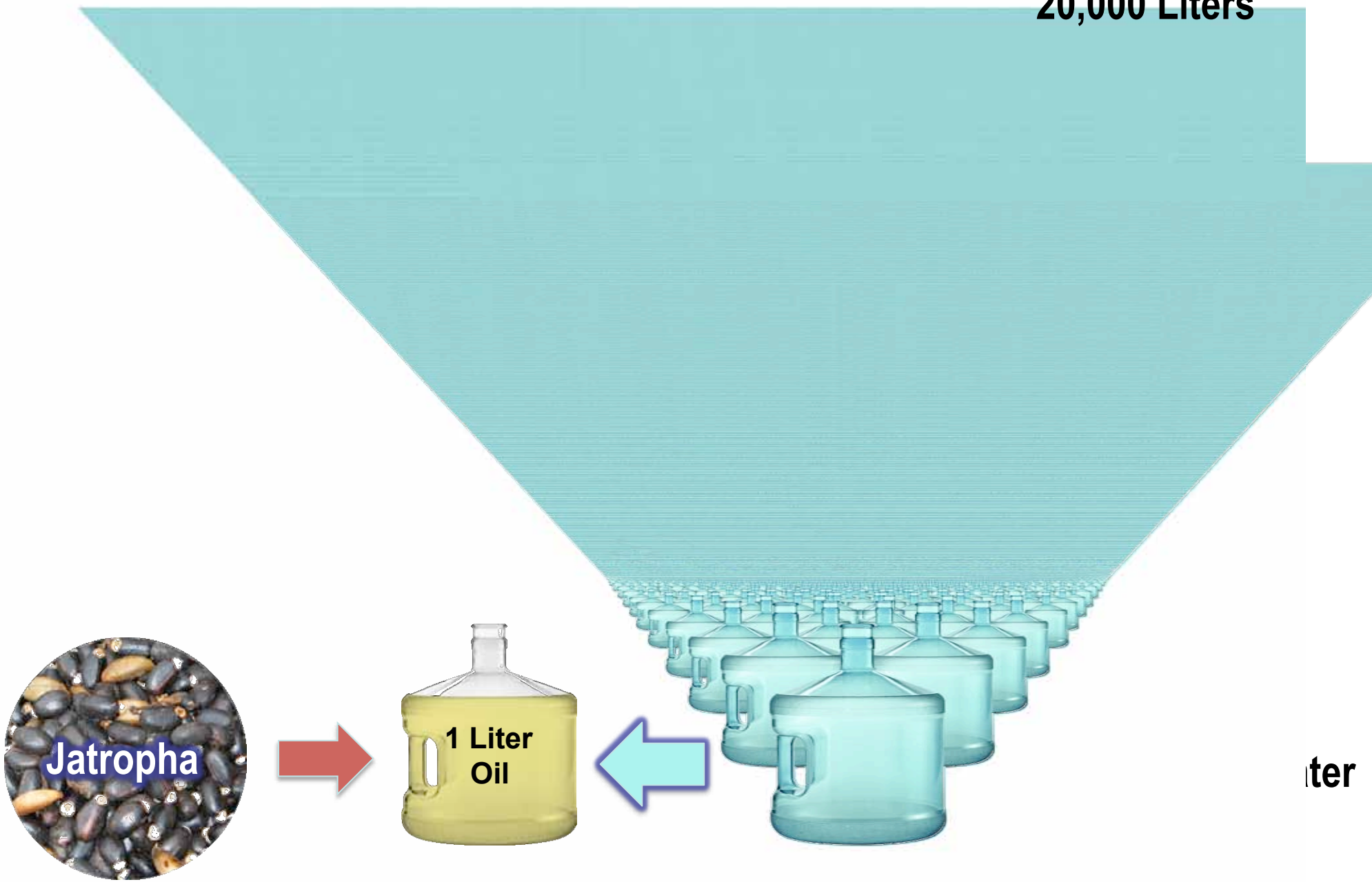
*CO_2 kg/MJ: Growing, harvesting, refining, burning fuel (cf., gas=94)

Gerbens-Leenesa, et al., 2009. The water footprint of bioenergy. **PNAS**.
http://www.pnas.org/content/106/25/10219




14,000 Liters
Soybean
1 Liter
Oil

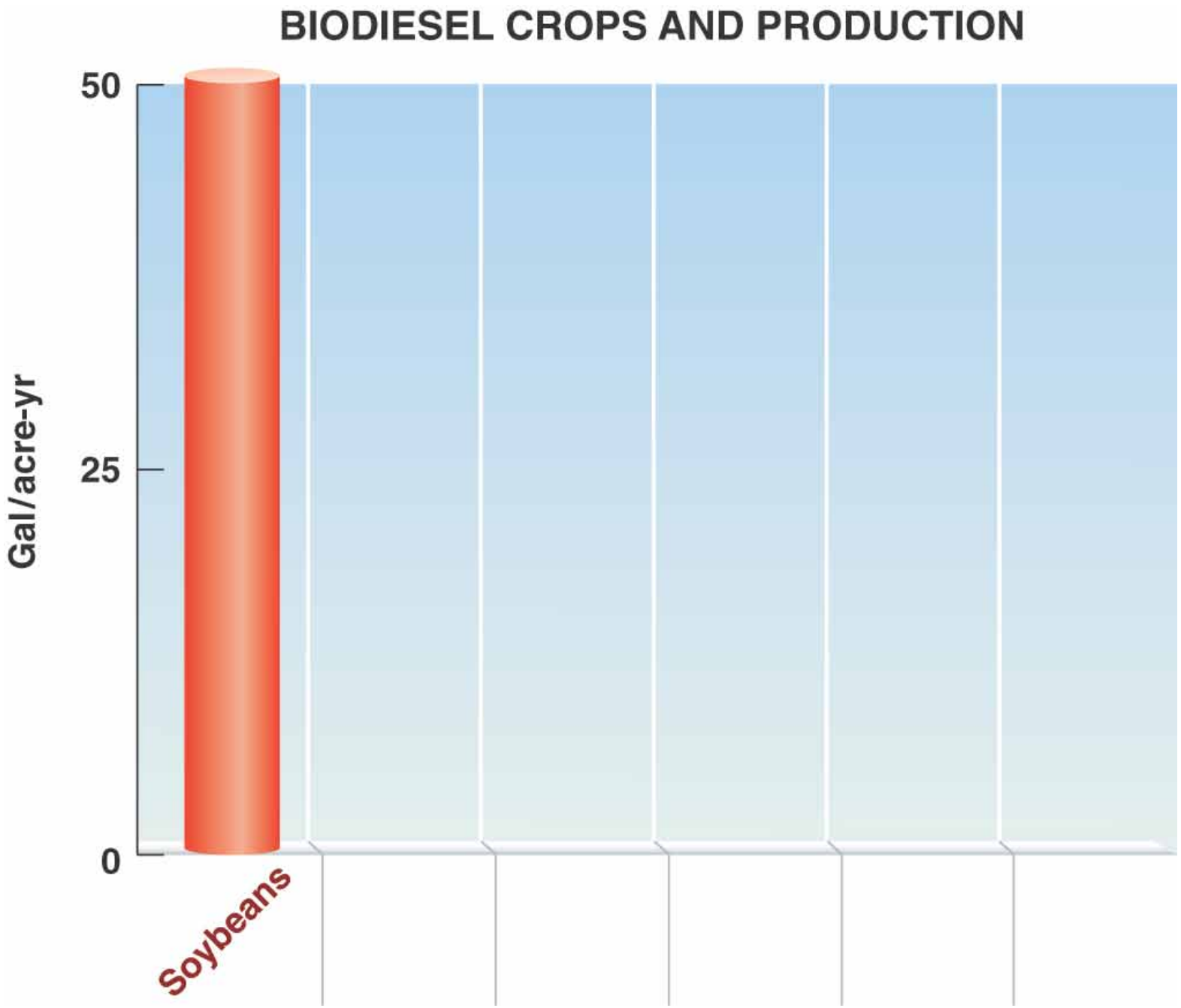

14,500 Liters
Rapeseed
1 Liter
Oil

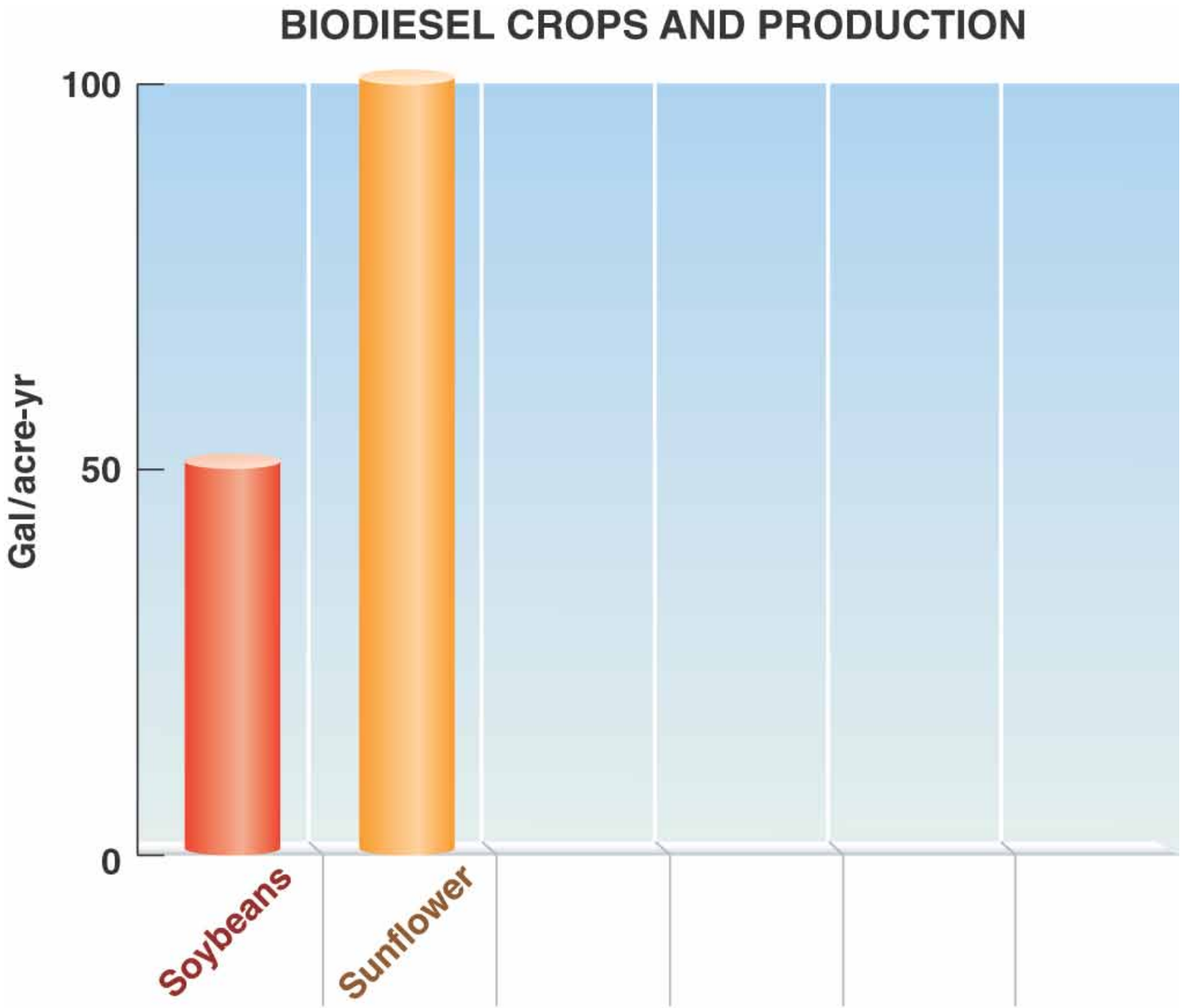

20,000 Liters
Jatropha
1 Liter
Oil

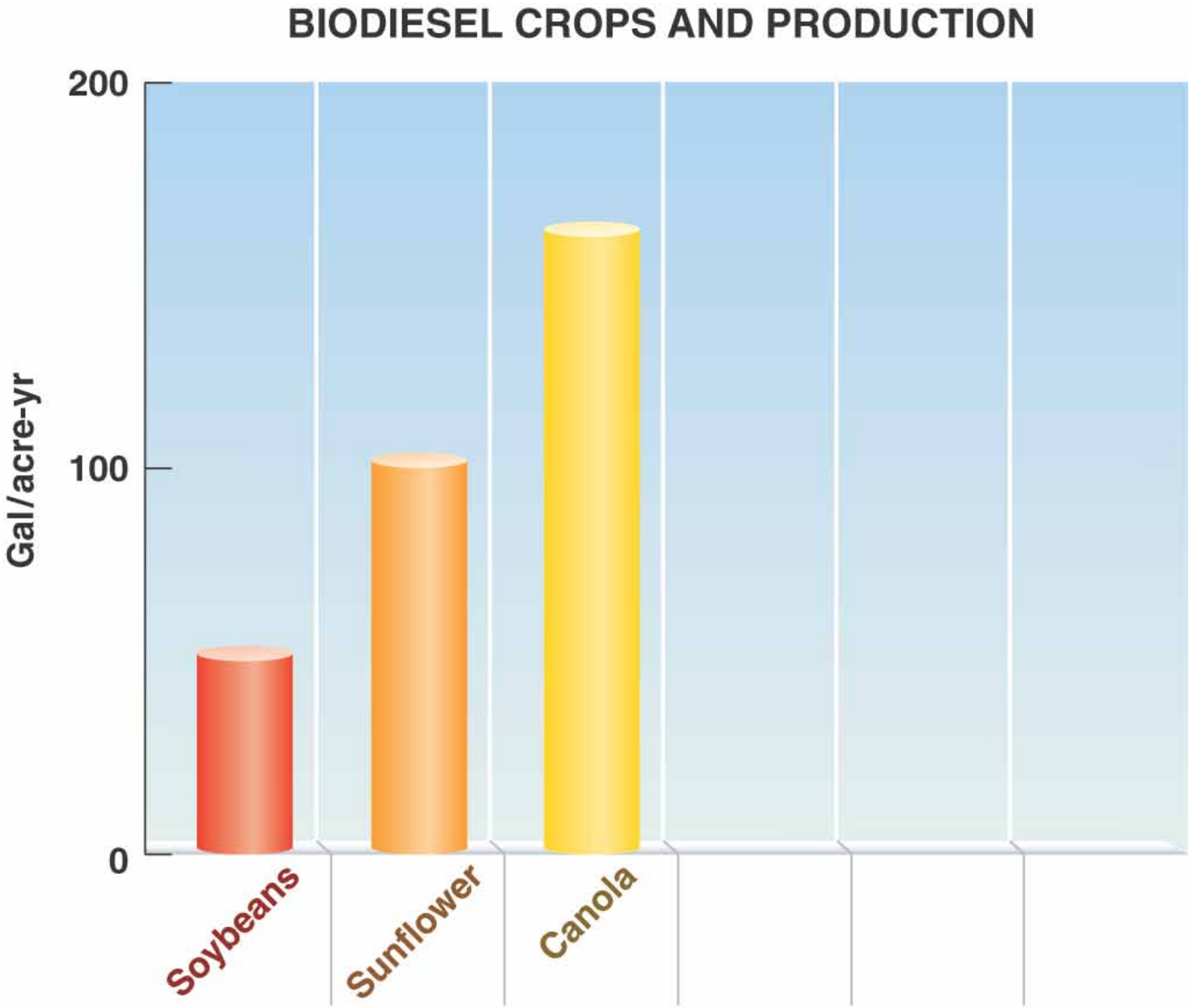
The problem with biodiesel…

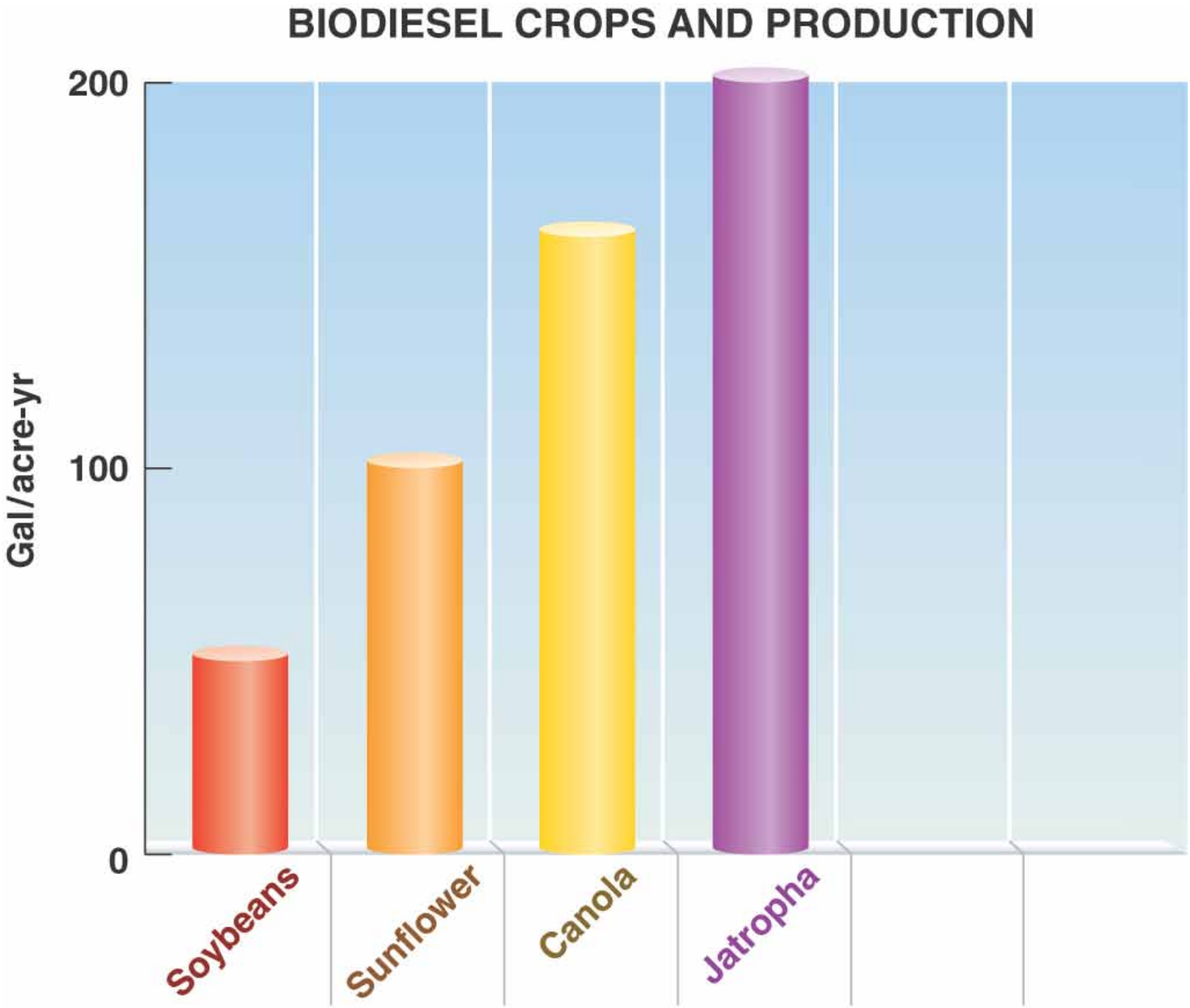
	Wood Residue	Soybeans	Rapeseed, Canola
Product	Ethanol, biodiesel	biodiesel	biodiesel
GHG output*	N/A	49	37
Water	low	HIGH	HIGH
Fertilizer	low	low-med	med
Pesticide	low	med	med
Energy	low	med-low	med-low
US crop land/ half demand	150 -250%	180-240%	30%

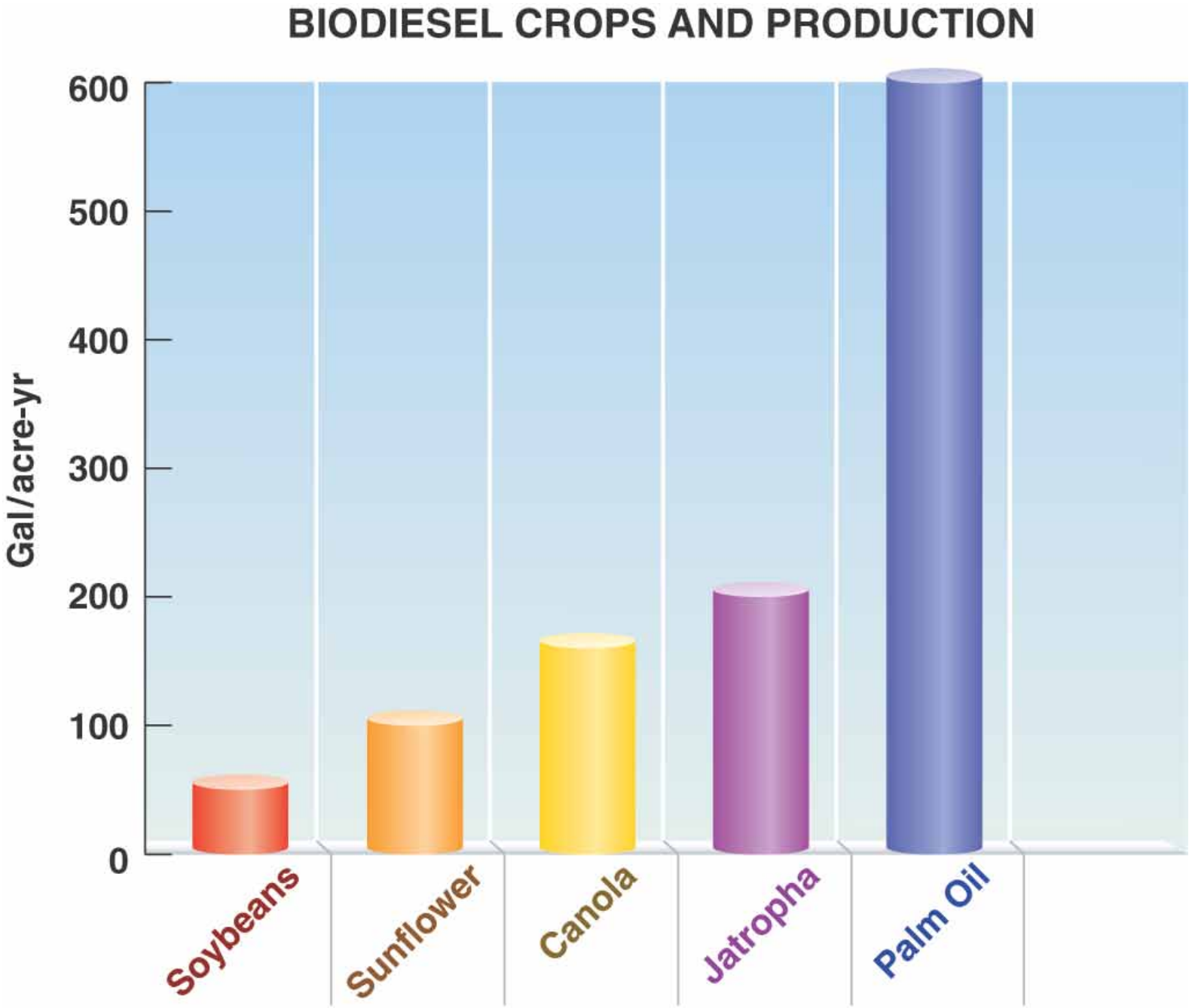
*CO_2 kg/MJ: Growing, harvesting, refining, burning fuel (cf., Diesel=83)

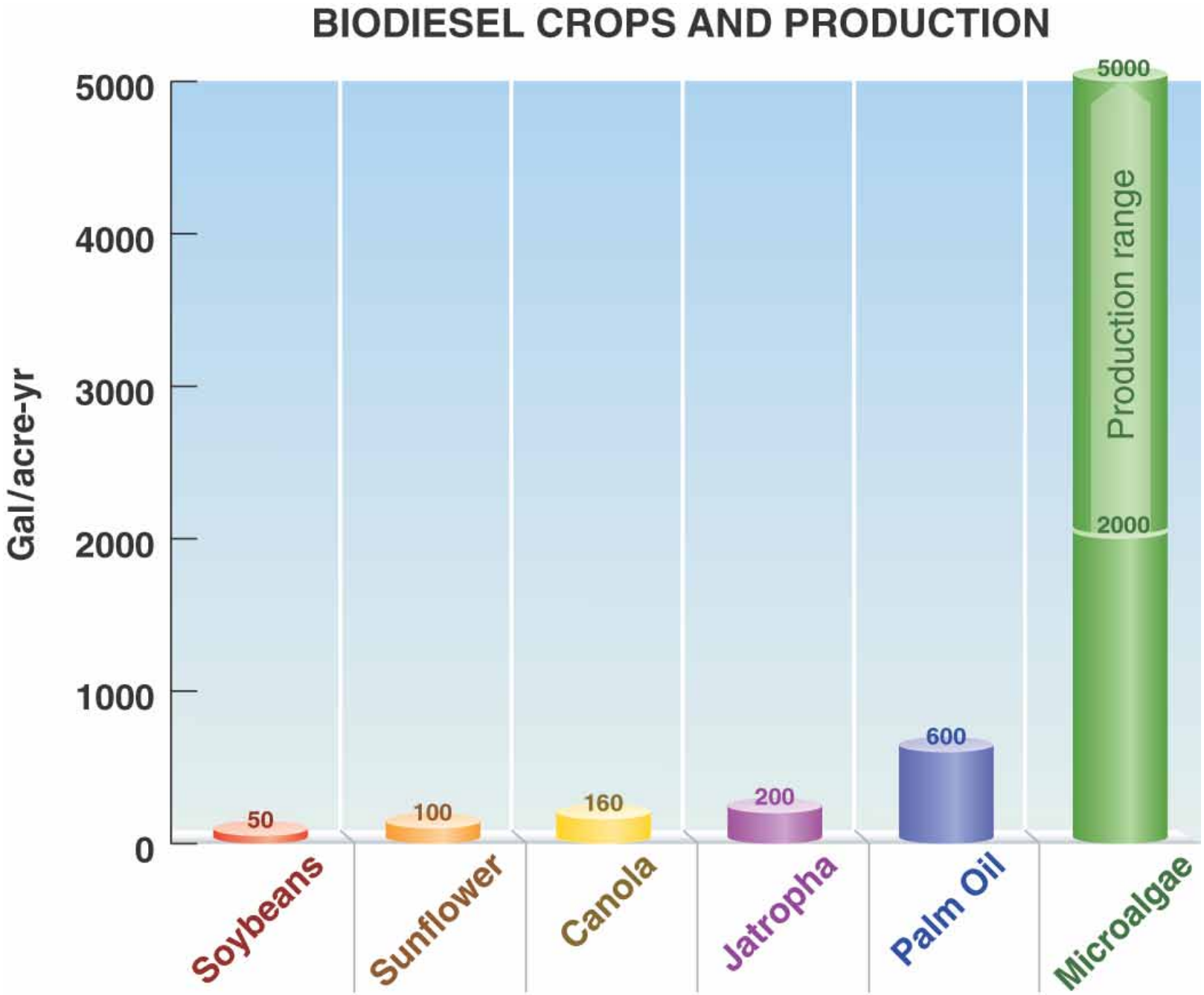

BIODIESEL CROPS AND PRODUCTION
Gal/acre-yr
50
25
0
Soybeans

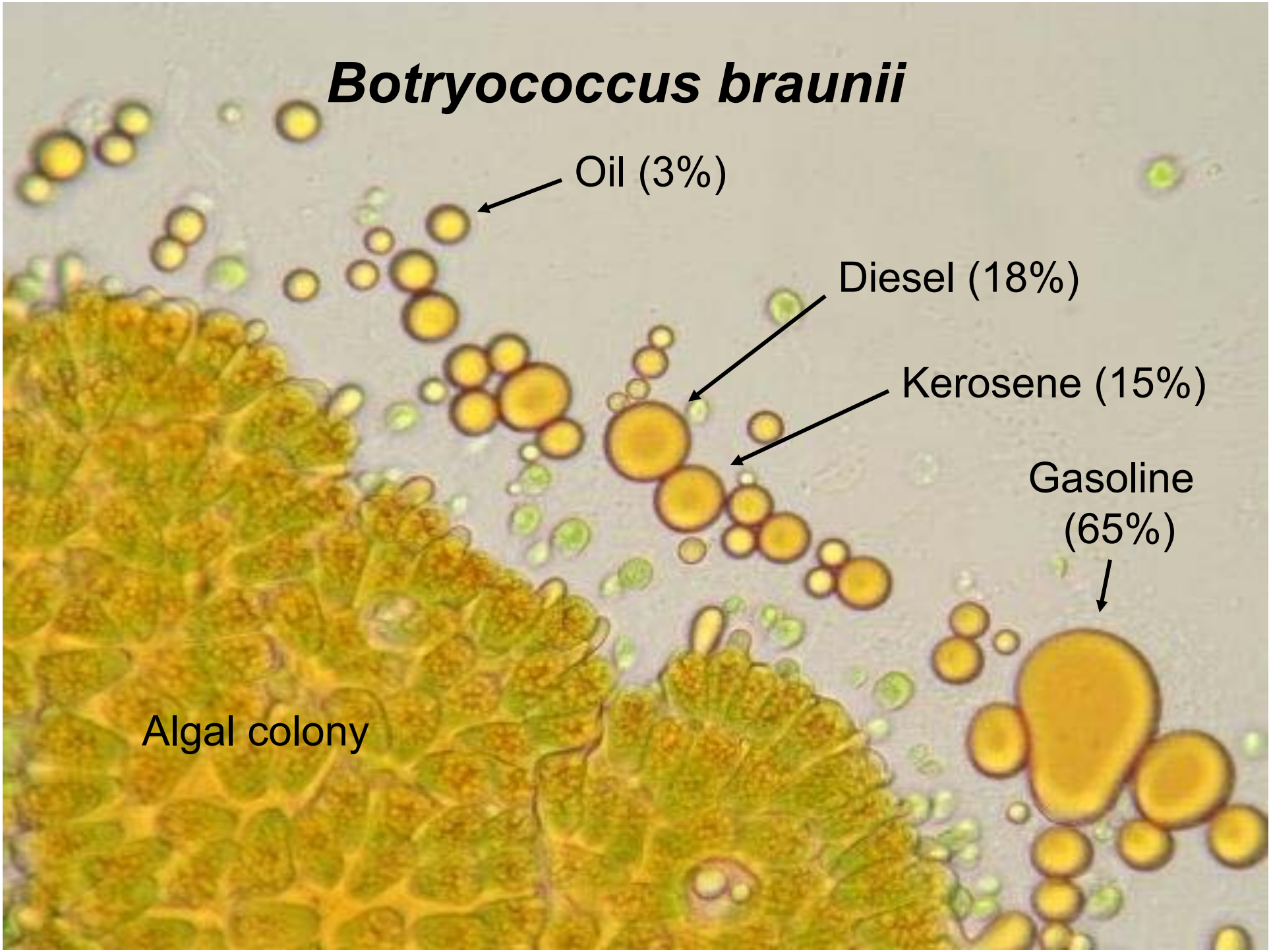

BIODIESEL CROPS AND PRODUCTION
100
50
0
Gal/acre-yr
Soybeans
Sunflower


BIODIESEL CROPS AND PRODUCTION
200
100
0
Gal/acre-yr
Soybeans
Sunflower
Canola


BIODIESEL CROPS AND PRODUCTION
200
100
0
Gal/acre-yr
Soybeans
Sunflower
Canola
Jatropha


BIODIESEL CROPS AND PRODUCTION
Gal/acre-yr
600
500
400
300
200
100
0
Soybeans
Sunflower
Canola
Jatropha
Palm Oil


BIODIESEL CROPS AND PRODUCTION
Gal/acre-yr
5000
4000
3000
2000
1000
0
50
100
160
200
600
5000
2000
Production range
Soybeans
Sunflower
Canola
Jatropha
Palm Oil
Microalgae

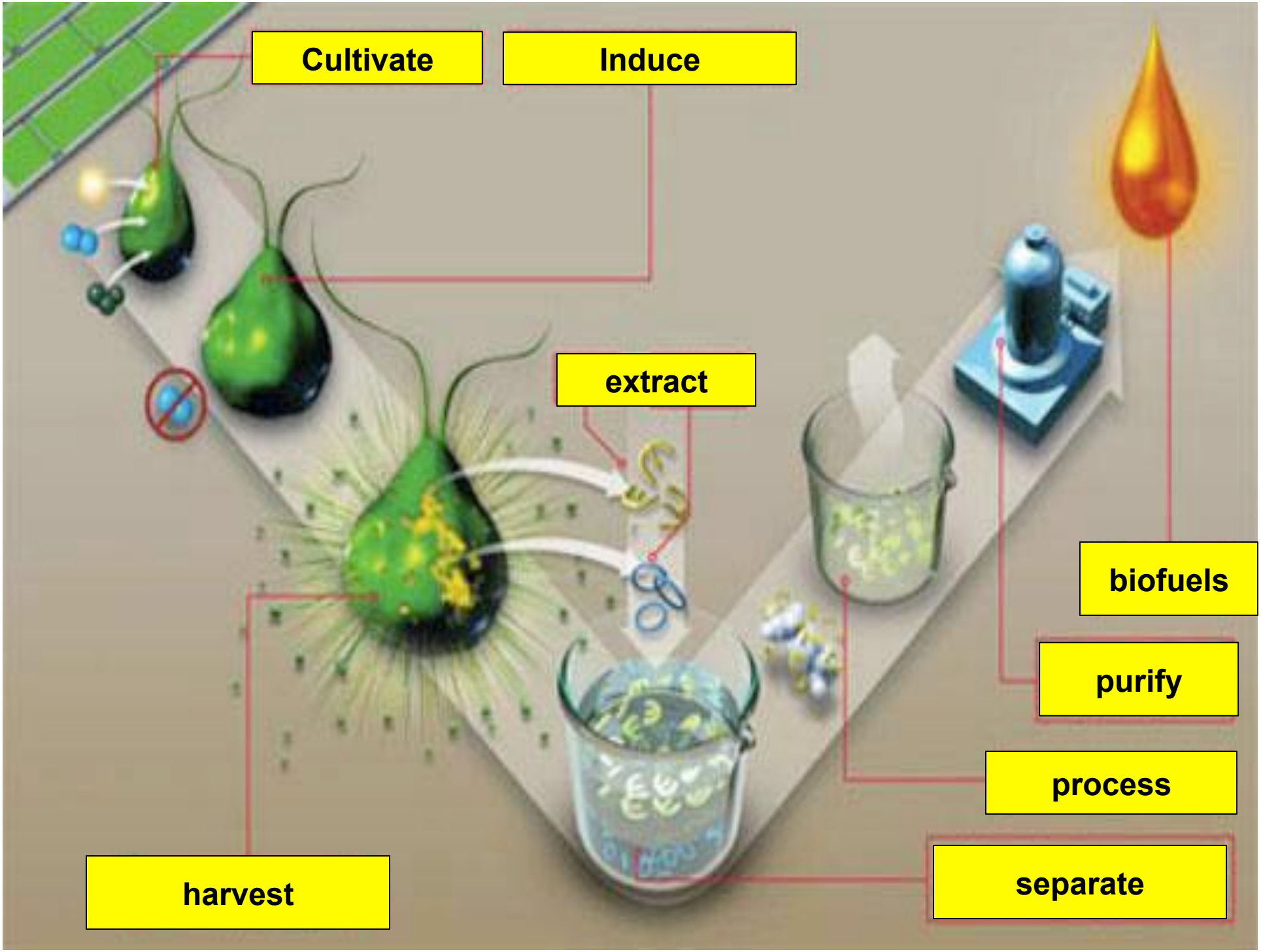

Botryococcus braunii
Oil (3%)
Diesel (18%)
Kerosene (15%)
Gasoline (65%)
Algal colony


CANADA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
PENNSYLVANIA
NEW YORK
MAINE
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
THE BAHAMAS
MEXICO
HAWAII
ALASKA
ARCTIC OCEAN
BERING SEA

Biodiesel crops and production:

Plant	**Gal/acre-yr**	**Barrels/yr**
Soybeans	50	>10,000,000
Sunflower	100	> 1,000,000
Canola	160	>10,000,000
Jatropha	200?	some, not much
Palm Oil	600	>10,000,000
Microalgae	2,000 to 5,000	~0.1

from: Benemann 2009. Algae Biomass Summit


Cultivate
Induce
extract
biofuels
purify
process
separate
harvest

Algae cultivation systems on land…

Open circulating ponds (raceways)

Closed bioreactors

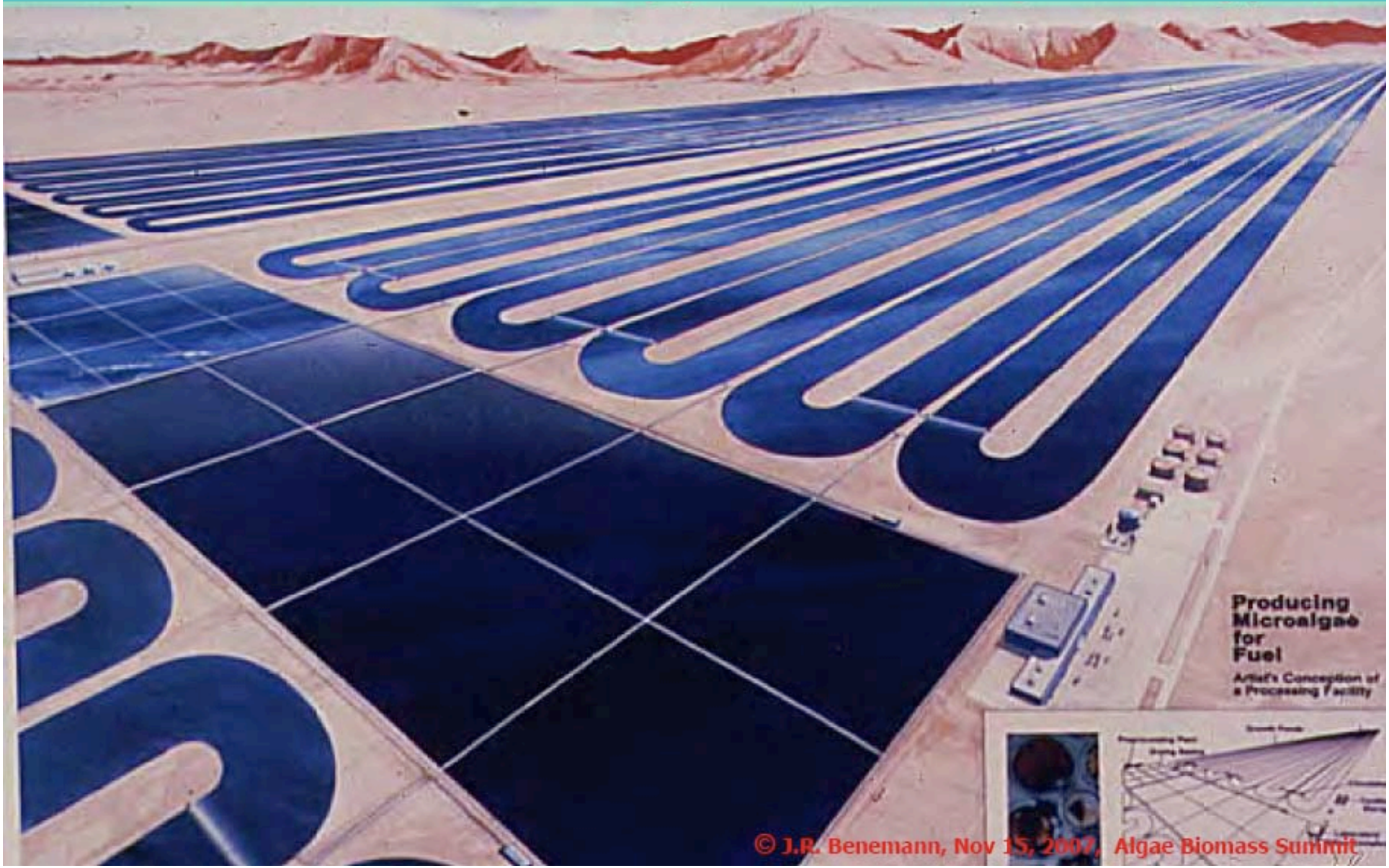
Cyanotech, HI

Yaeyama, Japan

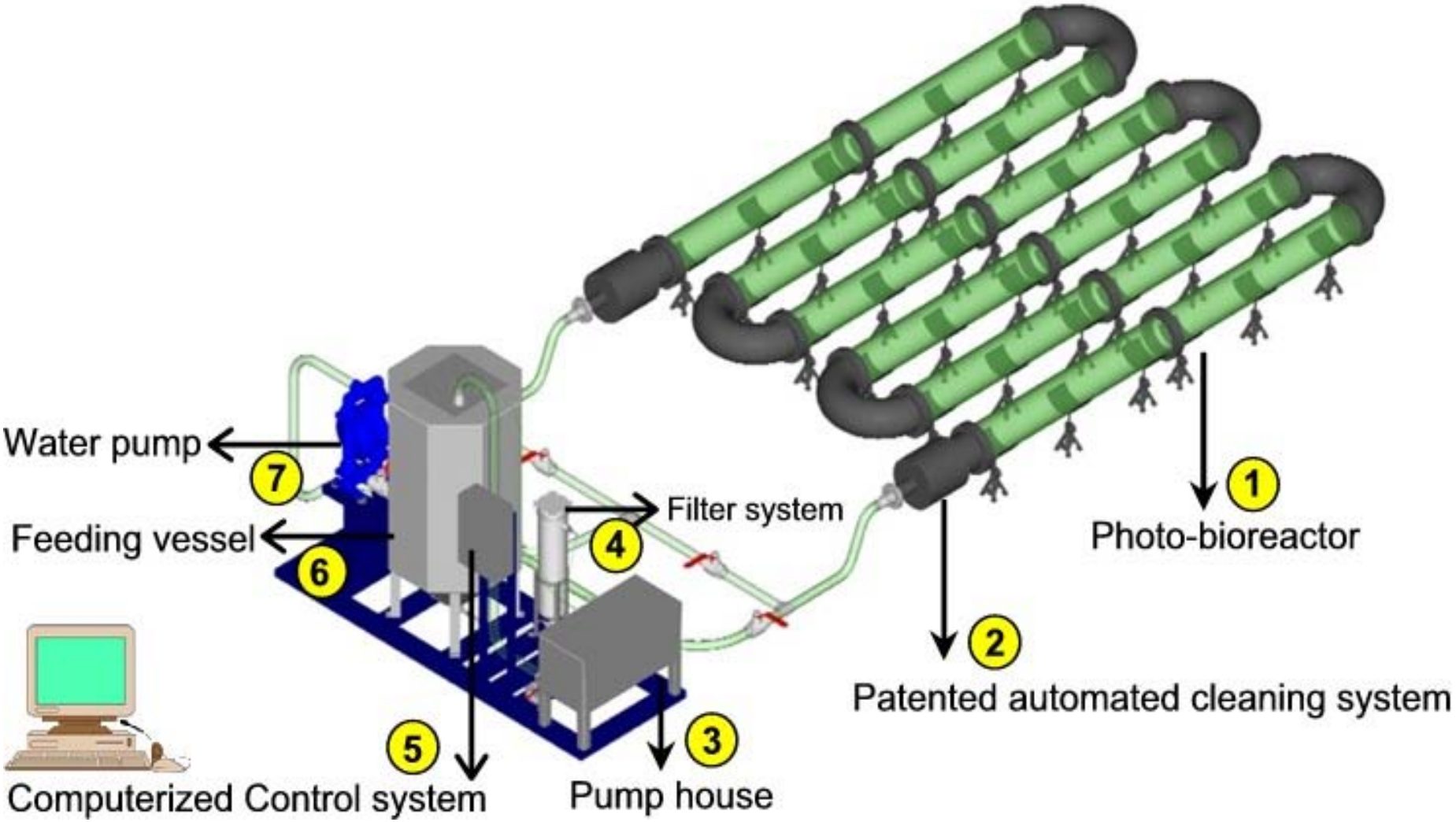
Aquacarotene, Australia

NBT/Seambiotics, Israel

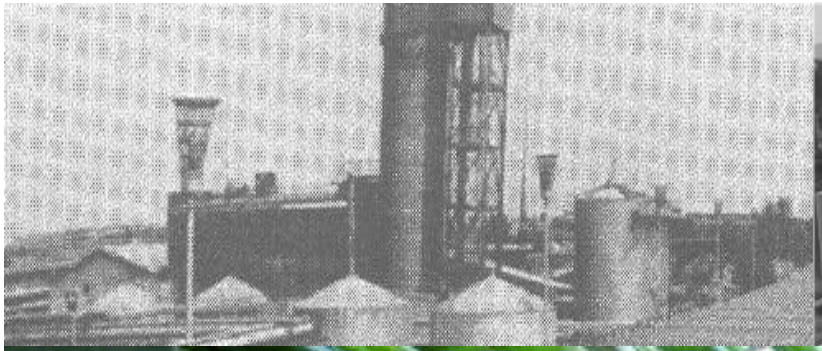
What's wrong with this picture?



Bioreactor



Algal Bioreactor




www.bioenergy-noe.org
Vertigro Energy, Texas
Subitec, Germany
NovaGreen, Germany
www.nerc.ac.uk

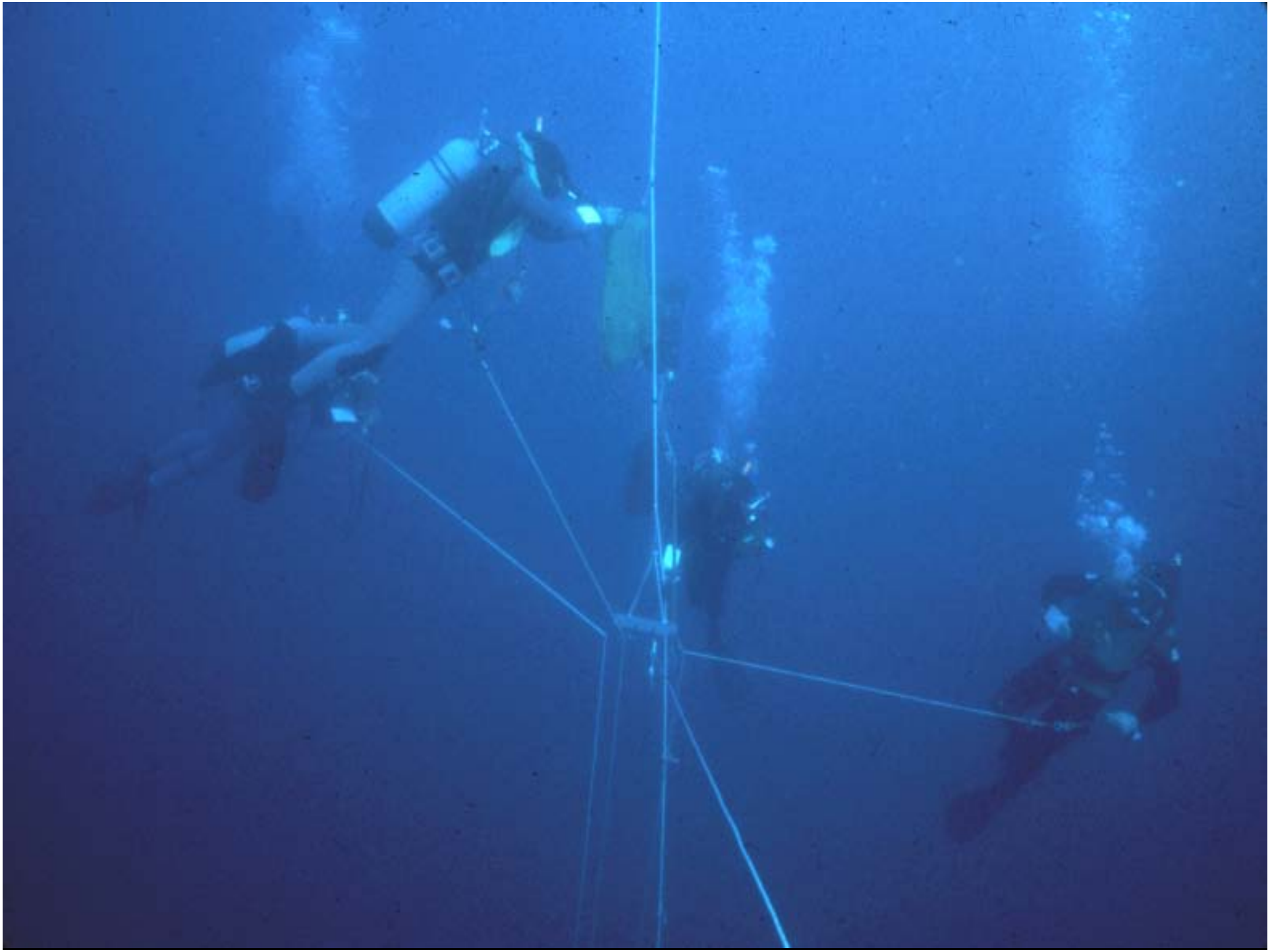
What's wrong with this picture?

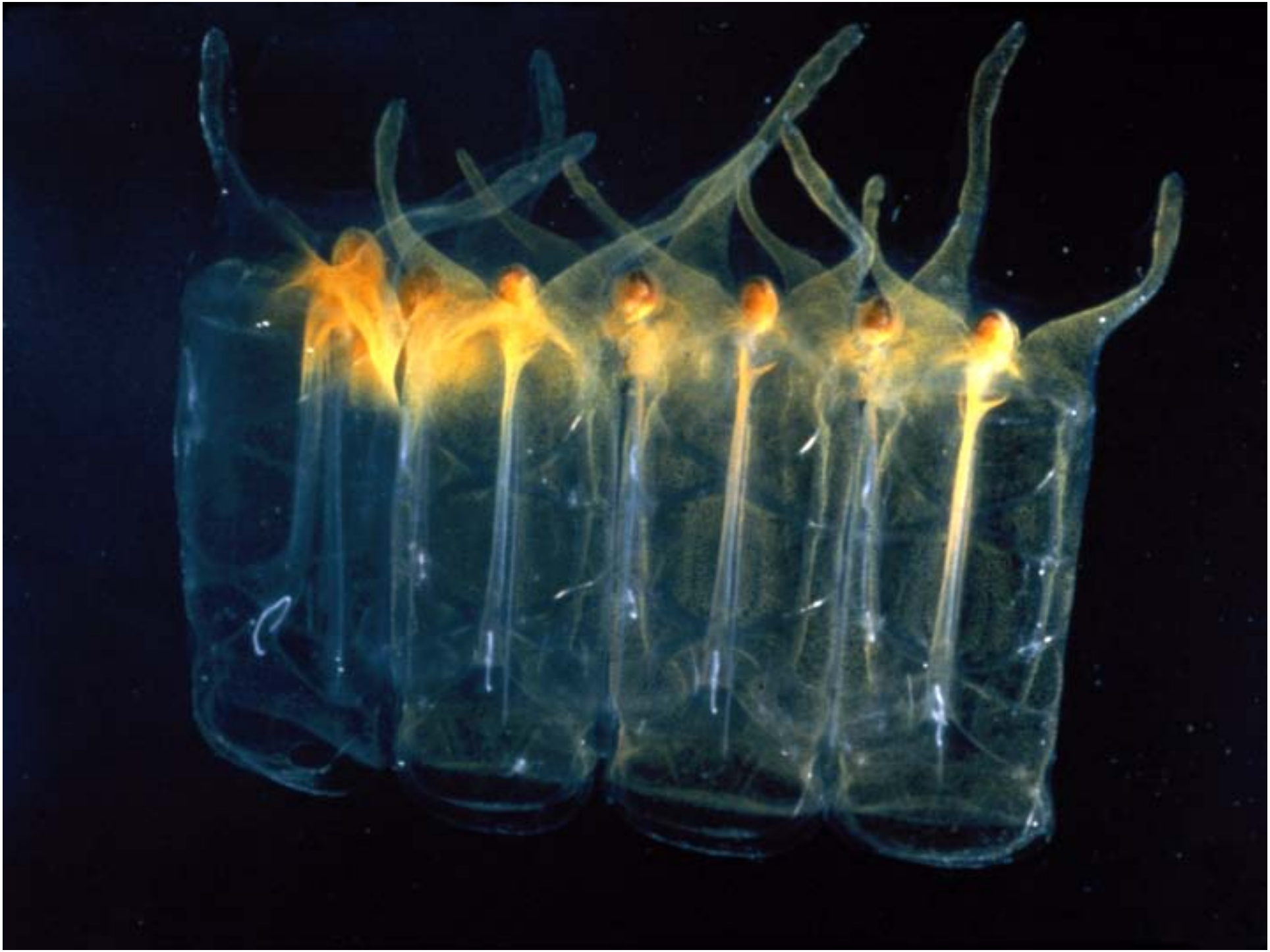
There are challenges growing algae on land…

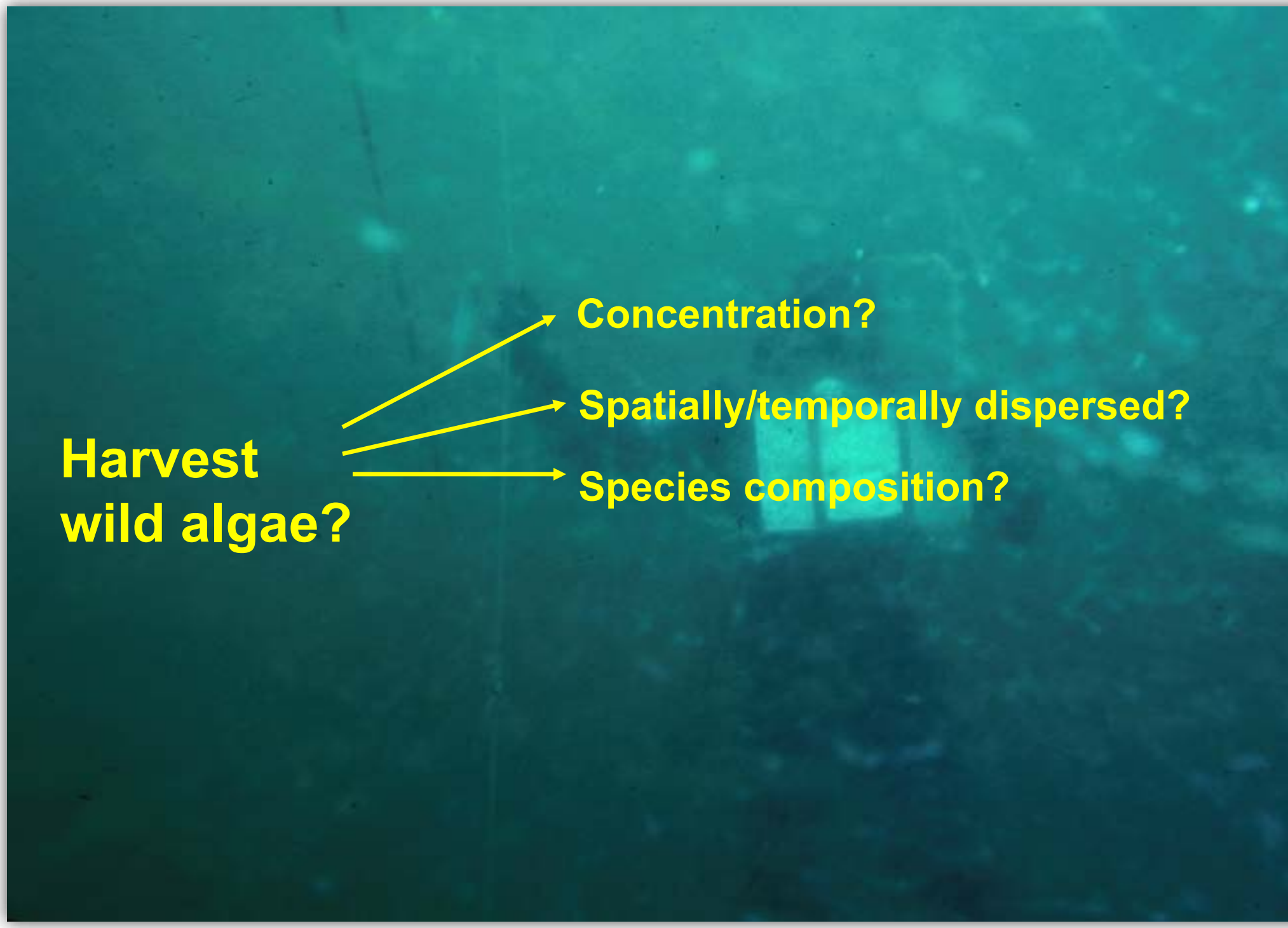
1: Open circulating ponds (raceways)

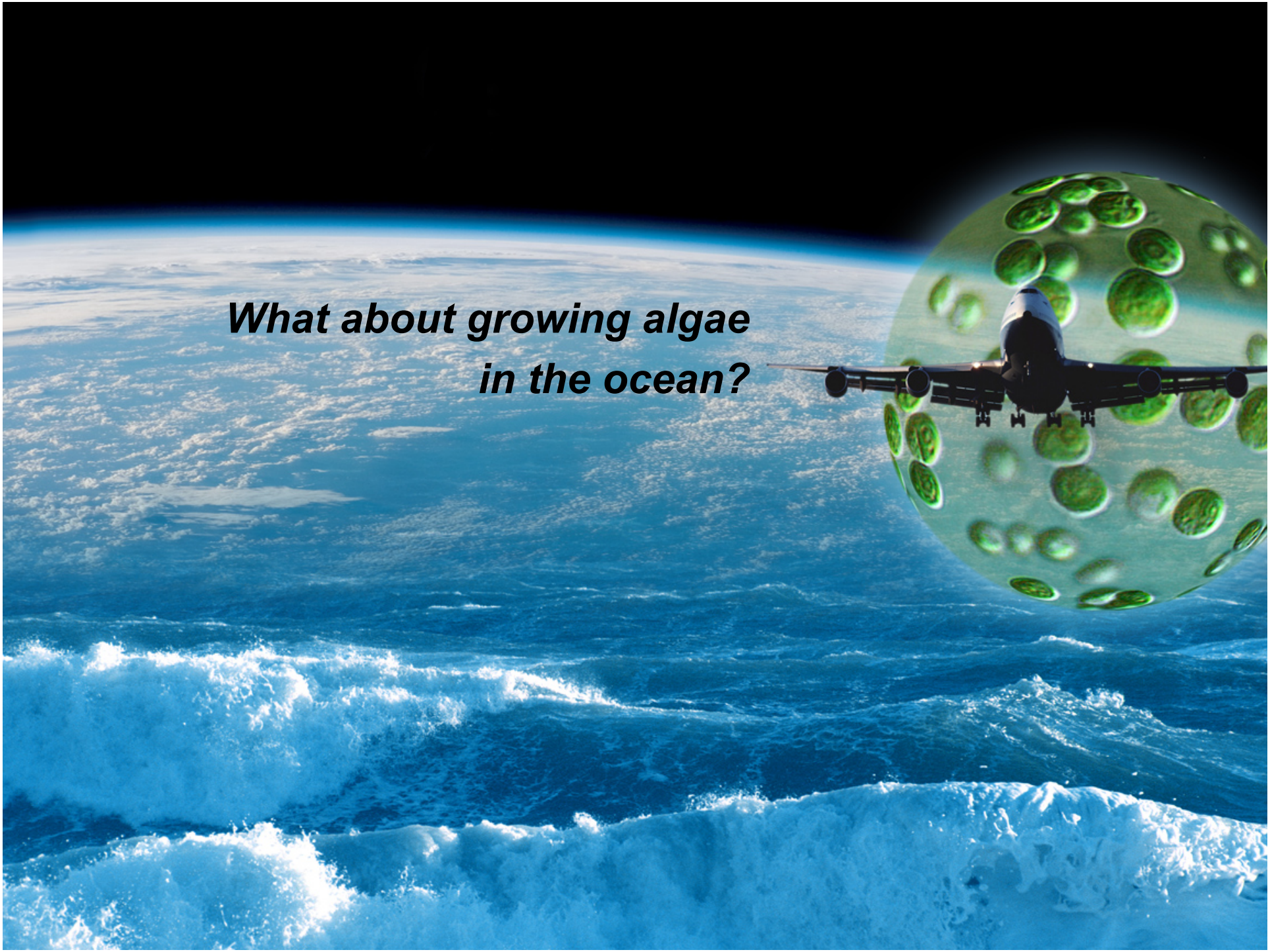
2: Closed photobioreactors (PBRs)


What about collecting algae
from the ocean?

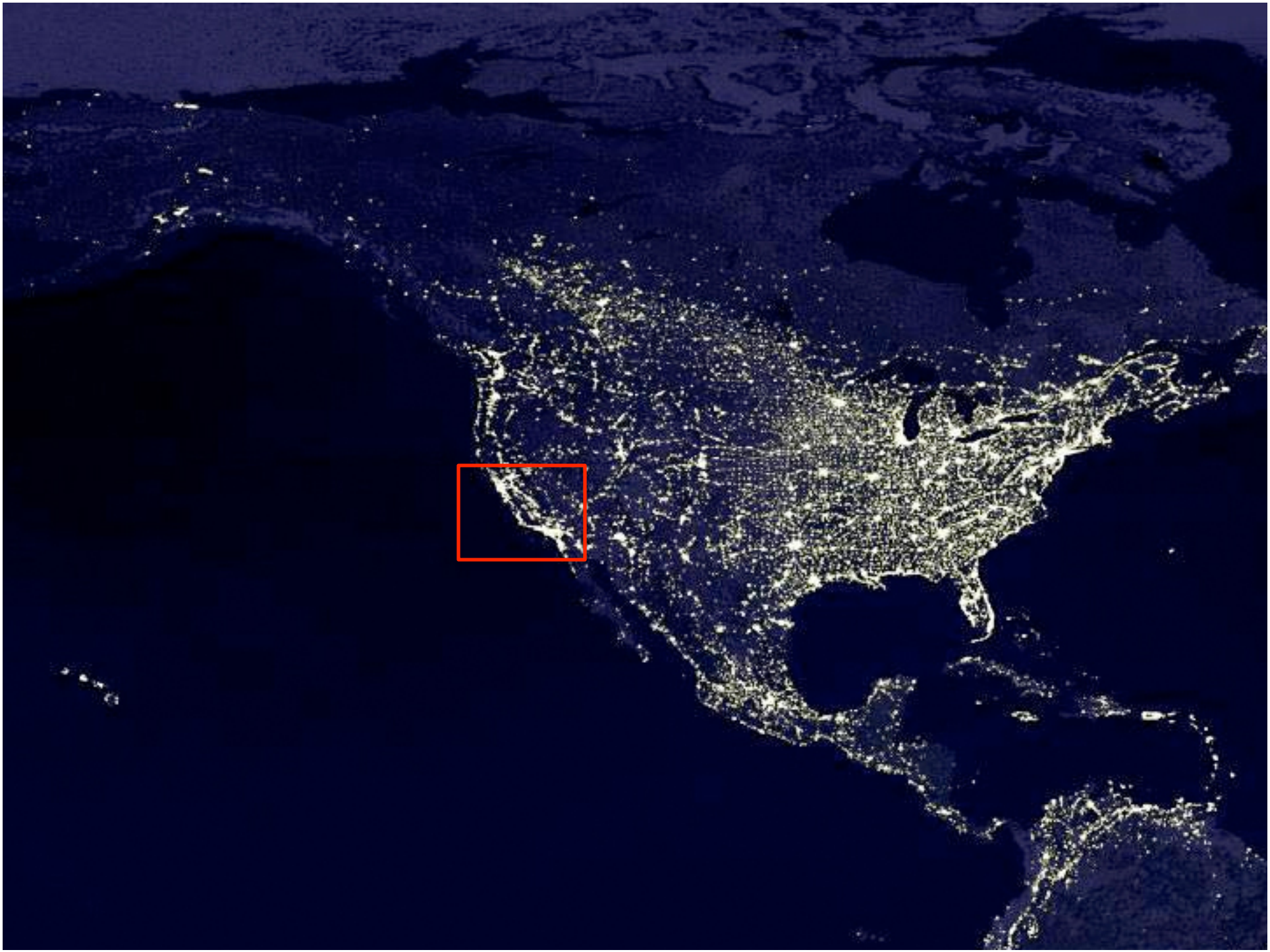


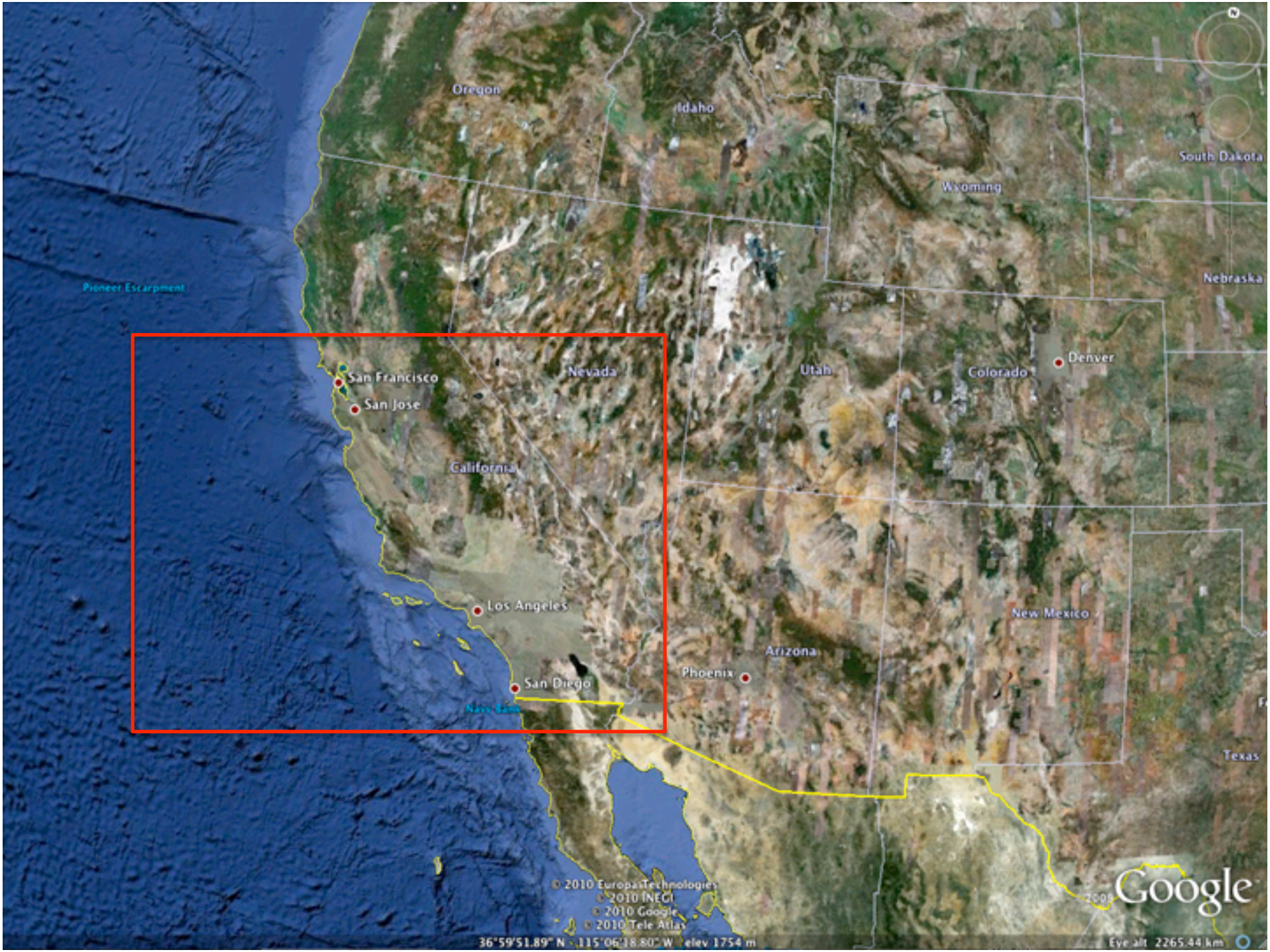


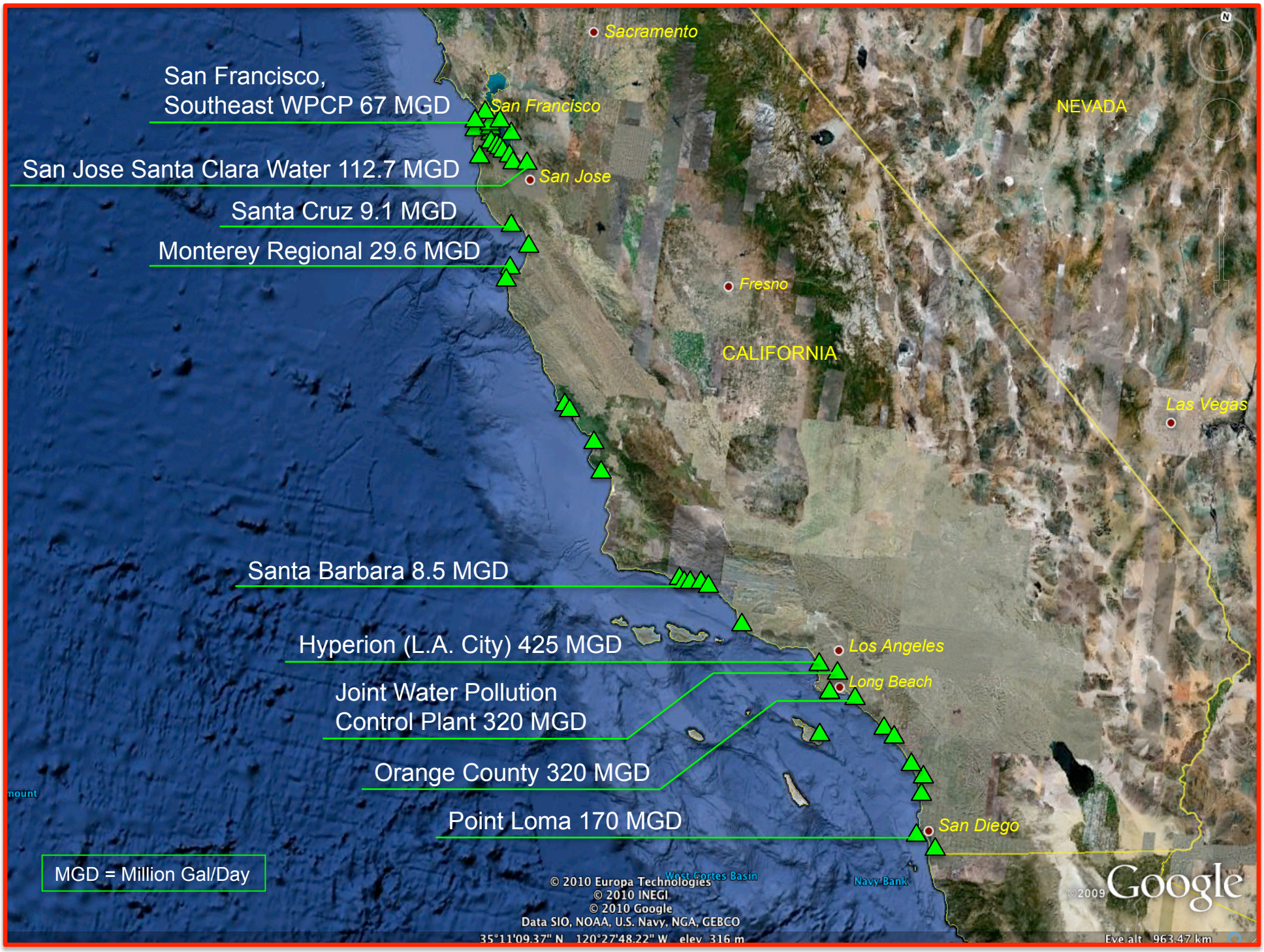

Harvest
wild algae?
Concentration?
Spatially/temporally dispersed?
Species composition?

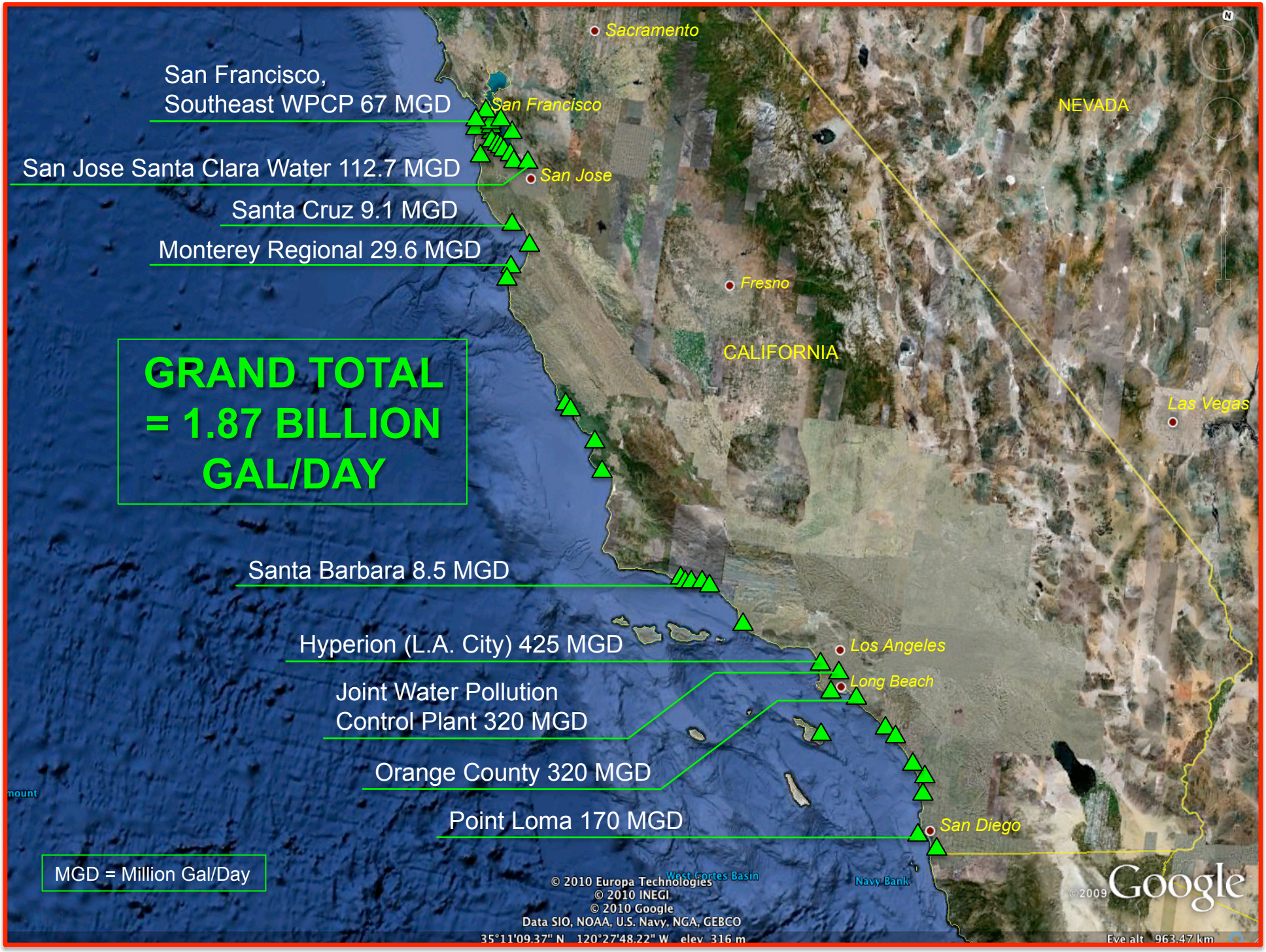

What about growing algae
in the ocean?


O ffshore
M embrane
E nclosures for
G rowing
A lgae




Oregon
Idaho
South Dakota
Wyoming
Nebraska
Pioneer Escarpment
Nevada
Utah
Colorado
Denver
San Francisco
San Jose
California
Los Angeles
New Mexico
Arizona
Phoenix
San Diego
Texas
© 2010 EuropaTechnologies
© 2010 INEGI
© 2010 Google
© 2010 Tele Atlas
Google
Eye alt 2265.44 km


Sacramento
San Francisco, Southeast WPCP 67 MGD
San Francisco
NEVADA
San Jose Santa Clara Water 112.7 MGD
San Jose
Santa Cruz 9.1 MGD
Monterey Regional 29.6 MGD
Fresno
CALIFORNIA
Las Vegas
Santa Barbara 8.5 MGD
Hyperion (L.A. City) 425 MGD
Los Angeles
Long Beach
Joint Water Pollution Control Plant 320 MGD
Orange County 320 MGD
Point Loma 170 MGD
San Diego
MGD = Million Gal/Day
West Cortes Basin
Navy Bank
© 2010 Europa Technologies
© 2010 INEGI
© 2010 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
35°11'09.37" N 120°27'48.22" W elev 316 m
©2009 Google
Eye alt 963.47 km


Sacramento
San Francisco, Southeast WPCP 67 MGD
San Francisco
NEVADA
San Jose Santa Clara Water 112.7 MGD
San Jose
Santa Cruz 9.1 MGD
Monterey Regional 29.6 MGD
Fresno
CALIFORNIA
GRAND TOTAL = 1.87 BILLION GAL/DAY
Las Vegas
Santa Barbara 8.5 MGD
Hyperion (L.A. City) 425 MGD
Los Angeles
Long Beach
Joint Water Pollution Control Plant 320 MGD
Orange County 320 MGD
Point Loma 170 MGD
San Diego
MGD = Million Gal/Day
West Cortes Basin
Navy Bank
© 2010 Europa Technologies
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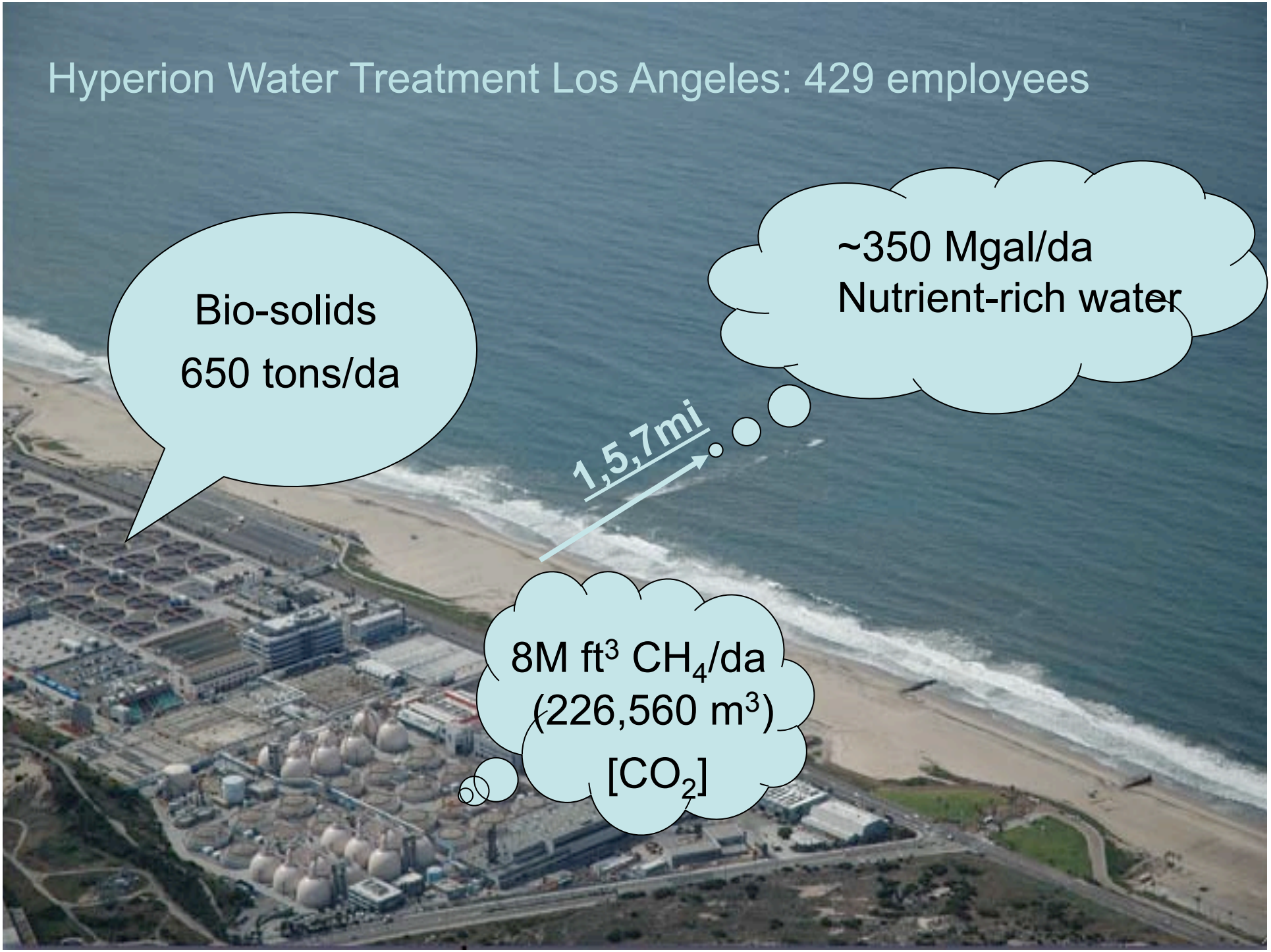
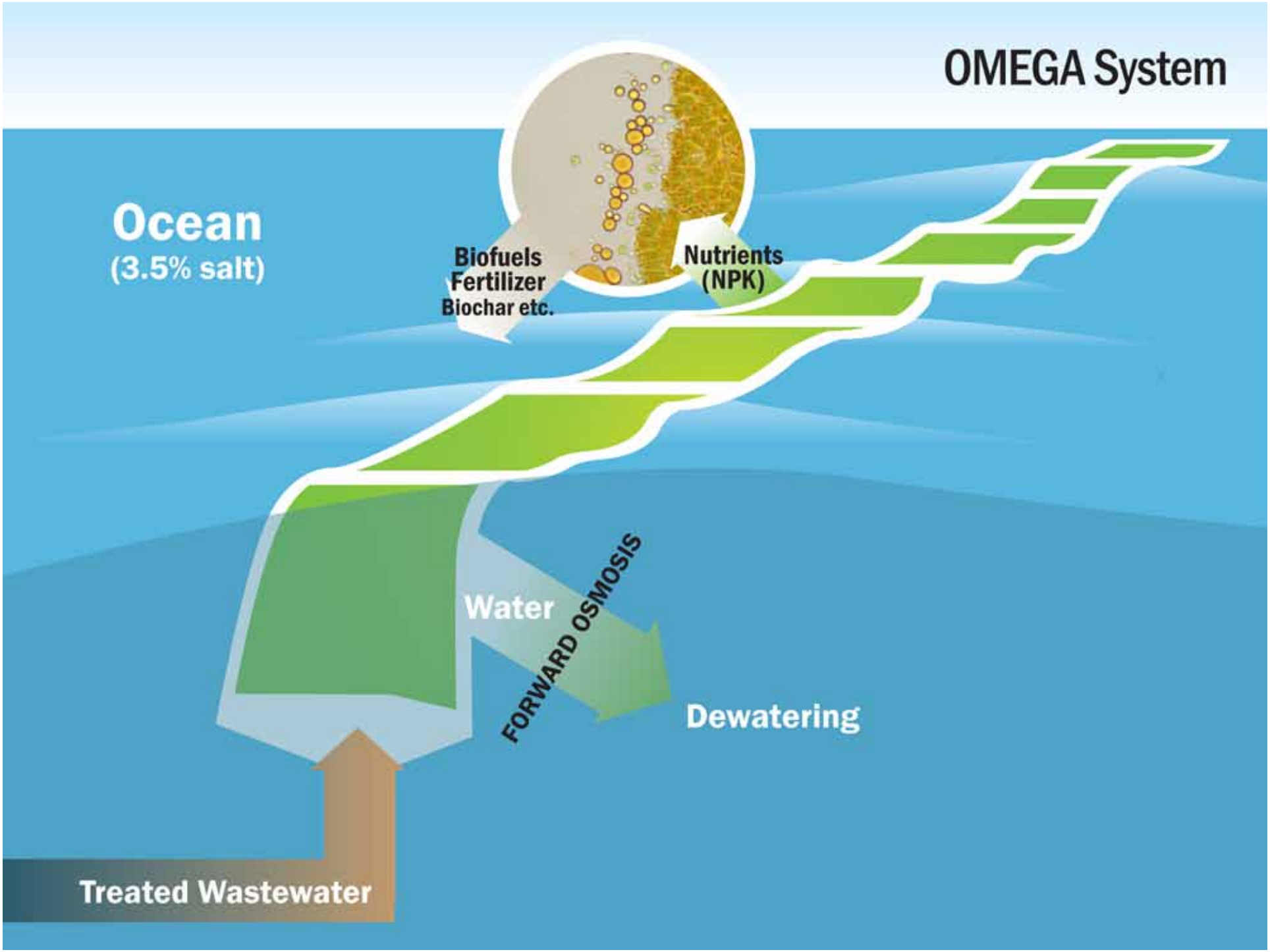
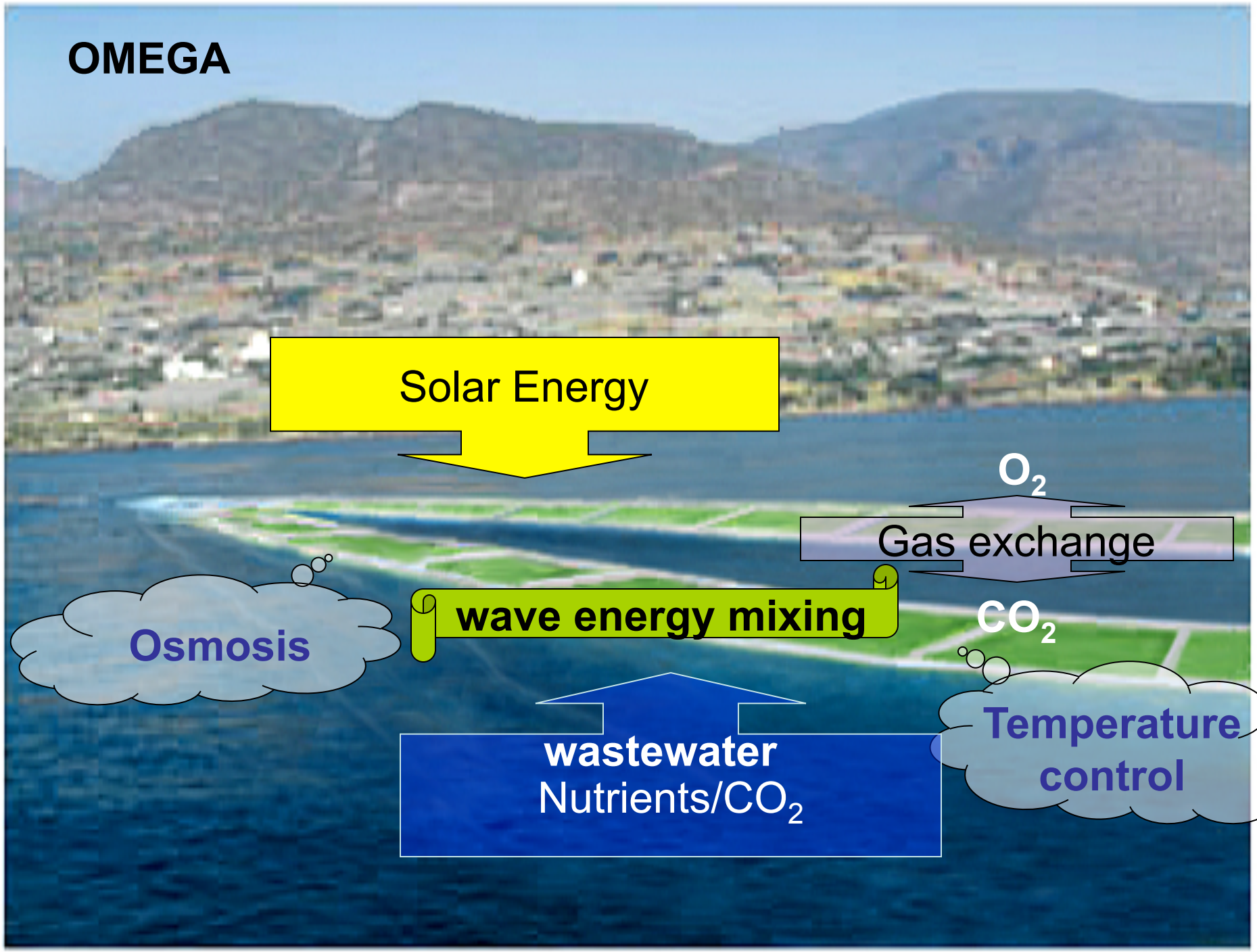
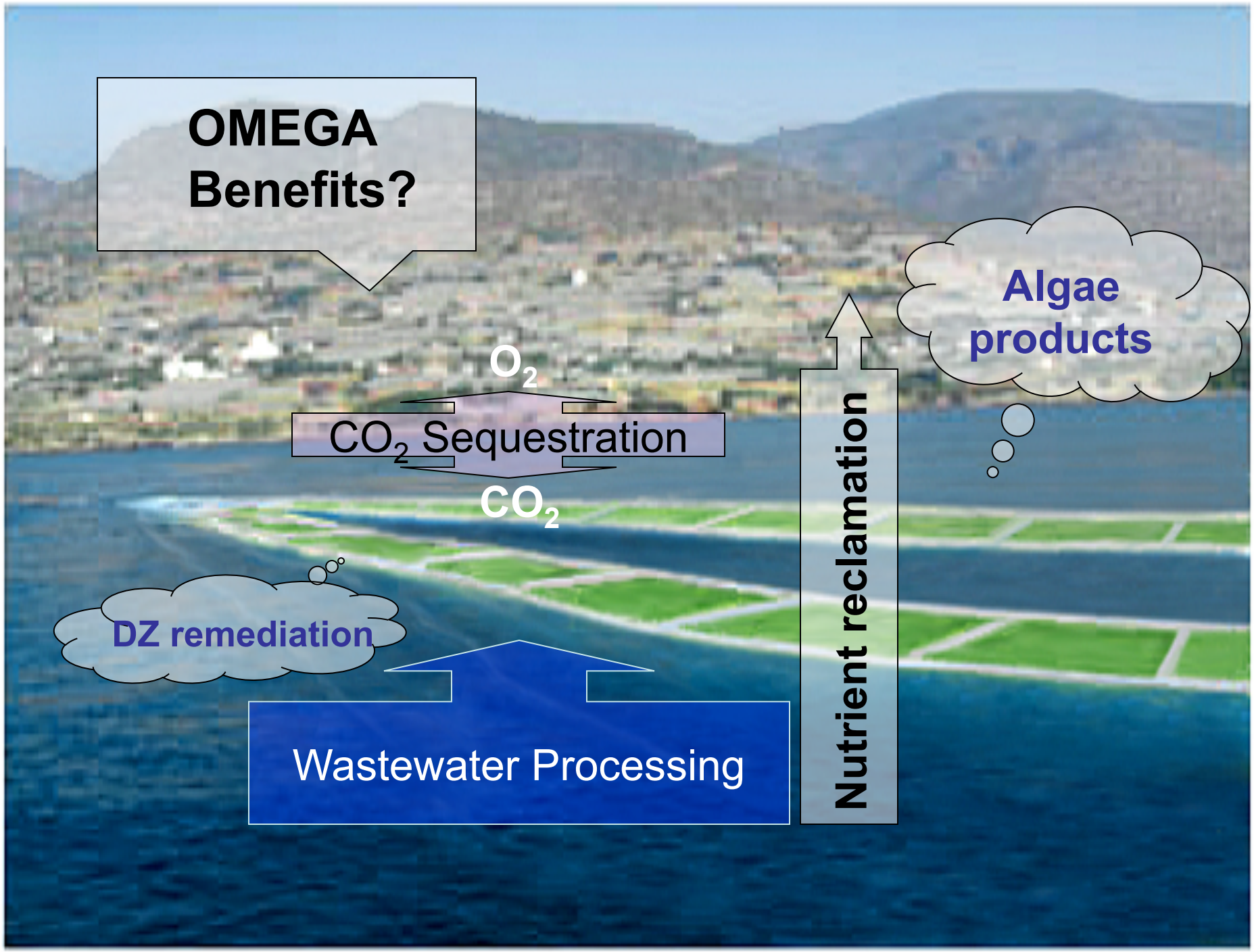
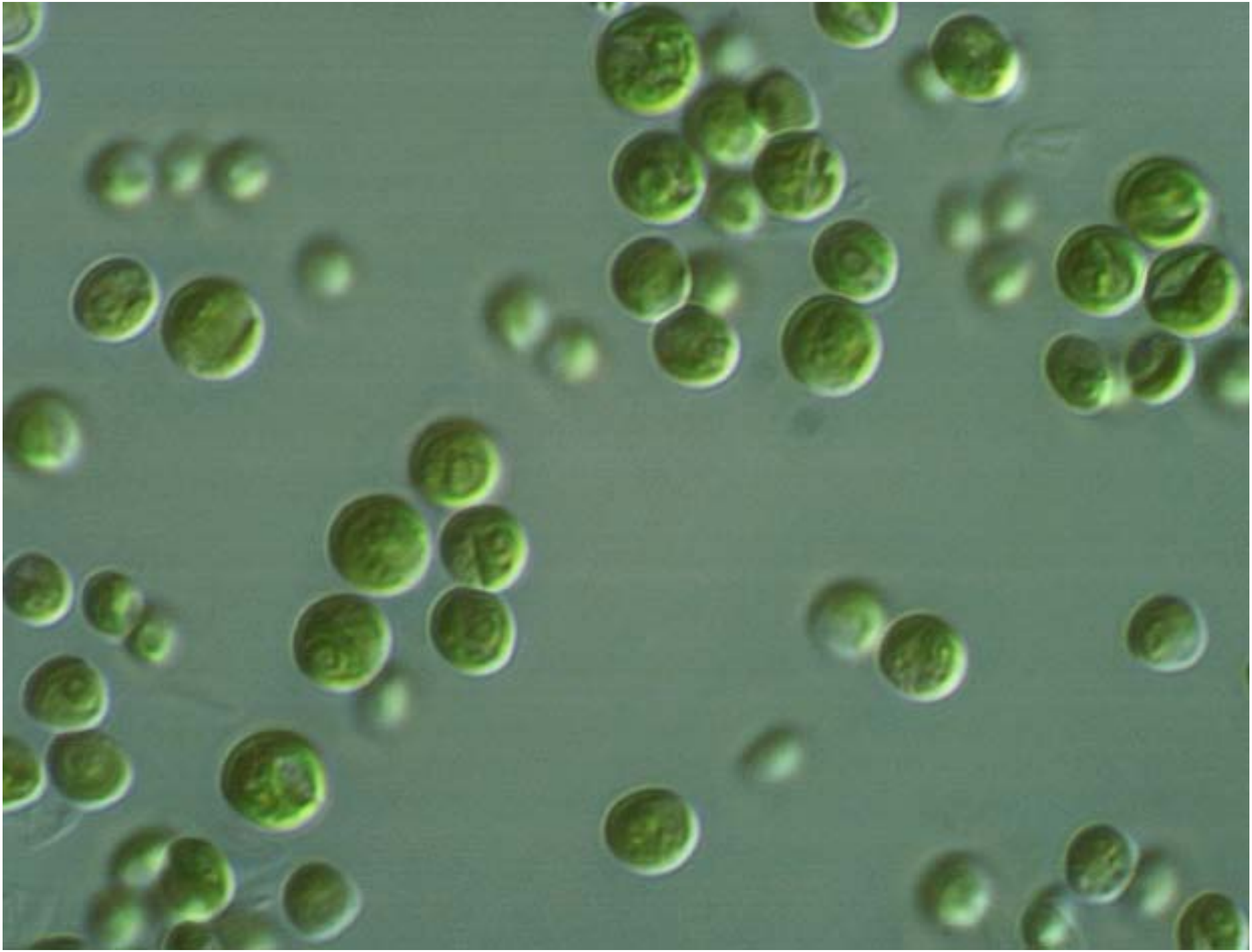
© 2010 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
35°11'09.37" N 120°27'48.22" W elev 316 m
©2009 Google
Eye alt 963.47 km

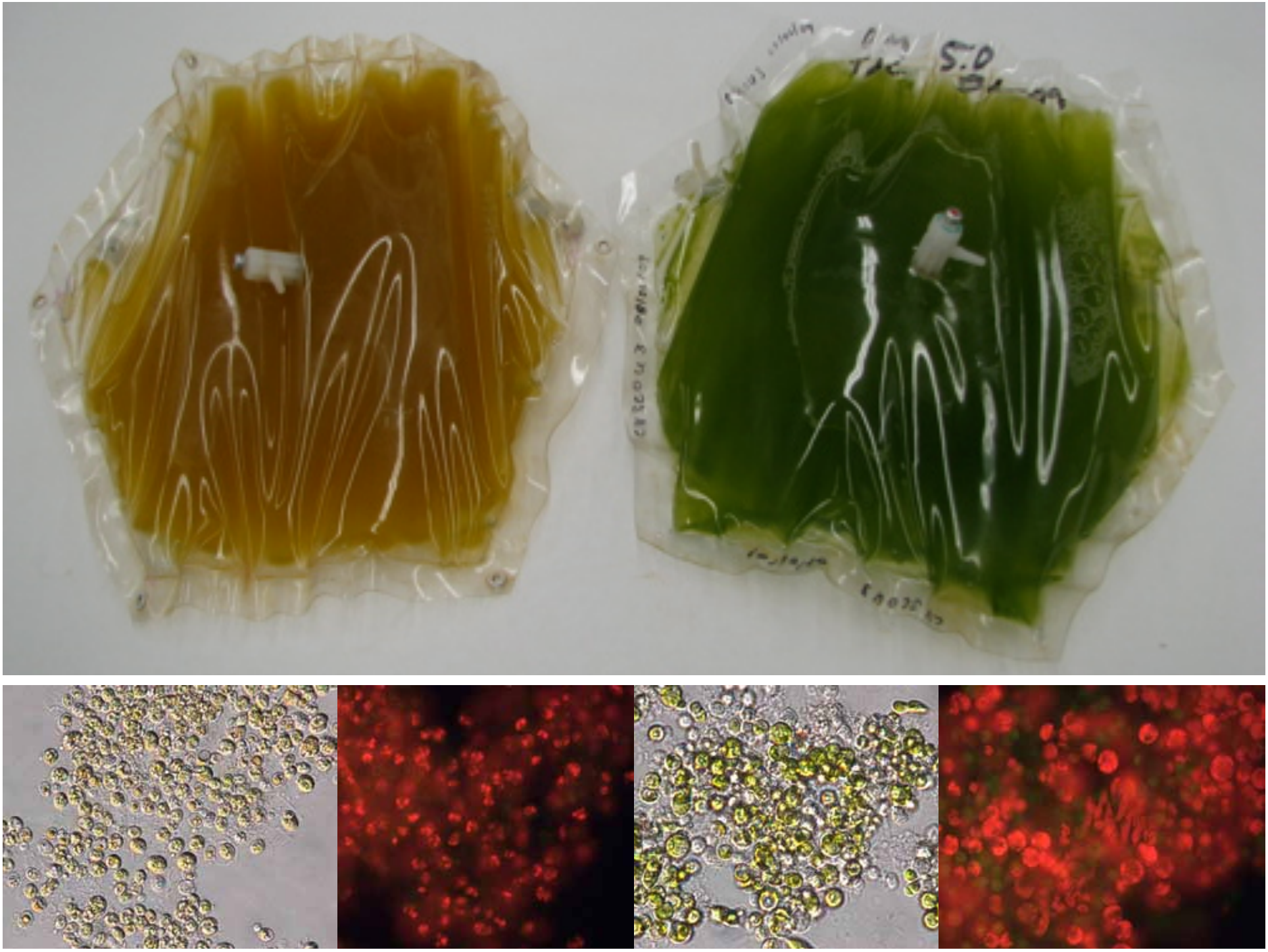

Hyperion Water Treatment Los Angeles: 429 employees
Bio-solids
650 tons/da
~350 Mgal/da
Nutrient-rich water
1,5,7mi
8M ft³ CH₄/da
(226,560 m³)
[CO₂]


OMEGA System
Ocean
(3.5% salt)
Biofuels
Fertilizer
Biochar etc.
Nutrients
(NPK)
Water
FORWARD OSMOSIS
Dewatering
Treated Wastewater

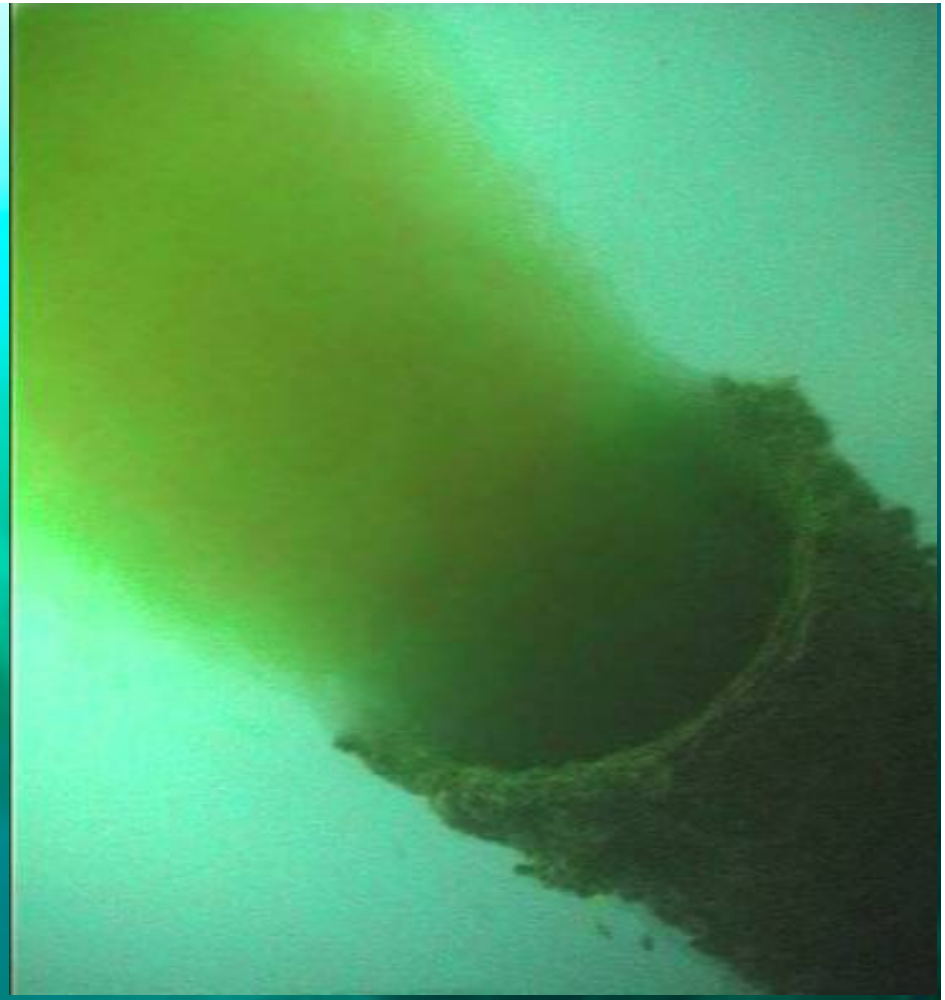

OMEGA
Solar Energy
O_2
Gas exchange
wave energy mixing
CO_2
Osmosis
wastewater
Nutrients/CO_2
Temperature control

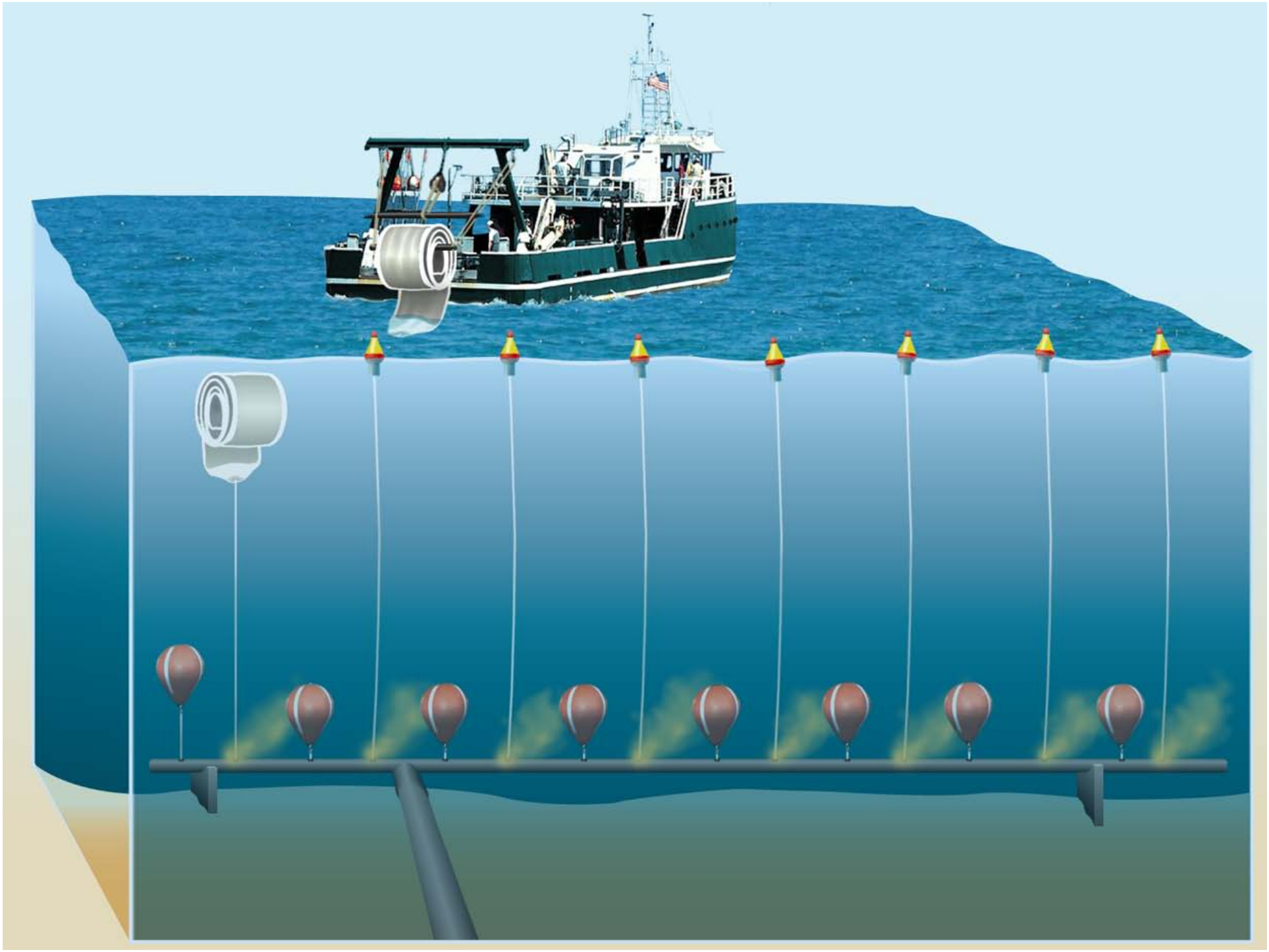

OMEGA Benefits?
Algae products
O_2
CO_2 Sequestration
CO_2
Nutrient reclamation
DZ remediation
Wastewater Processing

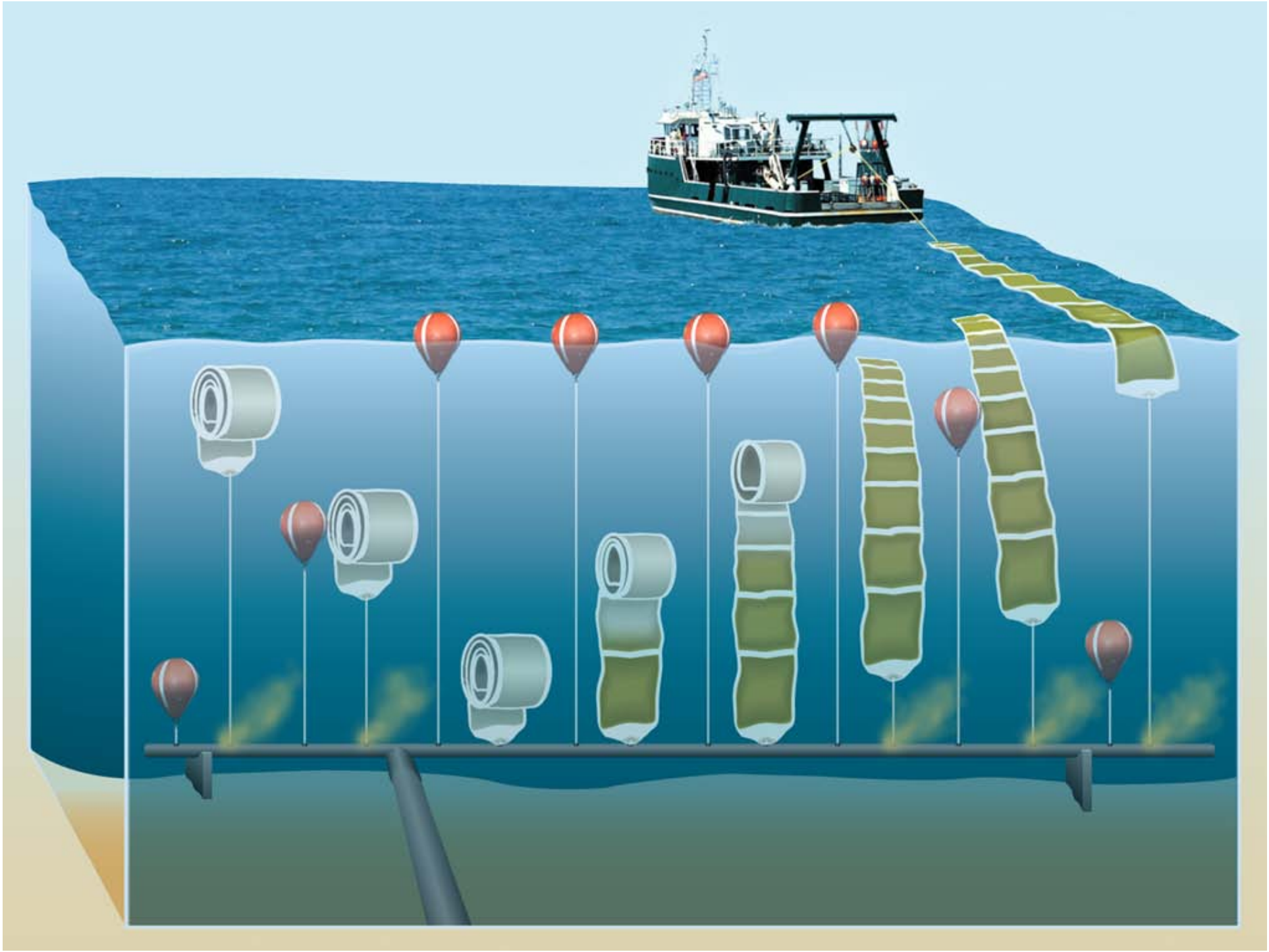


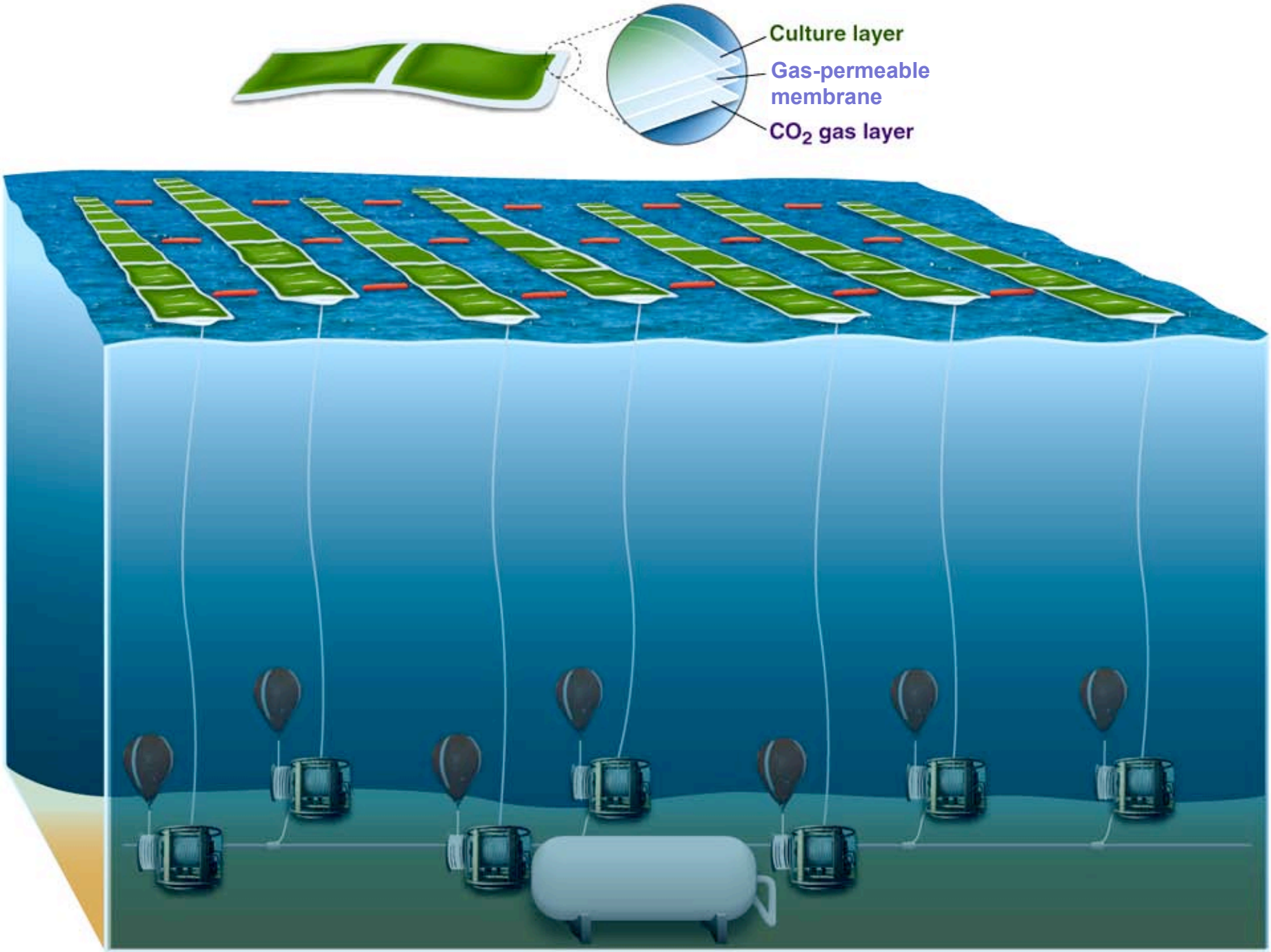


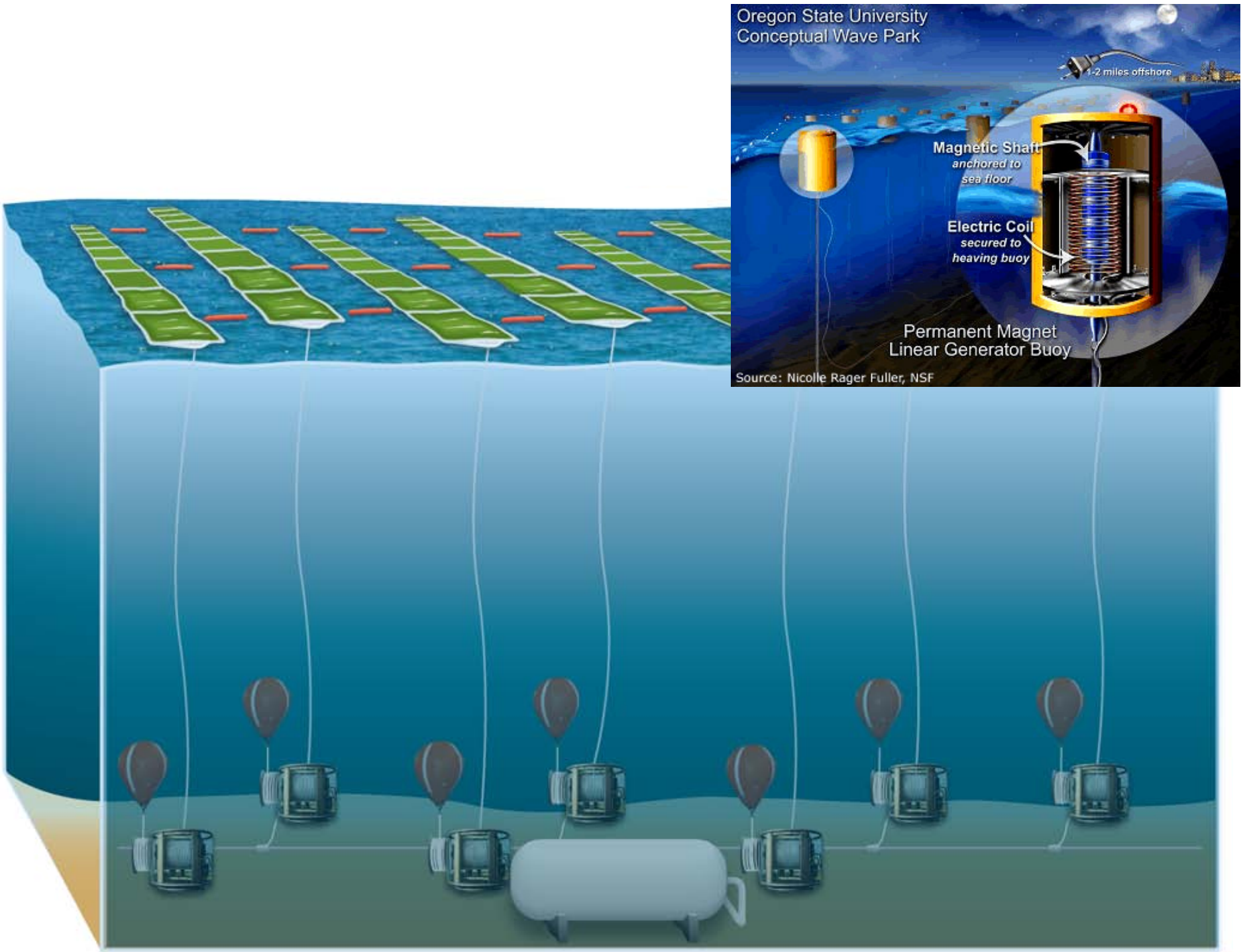
OMEGA logistics?

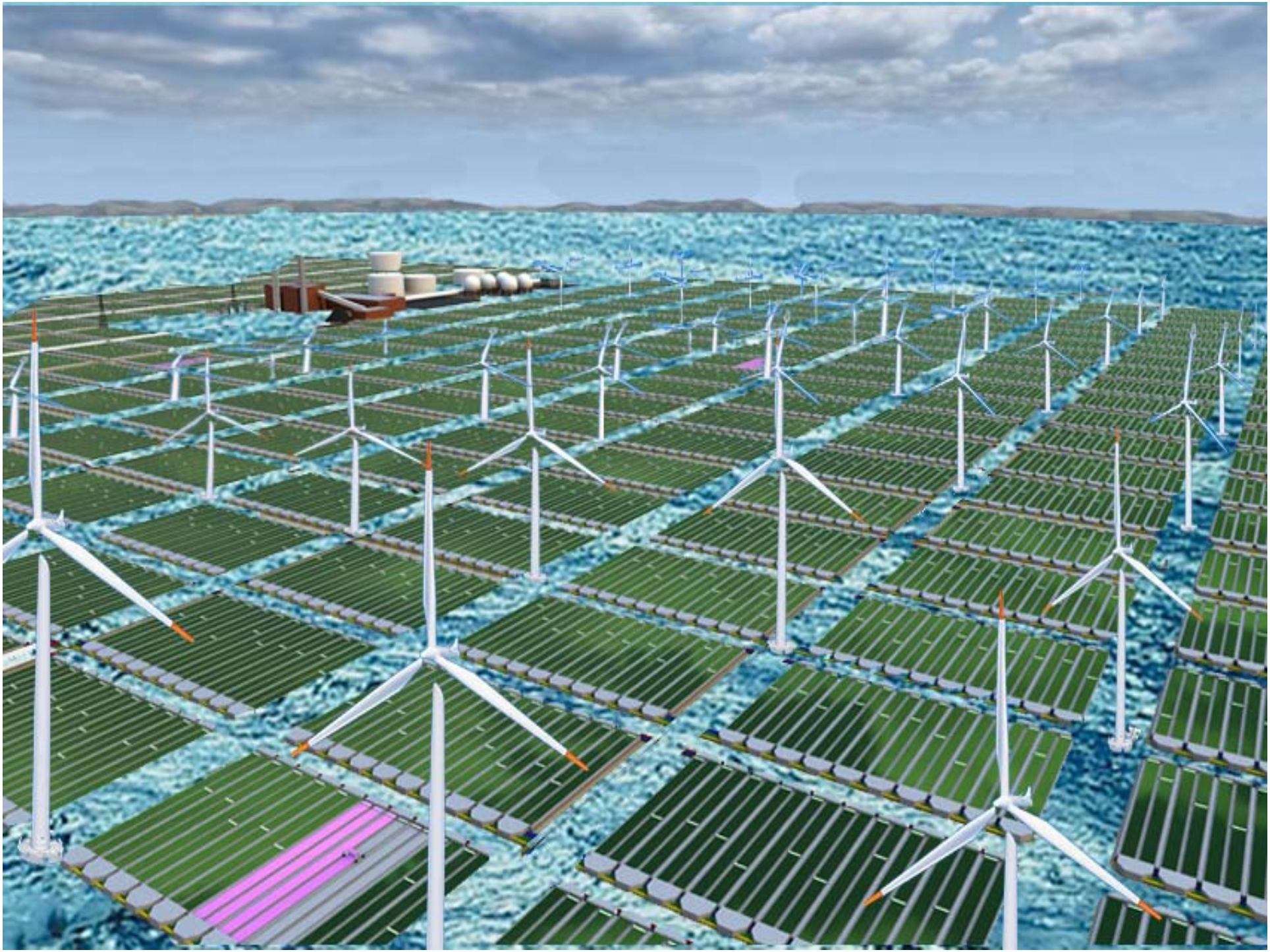


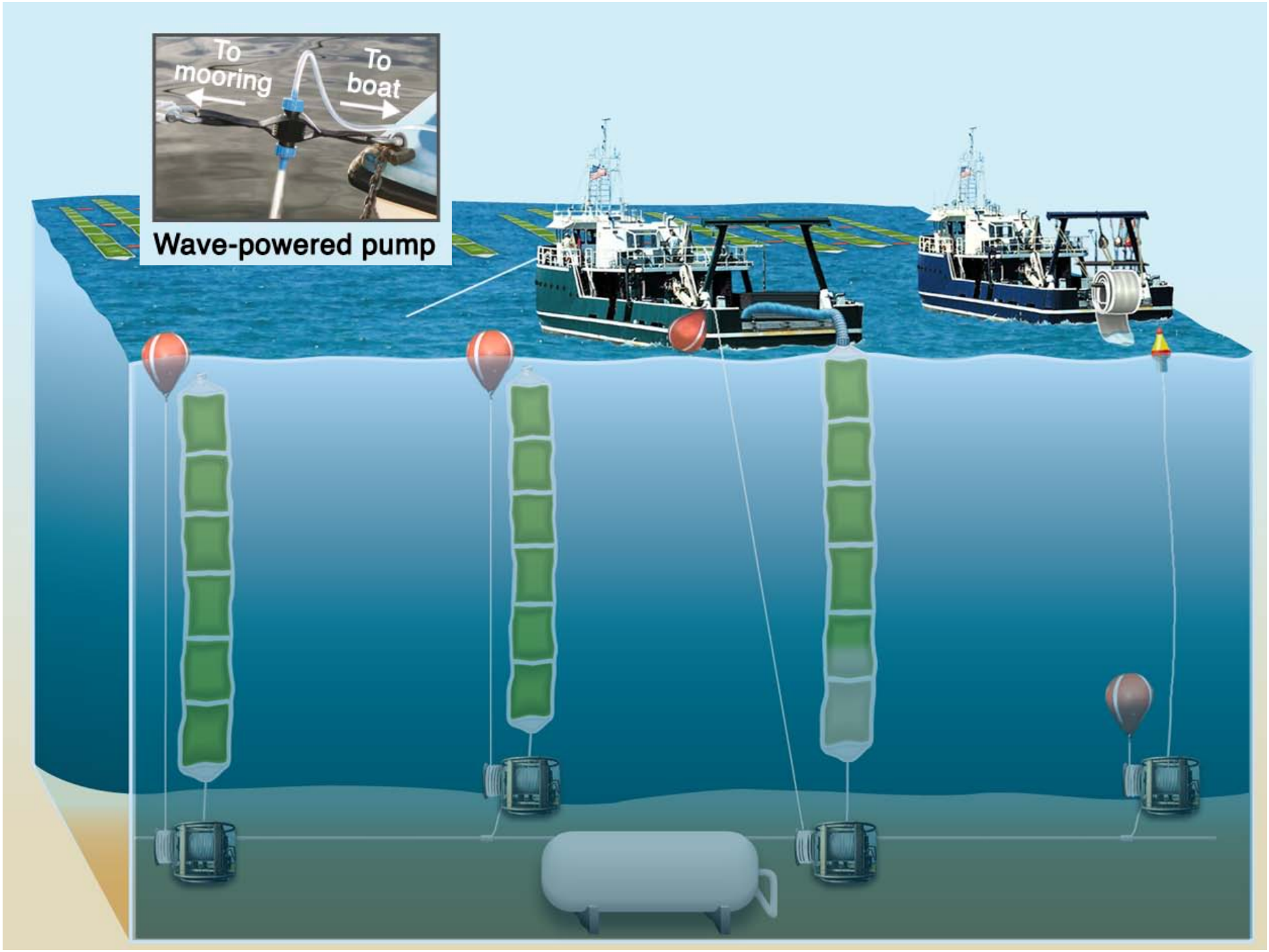





Culture layer
Gas-permeable membrane
CO_2 gas layer


Oregon State University
Conceptual Wave Park
1-2 miles offshore
Magnetic Shaft
anchored to
sea floor
Electric Coil
secured to
heaving buoy
Permanent Magnet
Linear Generator Buoy
Source: Nicolle Rager Fuller, NSF



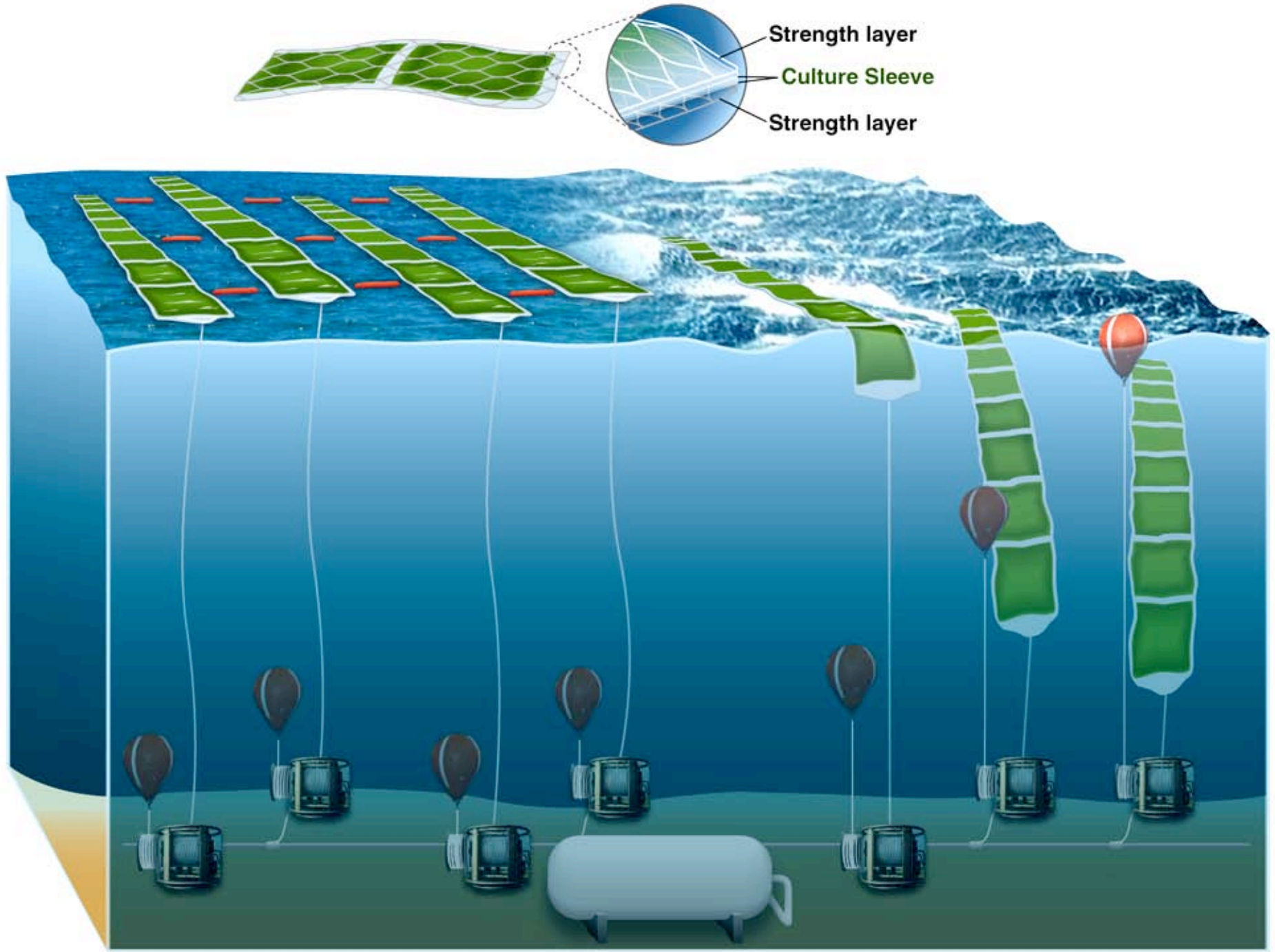

To mooring
To boat
Wave-powered pump

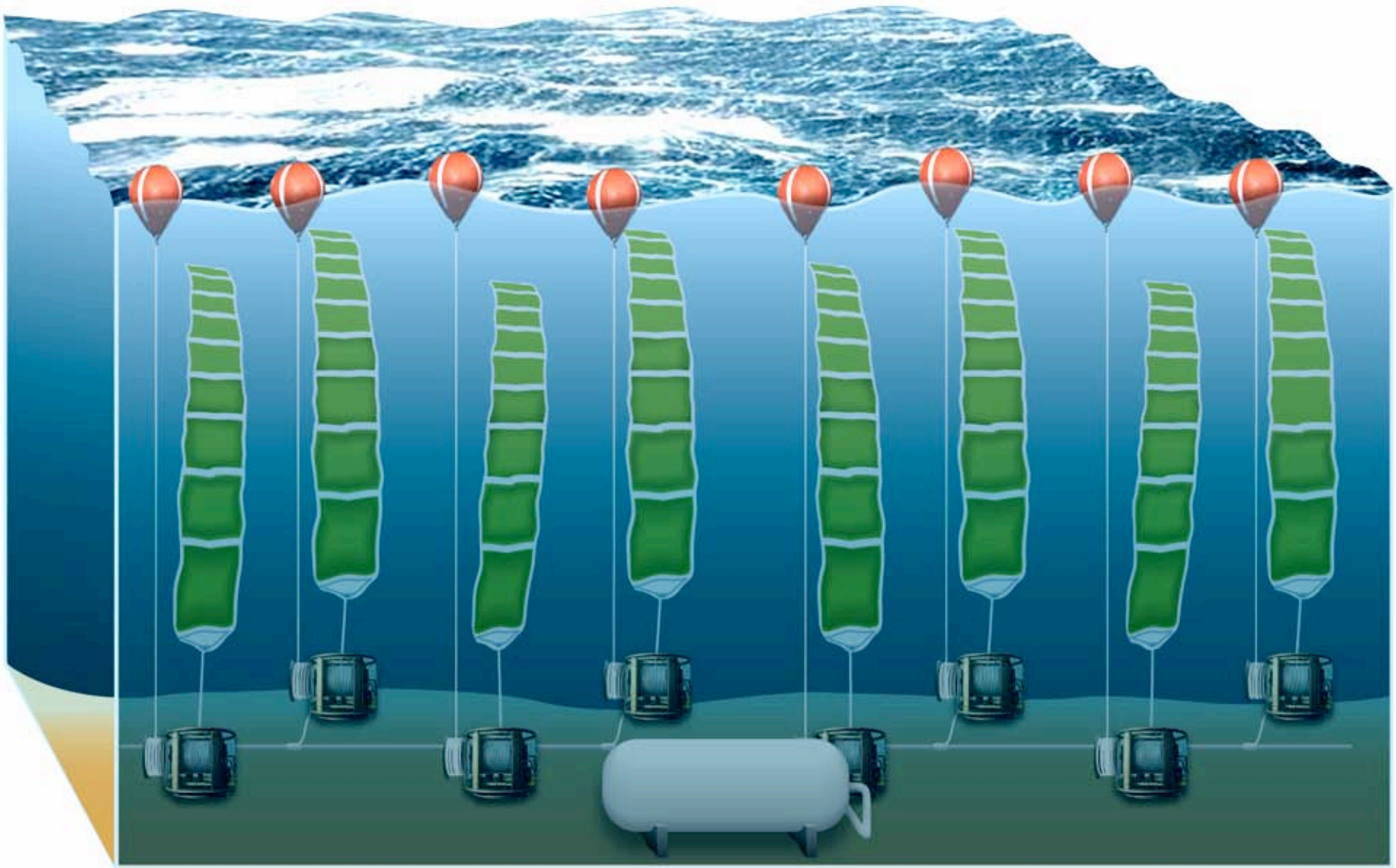

How realistic is OMEGA?


Are we up to the engineering challenge?


TEN


TEN REAL ESTATE


Strength layer
Culture Sleeve
Strength layer

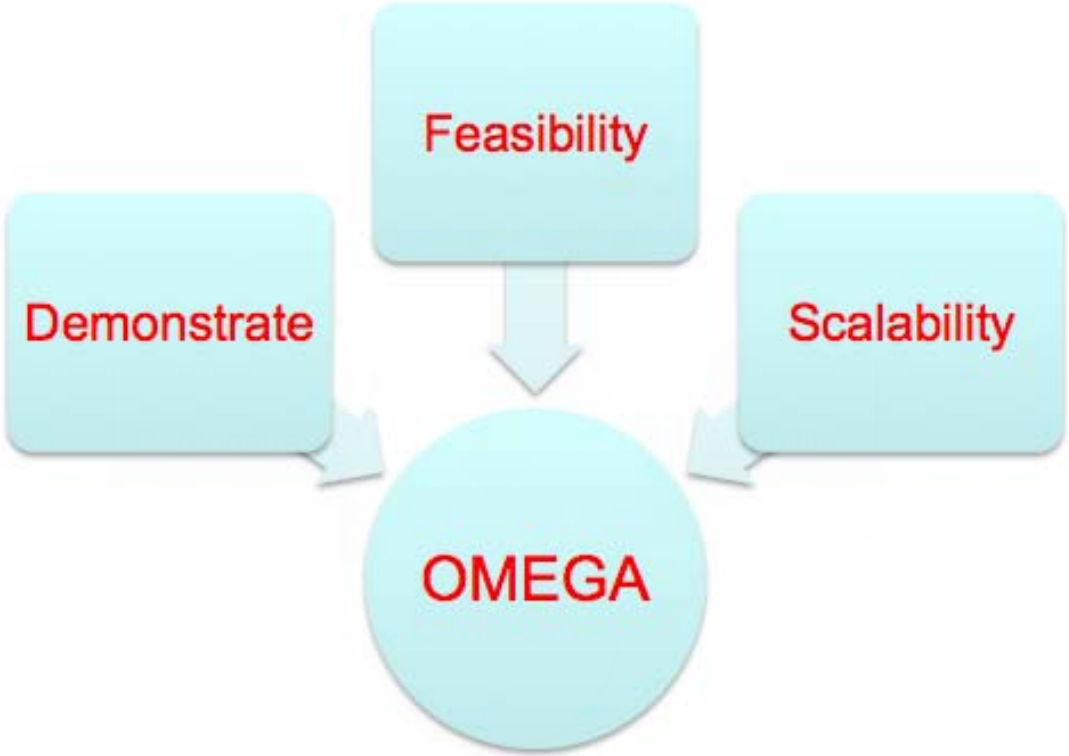


NASA OMEGA

Demonstration Project

Project Goals

- Demonstrate feasibility & scalability of OMEGA

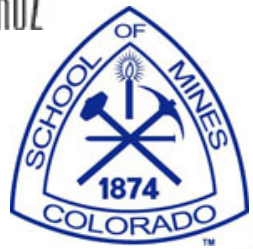


NASA OMEGA Demonstration Project

Phase I Design	Phase II Pilot	Phase III Demonstration	Phase IV Full-Scale Deployment	Spin out Commercialization
4 months	20 months	12 months	24 months	12 months
2010	**2012**	**2013**	**2015**	**2016**…
0 gal Oil	100 gal Oil	250 gal Oil	**25 barrels**	**100,000 + barrels**

This is about proof of concept and risk reduction…

UC SANTA CRUZ




Challenges for OMEGA
• Biology
• Engineering
• Economics
• Environment

Motivations for OMEGA

Does not compete with agriculture

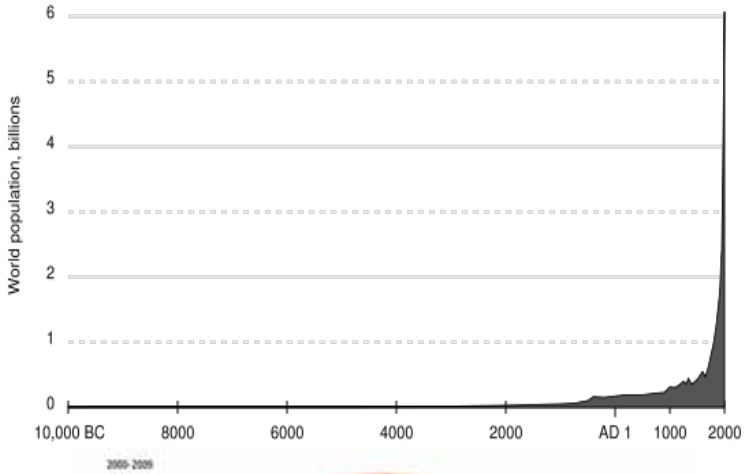
- Land
- Freshwater
- Fertilizer

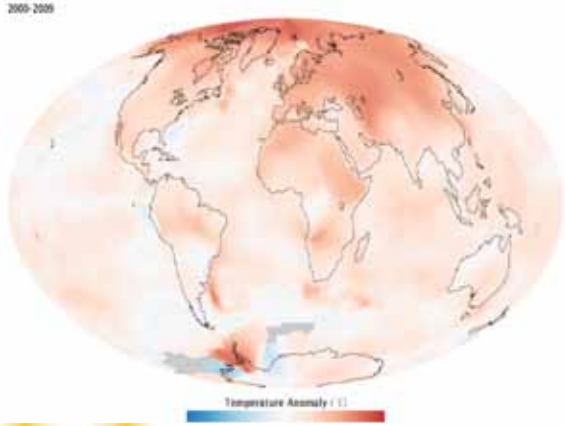
Compatible with climate change

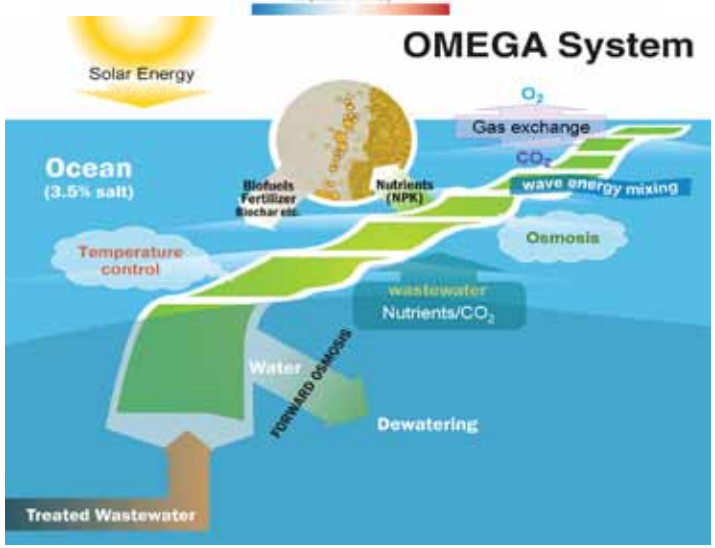
- Not dependent on rain
- Flooded coastal zones
- Warming ocean surface

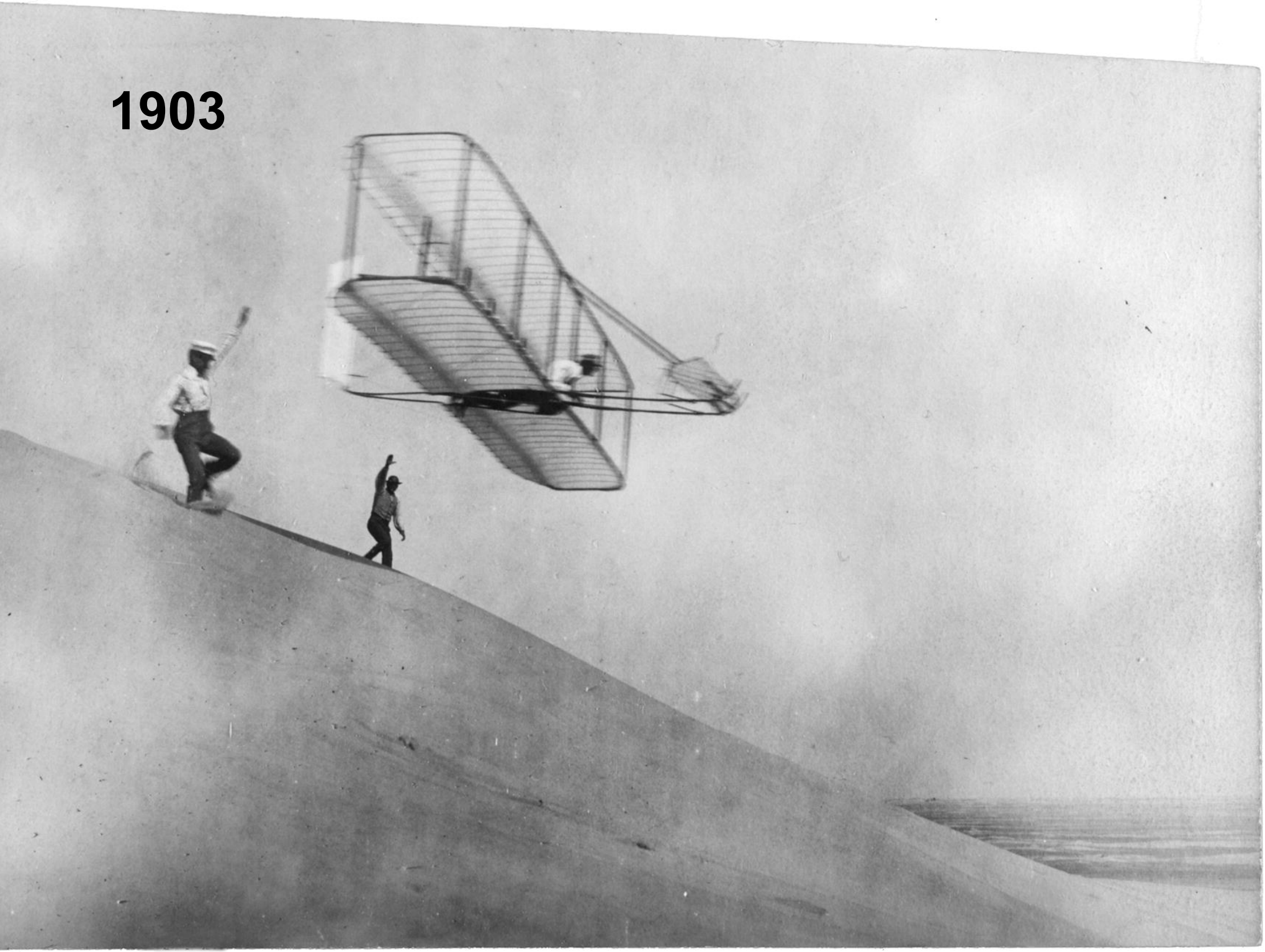
Creates an ecology of technology

- Waste = resource

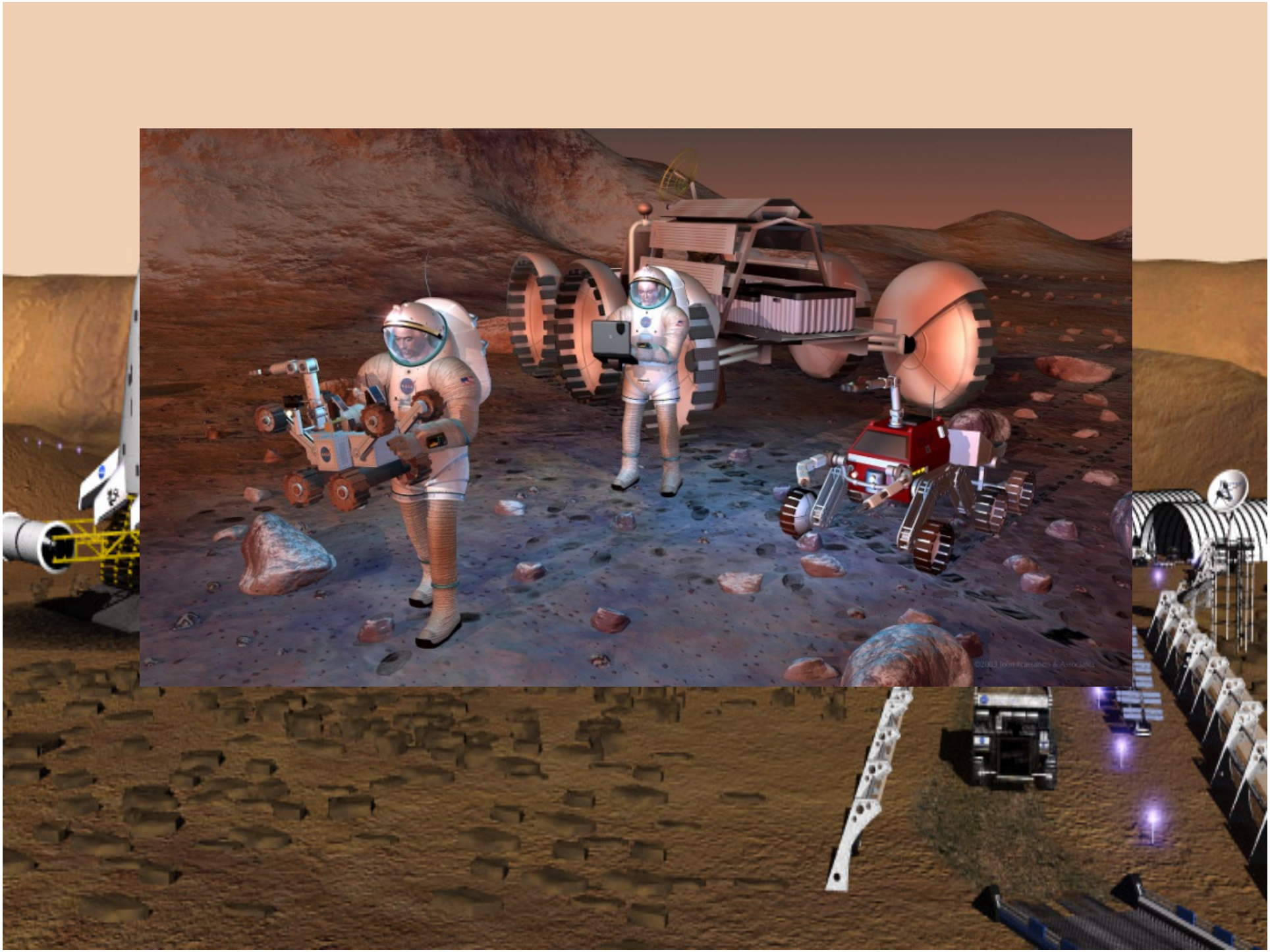







1903

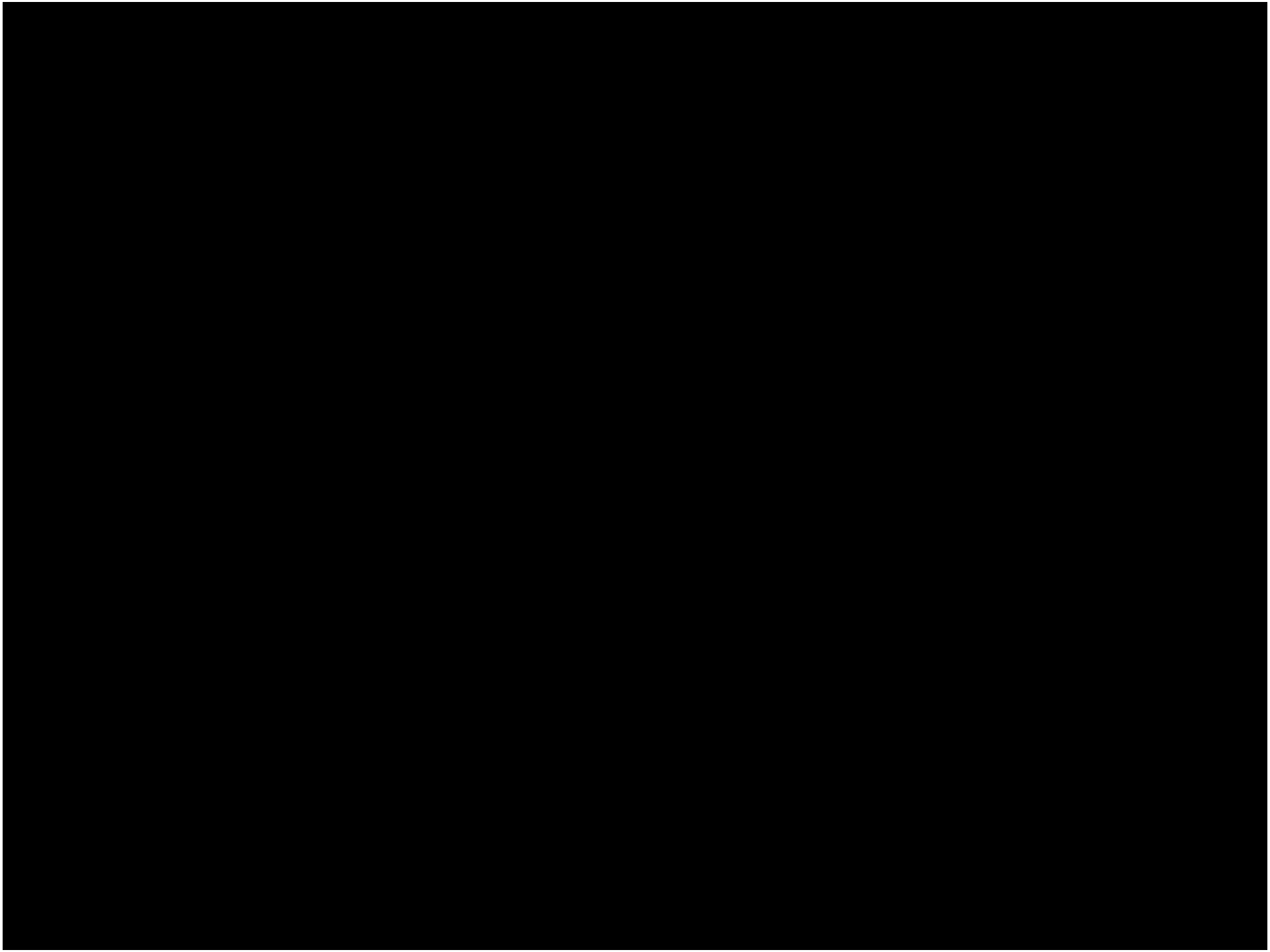

July 20, 1969

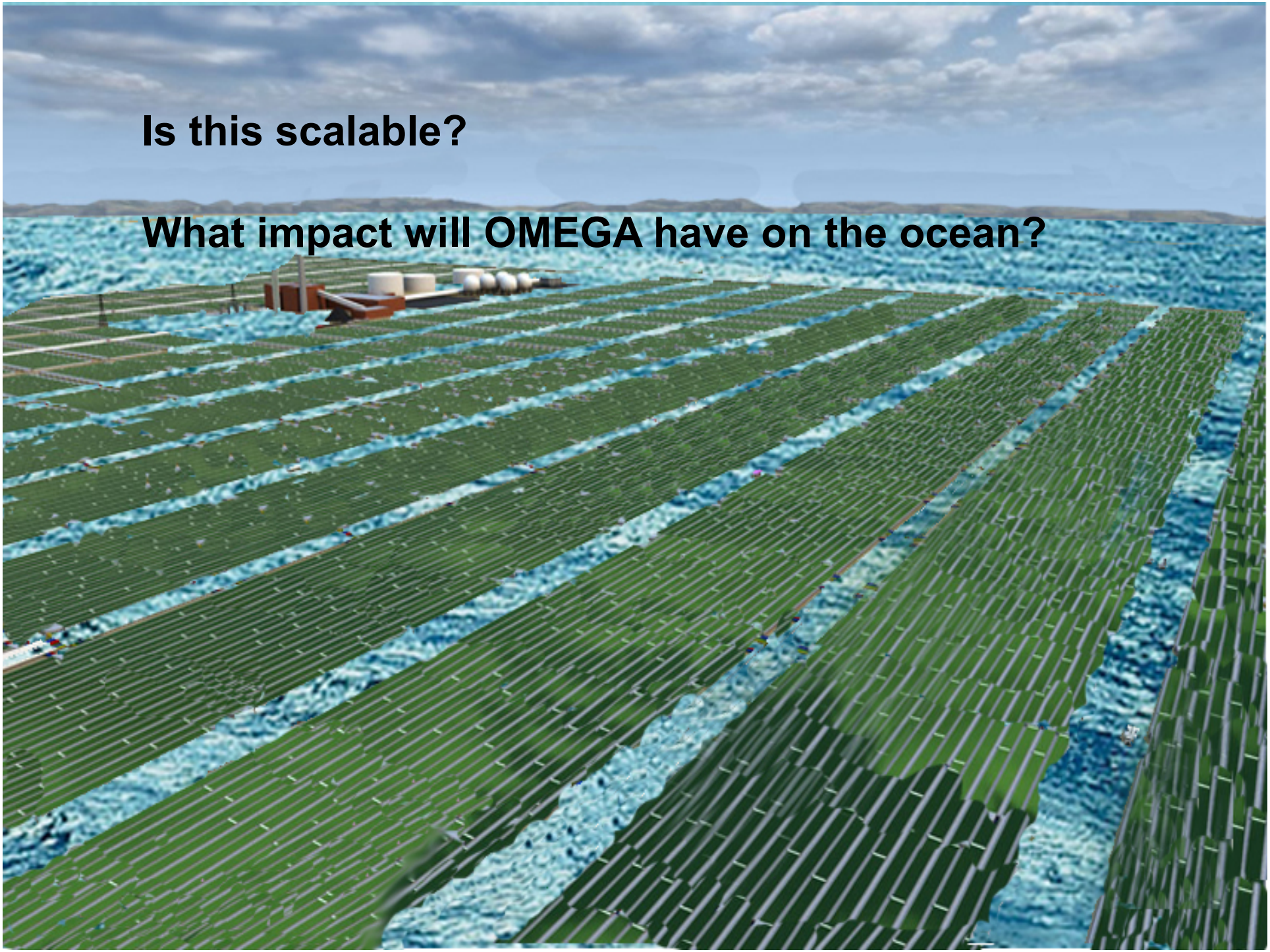


The stone age didn't end
because we ran out of stones… Yamani

There is no limit to what you can accomplish
If you don't care who gets the credit... Truman

A challenge and a call to action…




Is this scalable?
What impact will OMEGA have on the ocean?


14 16:04


Jan Parker 2006