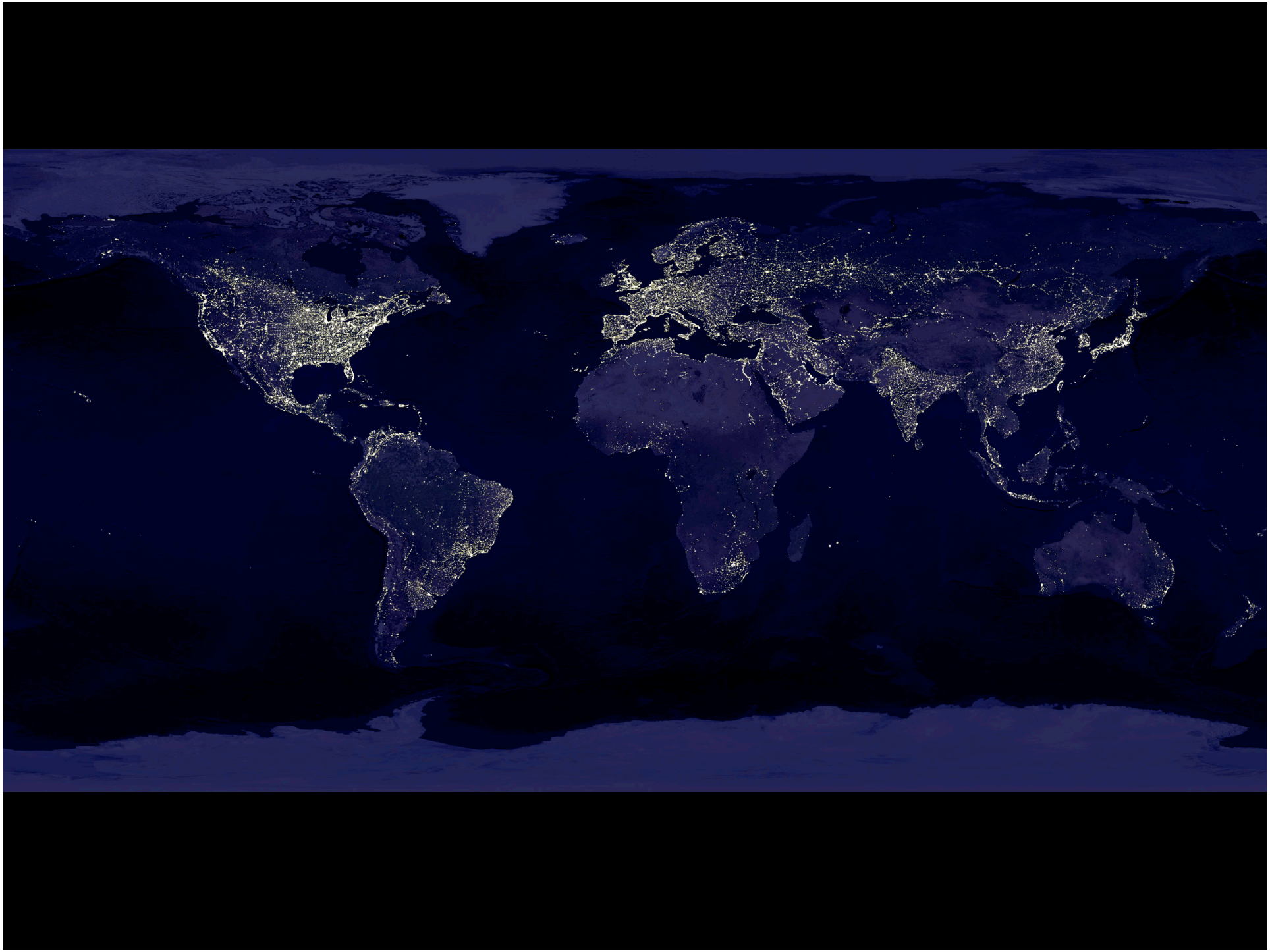
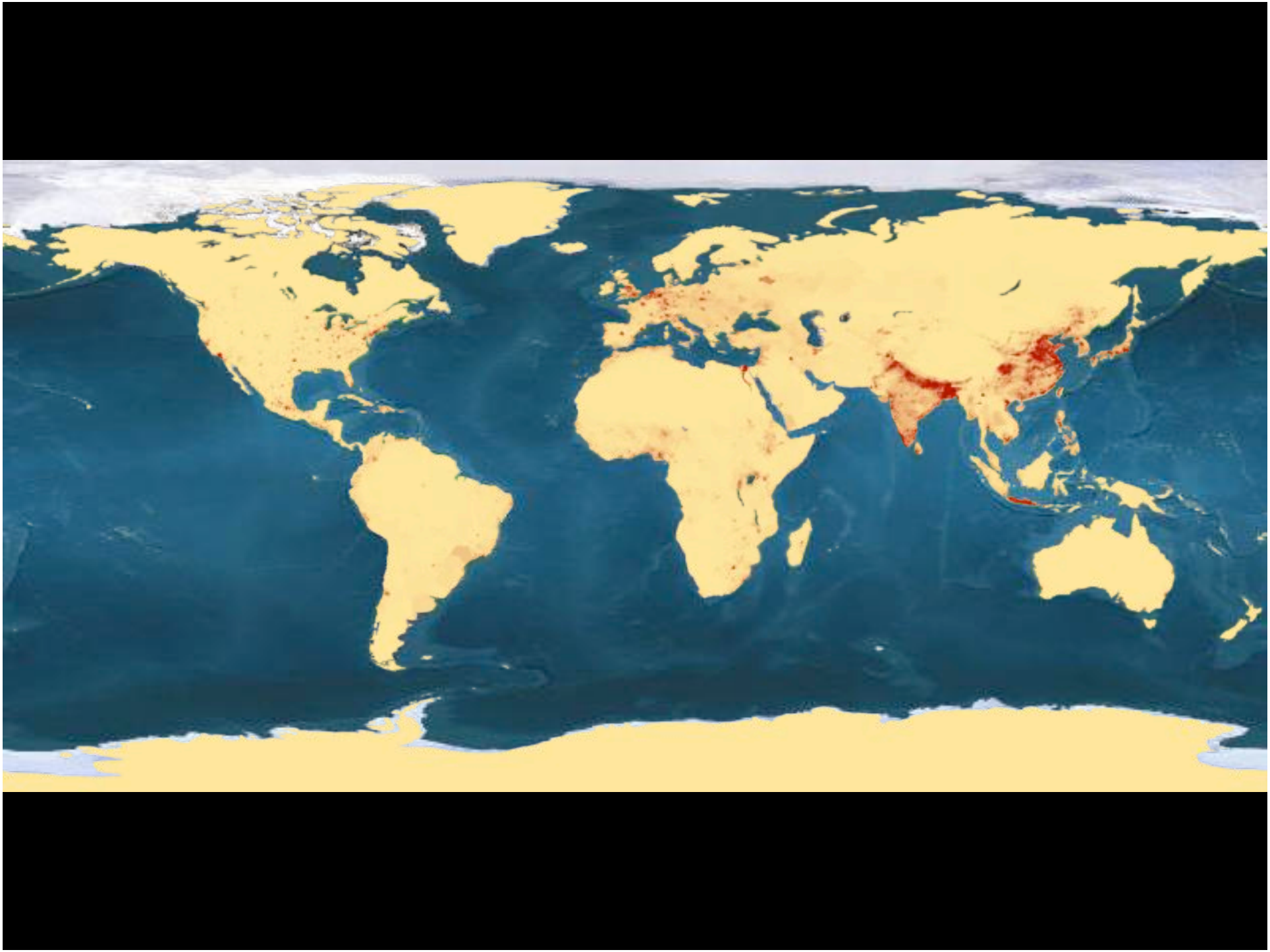
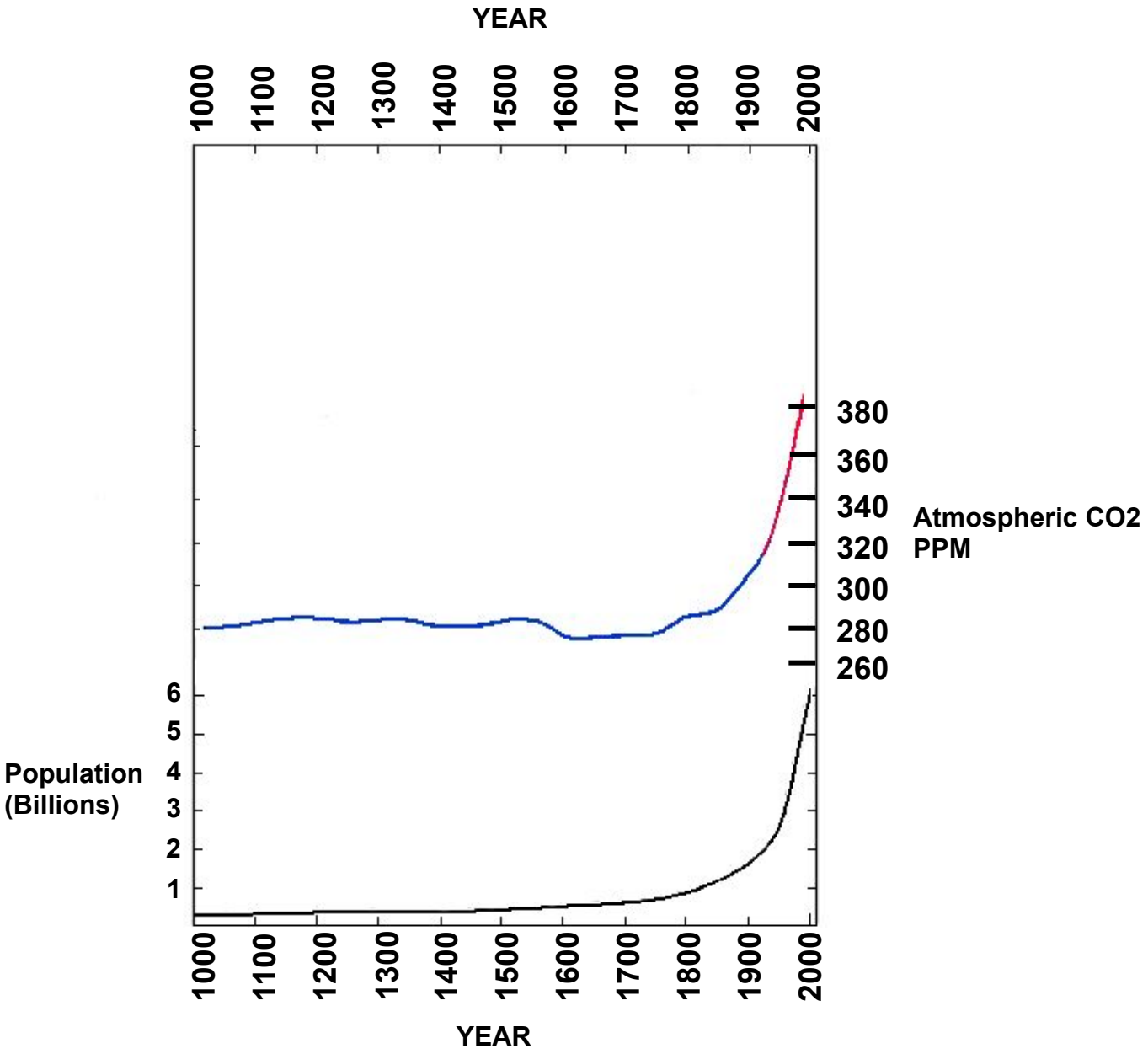
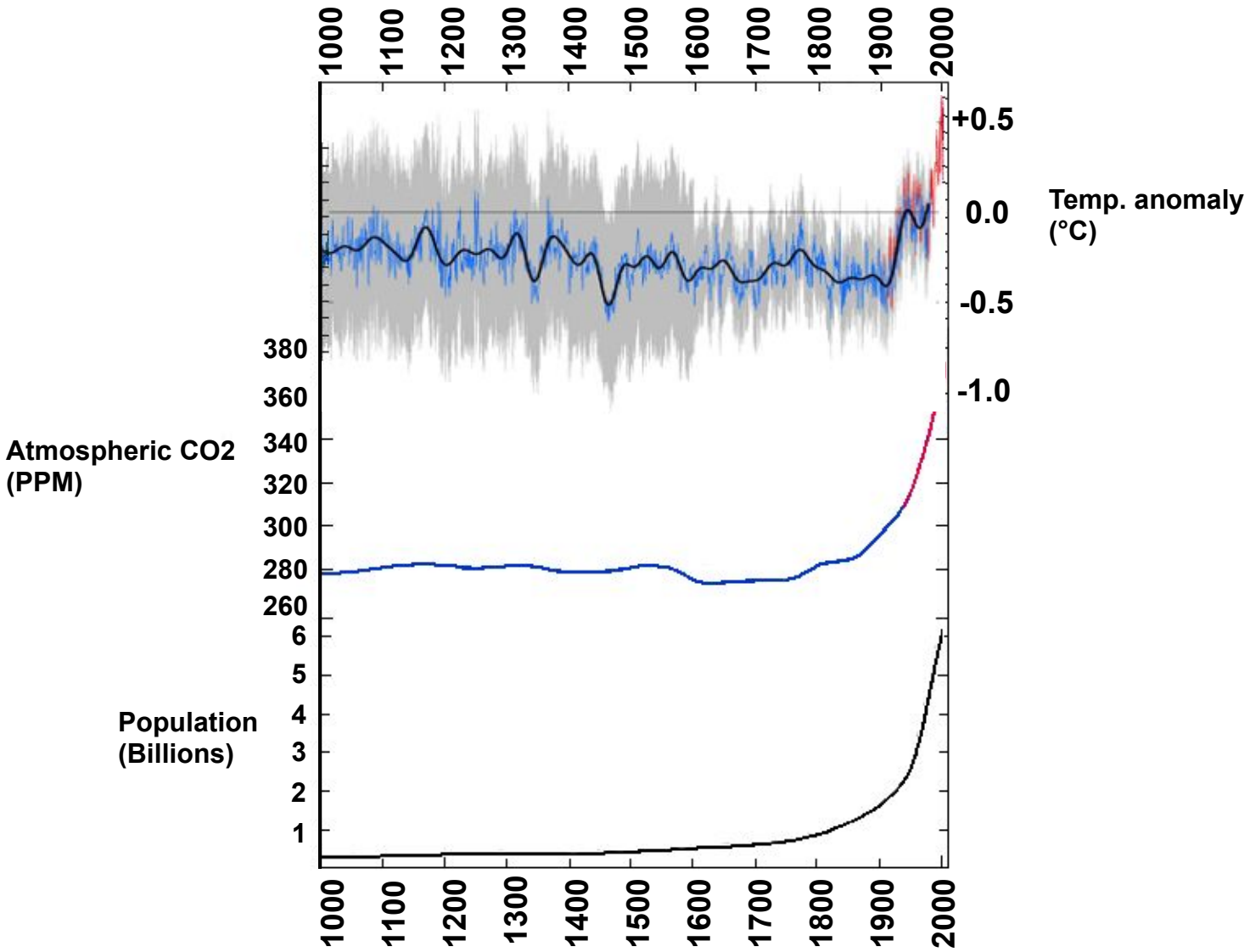


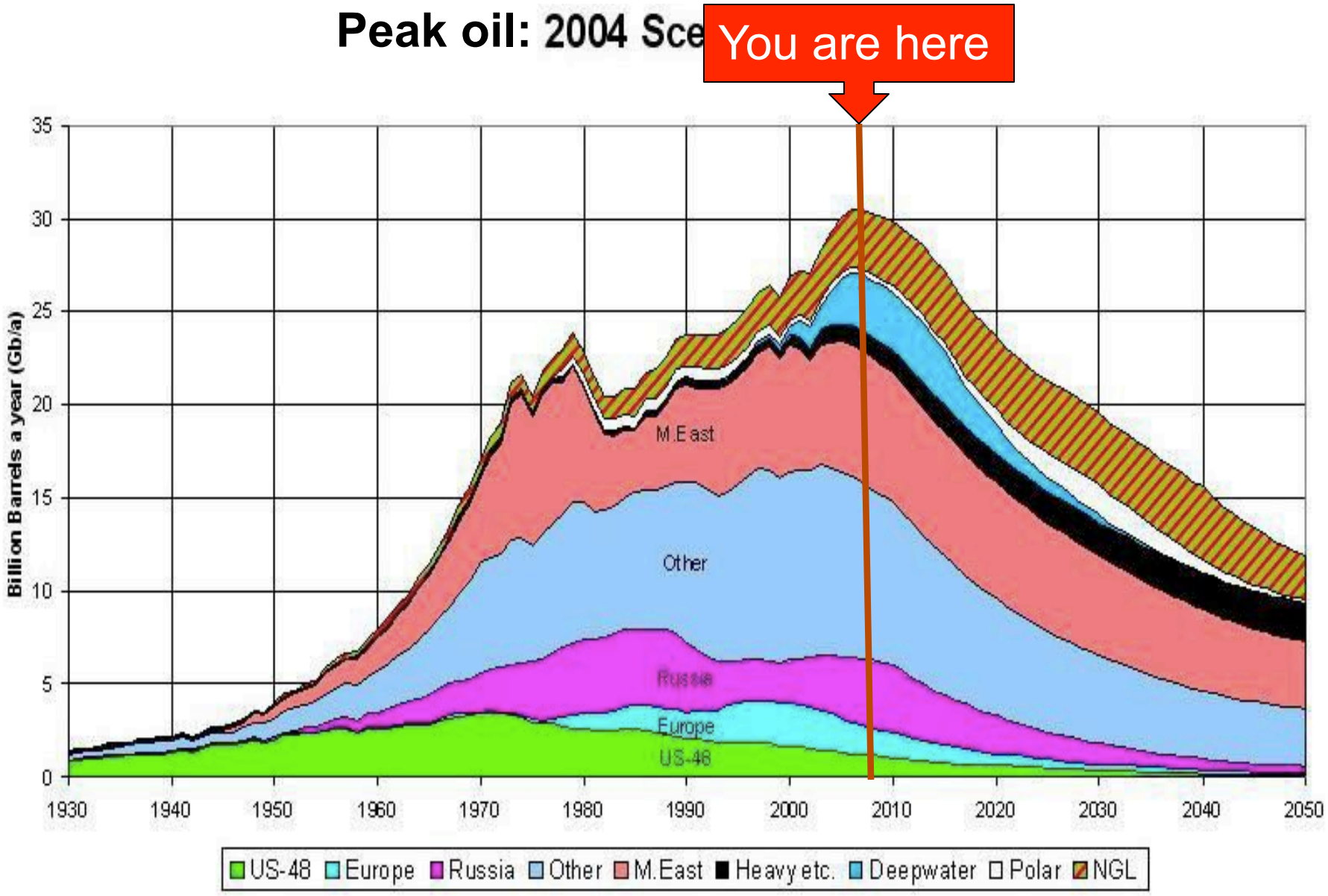


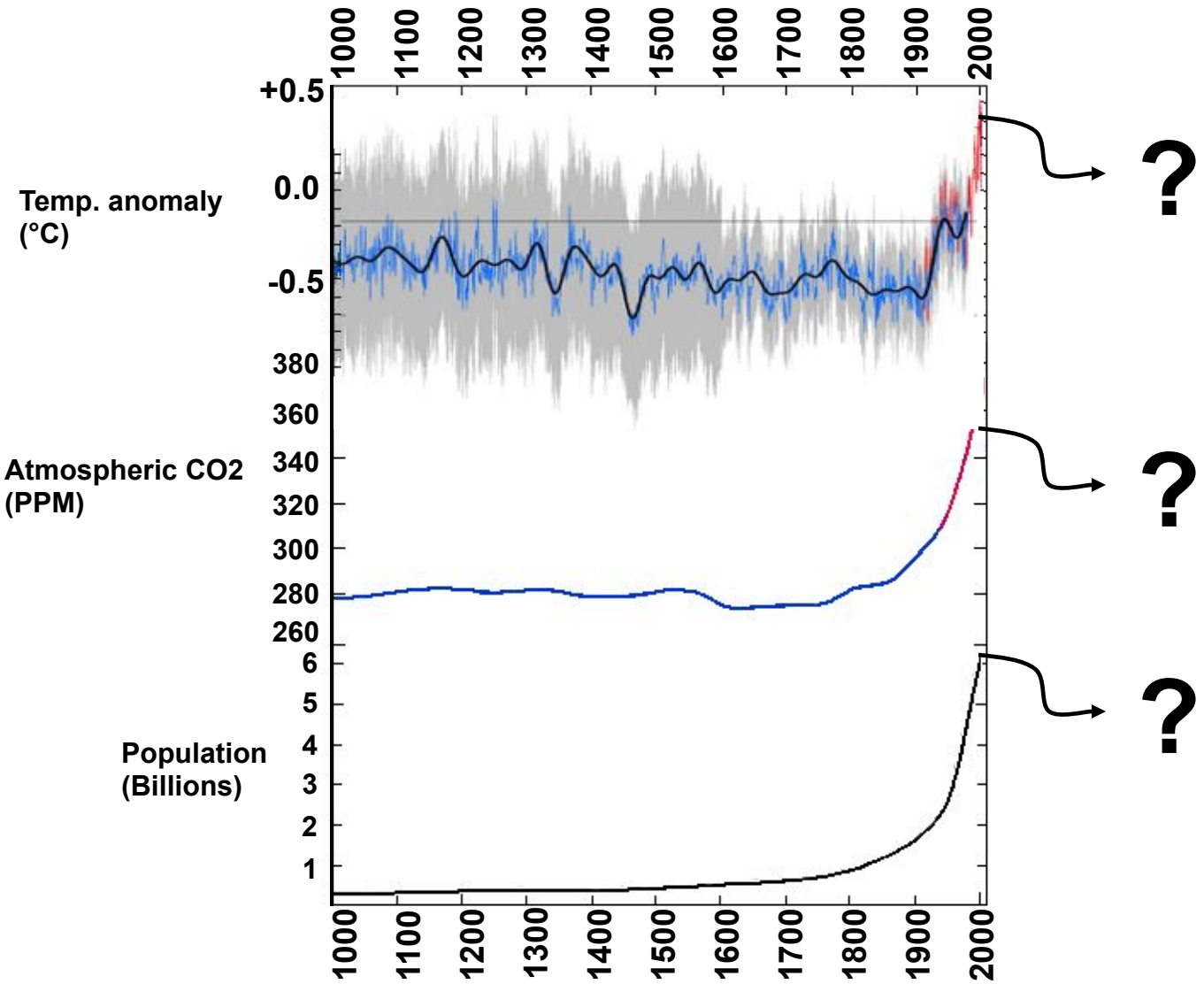
YEAR
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Population (Billions)
1
2
3
4
5
6
Vikings
Genghis Khan
Black plague
Ming dynasty
Columbus
Galileo
Newton
Steam engine
Wright Brothers
Electricity
Radio, movies, TV
Atomic bomb
Armstrong on Moon
Computers
Internet


YEAR
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
380
360
340
320
300
280
260
Atmospheric CO2
PPM
6
5
4
3
2
1
Population
(Billions)
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
YEAR


1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
+0.5
0.0
-0.5
-1.0
Temp. anomaly
(°C)
380
360
340
320
300
280
260
Atmospheric CO2
(PPM)
6
5
4
3
2
1
Population
(Billions)

Peak oil: 2004 Sce





What happens next?


Sustainability?
Population
Affluence
Species
Technology
Our Future?

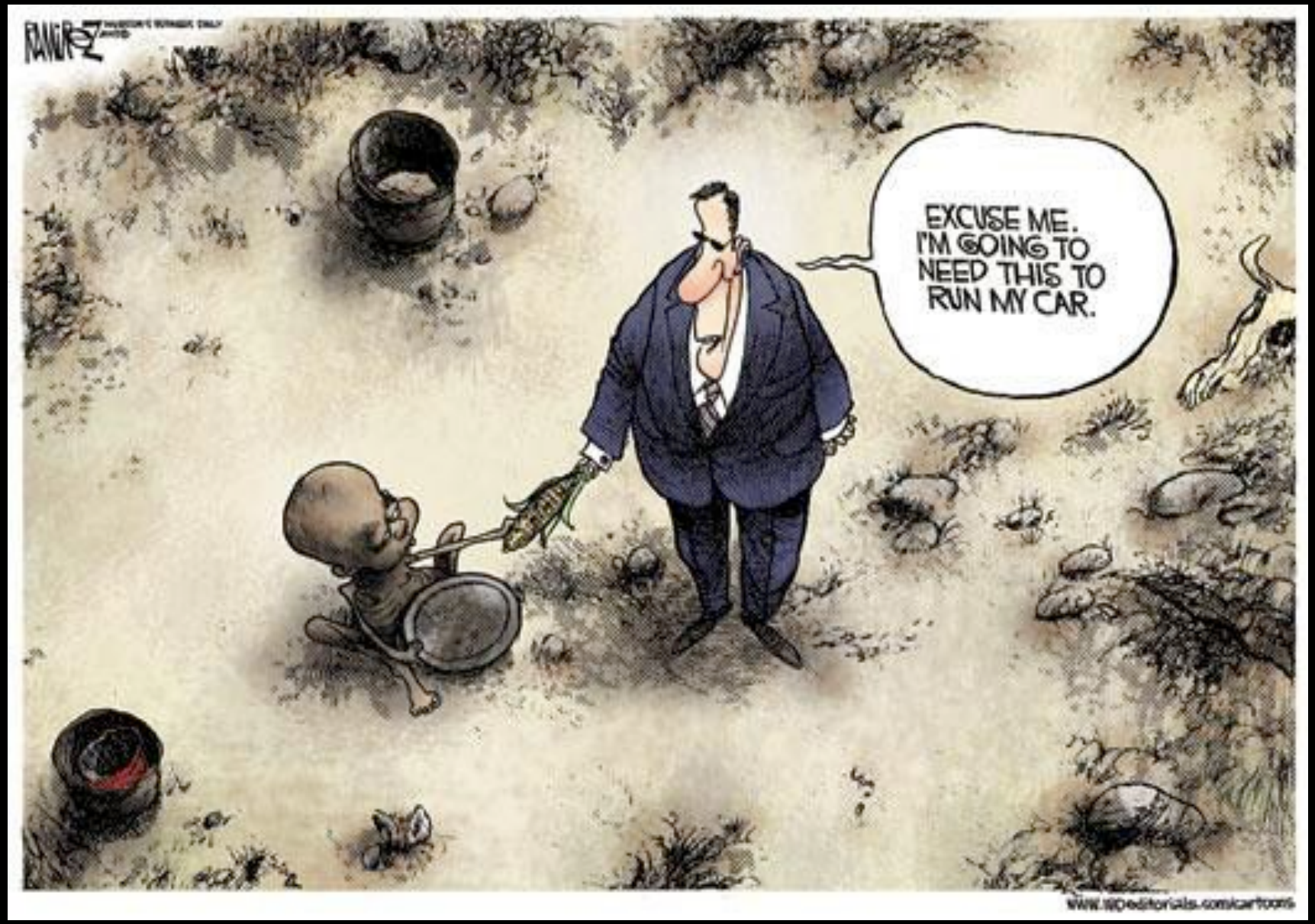
Title: Beyond Biofuels

Not use agricultural land

Not use freshwater

Feasible, affordable, scalable, sustainable…

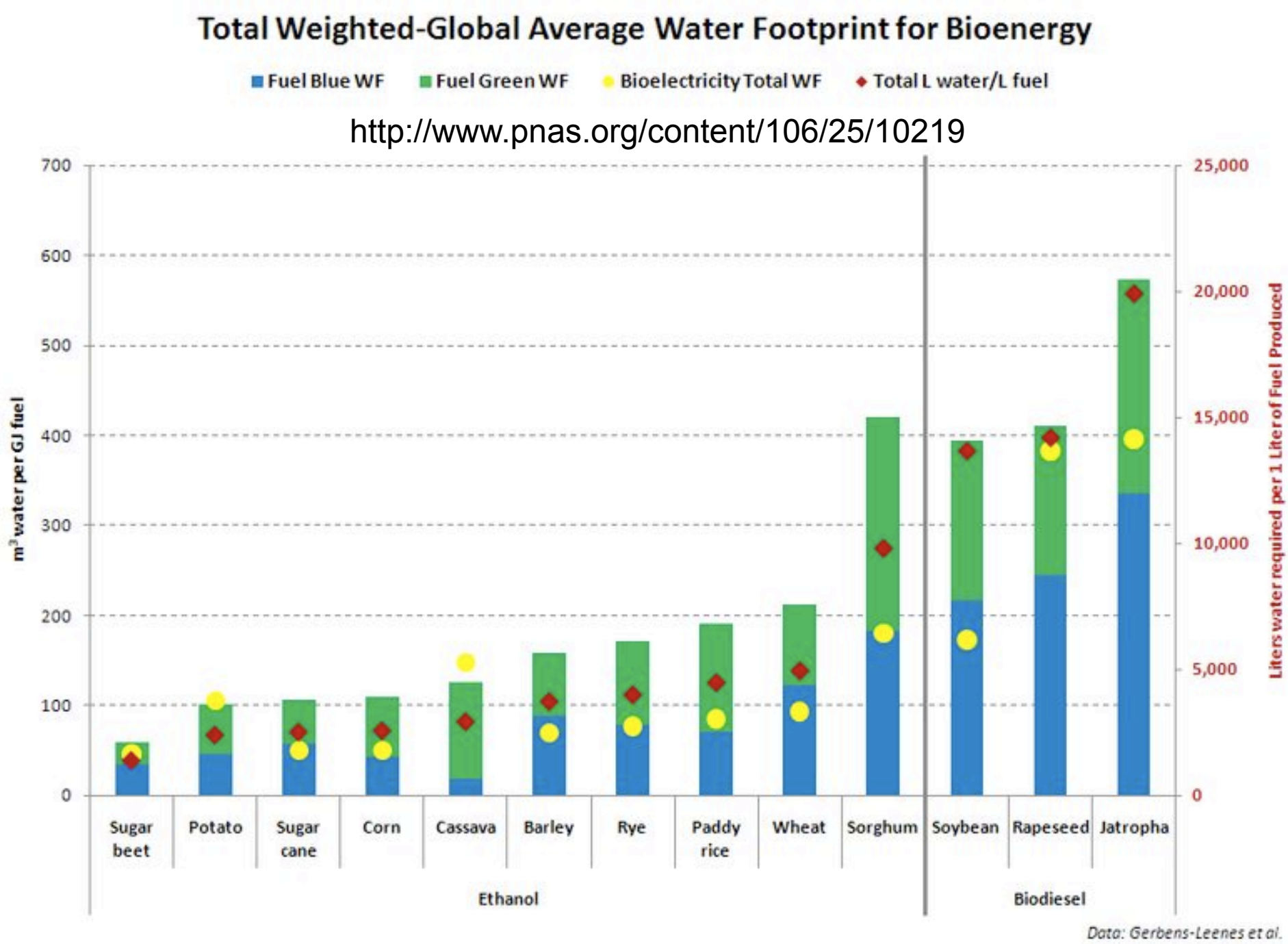
NOW!


RAMIREZ
EXCUSE ME. I'M GOING TO NEED THIS TO RUN MY CAR.
www.idEditorials.com/cartoons

How **green** are biofuels?

Product	
GHG output*	
Water	
Fertilizer	
Pesticide	
Energy	
US crop land/ half demand	

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


Total Weighted-Global Average Water Footprint for Bioenergy
Fuel Blue WF
Fuel Green WF
Bioelectricity Total WF
Total L water/L fuel
http://www.pnas.org/content/106/25/10219
m³ water per GJ fuel
Liters water required per 1 Liter of Fuel Produced
700
600
500
400
300
200
100
0
25,000
20,000
15,000
10,000
5,000
0
Sugar beet
Potato
Sugar cane
Corn
Cassava
Barley
Rye
Paddy rice
Wheat
Sorghum
Soybean
Rapeseed
Jatropha
Ethanol
Biodiesel
Data: Gerbens-Leenes et al.

The problem with biodiesel…

Product	
GHG output*	
Water	
Fertilizer	
Pesticide	
Energy	
US crop land/ half demand	

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

Biodiesel crops and production:

Plant	**Gal/acre-yr**
Soybeans	50
Sunflower	100
Canola	160
Jatropha	200?
Palm Oil	600

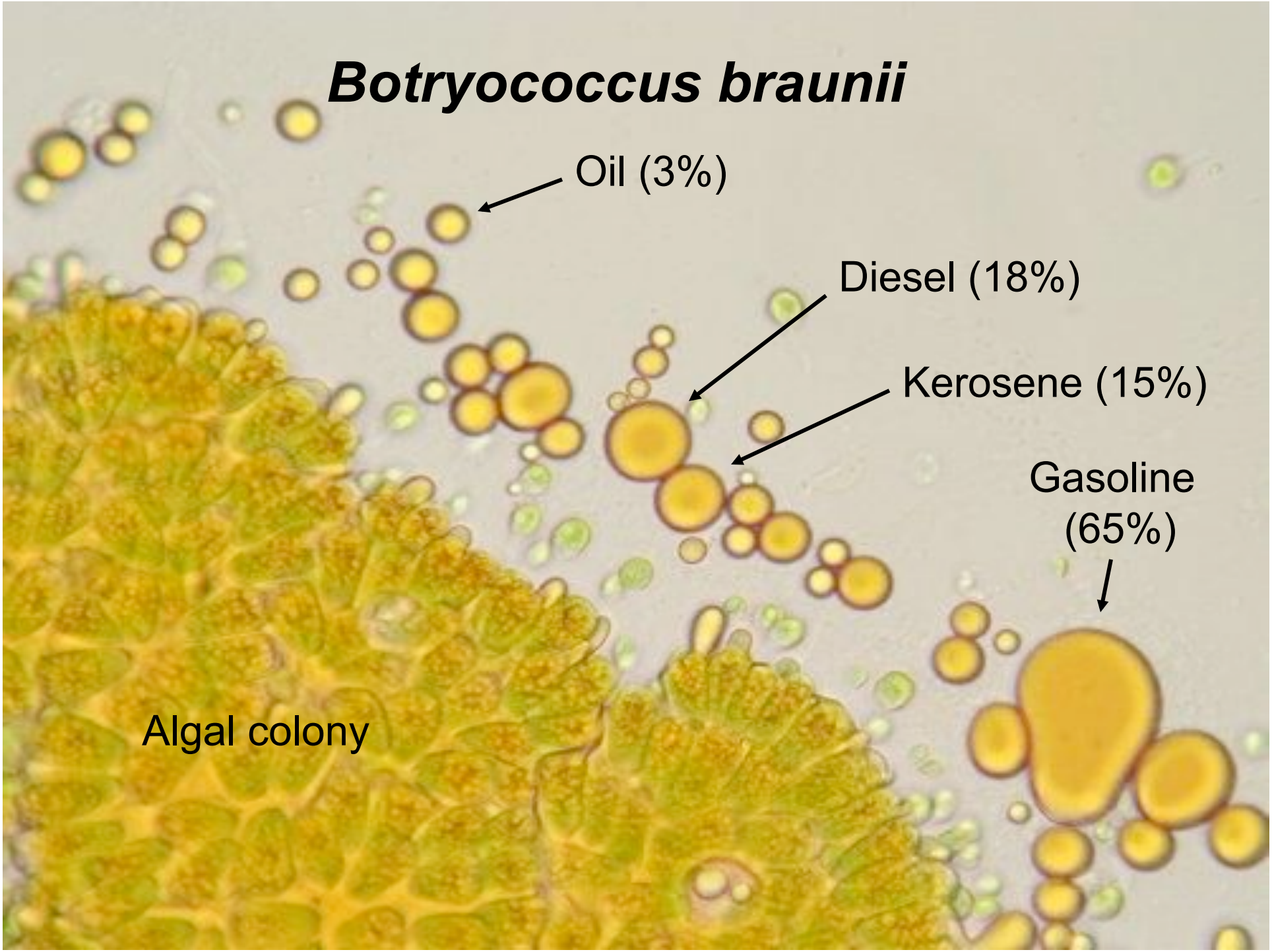
from: Benemann 2007. Algae Biomass Summit

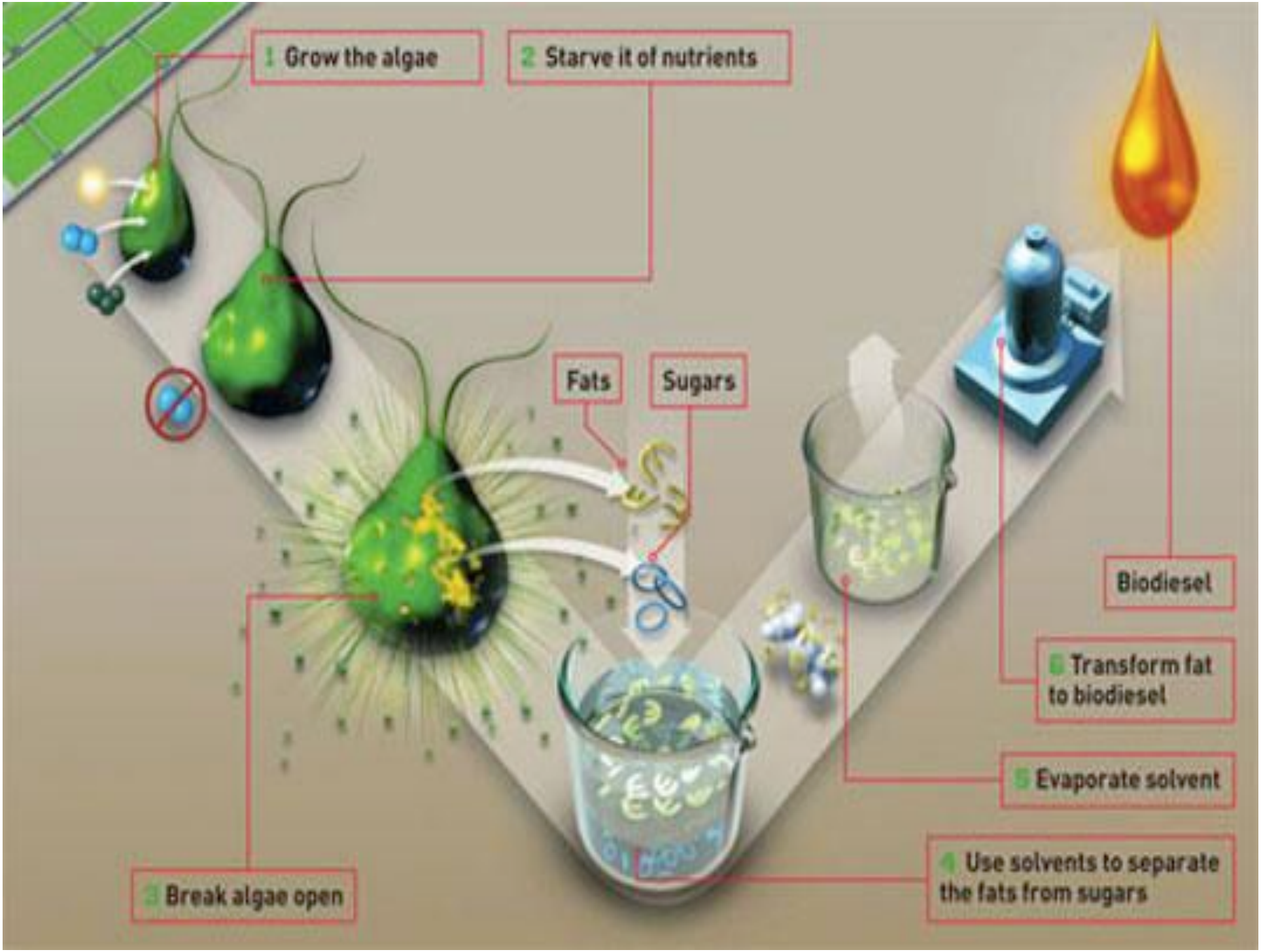
Biodiesel crops and production:

Plant	**Gal/acre-yr**
Soybeans	50
Sunflower	100
Canola	160
Jatropha	200?
Palm Oil	600
Microalgae	2,000 to ?

from: Benemann 2007. Algae Biomass Summit


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
MEXICO
THE BAHAMAS
HAWAII
ALASKA
ARCTIC OCEAN
BERING SEA


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


1 Grow the algae
2 Starve it of nutrients
Fats
Sugars
3 Break algae open
4 Use solvents to separate the fats from sugars
5 Evaporate solvent
6 Transform fat to biodiesel
Biodiesel

ALGAE:

Remove CO_2 from atmosphere

Remove nutrients from municipal wastewater…

(Remediate “dead zones”)

Produce fertilizer, food, cosmetics, medicine…

AND OIL (carbon-neutral biofuel, plastics, etc)

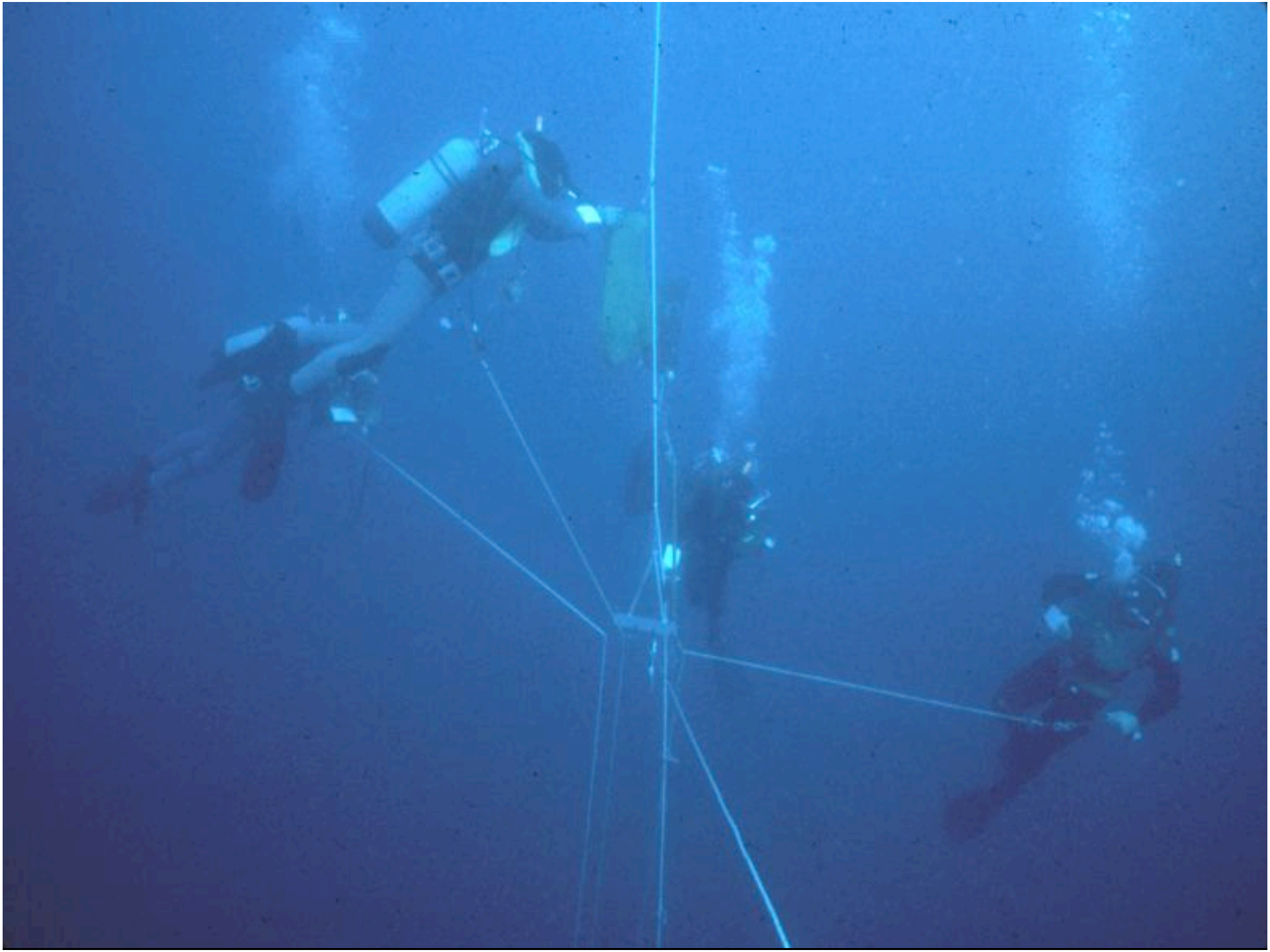
Biodiesel crops and production:

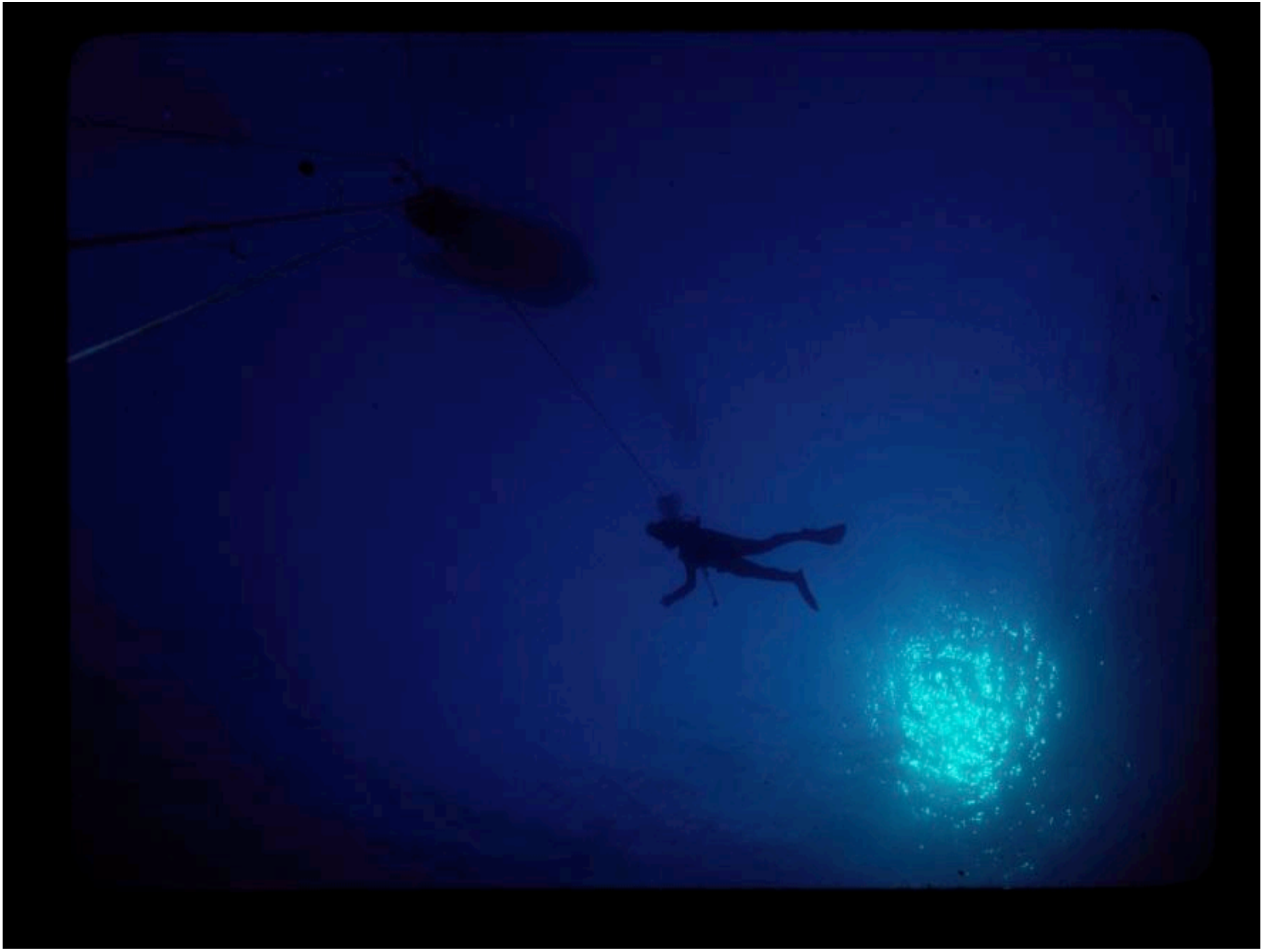
Plant	**Gal/acre-yr**	**Barrels/yr**
Soybeans	50	>10,000,000
Sunflower	100	> 1,000,000
Canola	160	>10,000,000
Jatropha	200?	some, not much
Palm Oil	600	>10,000,000
Microalgae	2,000 to ?	~0.1

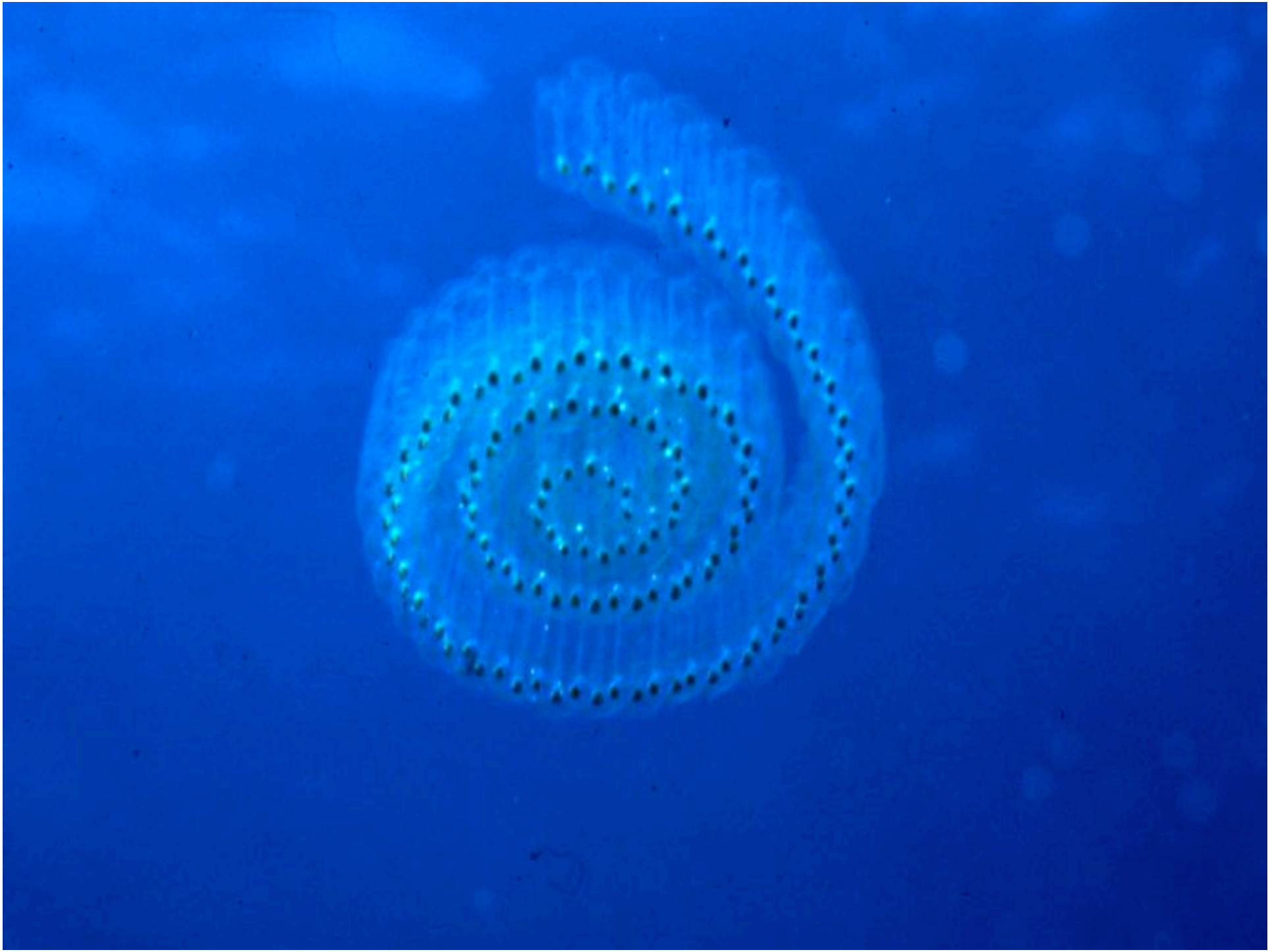
from: Benemann 2007. Algae Biomass Summit

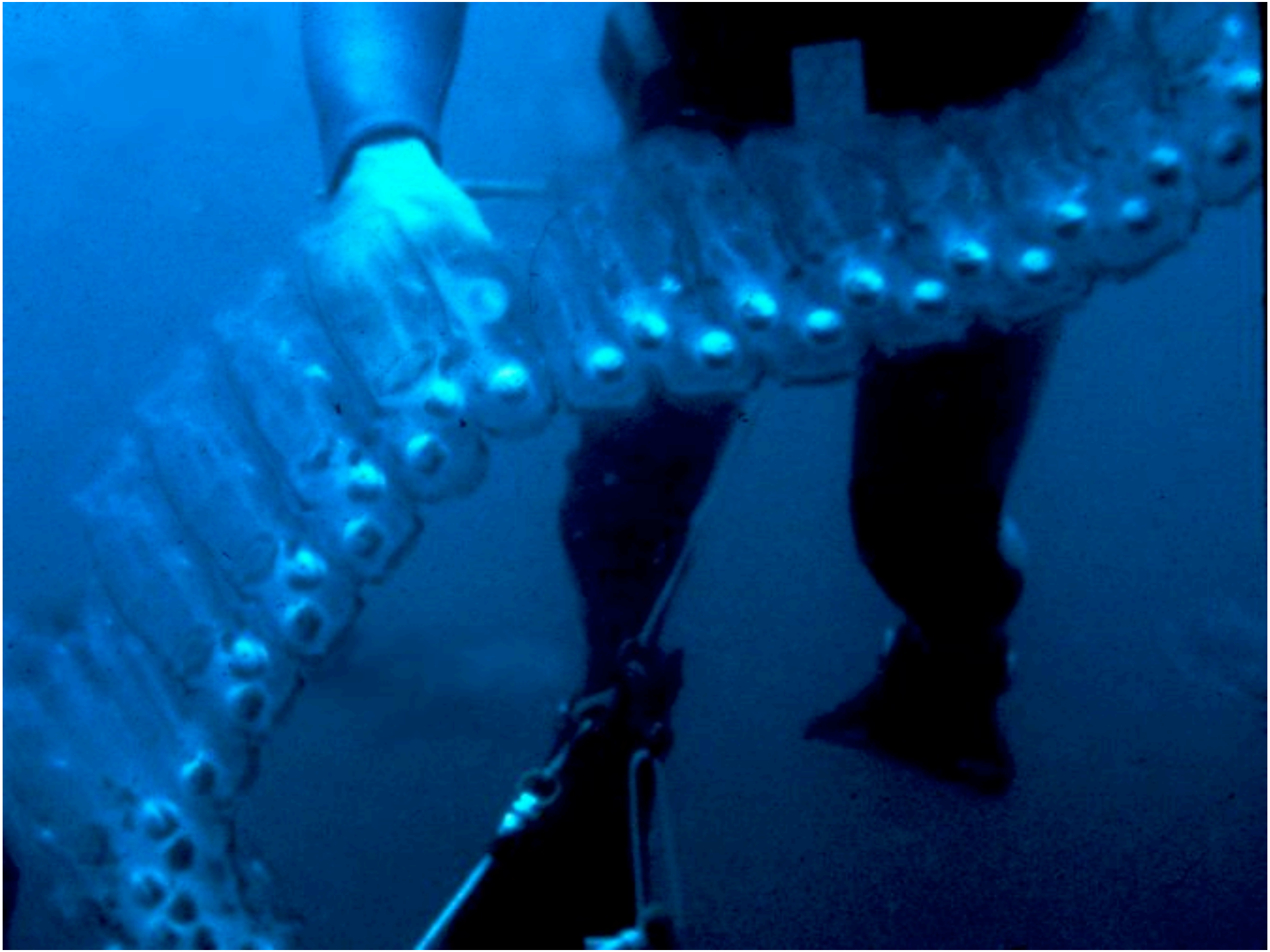

What about just collecting algae growing in the ocean?

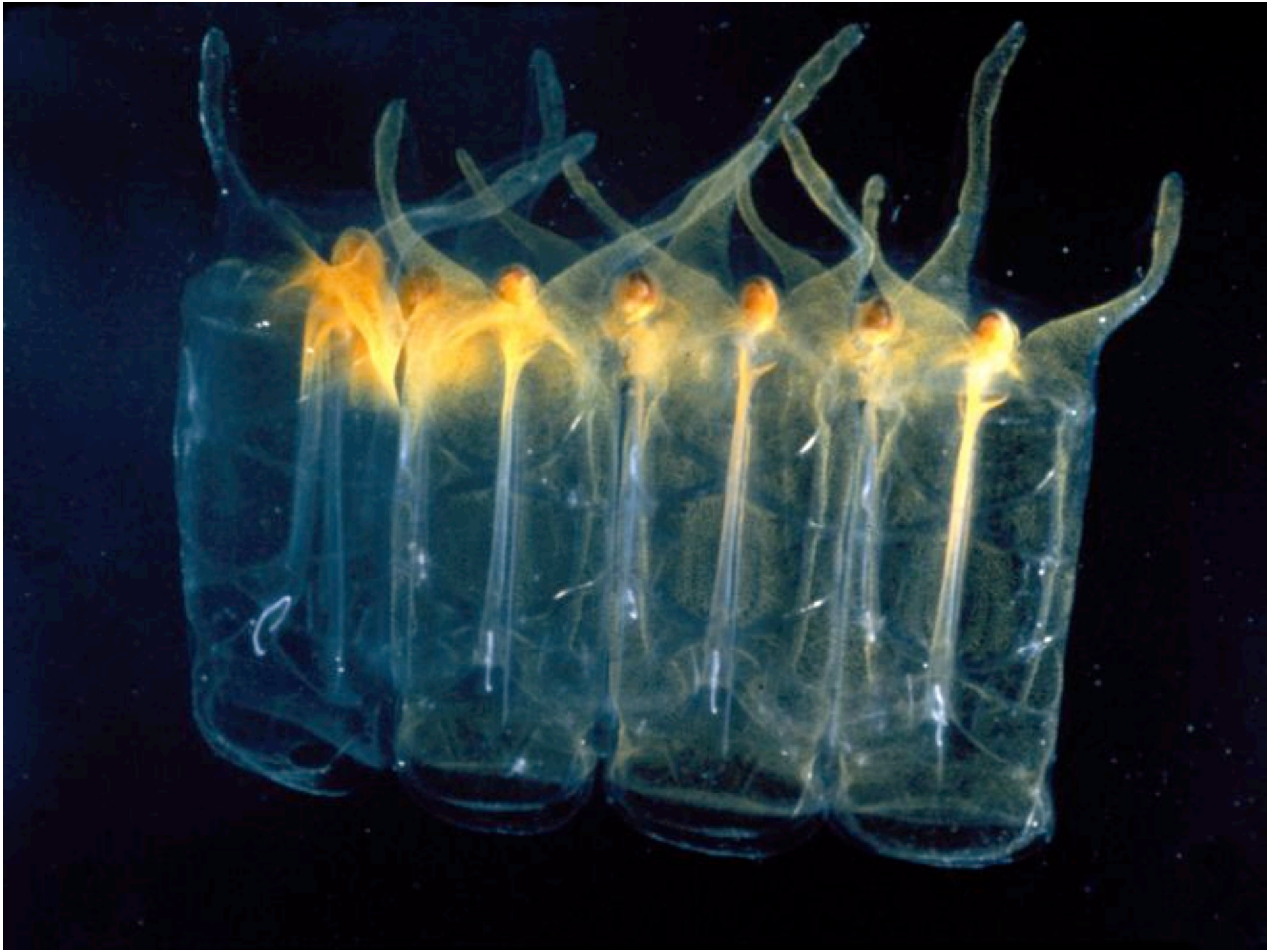

Too dilute
Spatially/temporally dispersed
Species composition wrong
Harvest
wild algae?

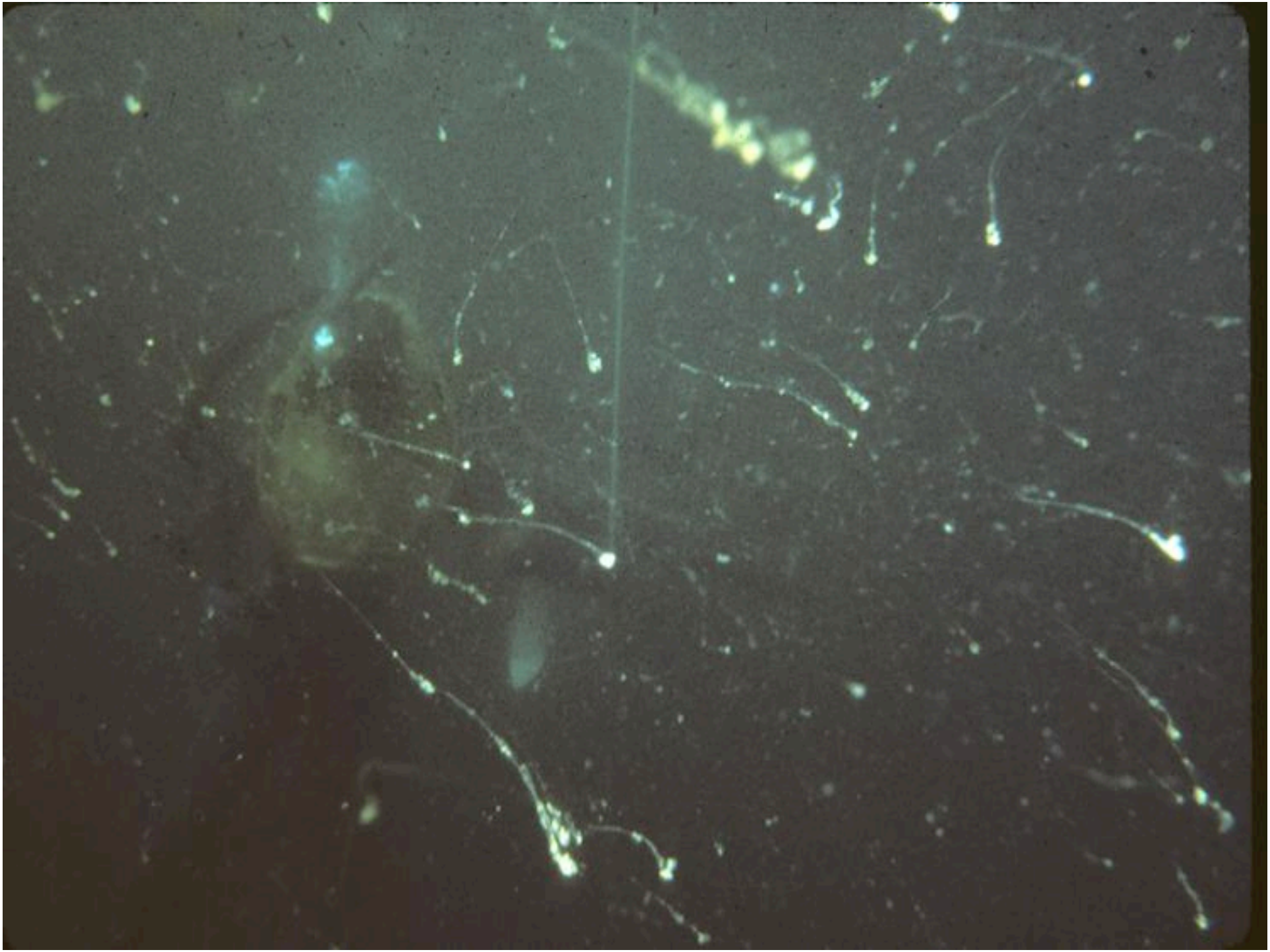


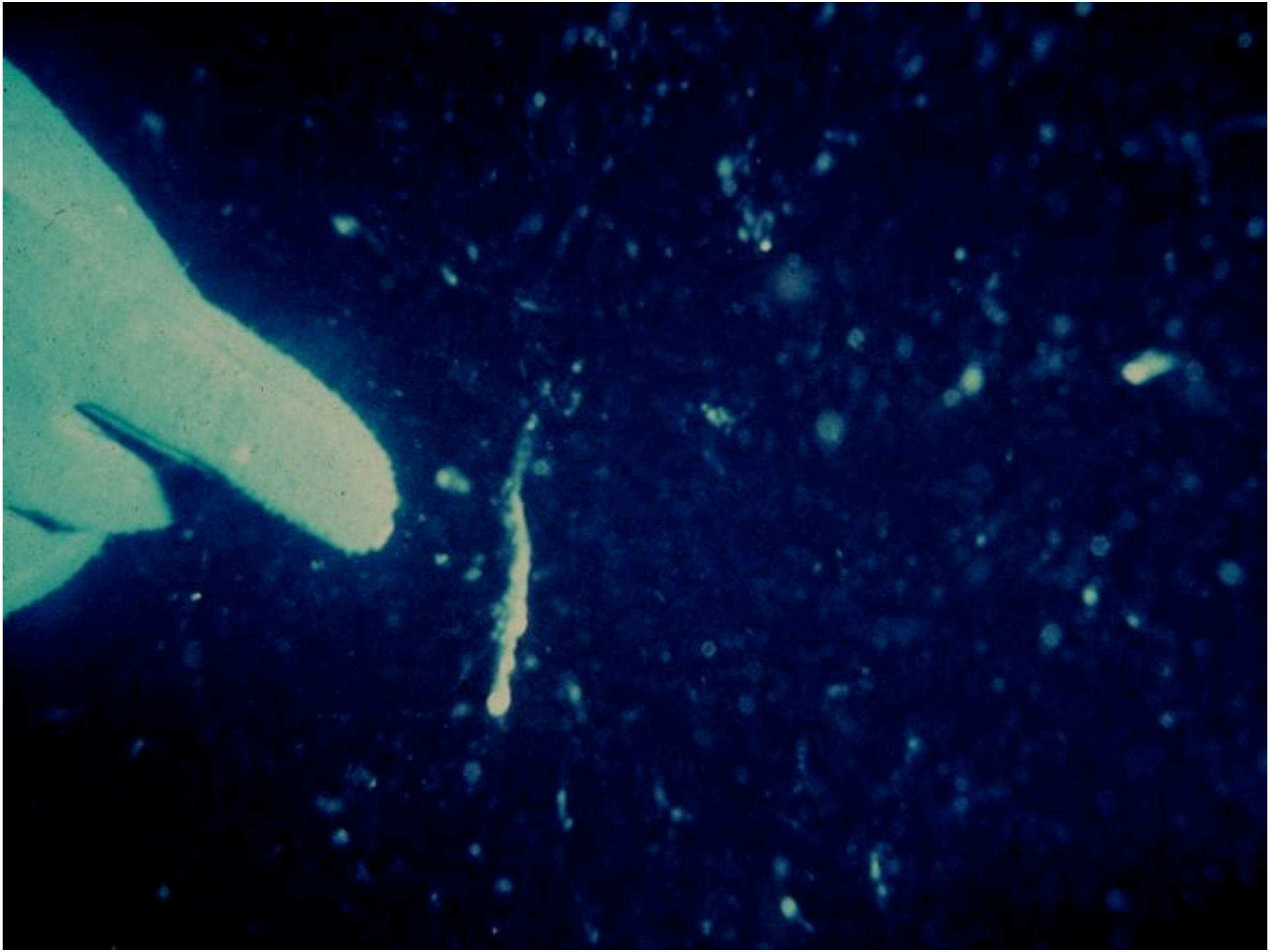


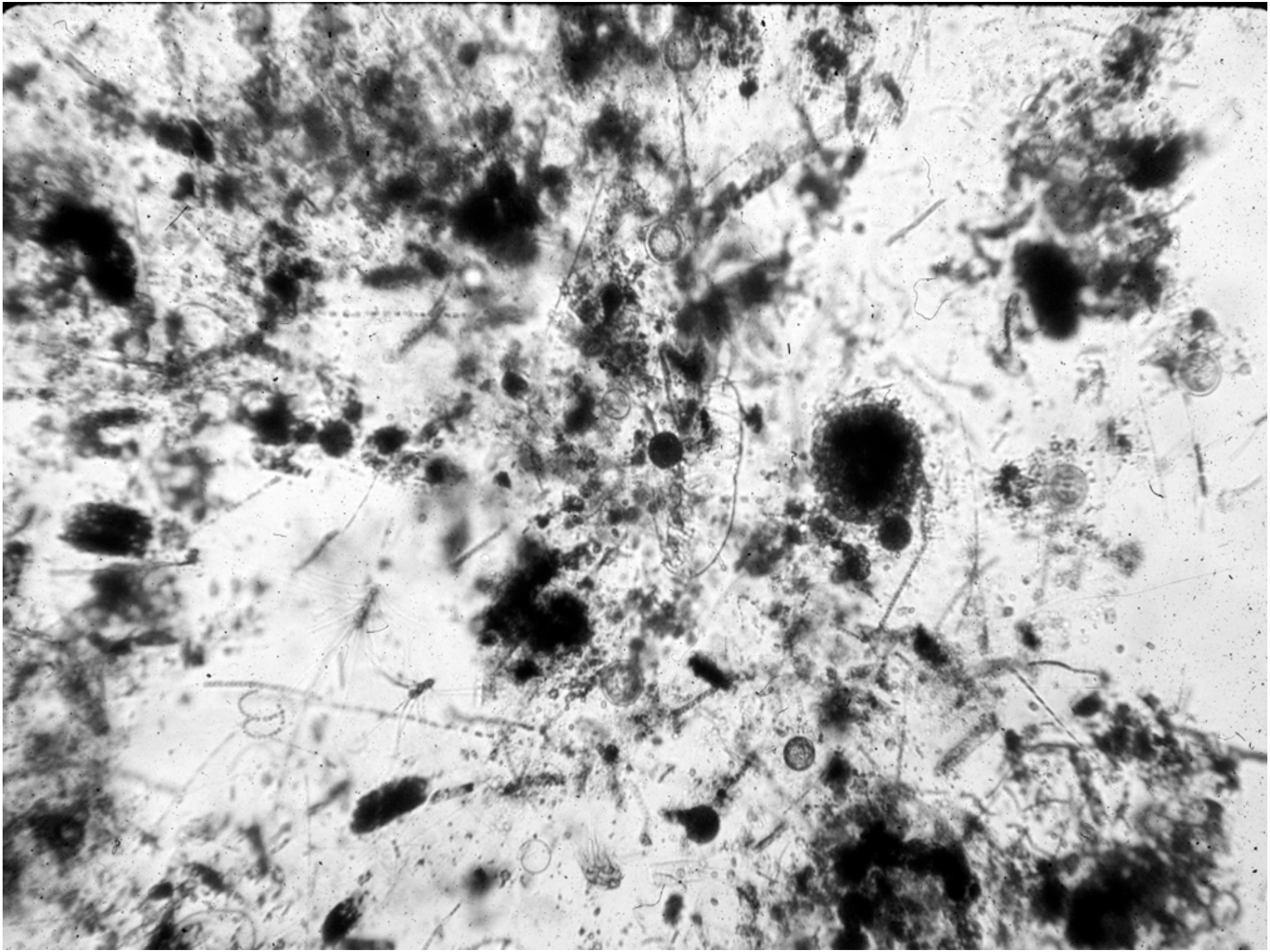


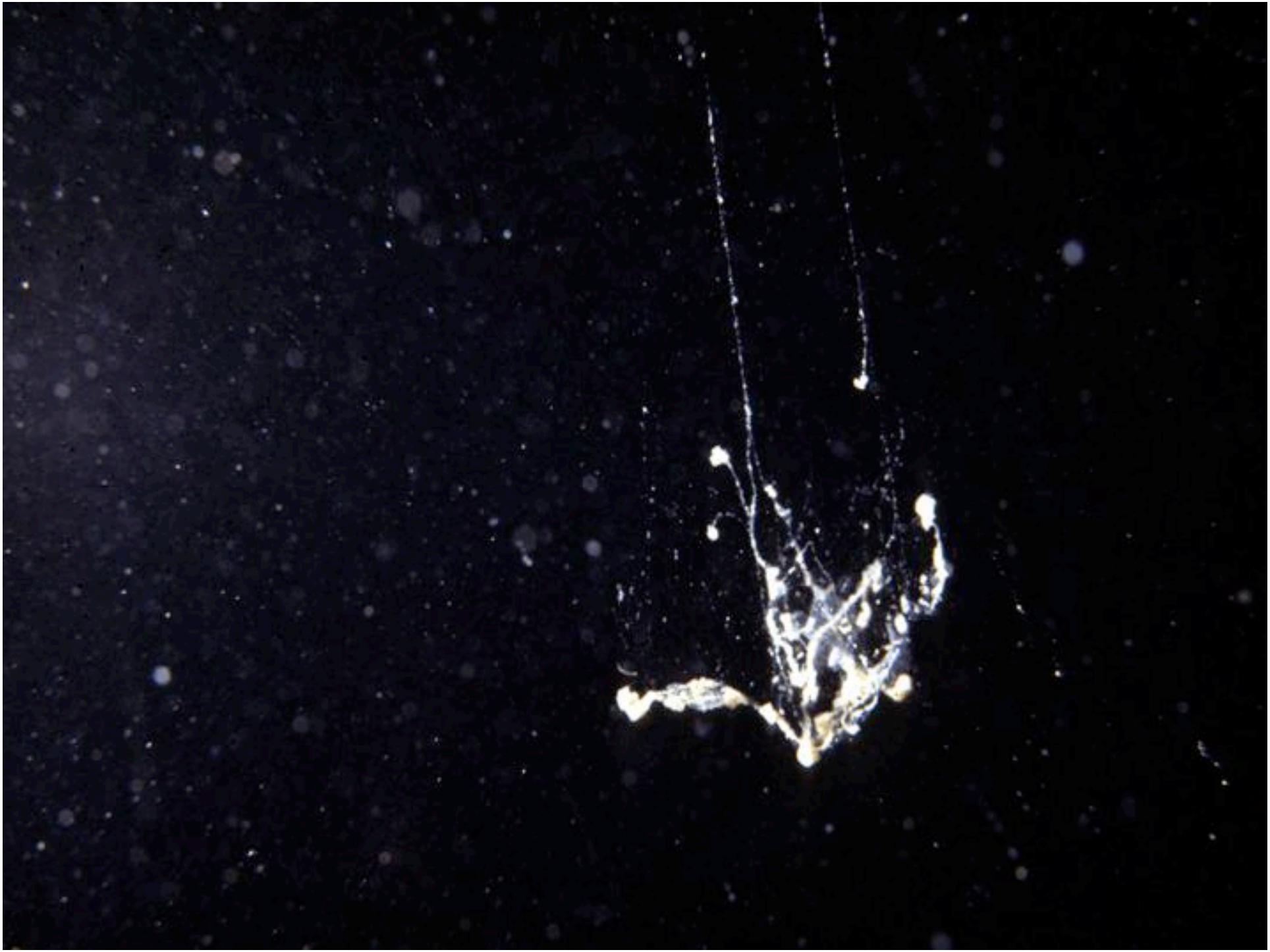












Algae Cultivation Systems

Open circulating ponds (raceways)

Closed bioreactors

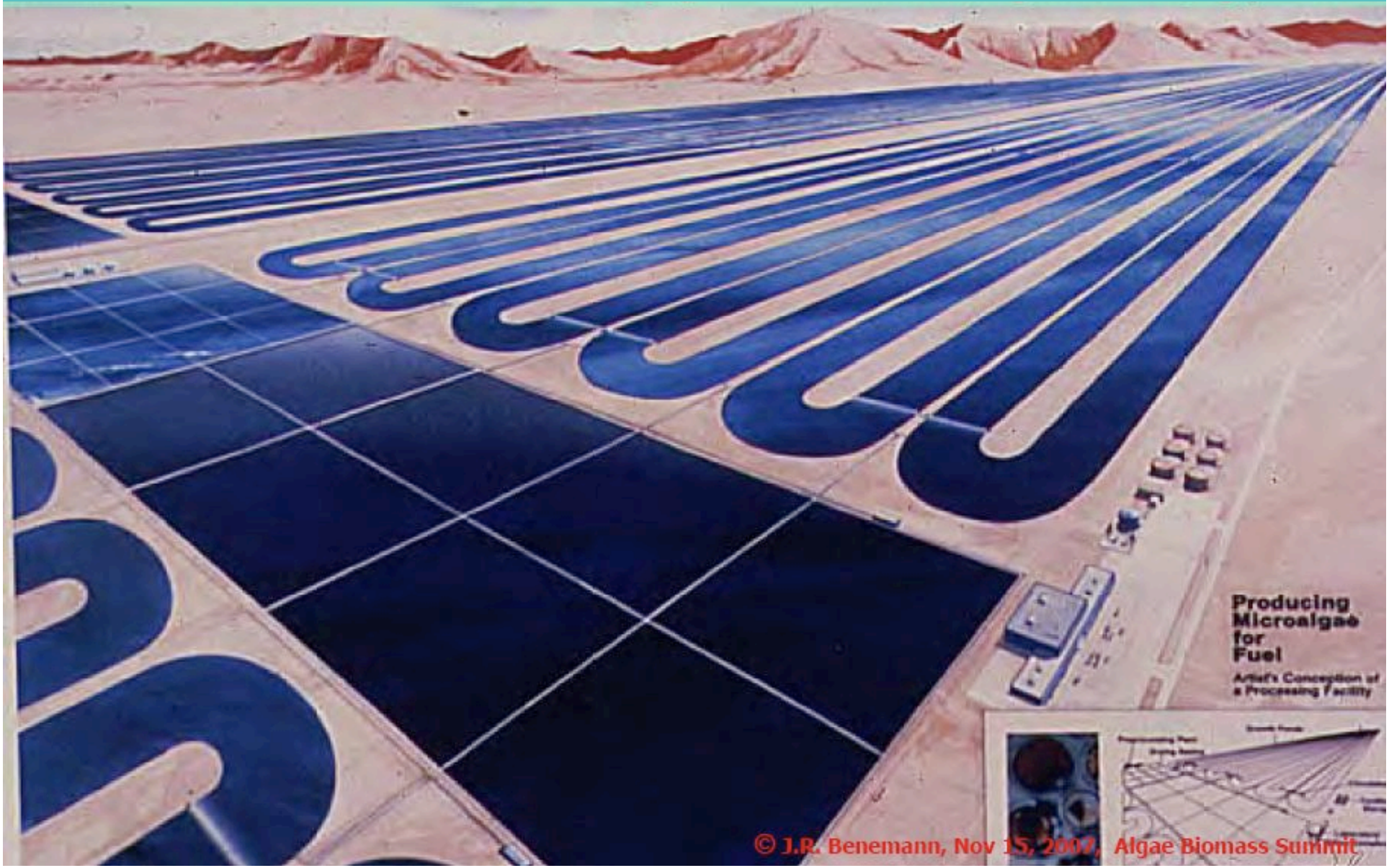

Cyanotech, HI


Yaeyama, Japan

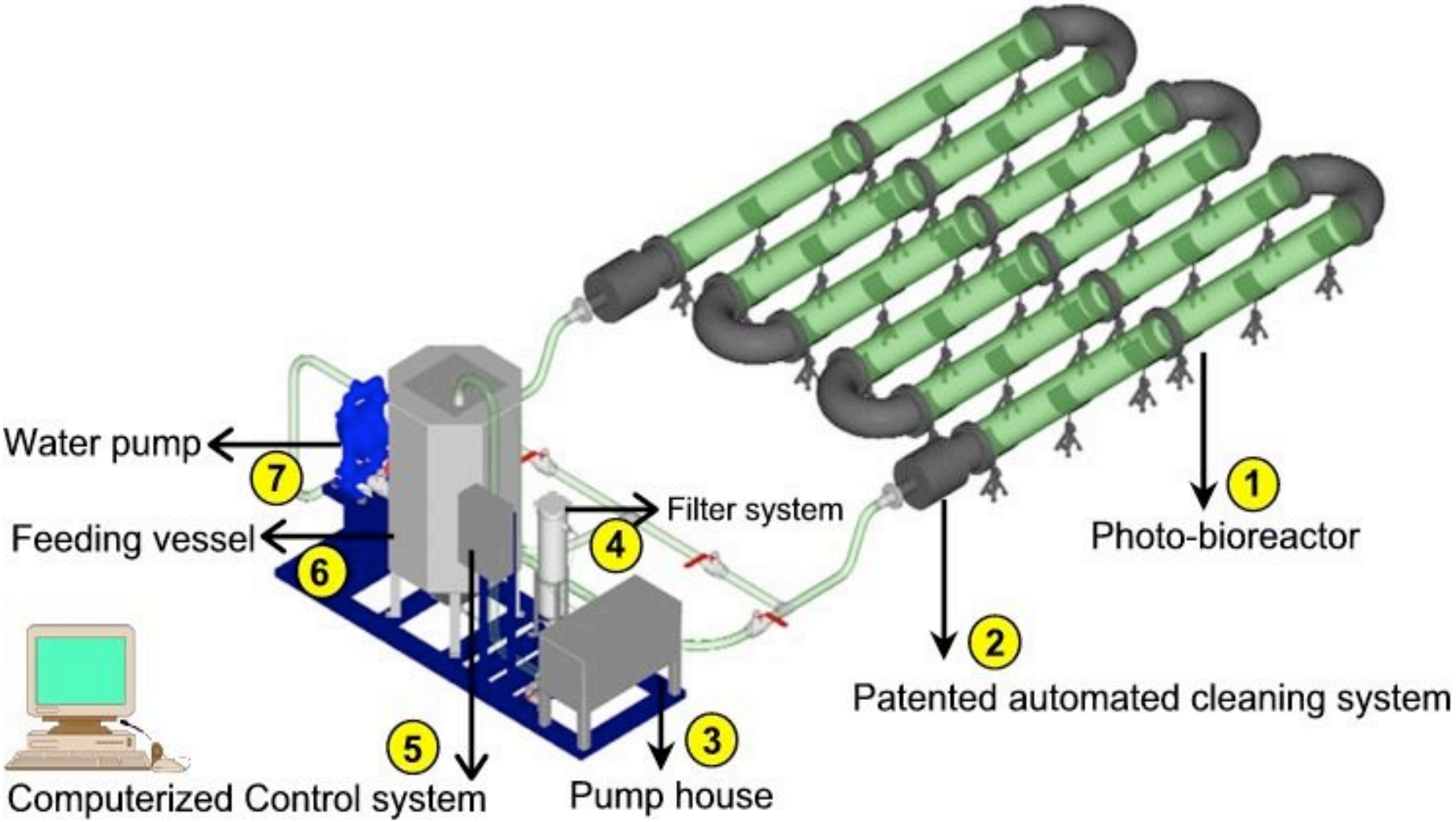

Aquacarotene, Australia


NBT/Seabiotics, Israel

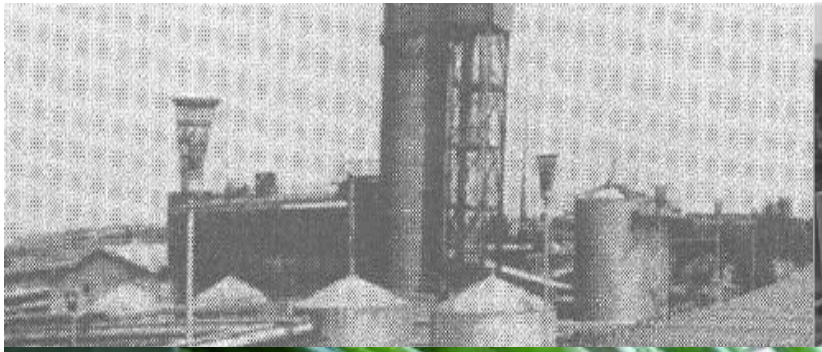
What's wrong with this picture?



Bioreactor



Algal Bioreactor




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

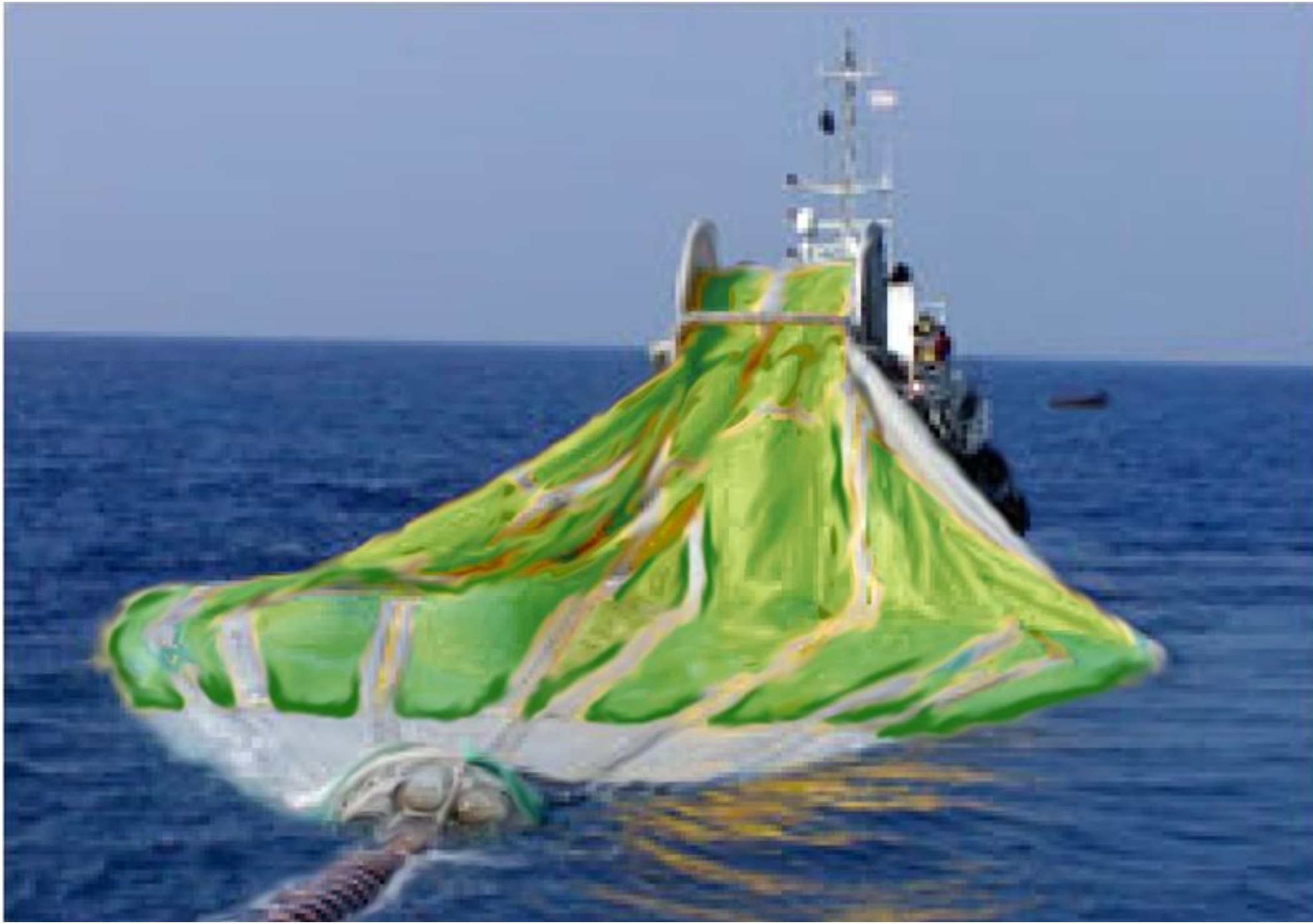
What's wrong with this picture?

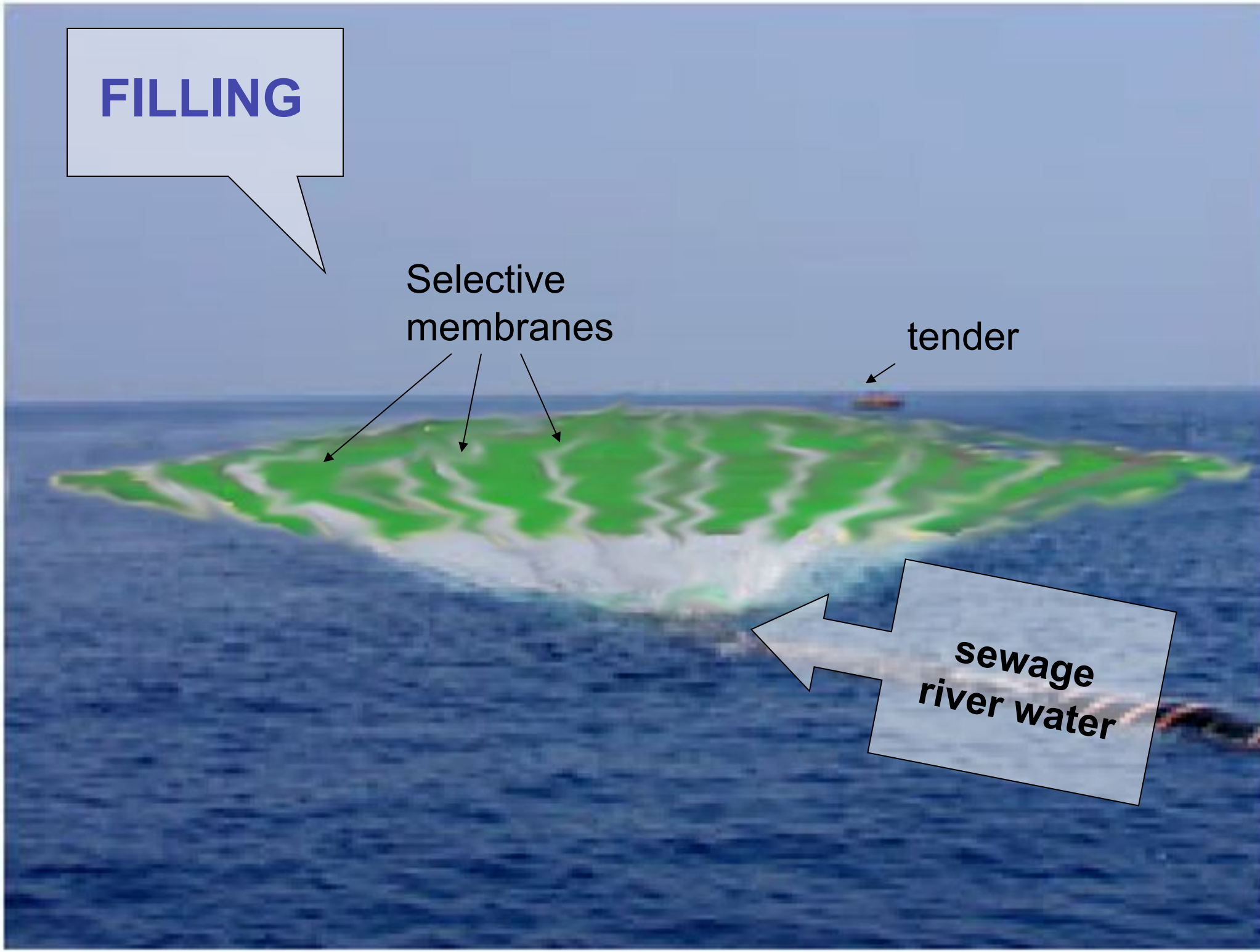
Not practical to grow algae on land…

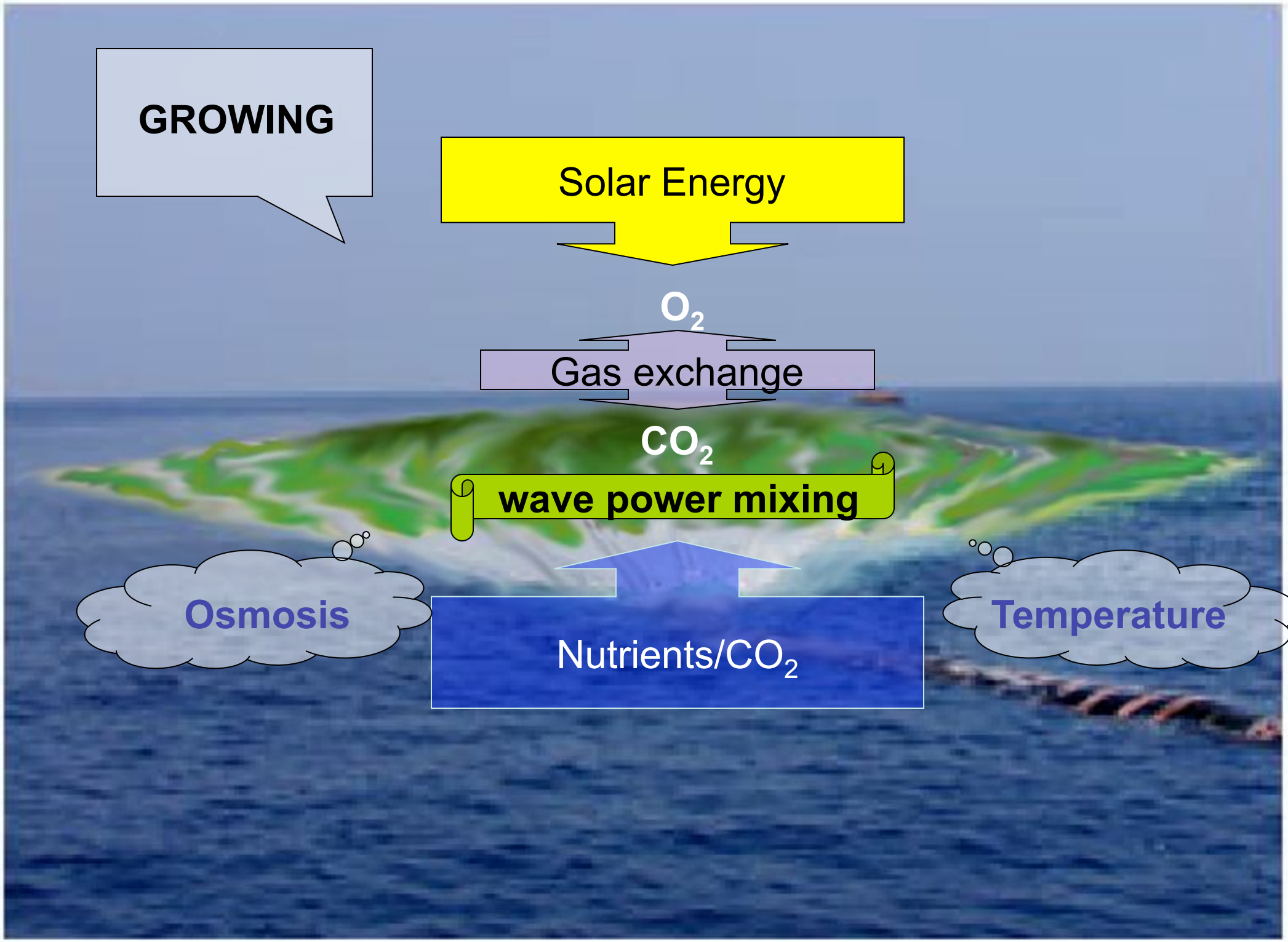
1: Open circulating ponds (raceways)

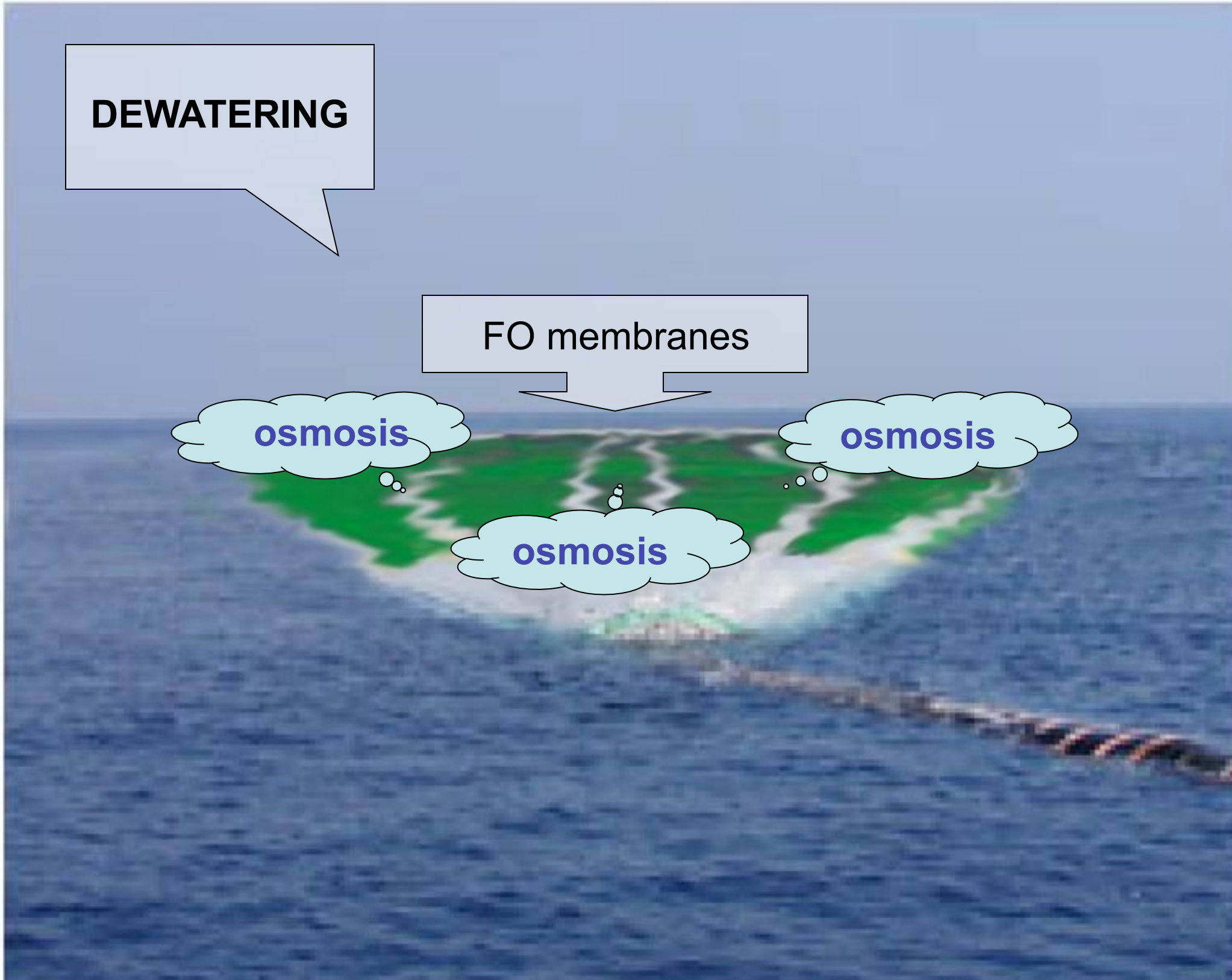
2: Closed photobioreactors (PBRs)

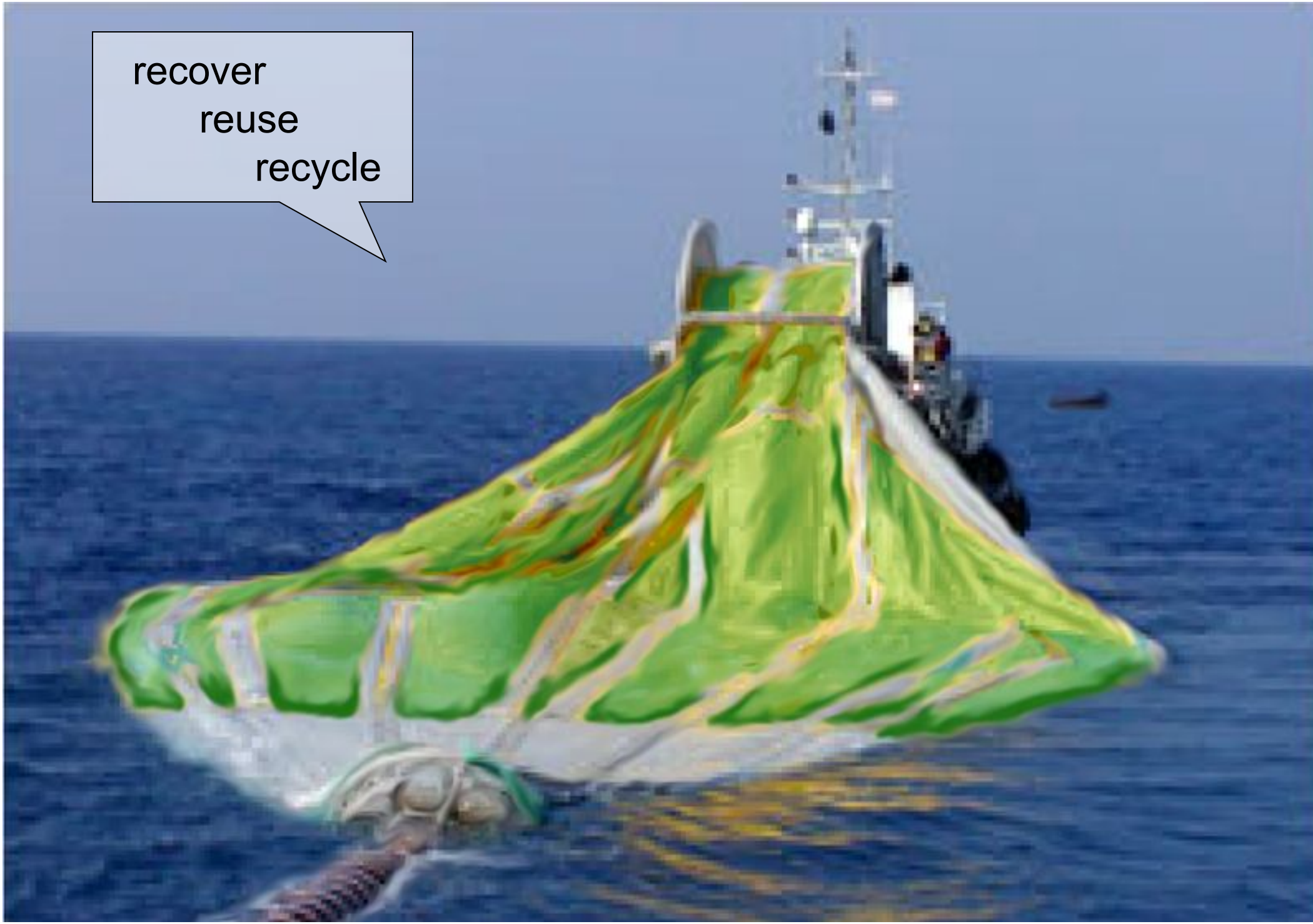

O ffshore
M embrane
E nclosures for
G rowing
A lgae

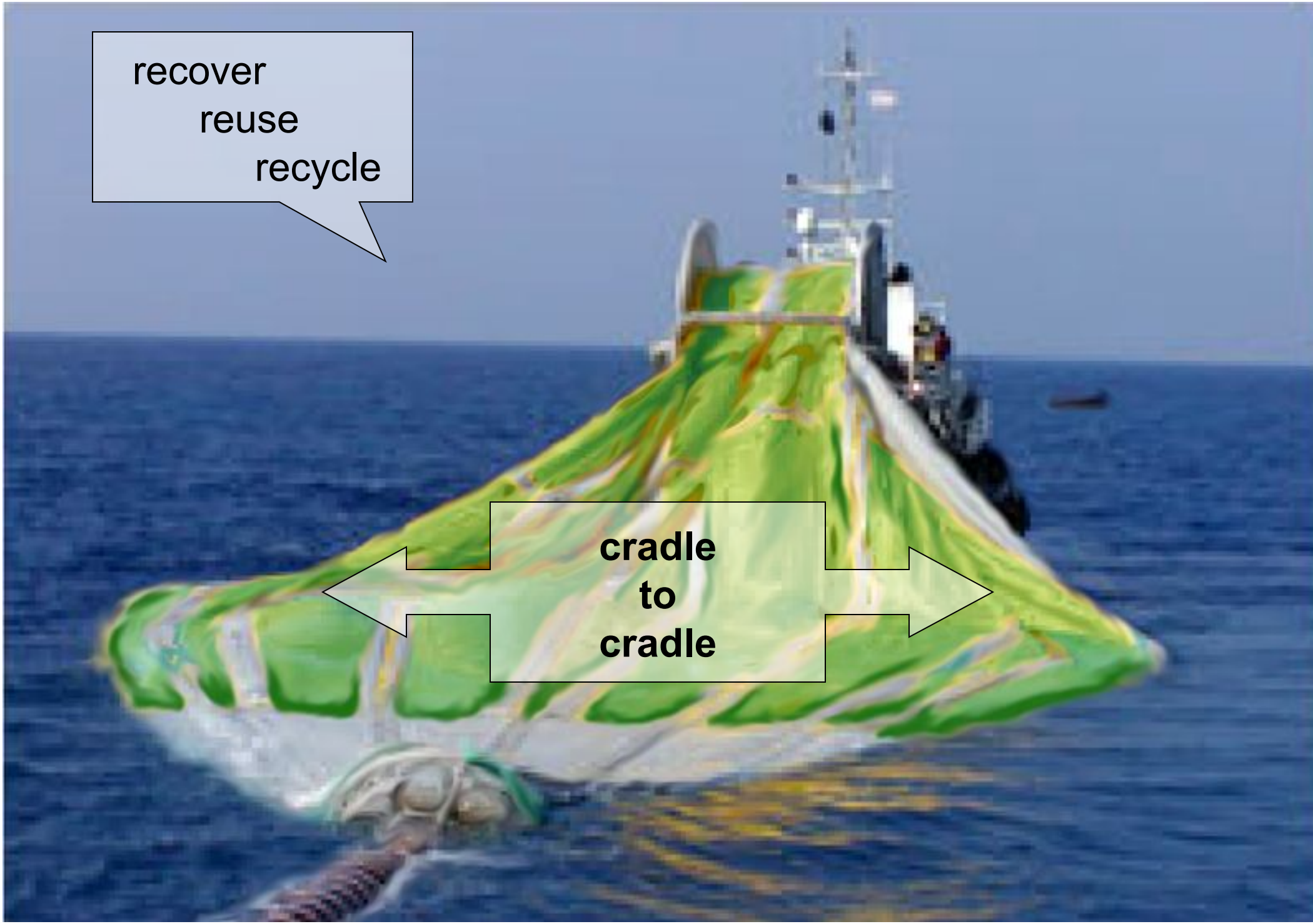


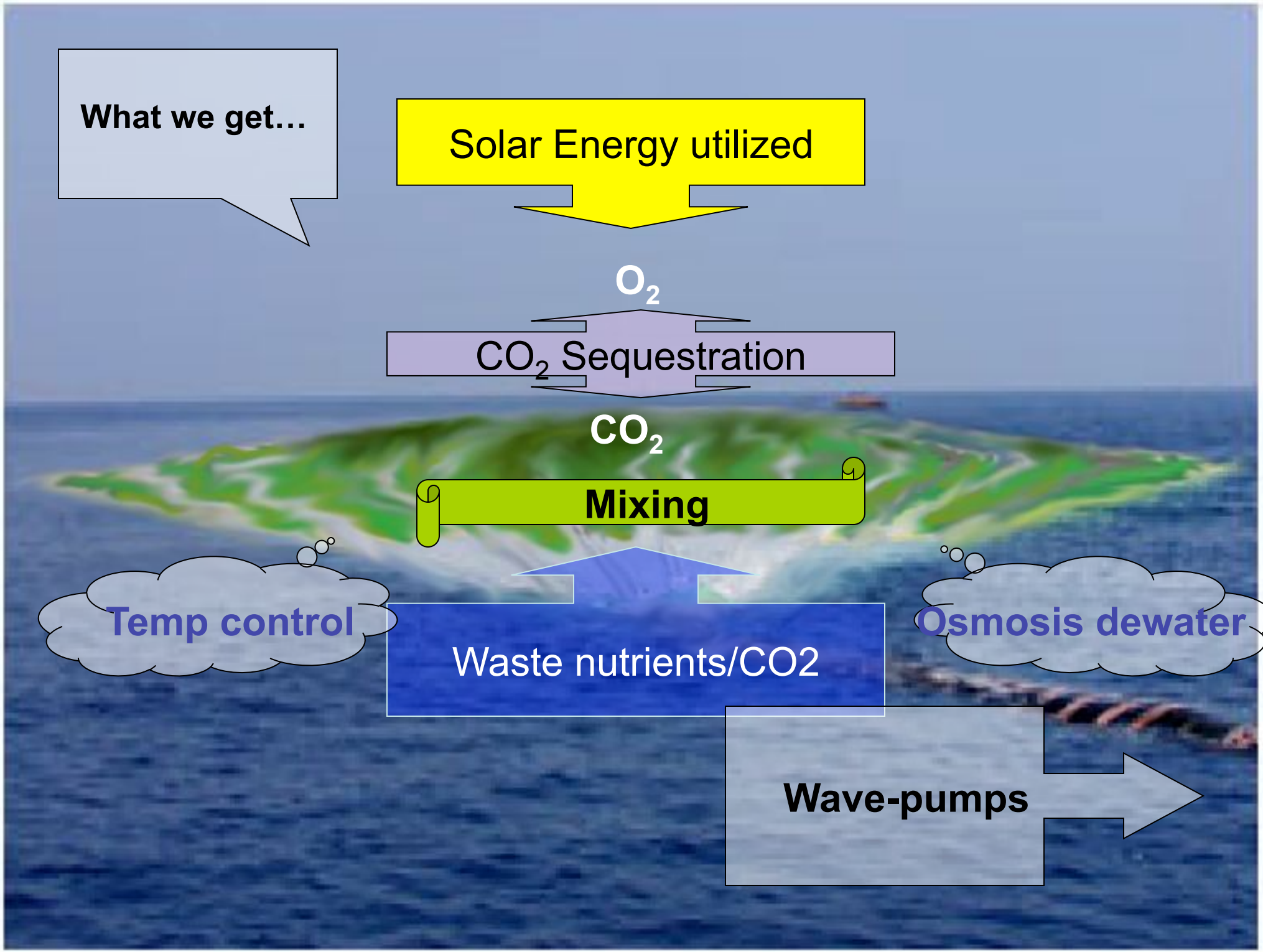

FILLING
Selective membranes
tender
sewage river water

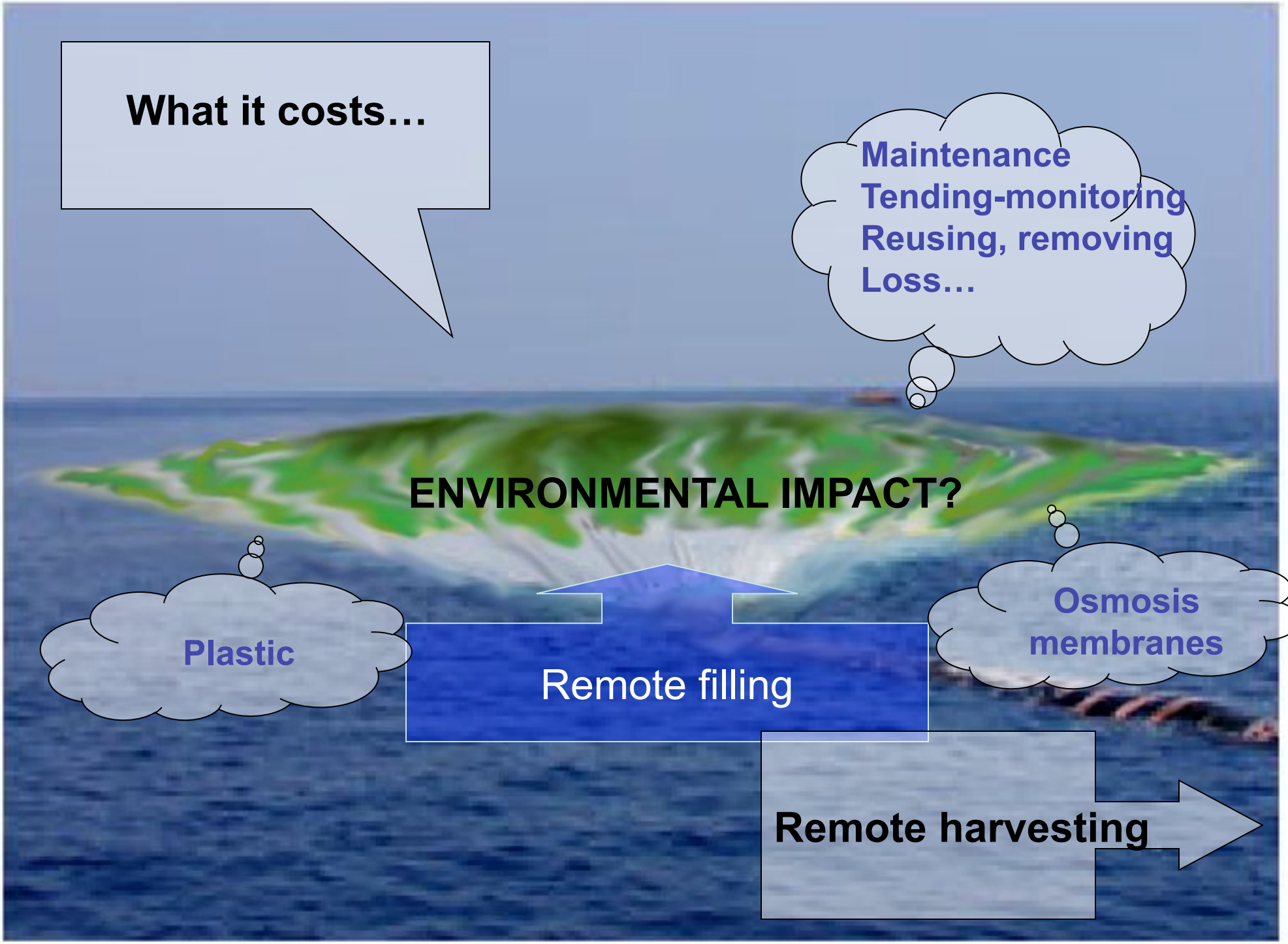

GROWING
Solar Energy
O_2
Gas exchange
CO_2
wave power mixing
Osmosis
Nutrients/CO_2
Temperature

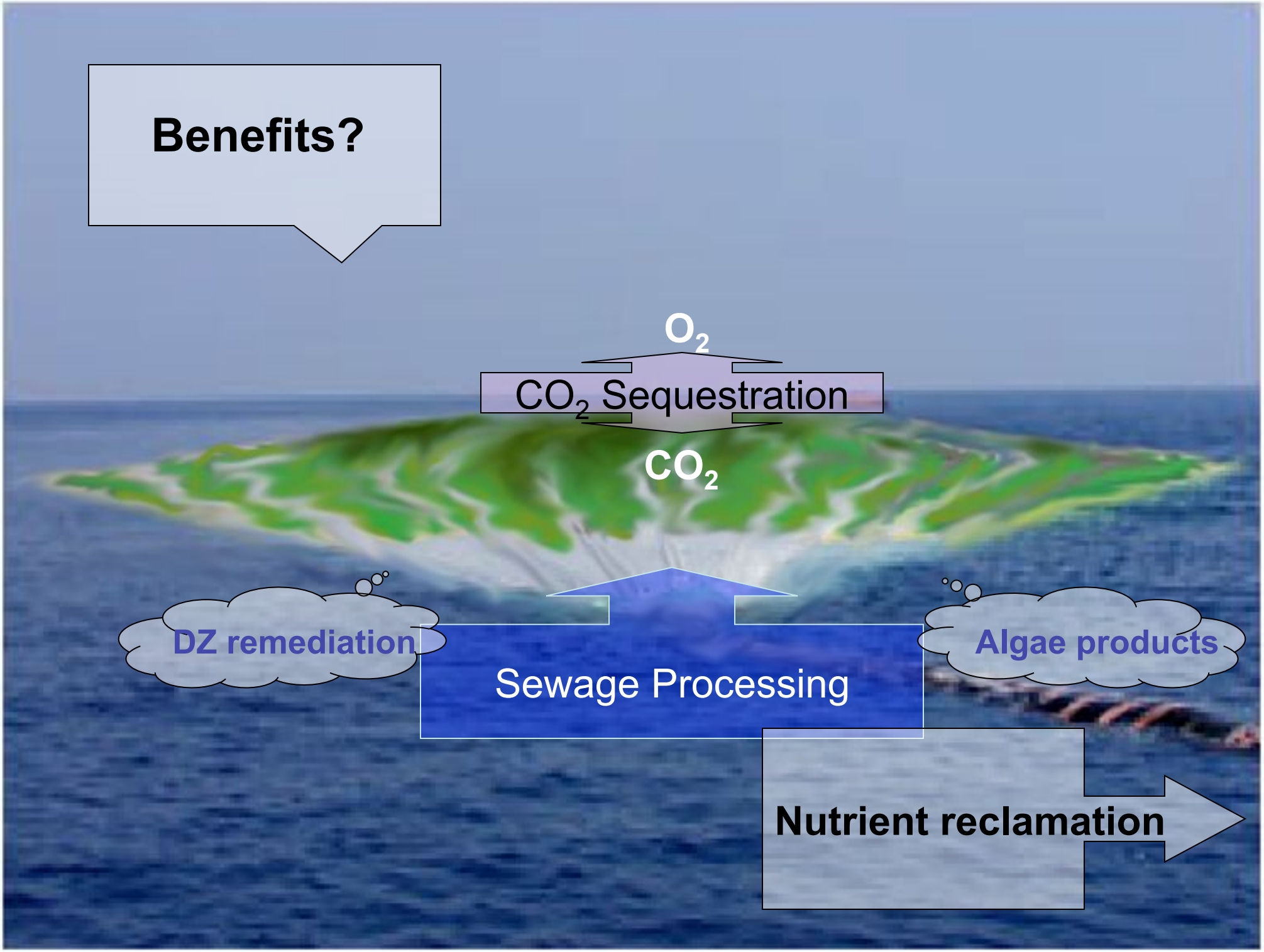

DEWATERING
FO membranes
osmosis
osmosis
osmosis


recover
reuse
recycle


recover
reuse
recycle
cradle
to
cradle


What we get…
Solar Energy utilized
O_2
CO_2 Sequestration
CO_2
Mixing
Temp control
Waste nutrients/CO2
Osmosis dewater
Wave-pumps

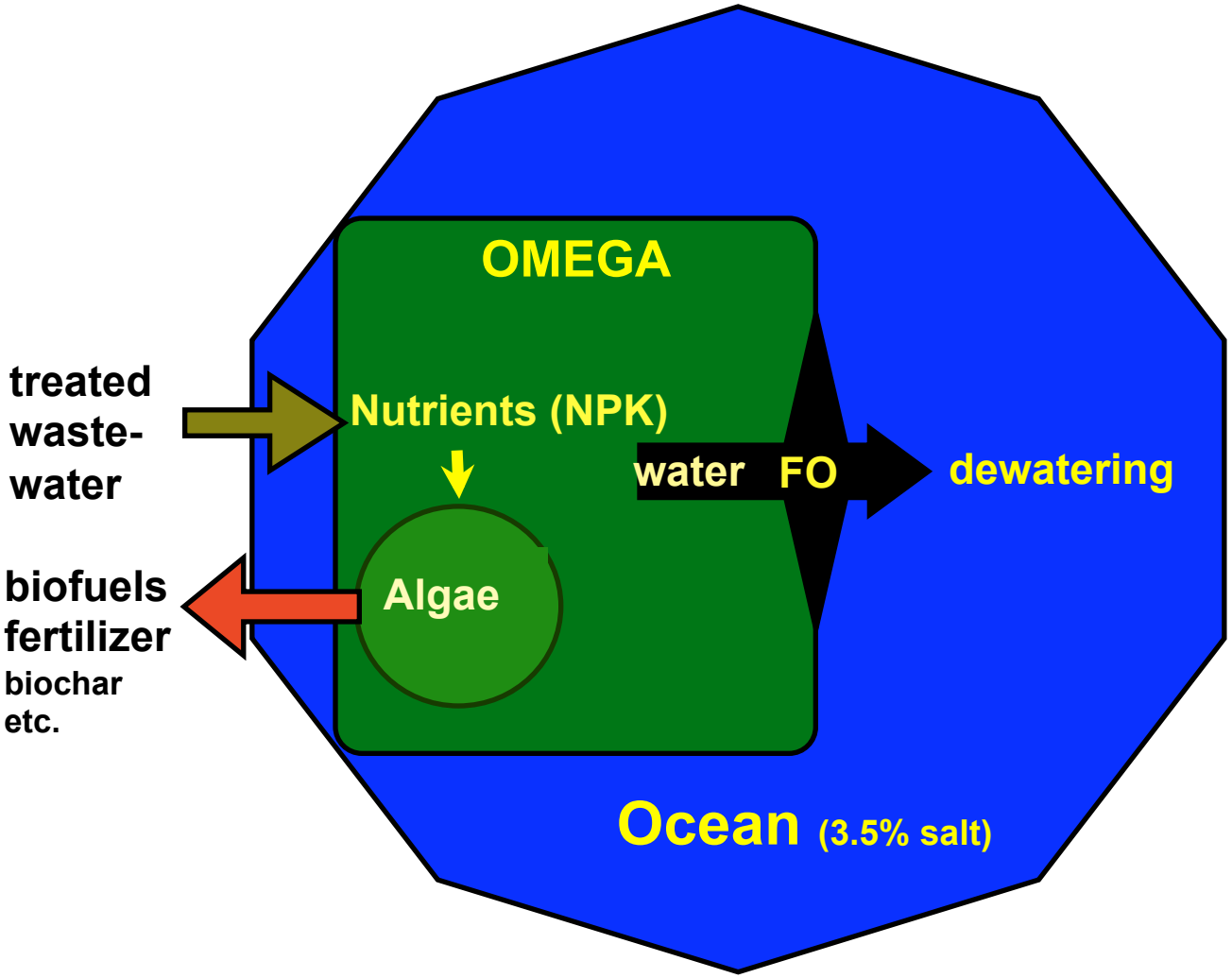

What it costs…
Maintenance
Tending-monitoring
Reusing, removing
Loss…
ENVIRONMENTAL IMPACT?
Plastic
Remote filling
Osmosis membranes
Remote harvesting


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

Critical Factors*	raceway	bioreactor	AlgaeOMEGA
			
Cap/op cost			?
Evaporation			?
Temp. control			?
Invasive spp.			?
Mixing			?
Harvesting			?
Envir. impact			?

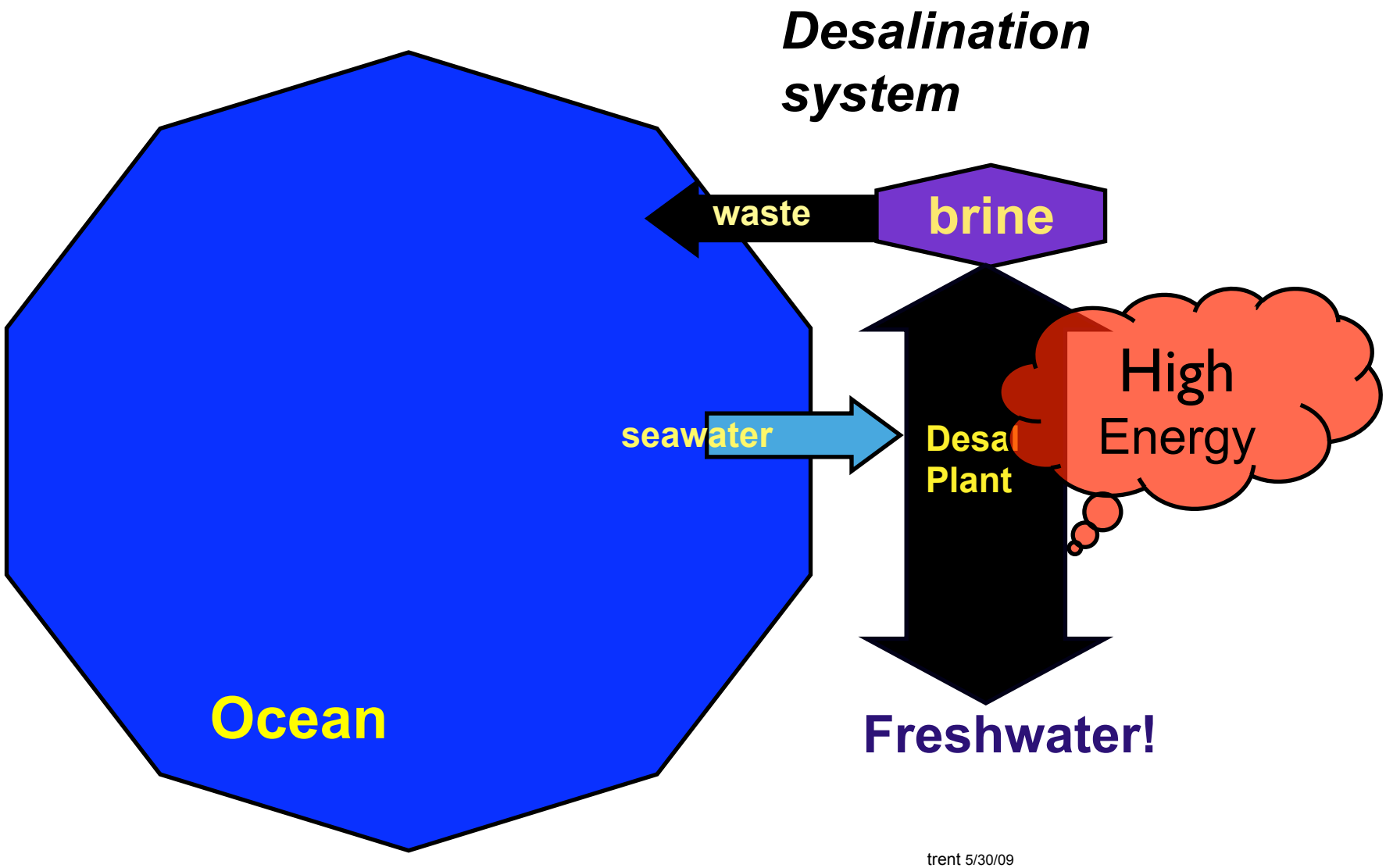
***Biology, Engineering, Environment, Economics**

OMEGA system

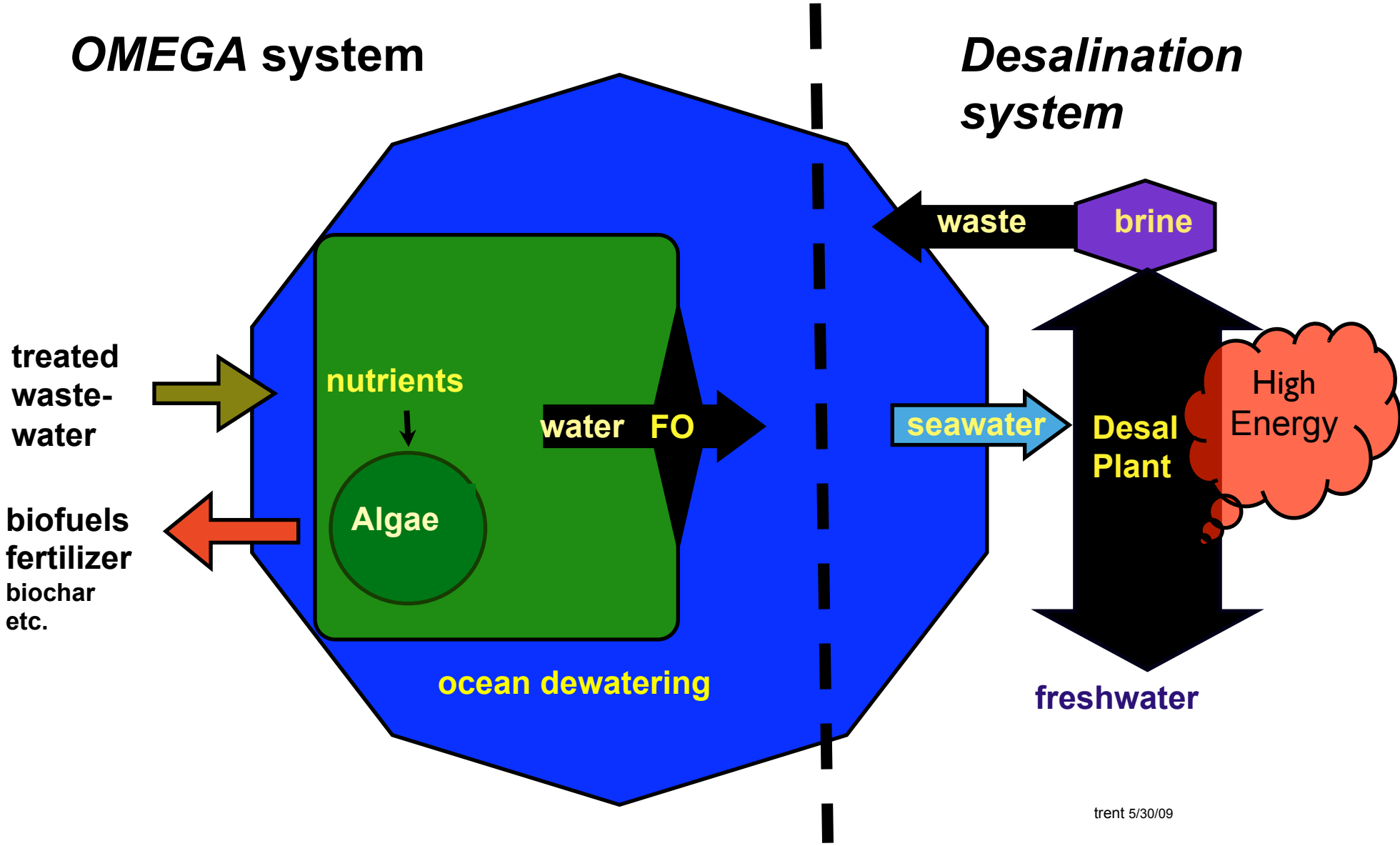


trent 5/30/09

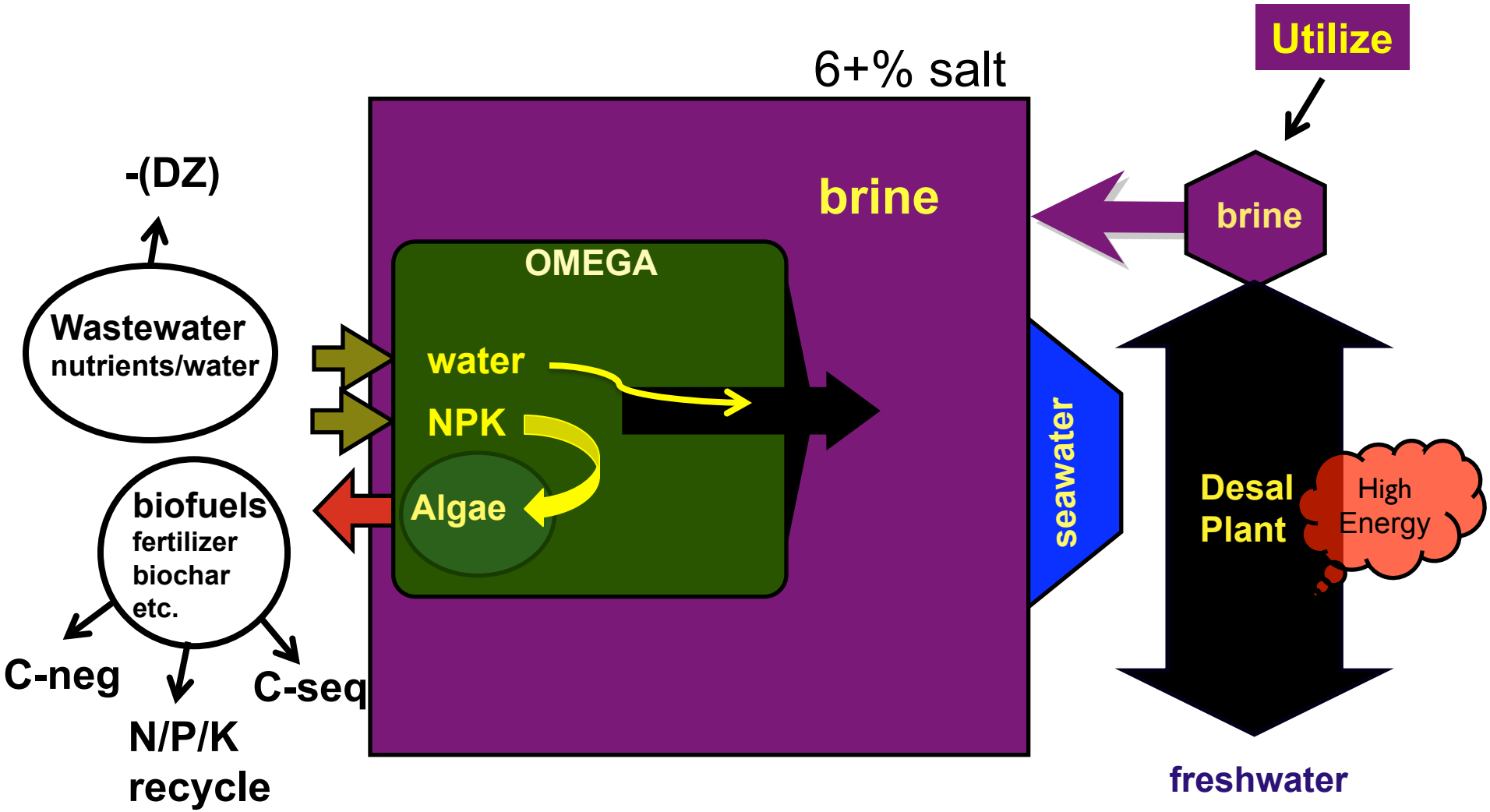
What about the water?


Desalination system
waste
brine
seawater
Desal Plant
High Energy
Ocean
Freshwater!

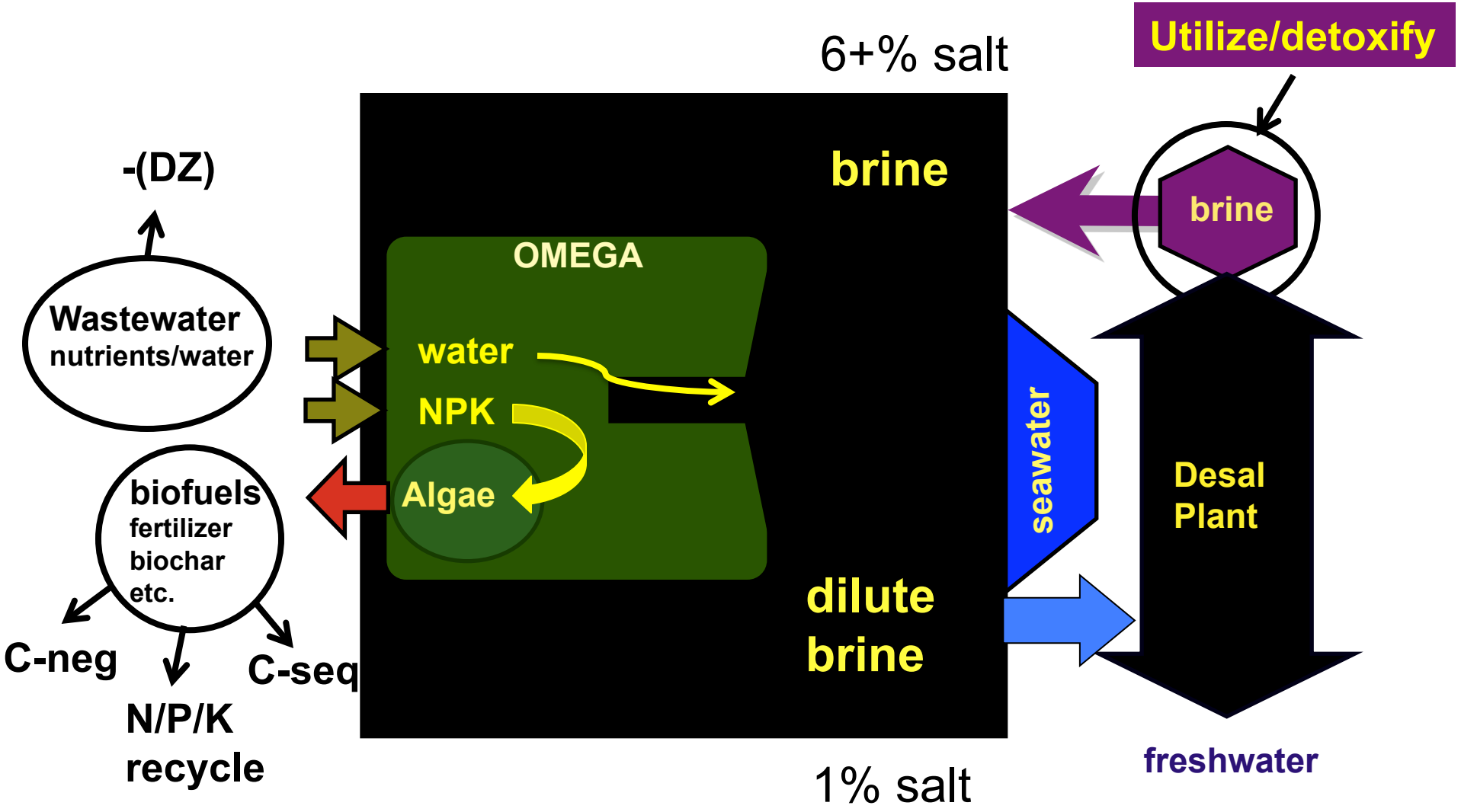
trent 5/30/09


OMEGA system
Desalination system
waste
brine
treated waste-water
nutrients
water
FO
seawater
Desal Plant
High Energy
biofuels
fertilizer
biochar
etc.
Algae
ocean dewatering
freshwater
trent 5/30/09

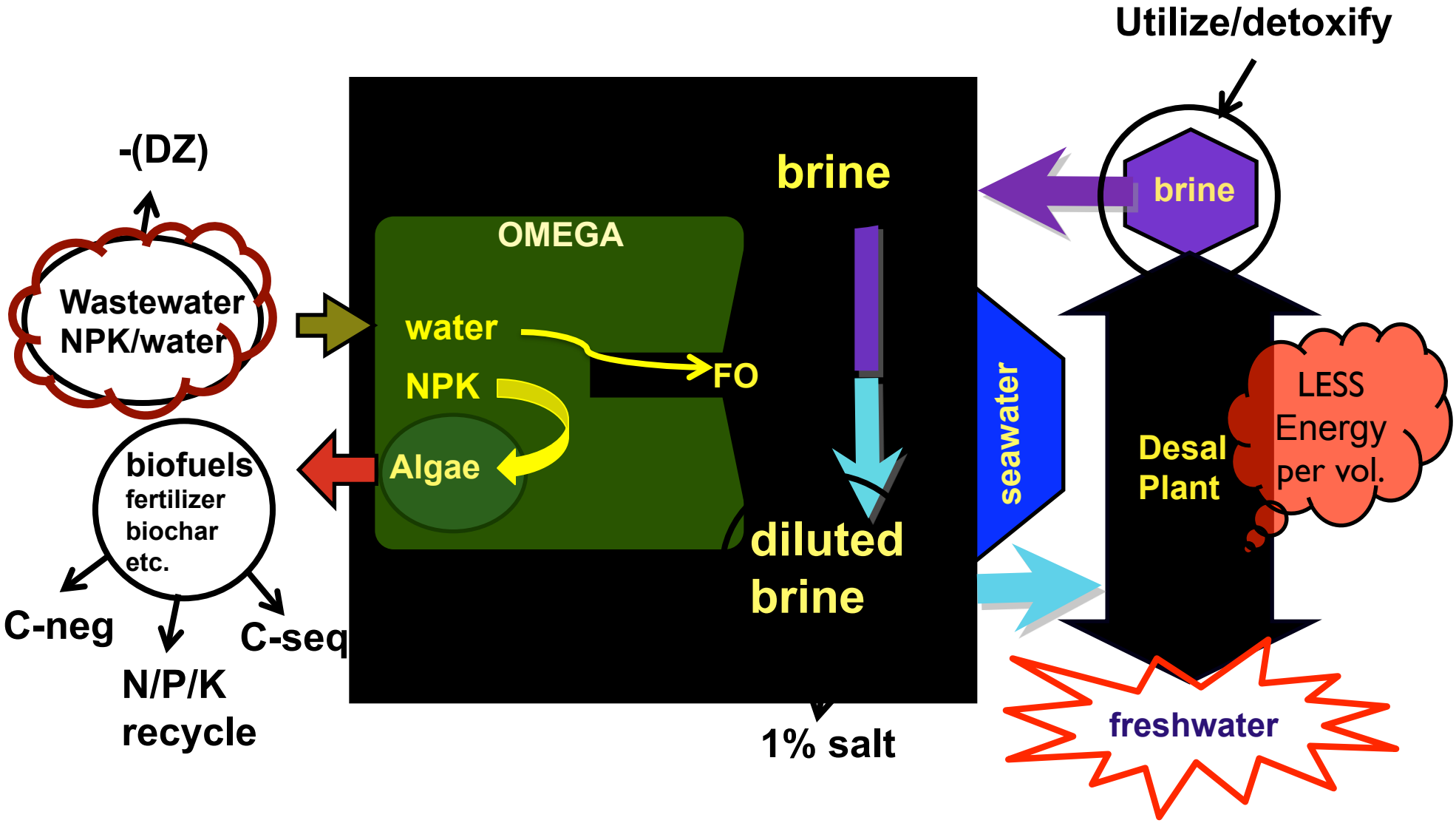
Desalgae system (OMEGA + Desalination)



Desalgae system (OMEGA + Desalination)

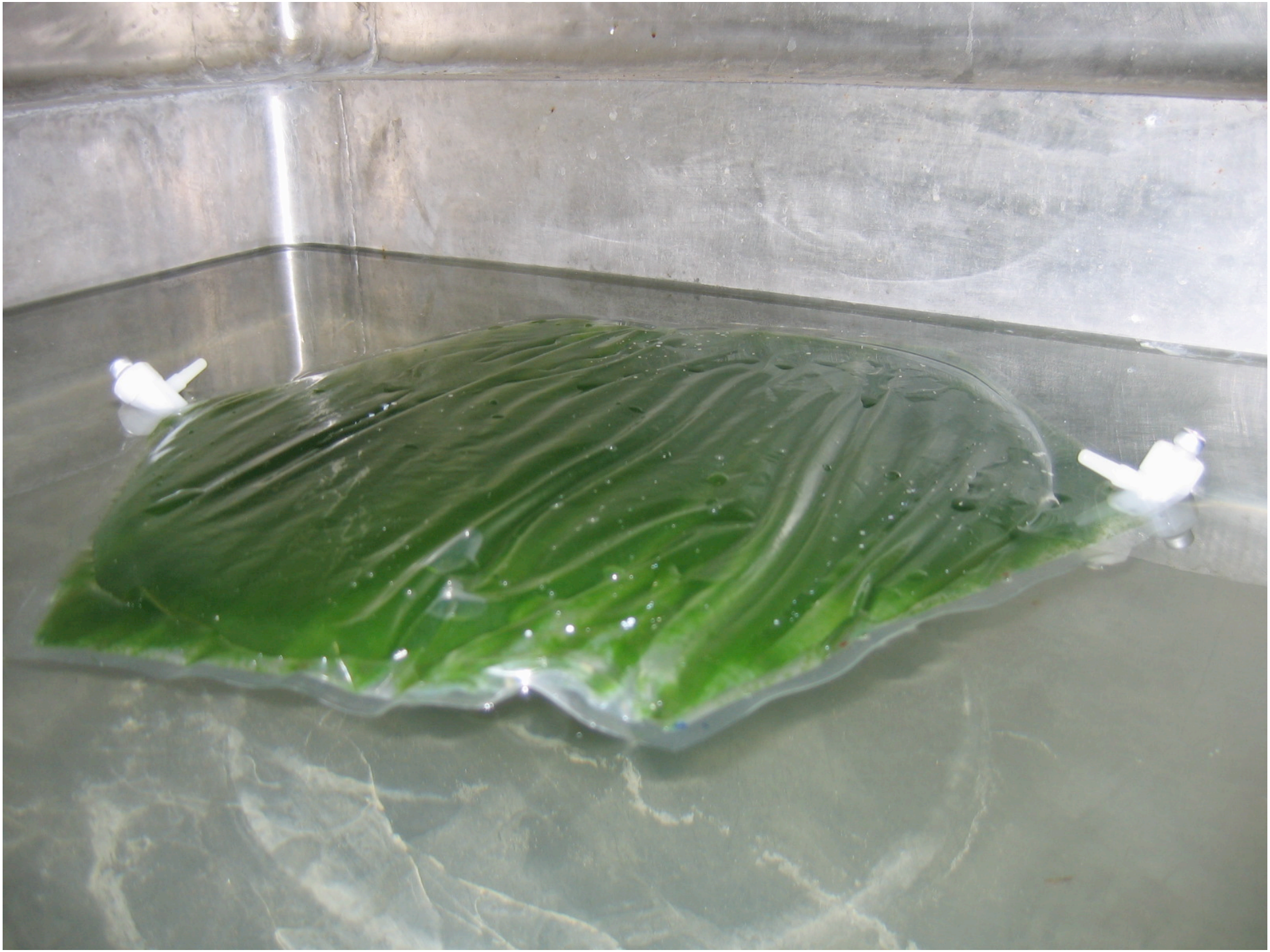


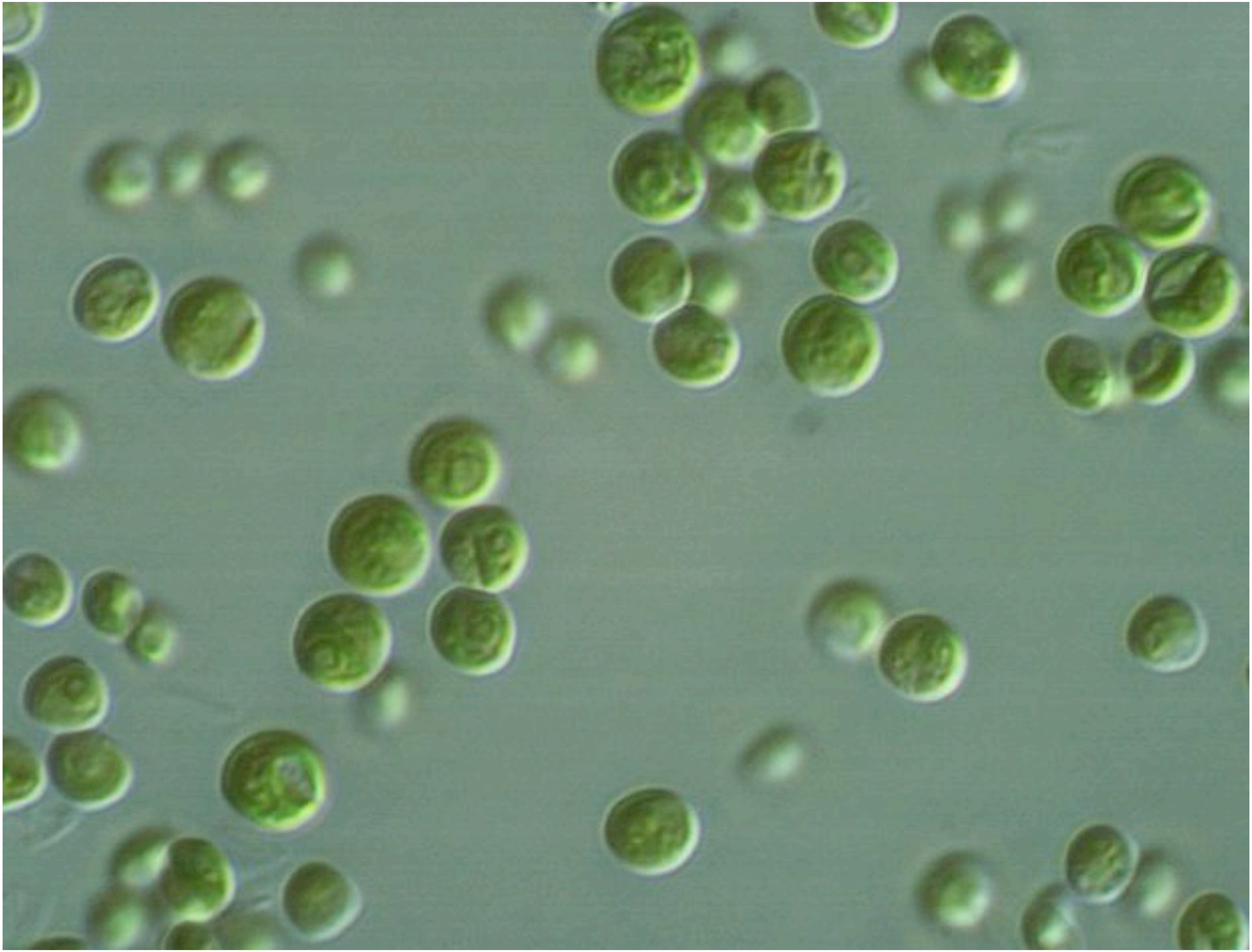
Desalgae system (OMEGA + Desalination)

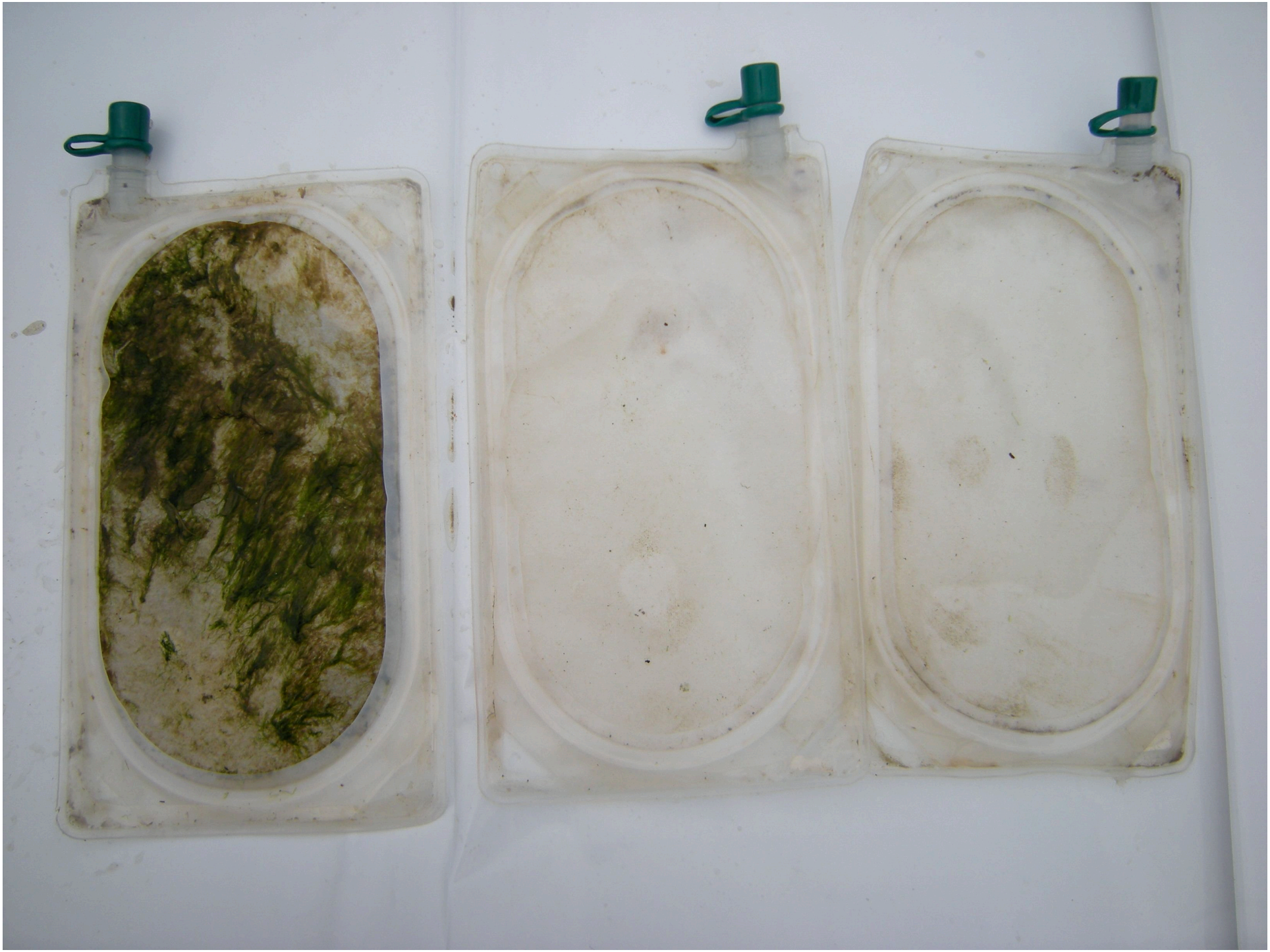


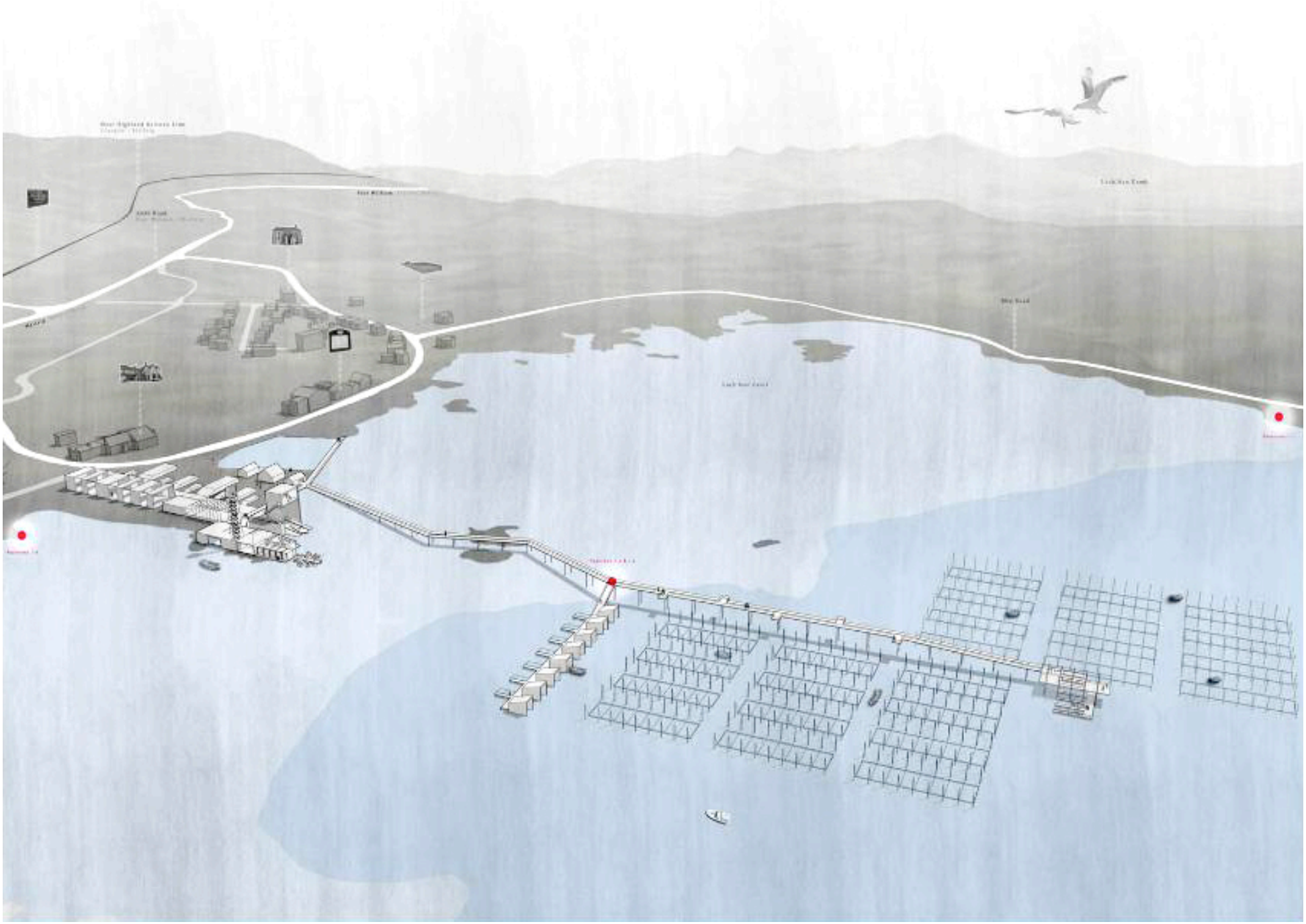

OMEGA Challenges?
•Biology
•Engineering
•Economics
•Environment (policy, politics)


OMEGA
•What have we done?
•Barriers to success?
•Materials
•Logistics
•Collaboration?

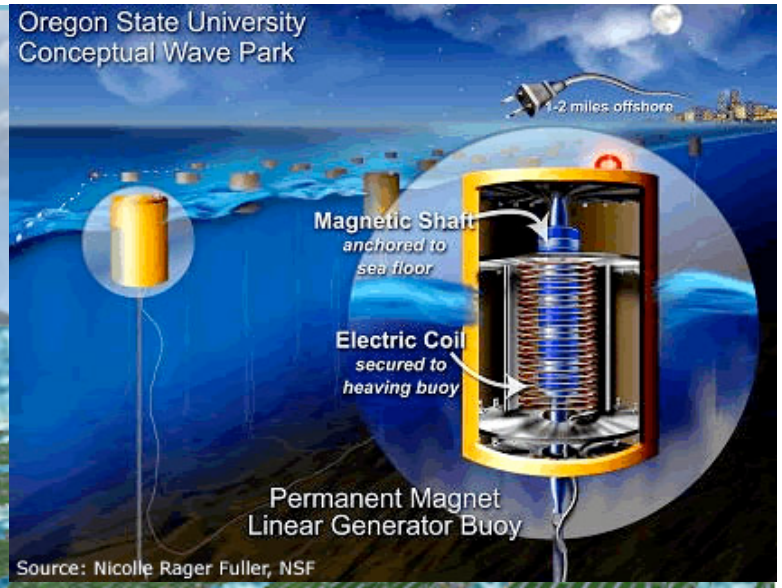


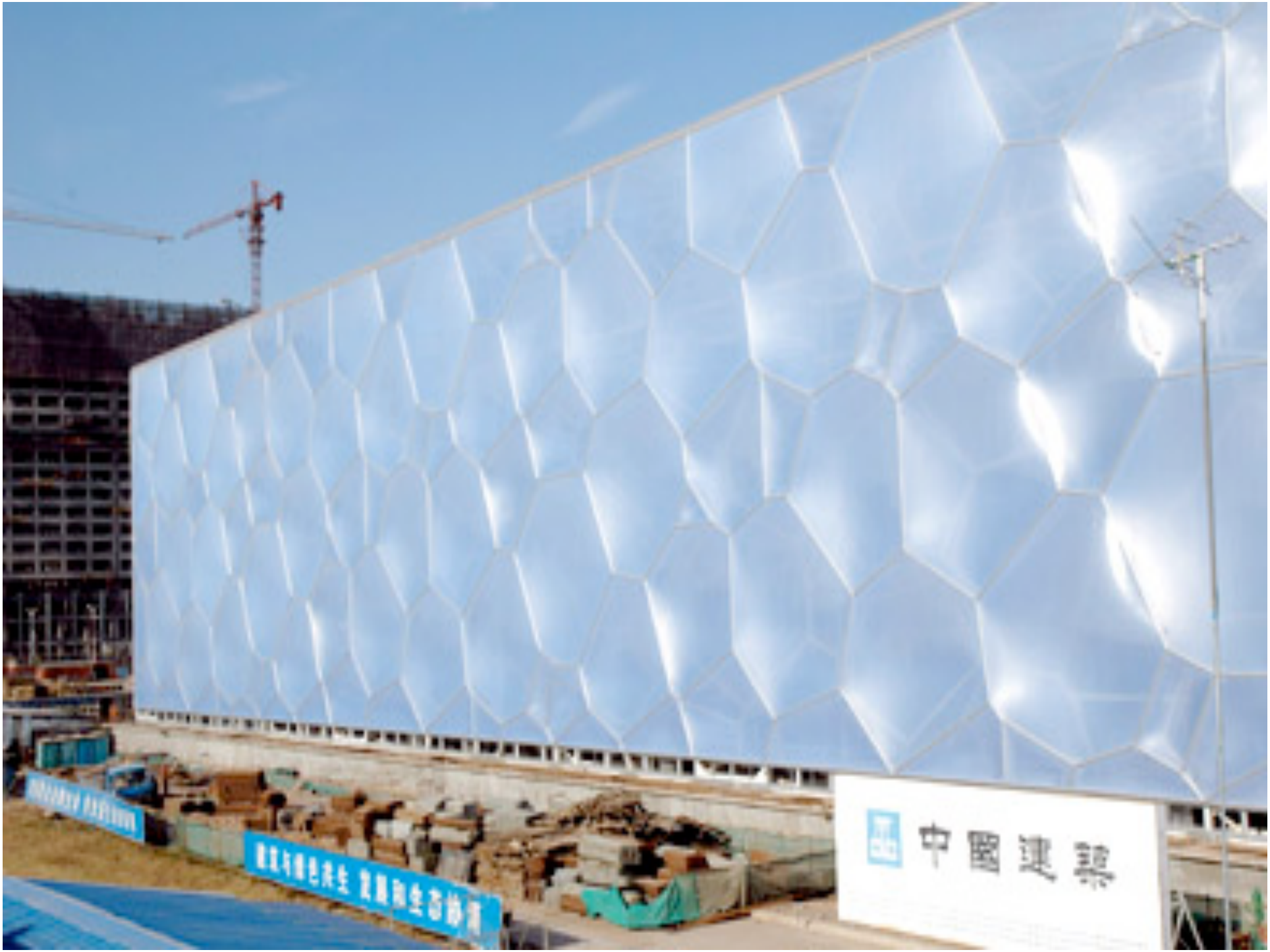


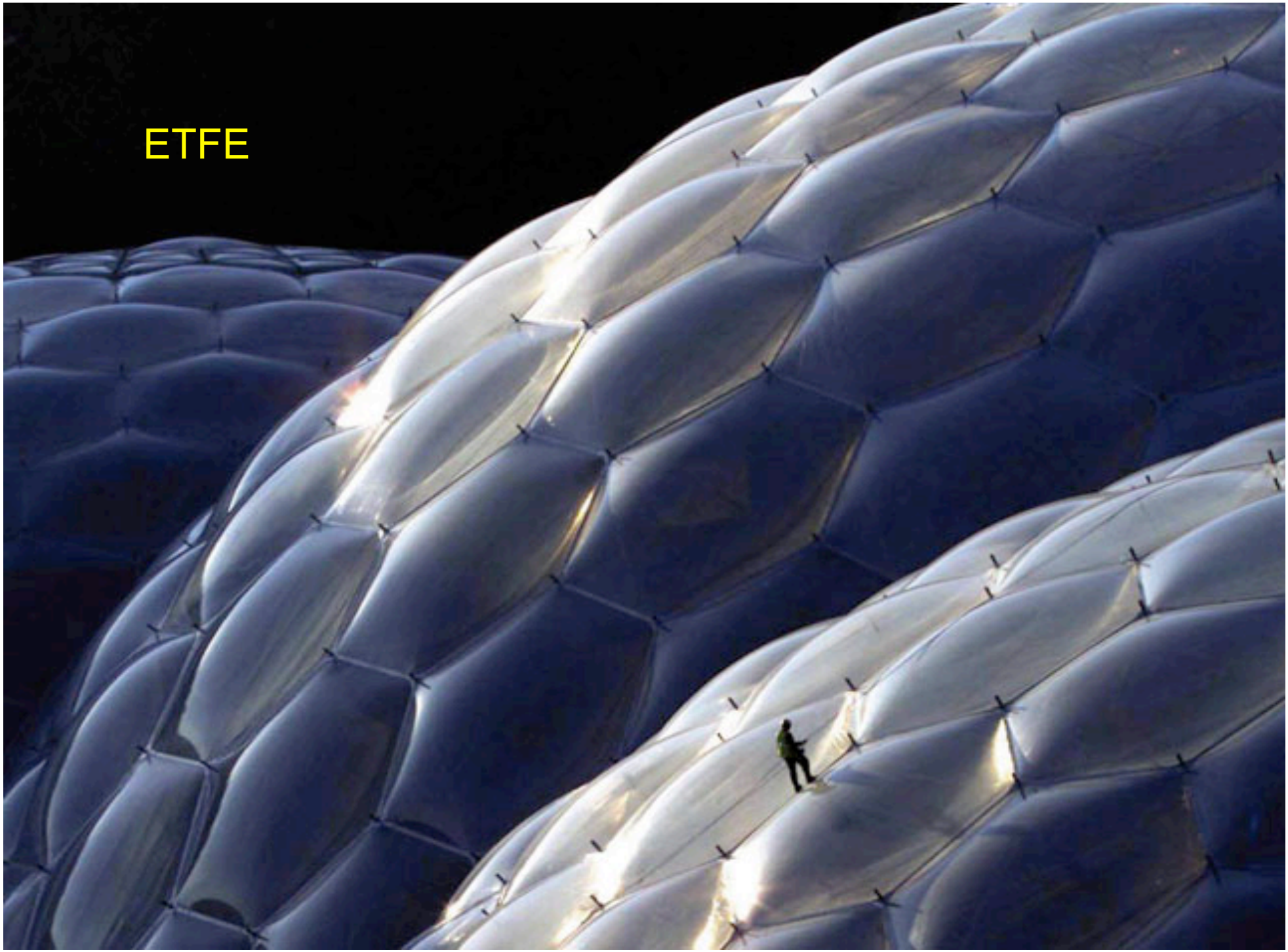




The vision…

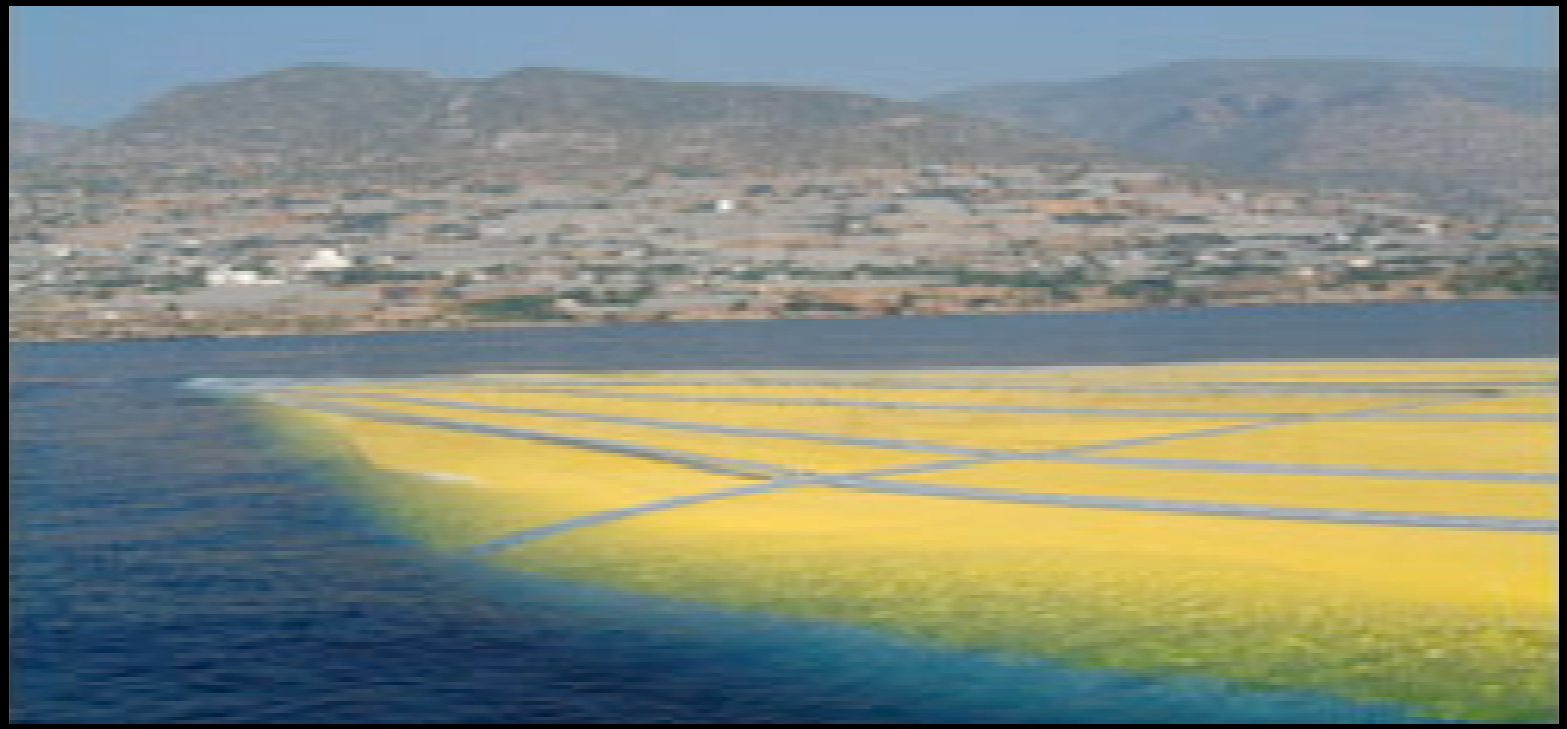

Oregon State University
Conceptual Wave Park
1-2 miles offshore
Magnetic Shaft
anchored to
sea floor
Electric Coil
secured to
heaving buoy
Permanent Magnet
Linear Generator Buoy
Source: Nicolle Rager Fuller, NSF


中国建筑


ETFE


OMEGA Logistics
•Biology
•Engineering
•Environment
•Economics

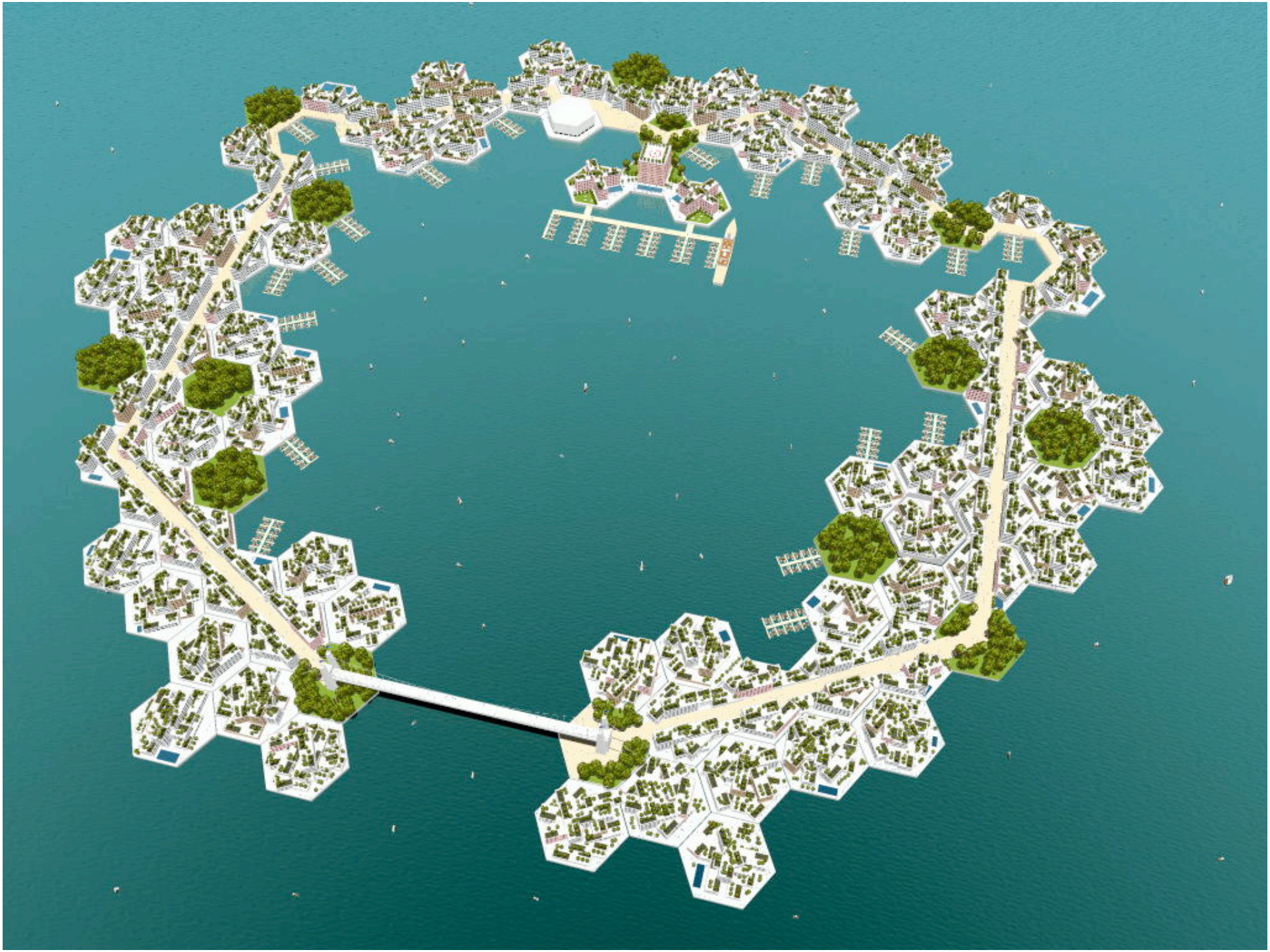

Come to the edge, he said.
We're afraid, they said.
Come to the edge, he said.
He pushed them…
And they flew…
Apollonaire



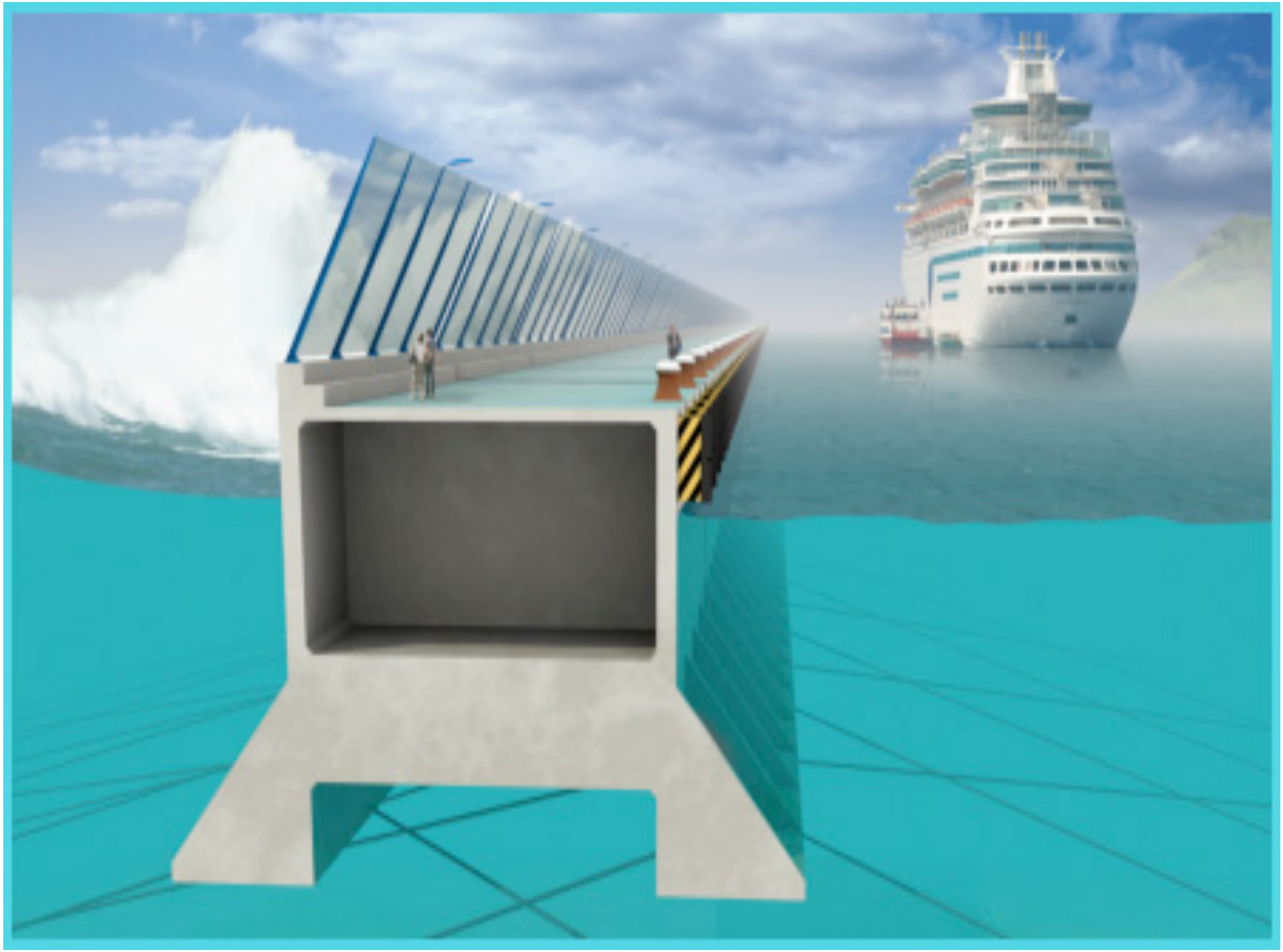
How much energy does it take to move big structures in water?


How realistic is OMEGA?


FREEDOM SHIP




Are we up to the engineering challenge?



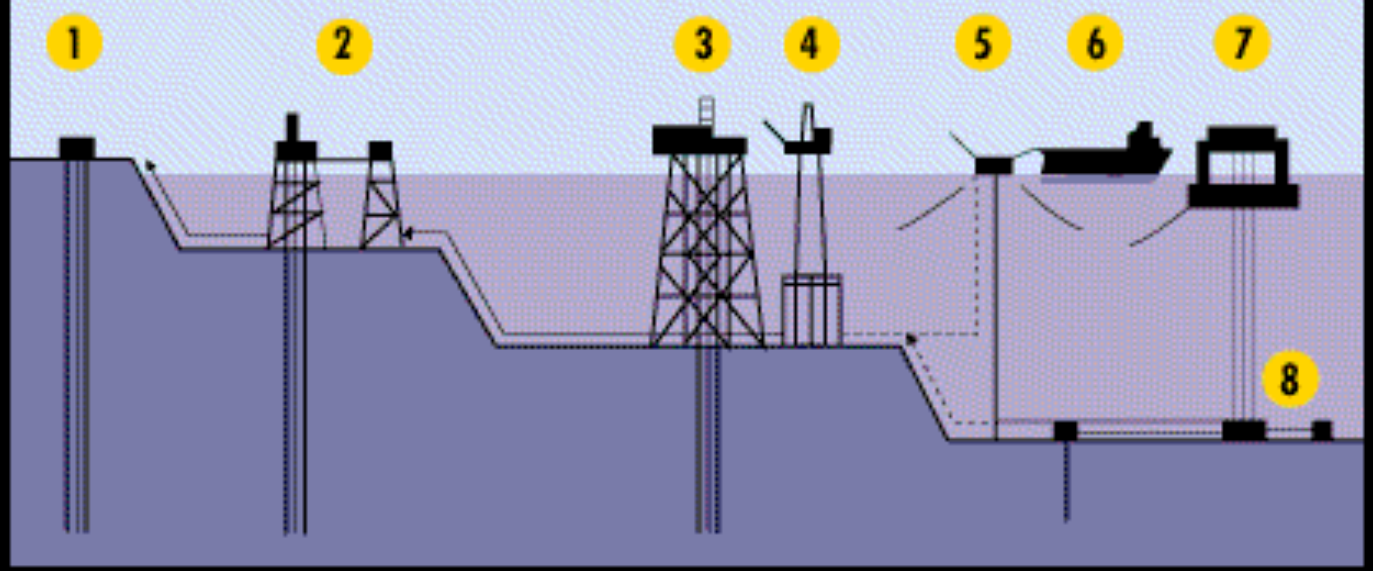

TEN REAL ESTATE

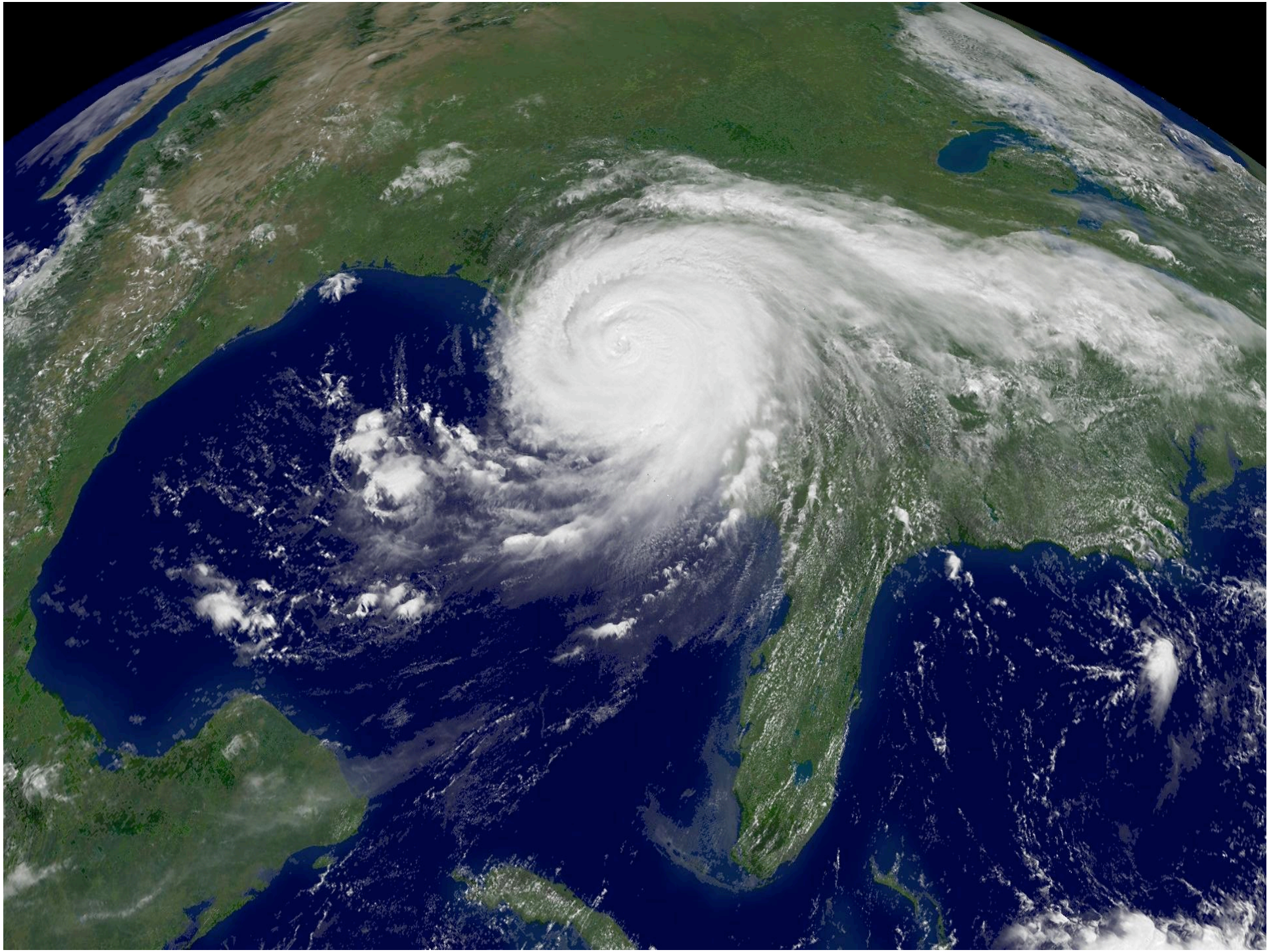

TEN

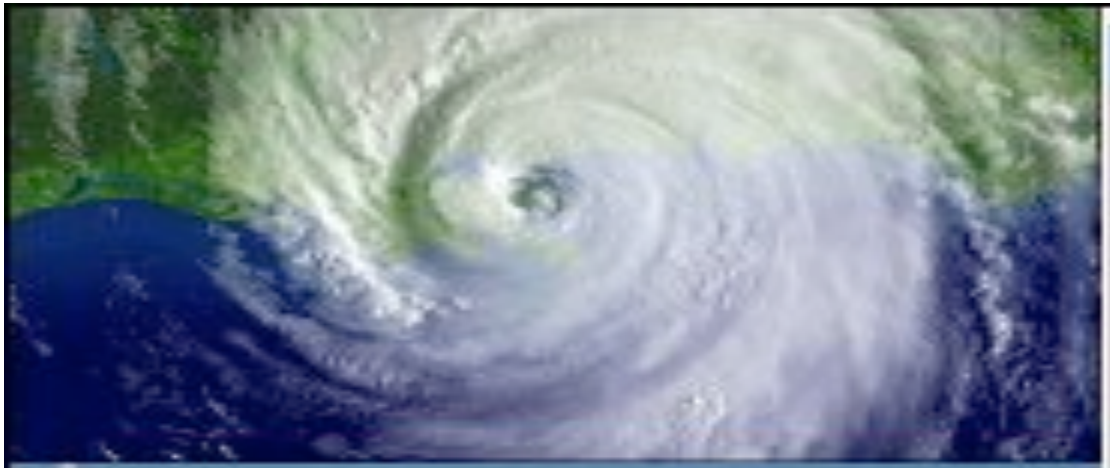

TEN REAL ESTATE

Types of drilling stations

1. ONSHORE WELL
2. OFFSHORE, FIXED, MULTI PLATFORMS
3. OFFSHORE, FIXED, SELF-CONTAINED PLATFORMS
4. OFFSHORE, SELF-CONTAINED, CONCRETE GRAVITY PLATFORMS
5. OFFSHORE, FLOATING, SINGLE-POINT MOORING
6. STORAGE/SHUTTLE TANKER
7. OFFSHORE, FLOATING, TENSION LEG PLATFORMS
8. SUBSEA MANIFOLDS







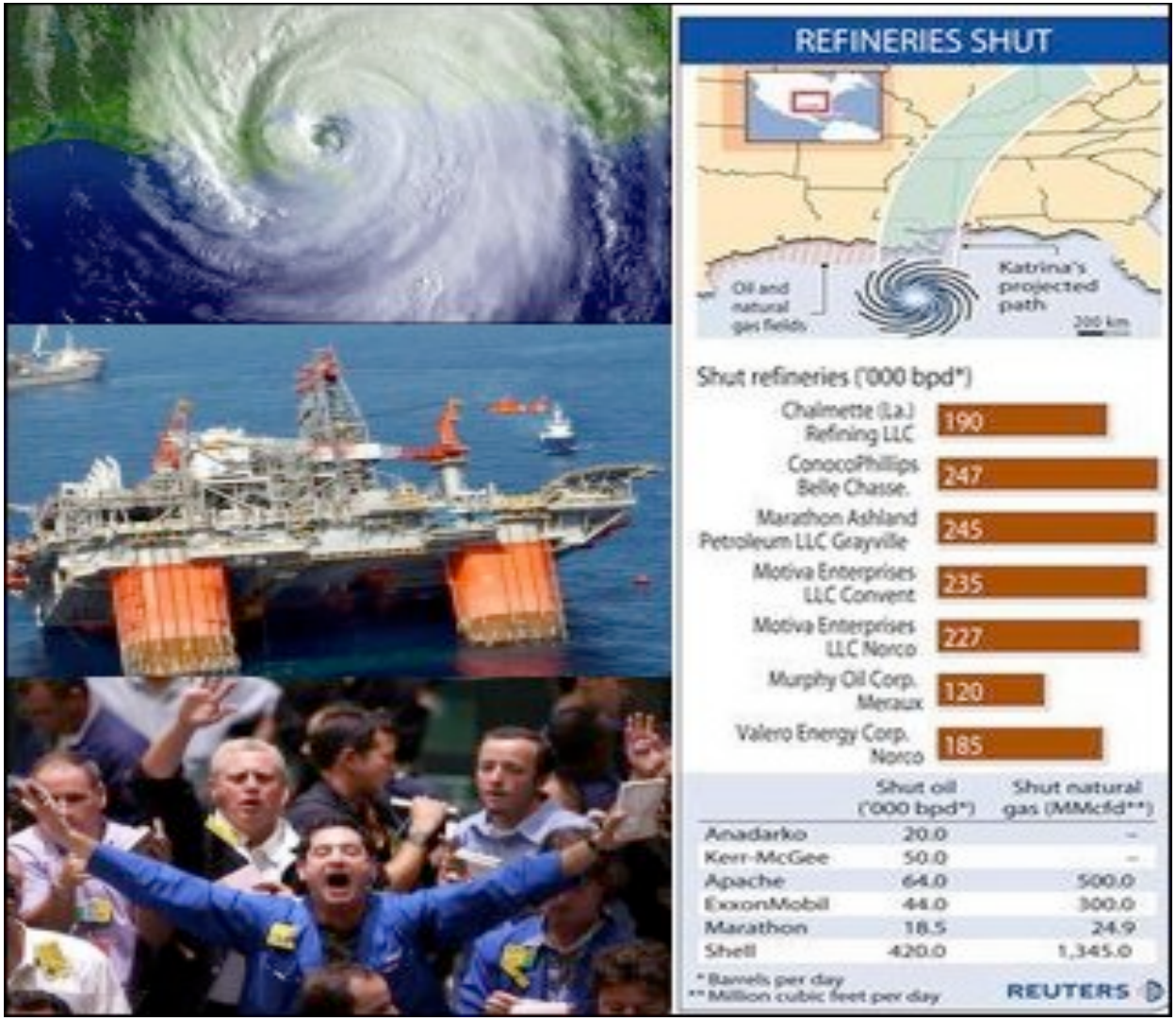
REFINERIES SHUT

Shut refineries ('000 bpd*)

	Shut oil ('000 bpd*)	Shut natural gas (MMcfd**)
Anadarko	20.0	–
Kerr-McGee	50.0	–
Apache	64.0	500.0
ExxonMobil	44.0	300.0
Marathon	18.5	24.9
Shell	420.0	1,345.0

* Barrels per day
** Million cubic feet per day

REUTERS



** 15 production facilities significant damaged.*

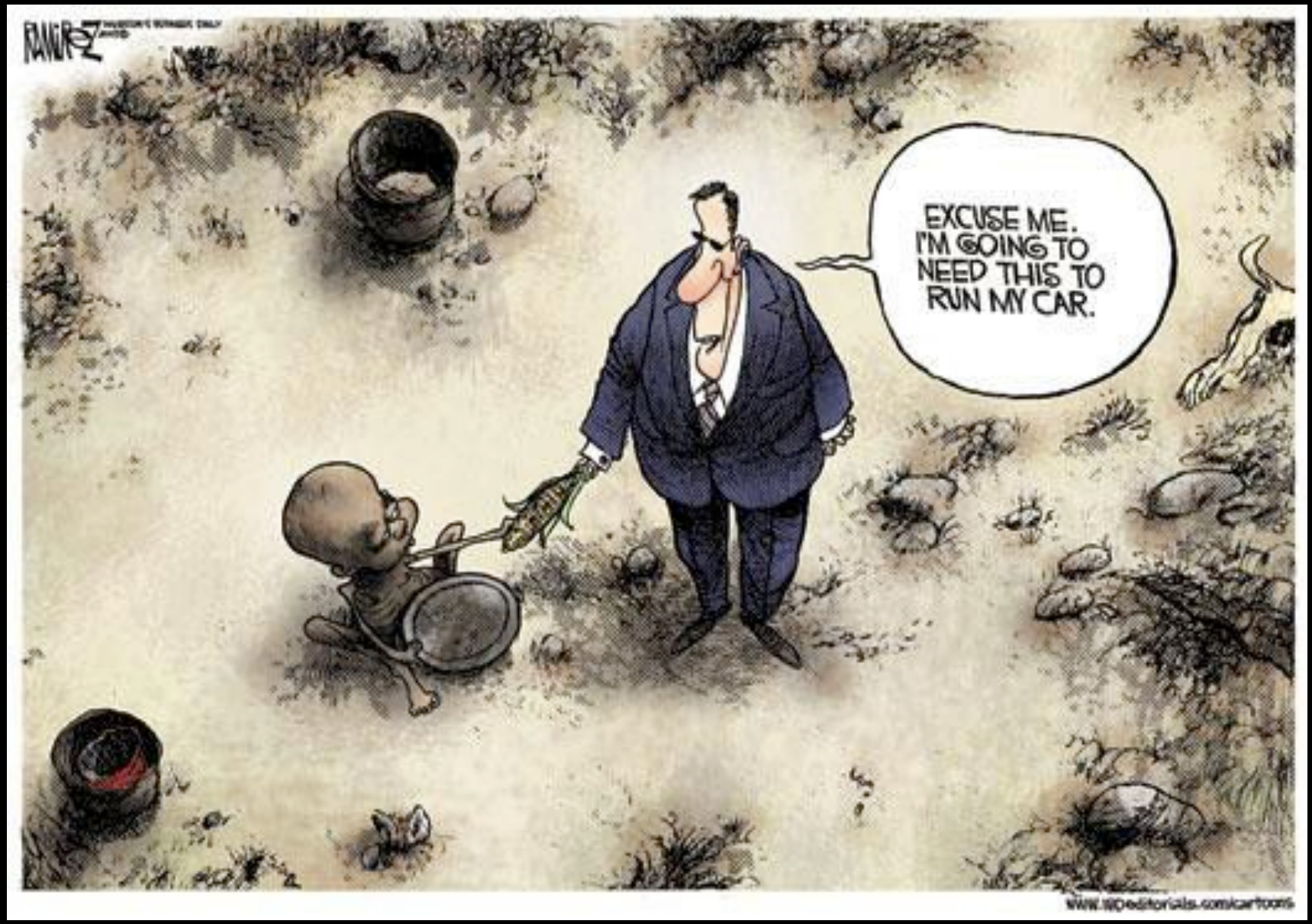
** Four accounted for nearly all delayed production.*

** Repair time estimates: 3 to 6 months.*


Are we up to the OMEGA challenges?
•Biology
•Engineering
•Environment
•Economics


URS & OMEGA?


Sustainability?
Population
Affluence
Species
Technology
Our future?



Failure is not an option…

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

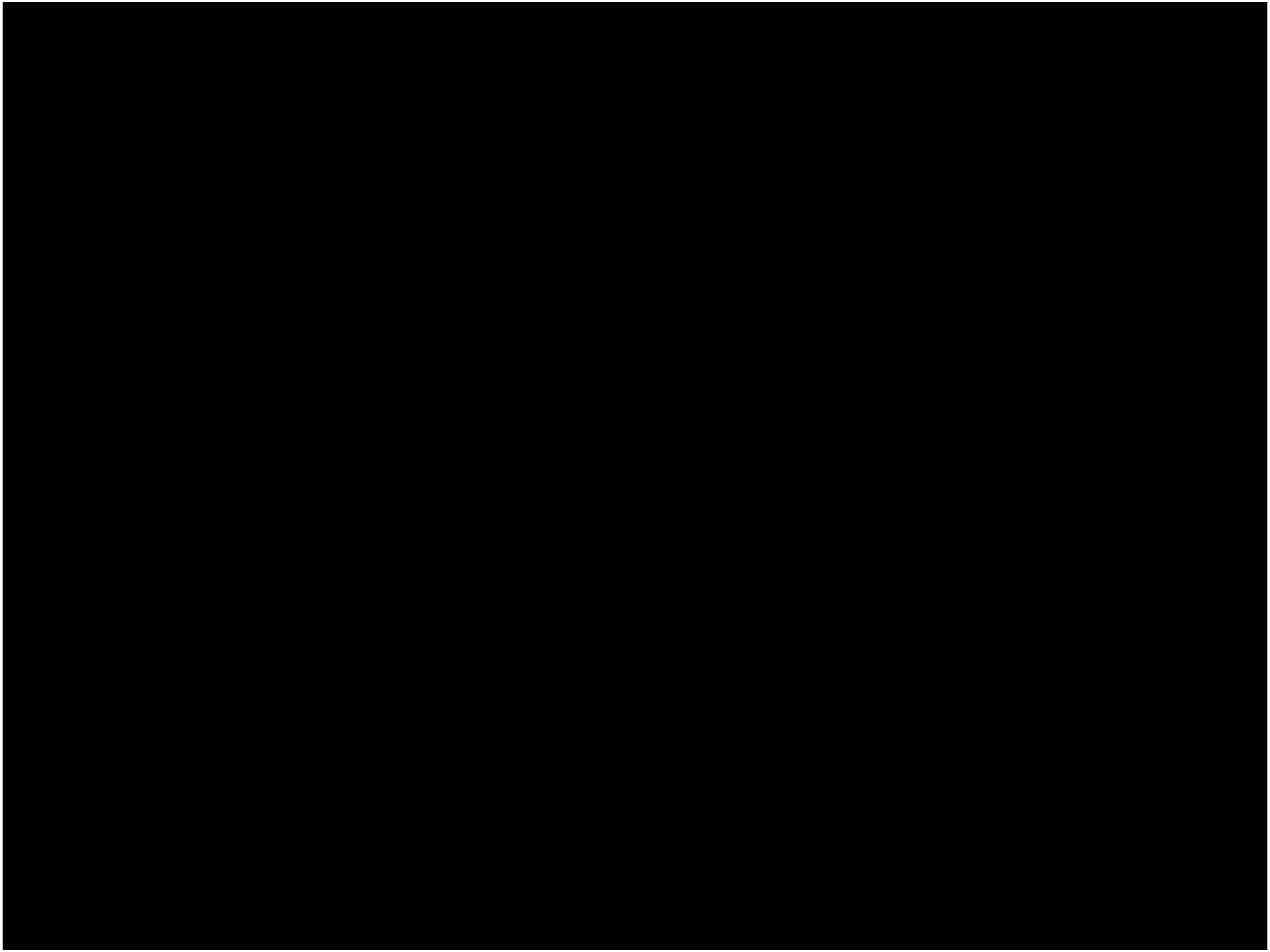
There is no limit to what you can accomplish
If you don't care who gets the credit... Truman

OMEGA TEAM
Google GREEN project/CEC PIER Grant

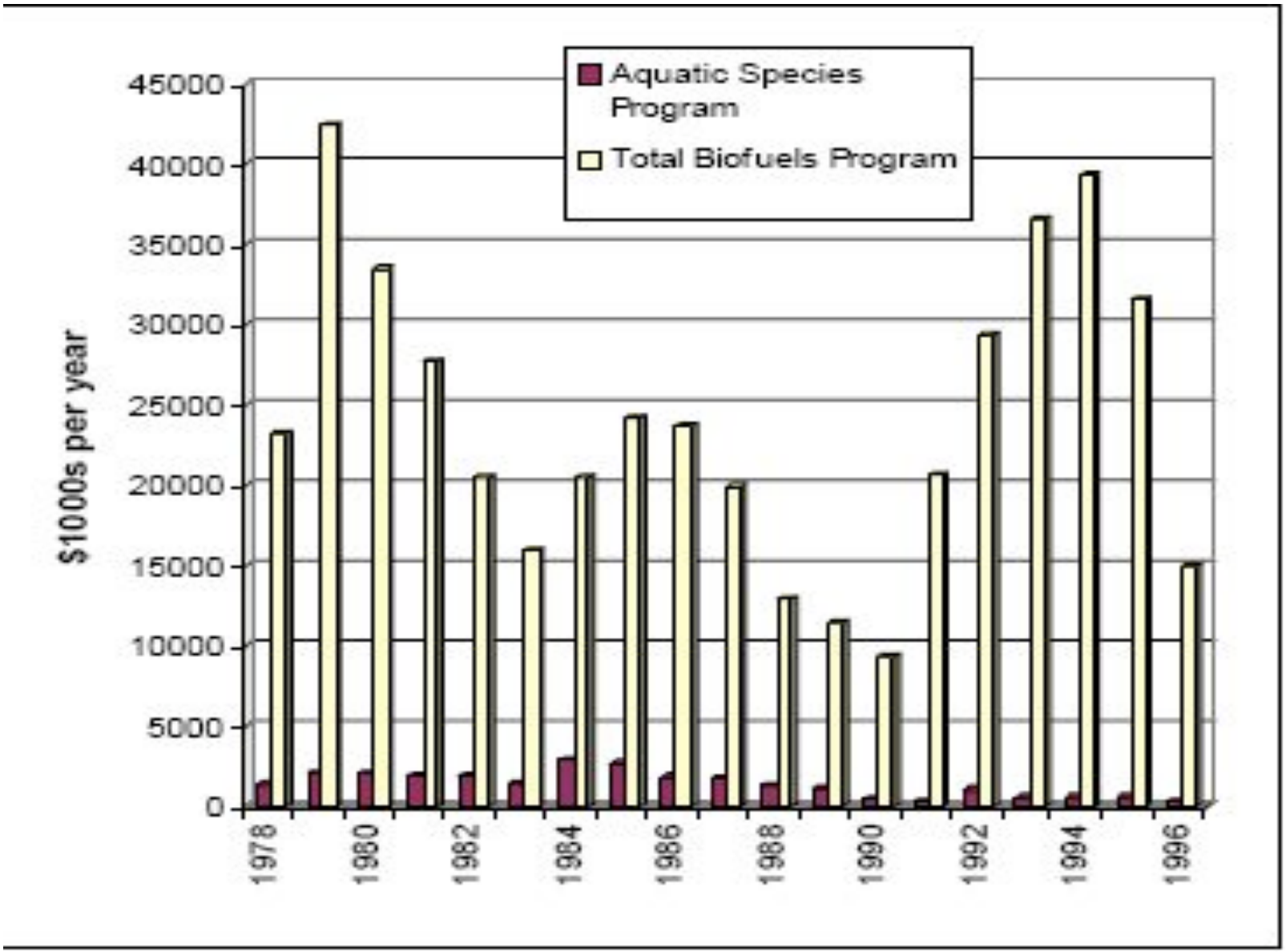
- **NASA Ames:**
  Jonathan Trent (PI), Tsege Embaye, Patrick Buckwalter, Sigrid Reinsch, Travis Liggett, Robert Baertsch, Sherwin Gormly
  Interns: Craig Foster, Graham Akeson, Marlowe Primack, Jenny Kaehms, Jonathan Bach, Stefan Eckhardt

Collaborators:

- **Algae Lab:** Aaron Baum
- **JPL**: Bob Easter, Gerald Voecks, Robert Danziger, Ken Johnson
- **Cal Poly:** Tryg Lundquist
- **SRI International:** Brian Bedwell, Barbara Heydorn
- **MBARI/UCSC**: Zbigniew Kolber
- **UCSC:** John & Vicki Pearse, Mary Silver, Raphel Kudela, Mark Carr
- **Sembiotics**: Ami Ben Amotz (Israel)
- **Poseidon:** Chris Costello, Jon Deitrich
- **Scripps Institution of Oceanography**: Richard Seymour
- **Harbor Branch Oceanographic**: Brian LaPoint
- **UOP:** Steve Lupton
- **Aquaculture:** Peter Lindgrin



DOE Funding of biofuels




Allianz Arena


San Francisco, CA 94103
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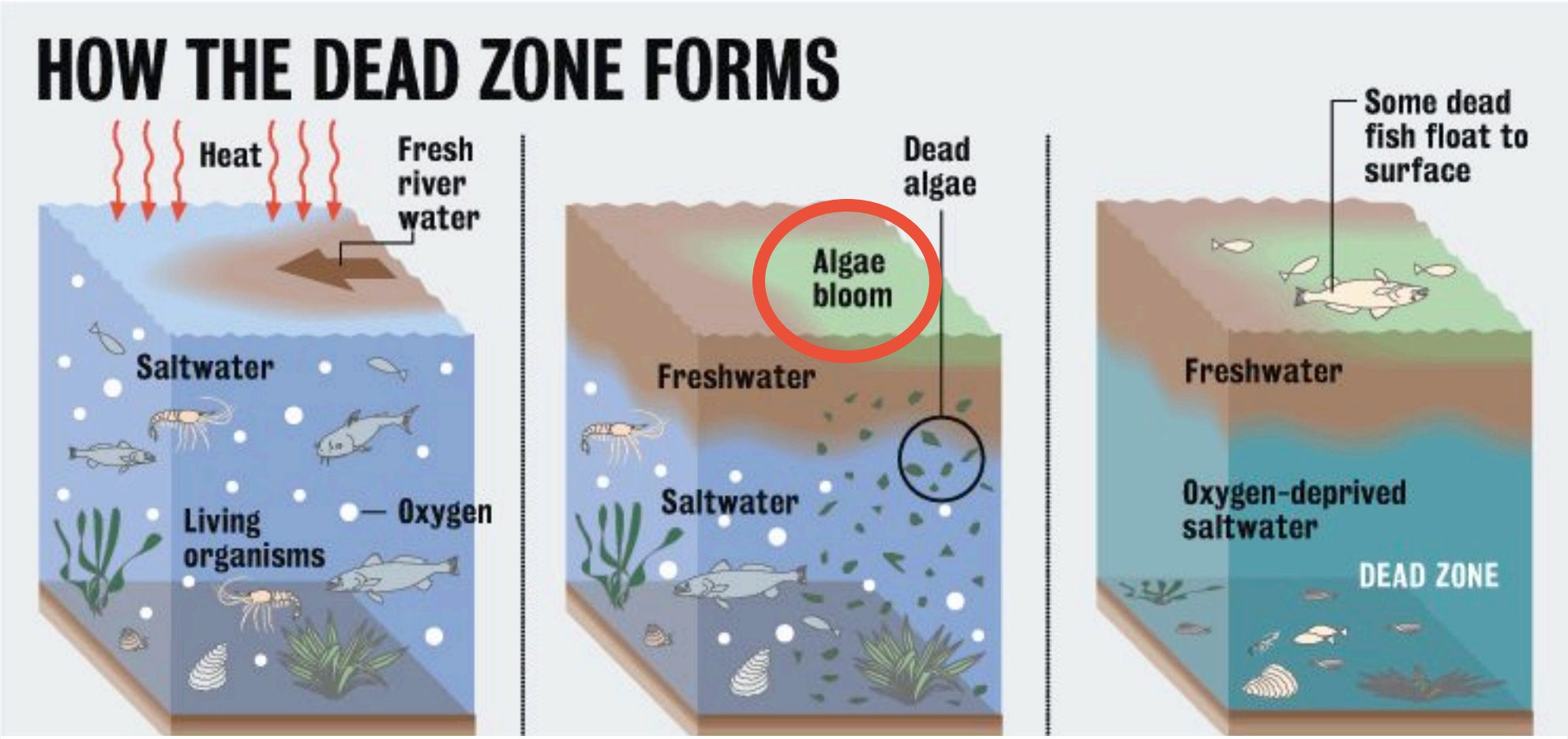
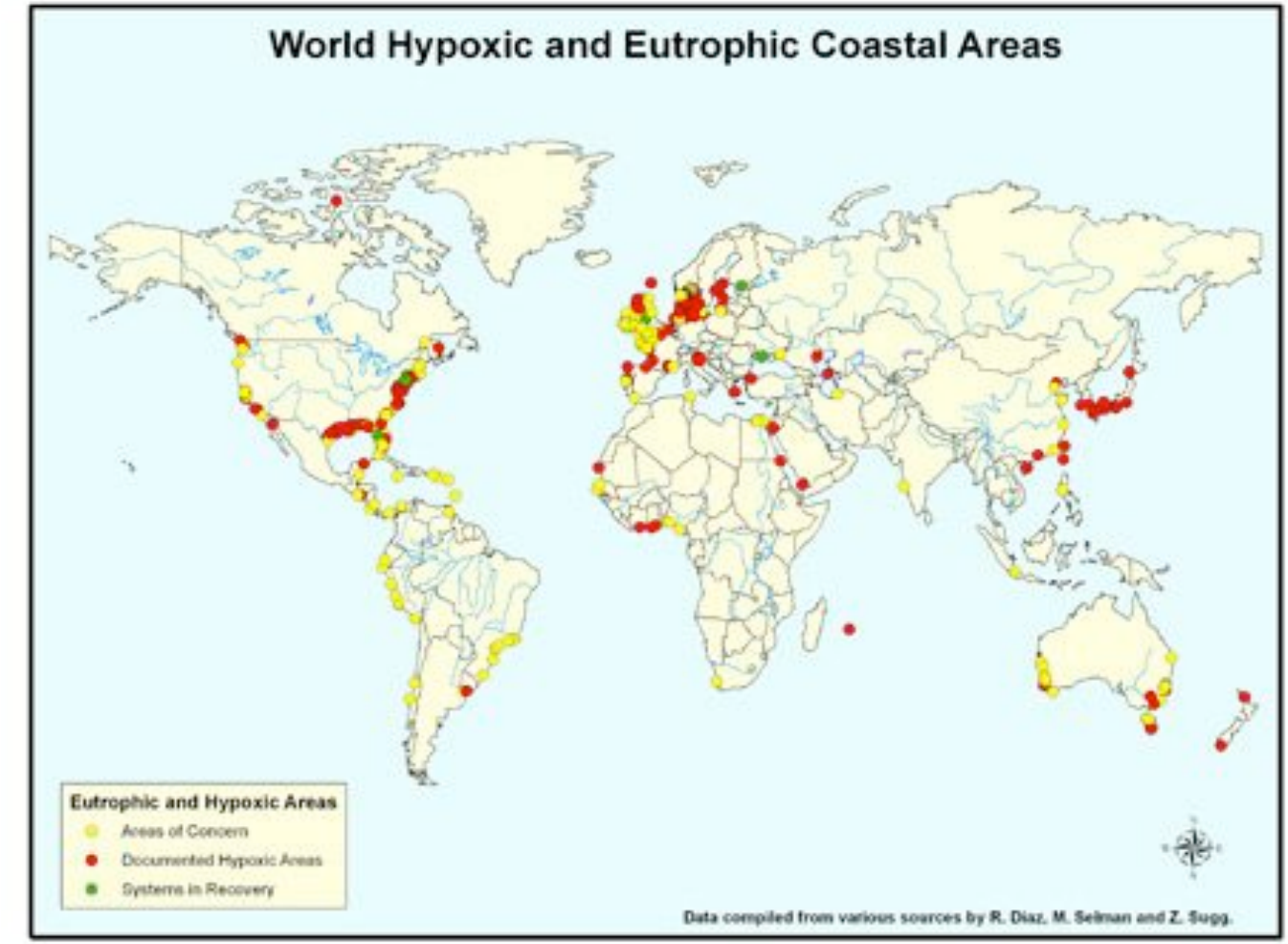


Fertilizer runoff

Stratified water column

Suffocation

Dead Zones 2008



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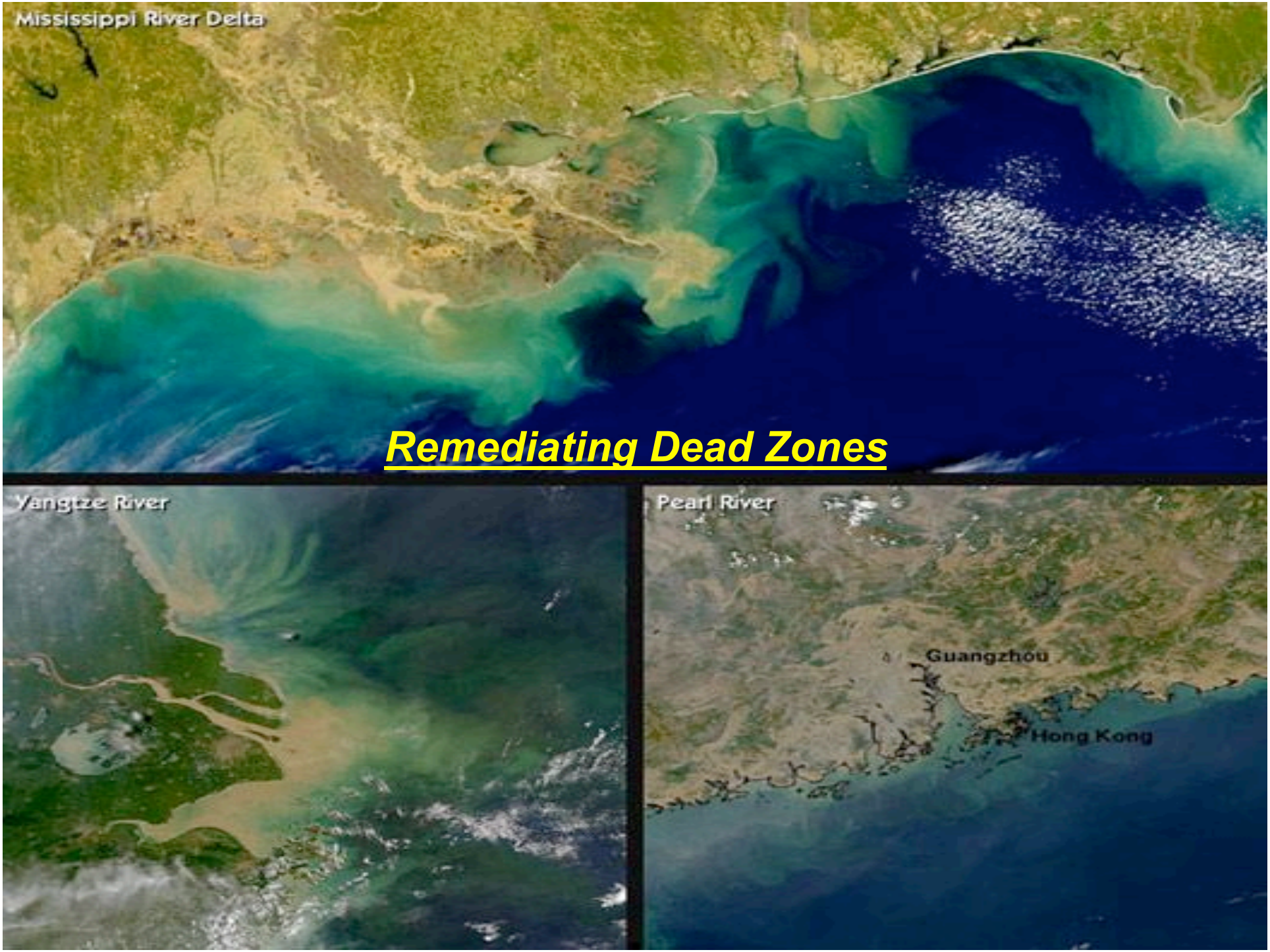
Mississippi River Delta
Remediating Dead Zones
Yangtze River
Pearl River
Guangzhou
Hong Kong

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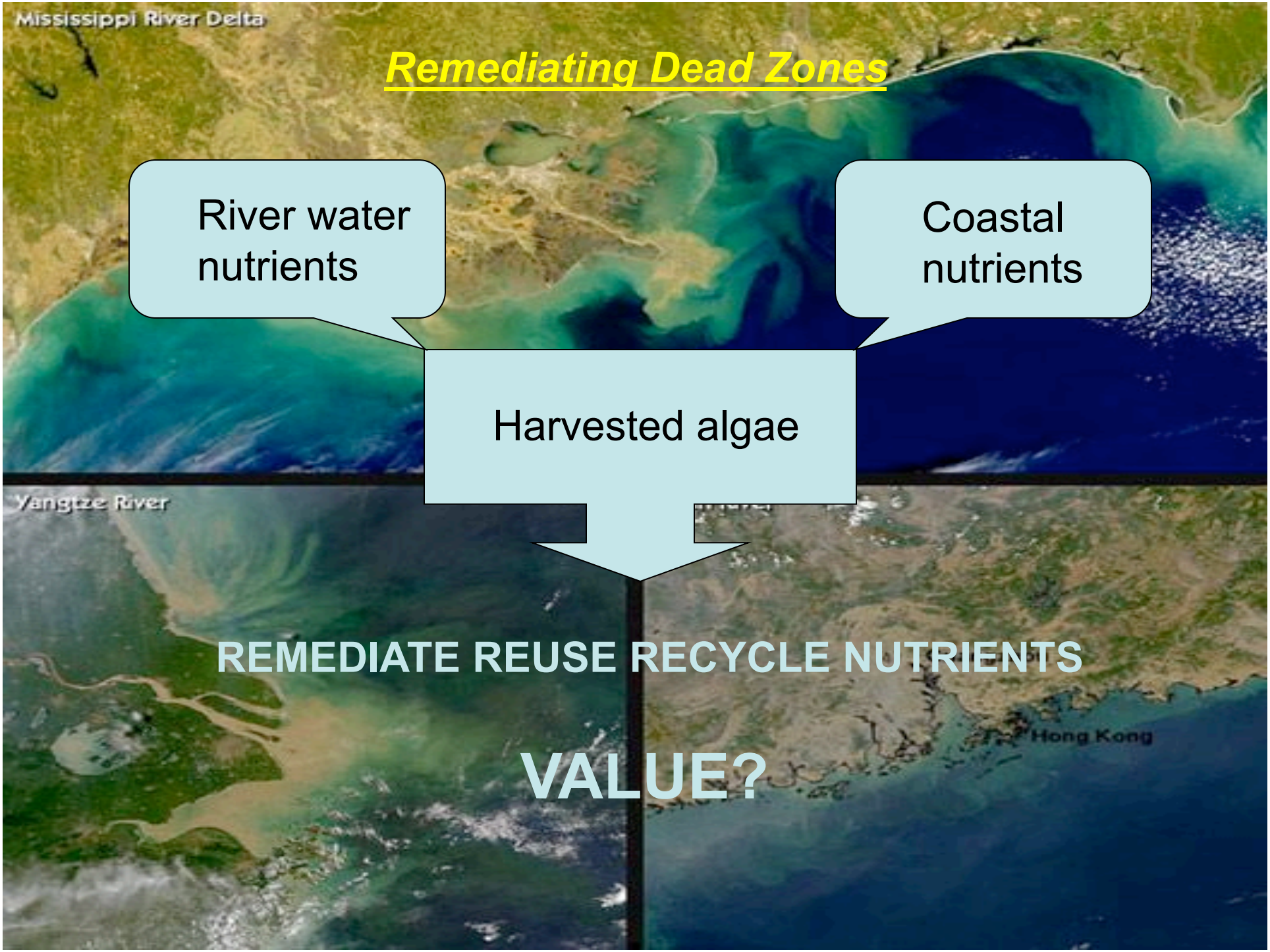
Mississippi River Delta
Remediating Dead Zones
River water nutrients
Coastal nutrients
Harvested algae
Yangtze River
REMEDIATE REUSE RECYCLE NUTRIENTS
VALUE?
Hong Kong