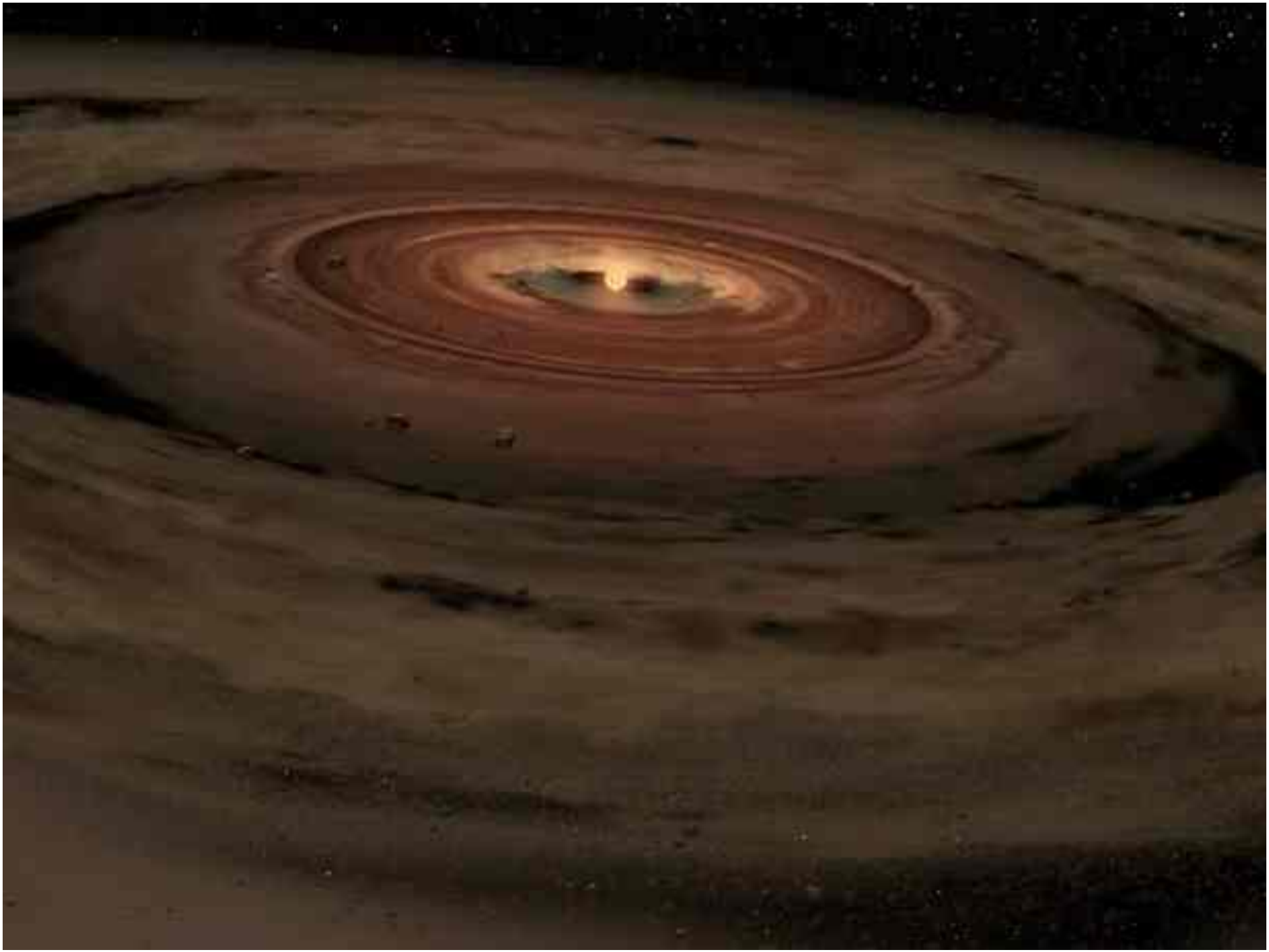
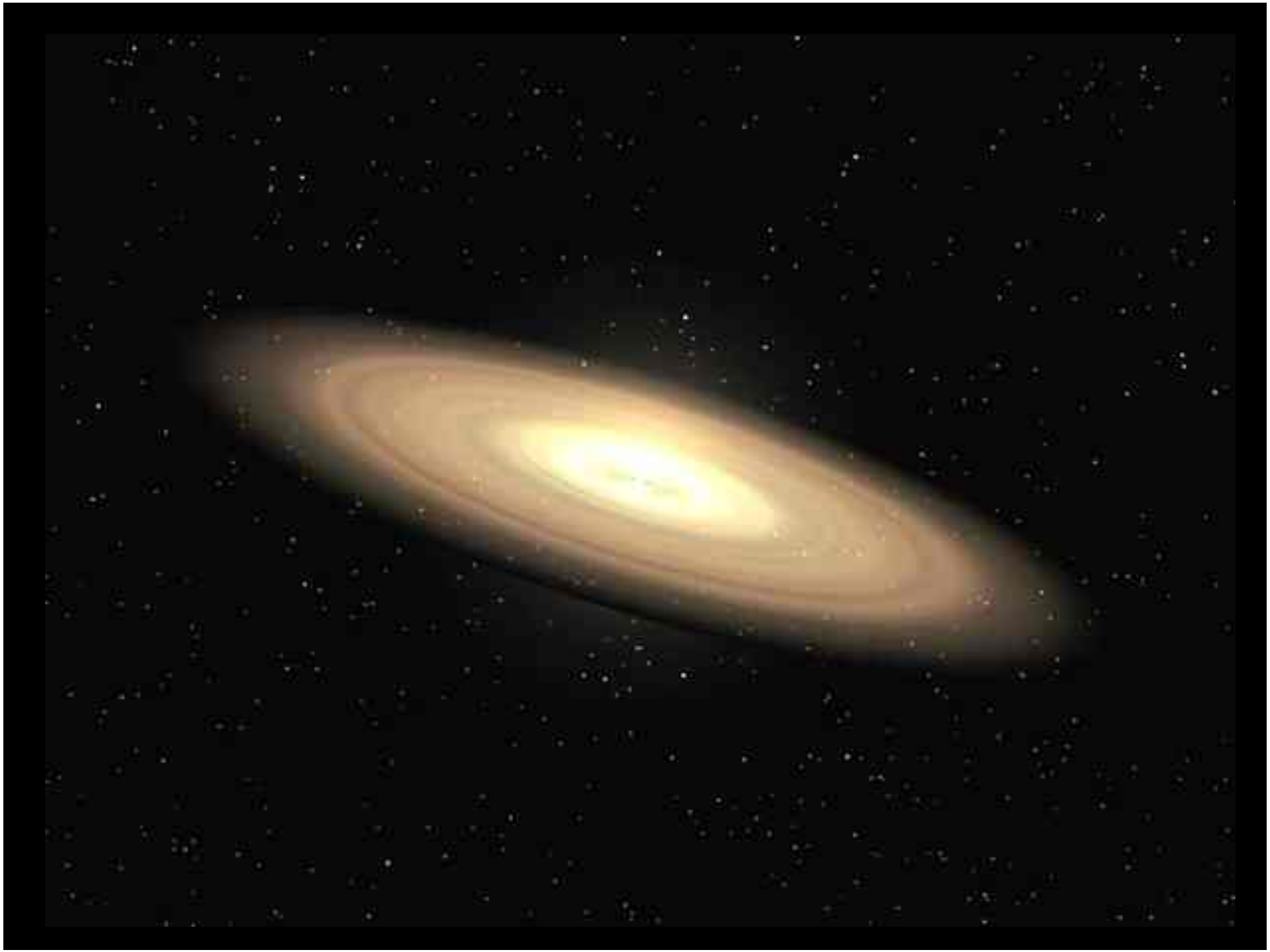
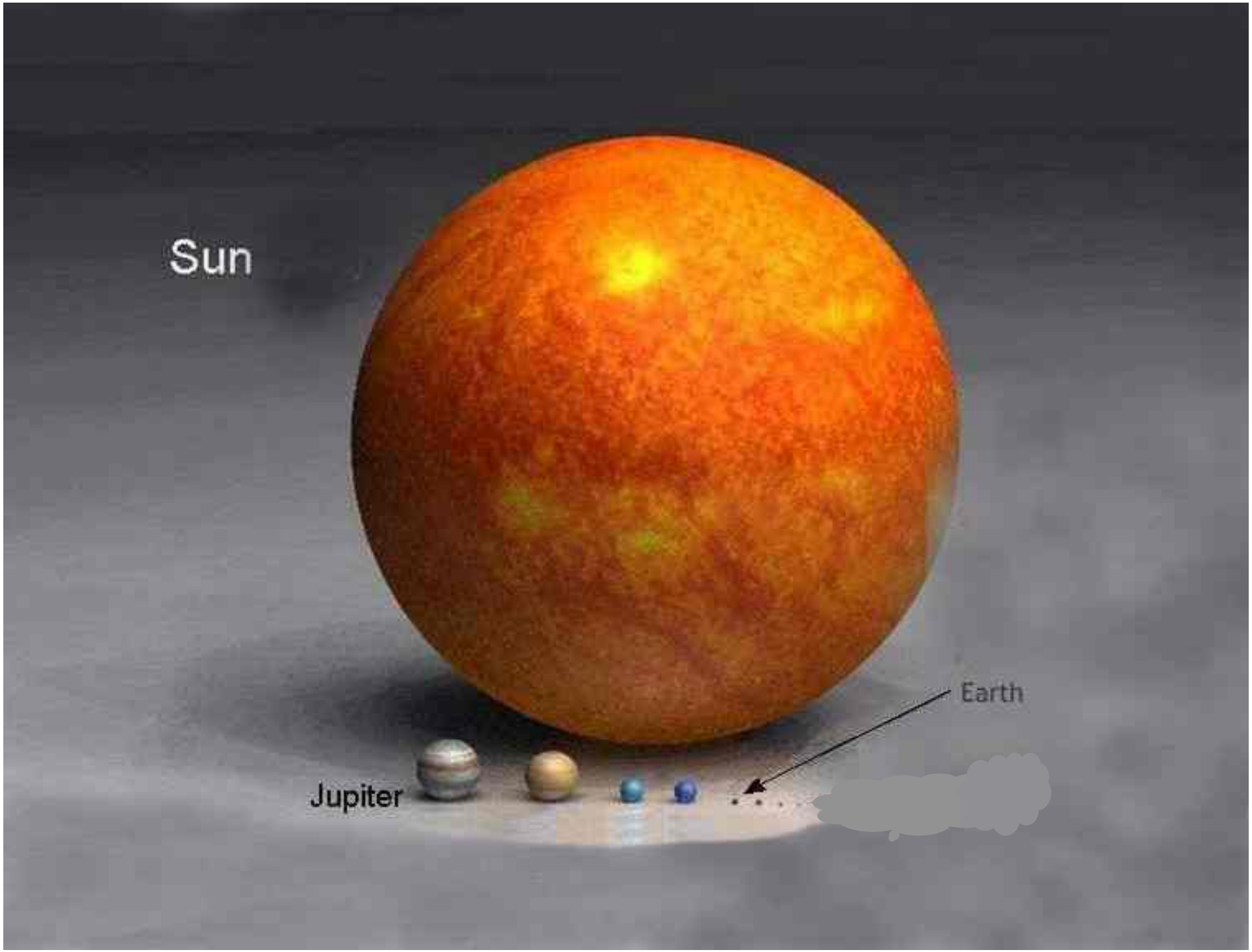
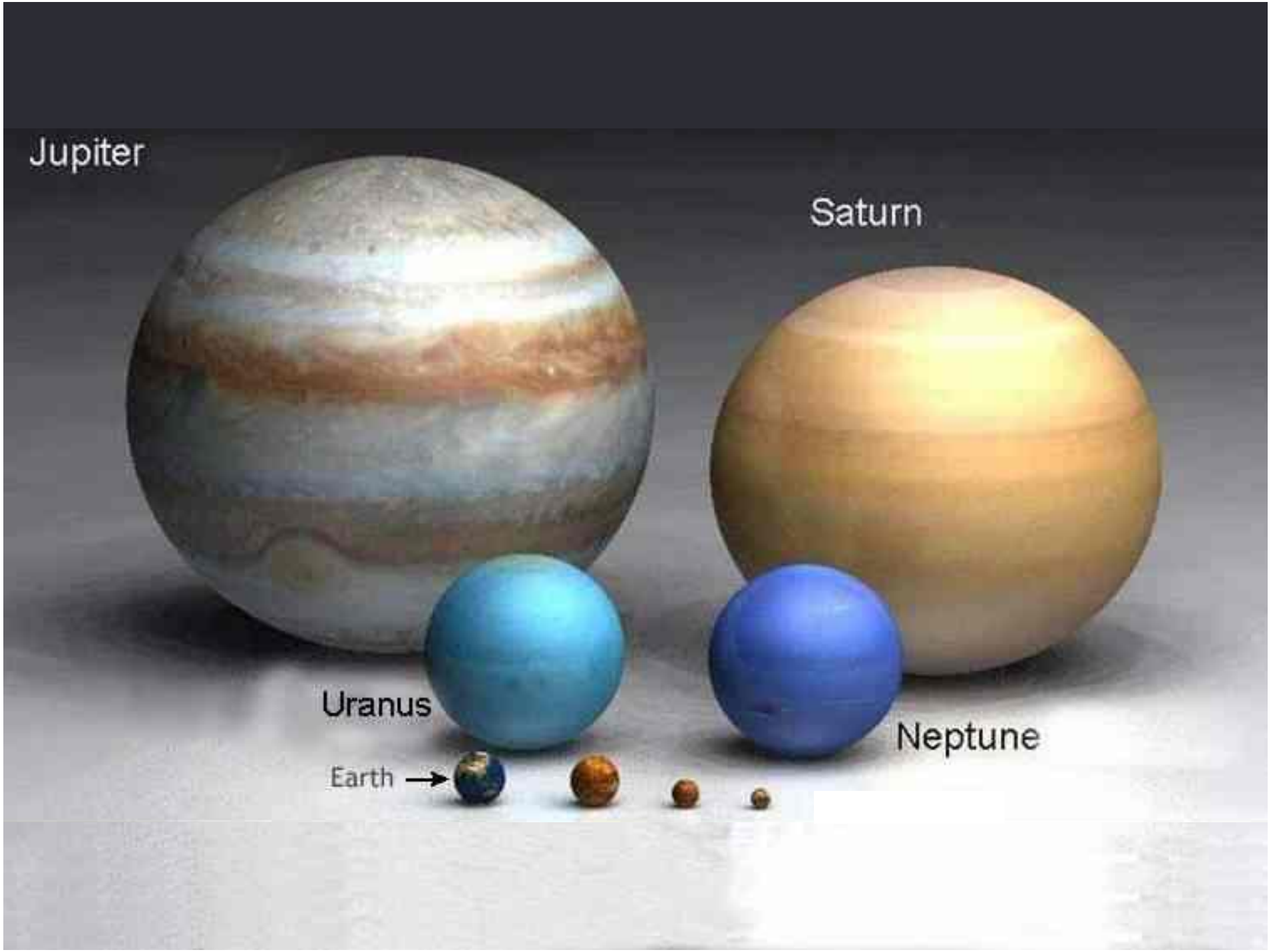
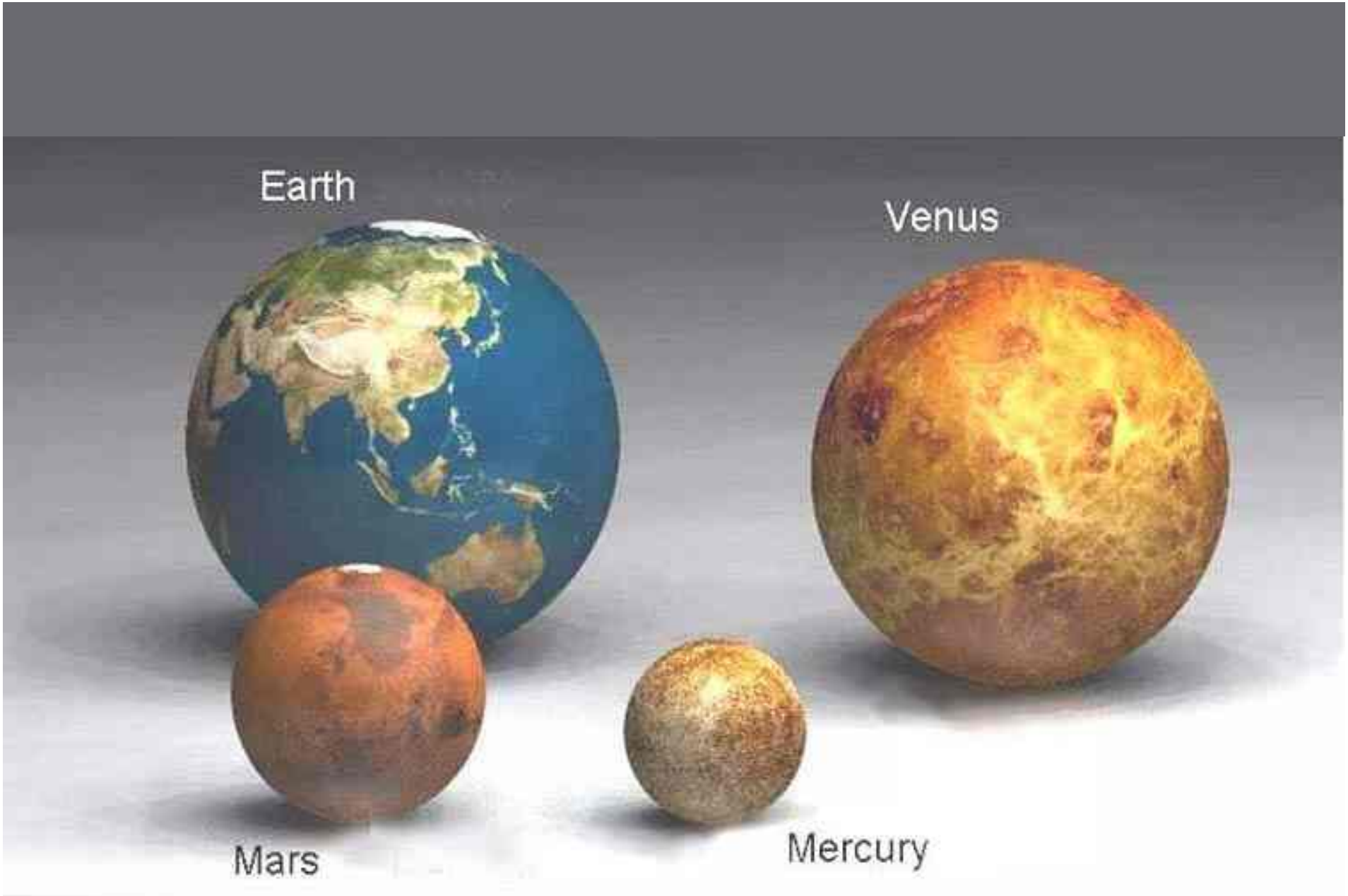

In the beginning…



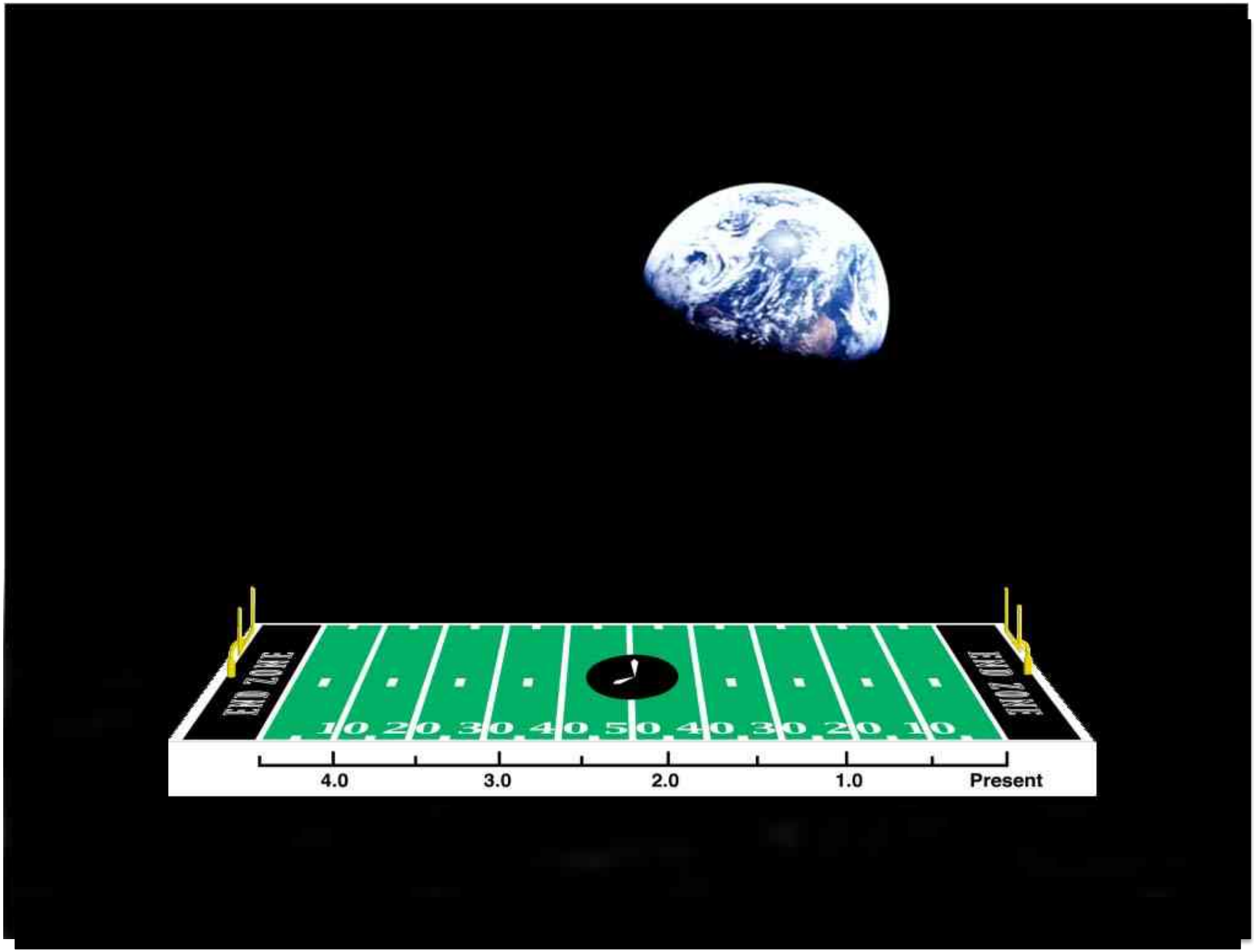


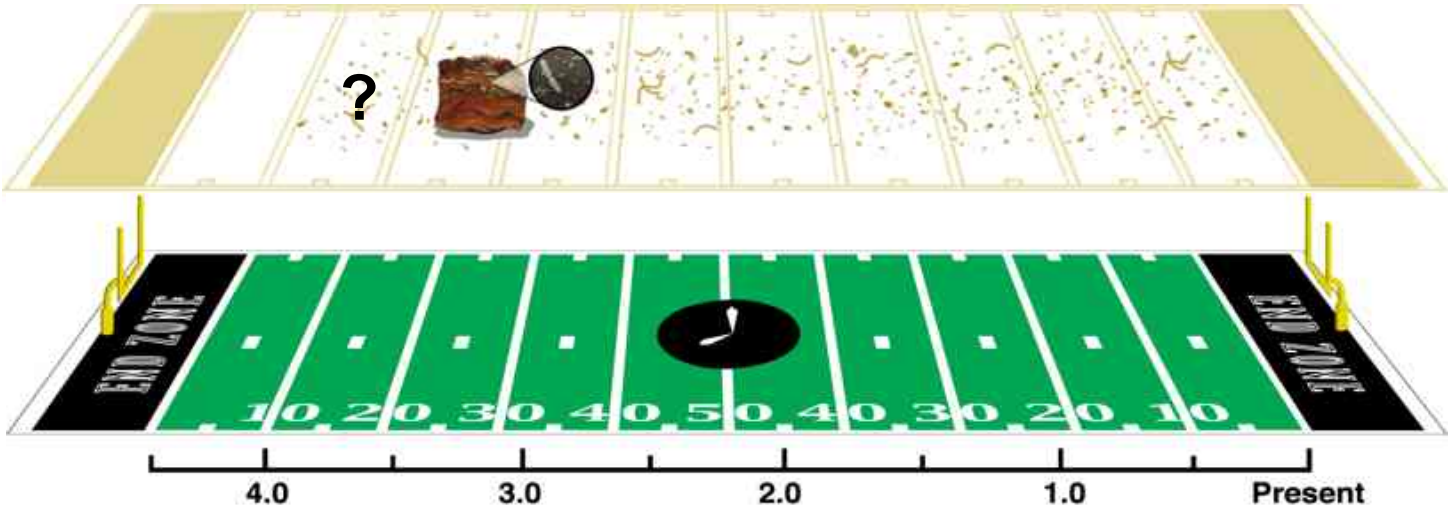

Sun
Earth
Jupiter


Jupiter
Saturn
Uranus
Neptune
Earth


Earth
Venus
Mars
Mercury


The timeline…


END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present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END ZONE
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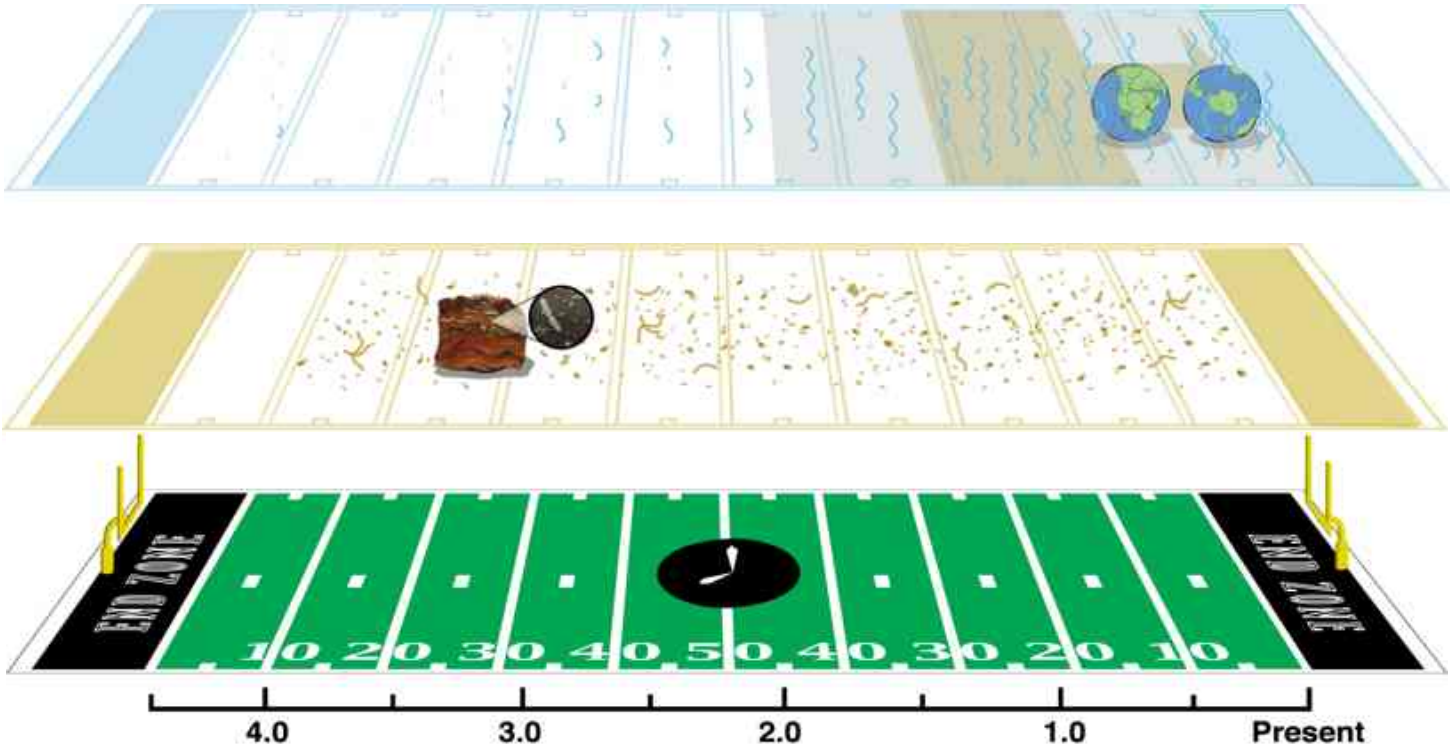
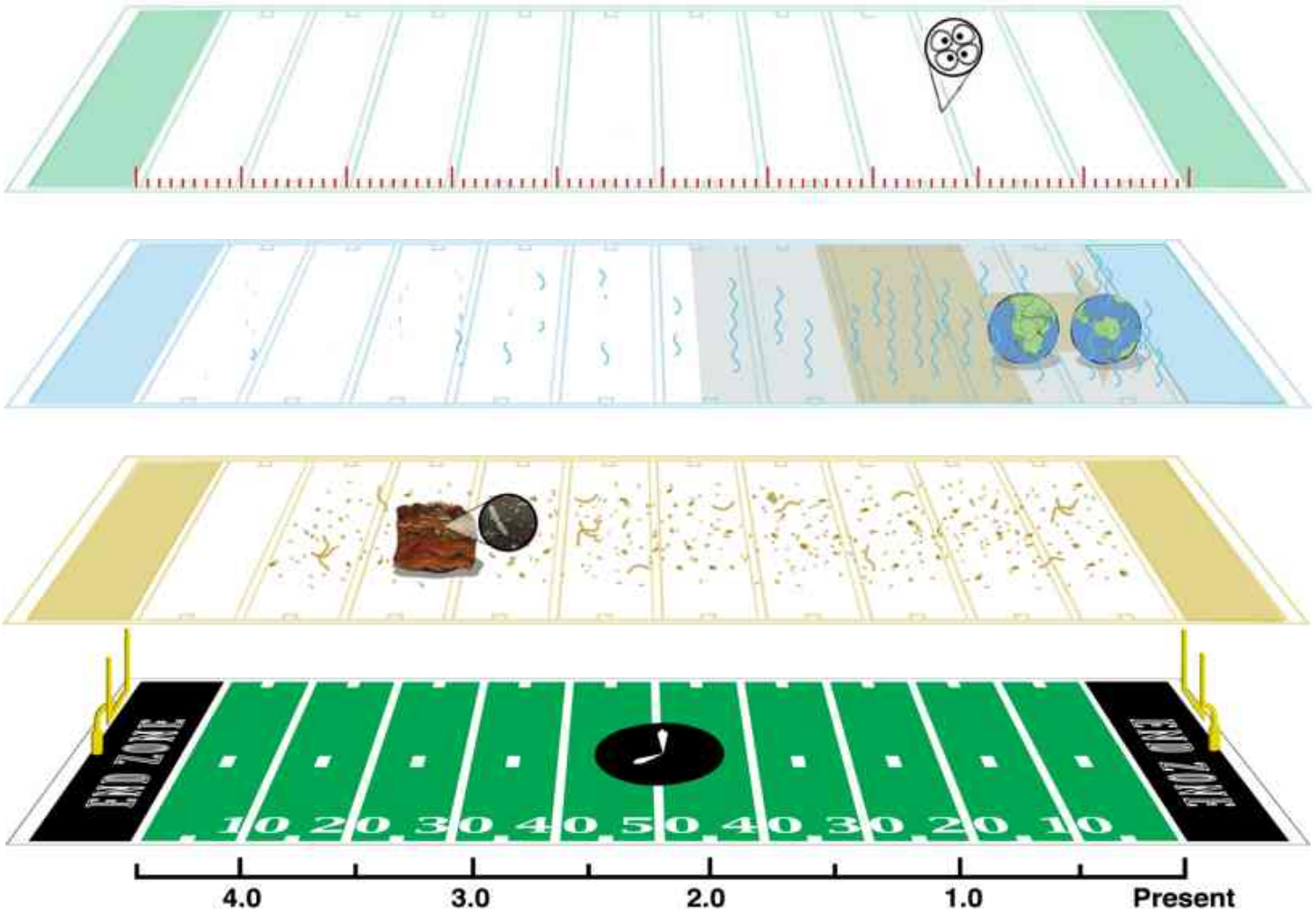
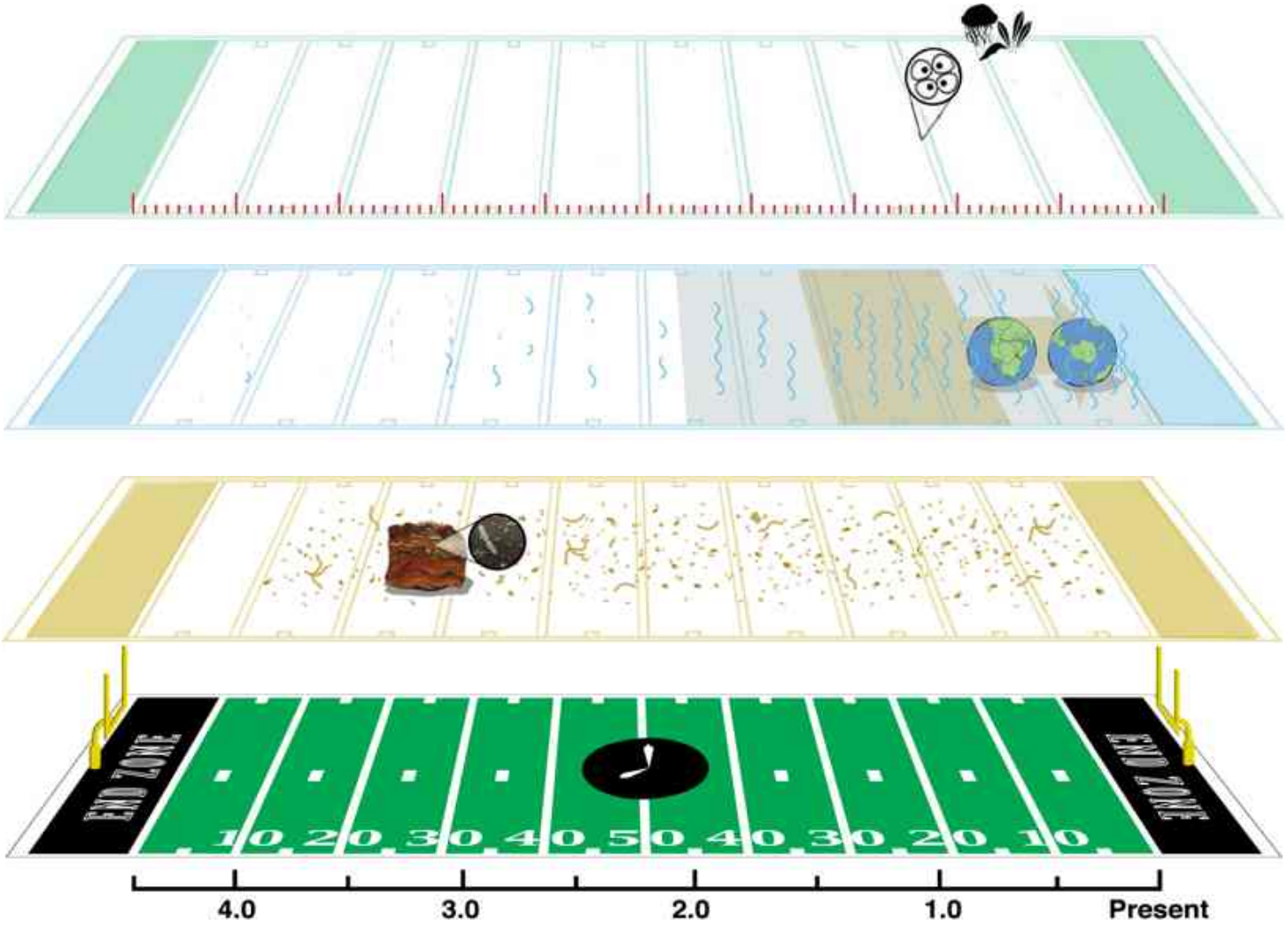
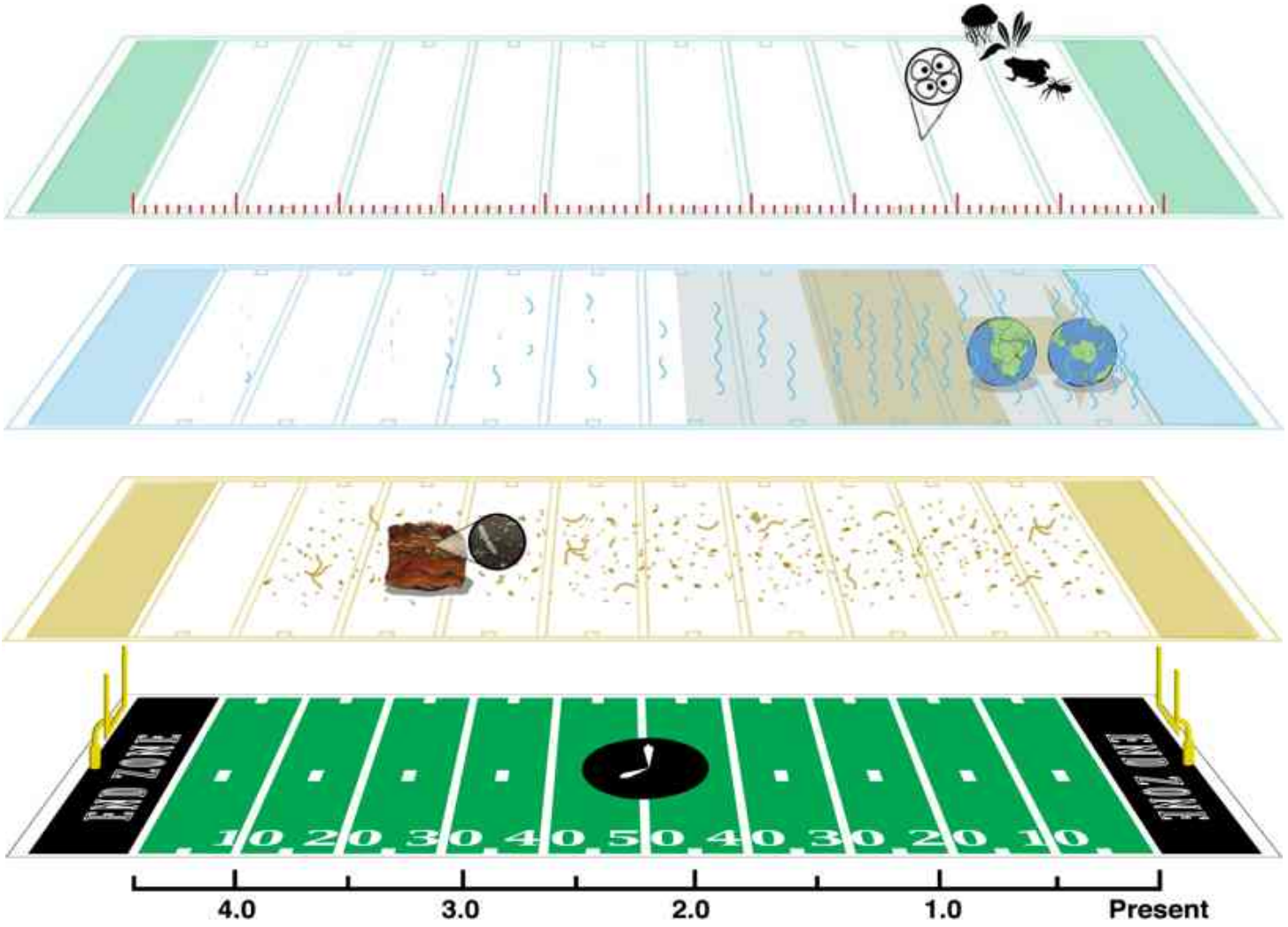
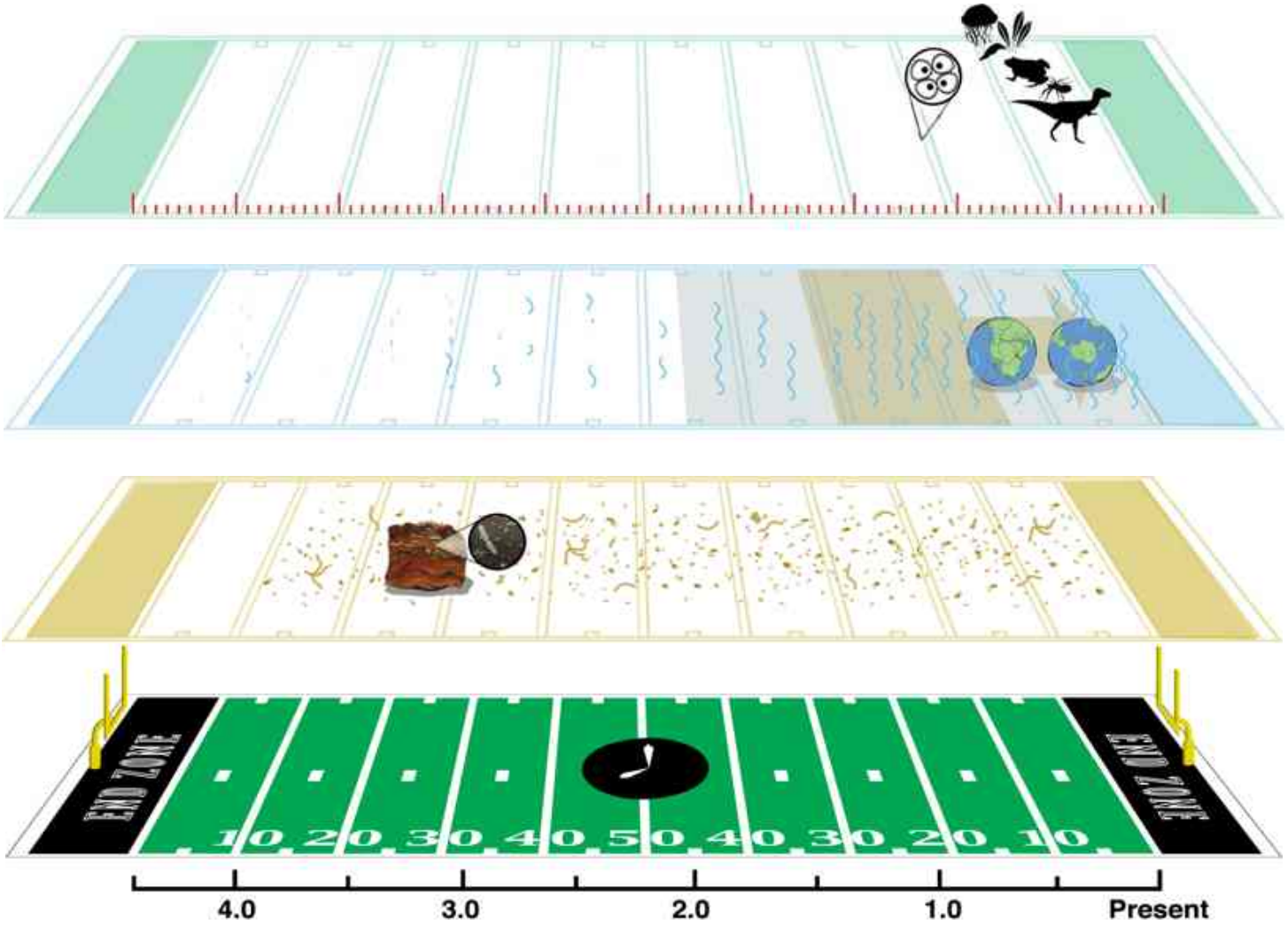
4.0
3.0
2.0
1.0
Present


END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present


END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present


END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present


END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present


END ZONE
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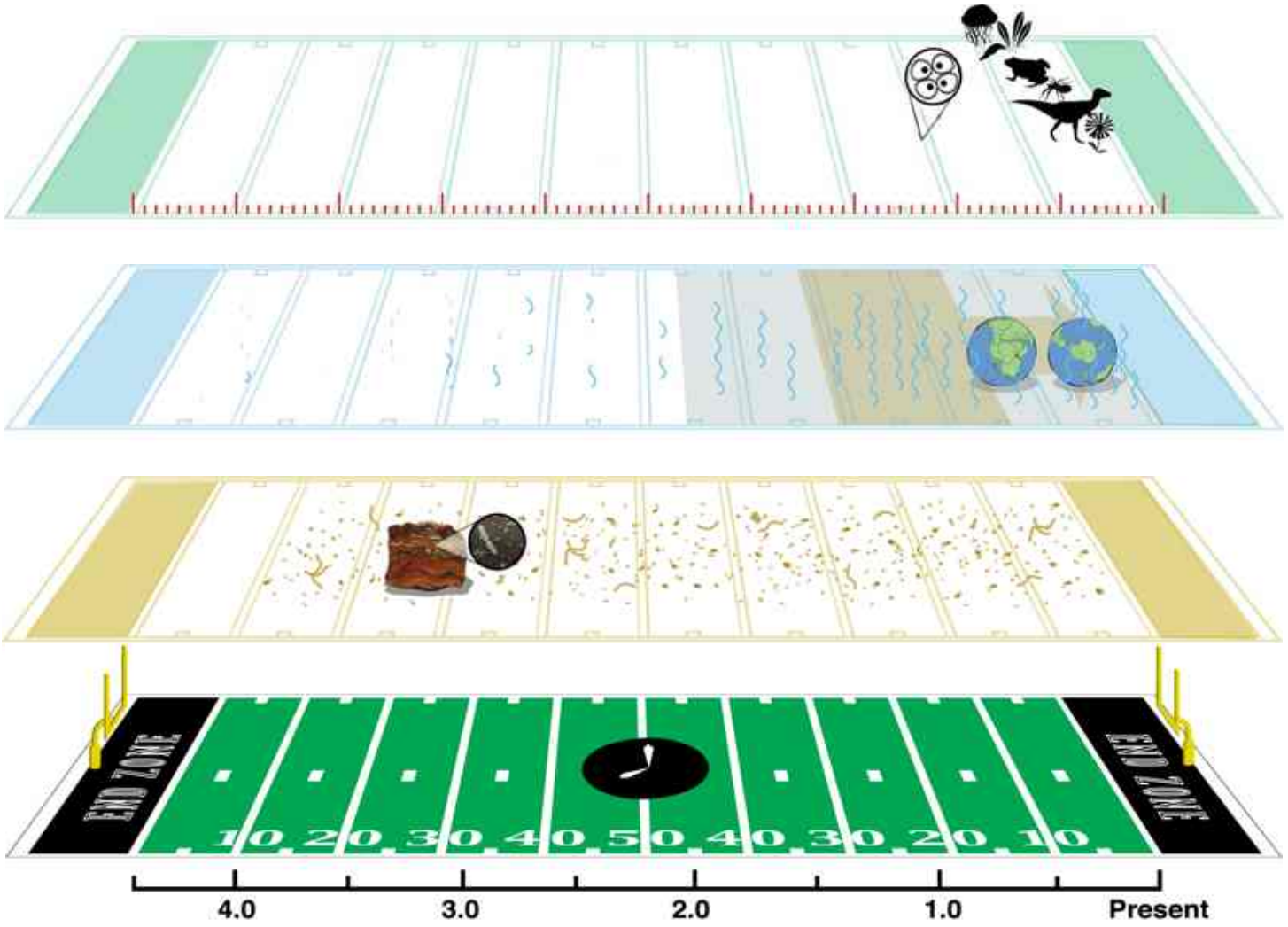
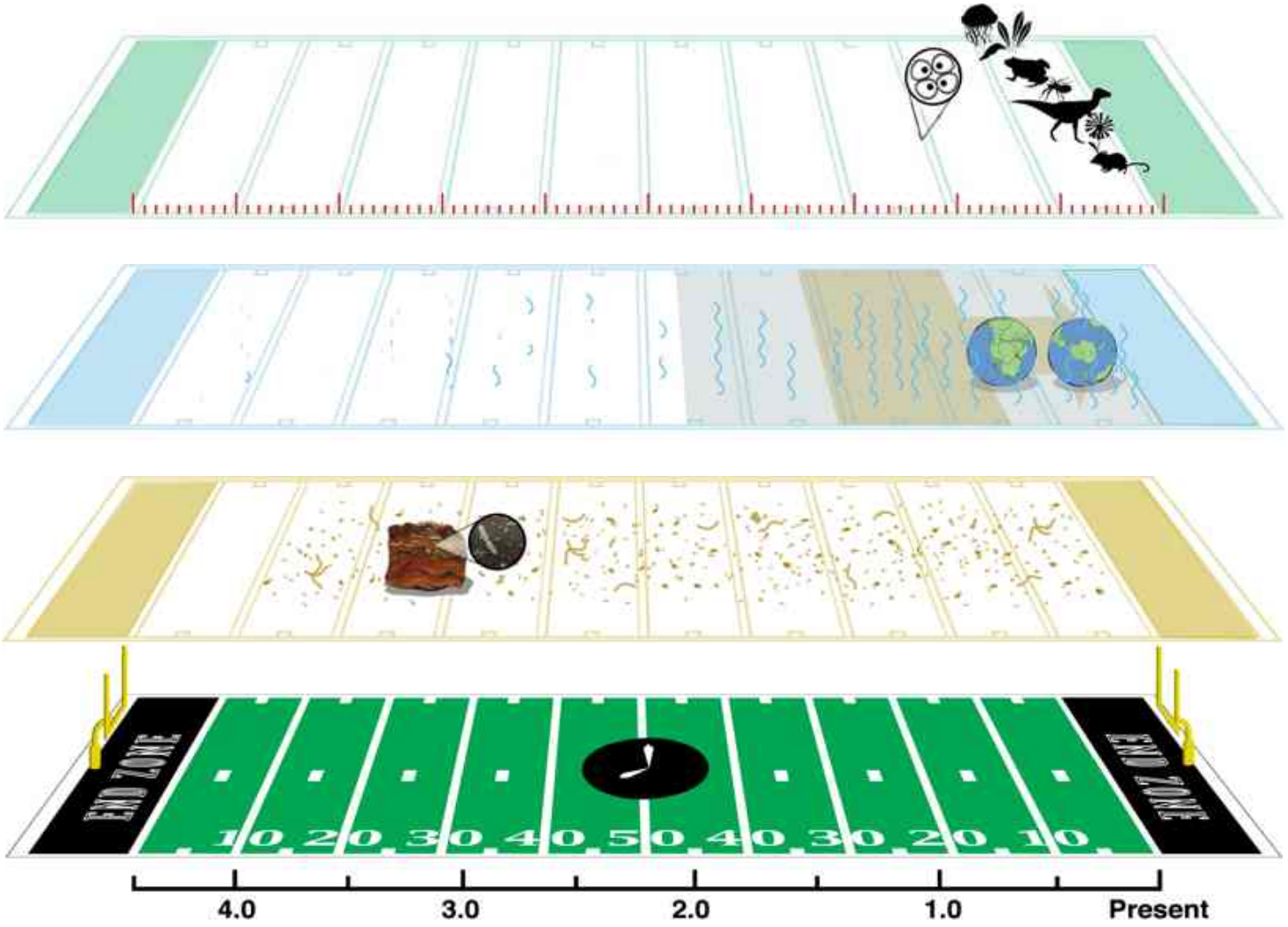
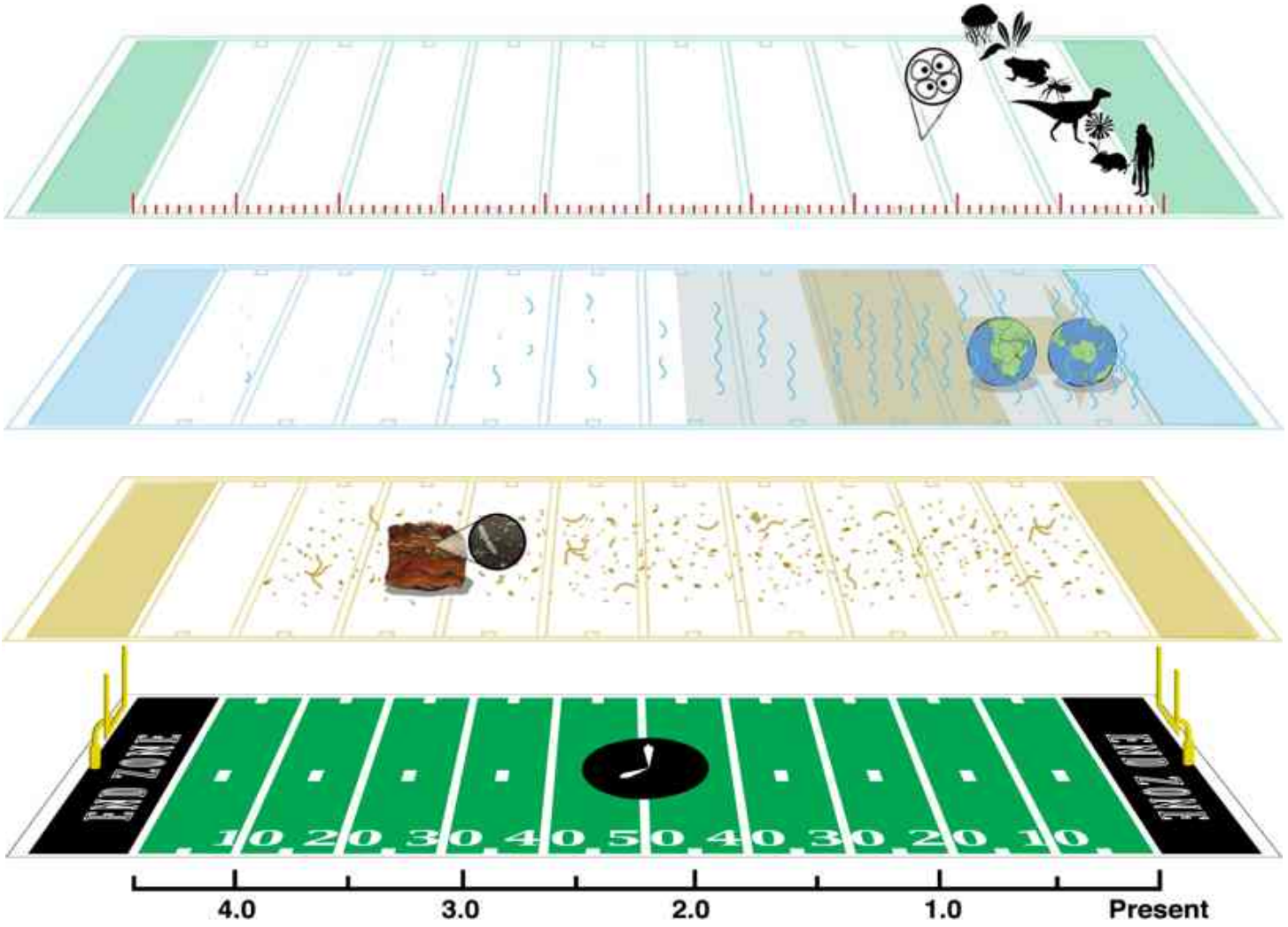
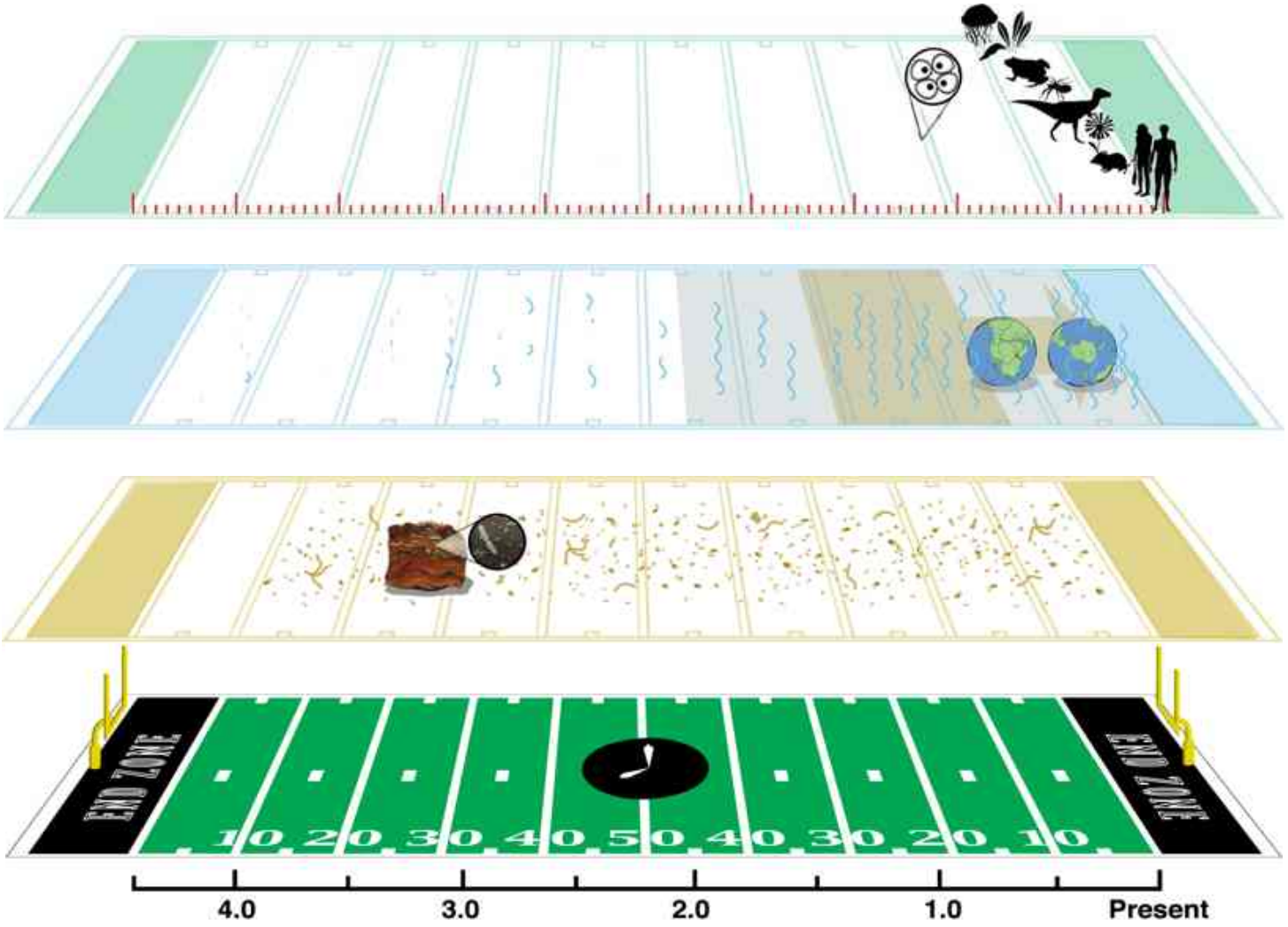
END ZONE
4.0
3.0
2.0
1.0
Present

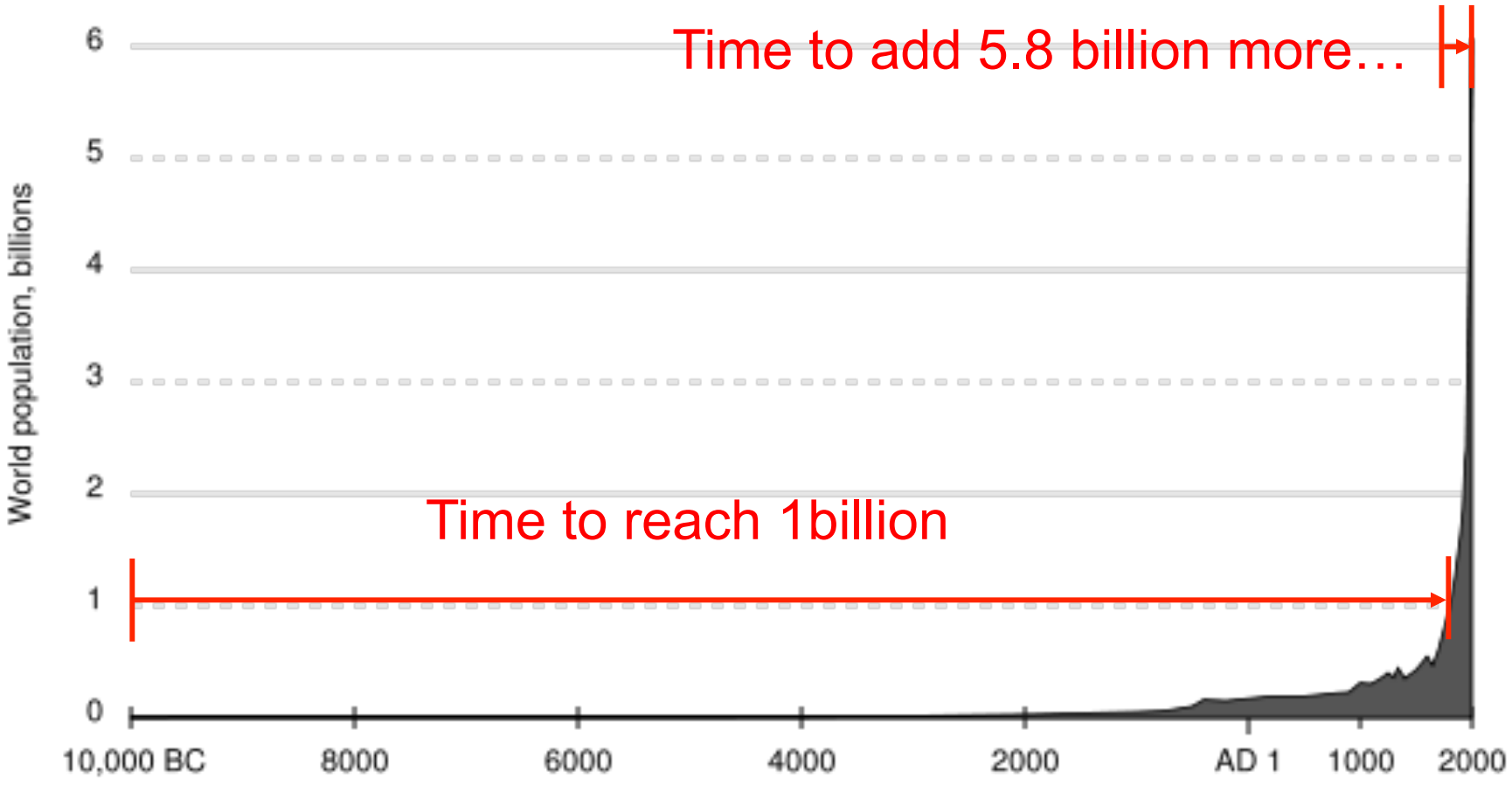

END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present

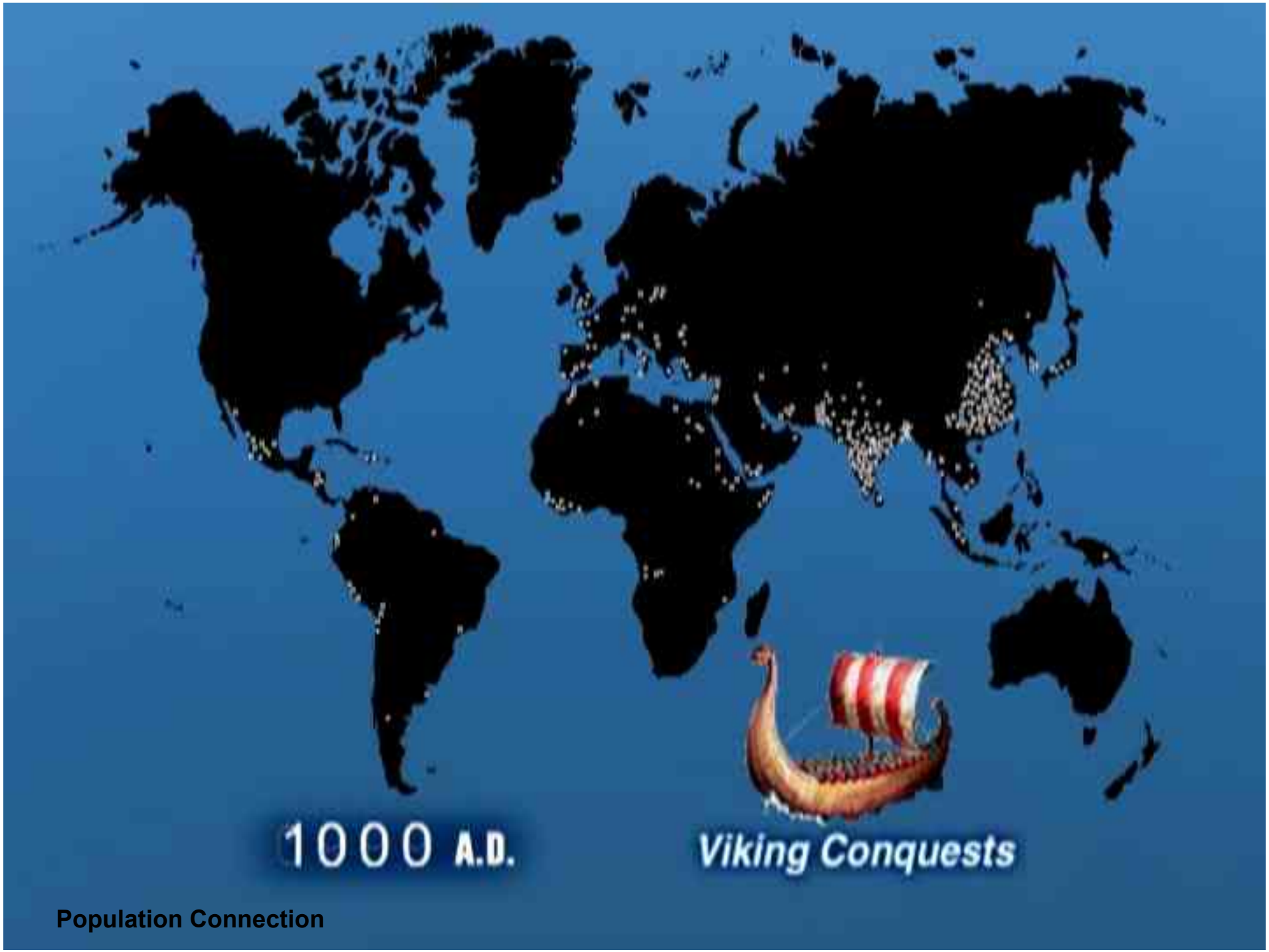

END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present


END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present

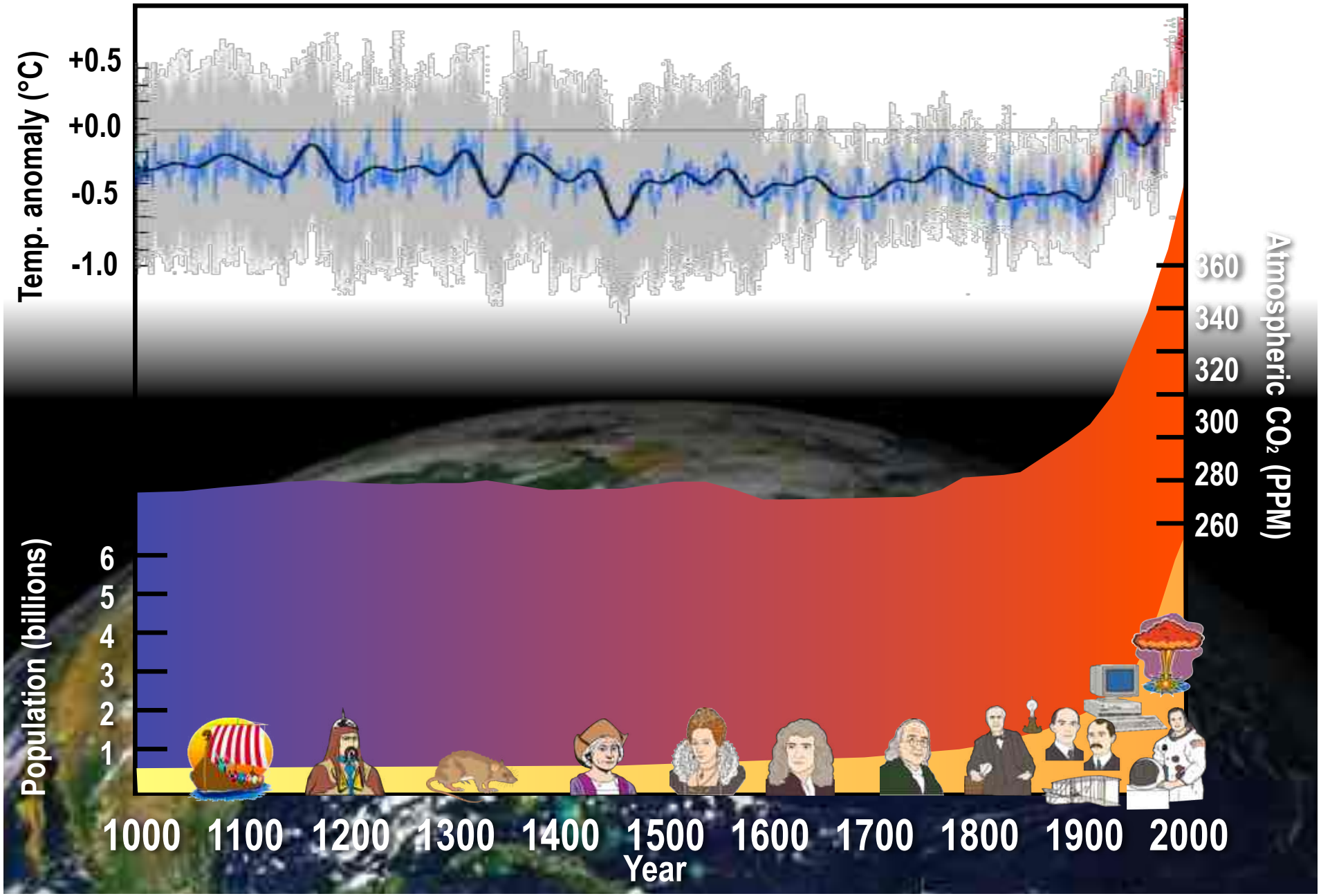

END ZONE
10 20 30 40 50 40 30 20 10
END ZONE
4.0
3.0
2.0
1.0
Present

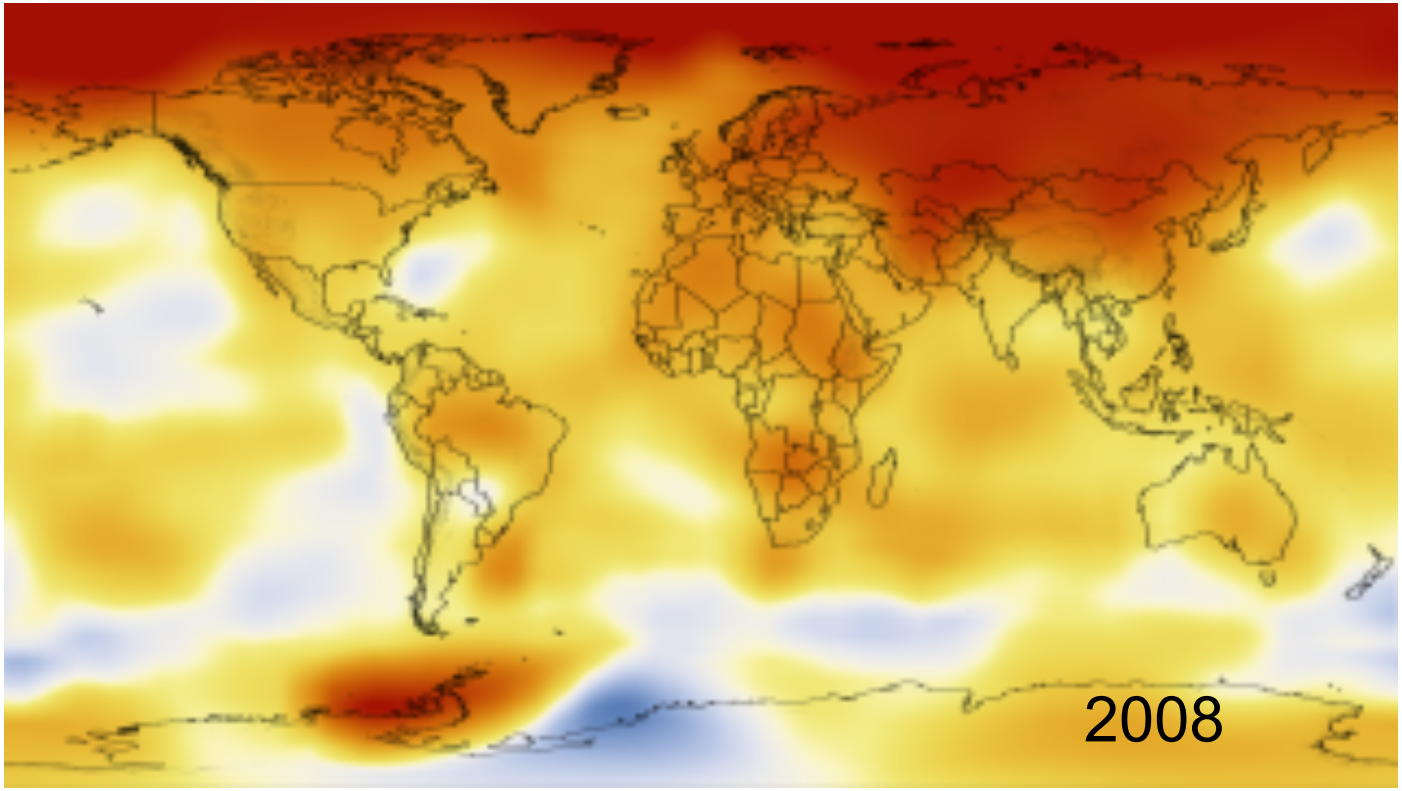
Exponential growth…





Population Connection

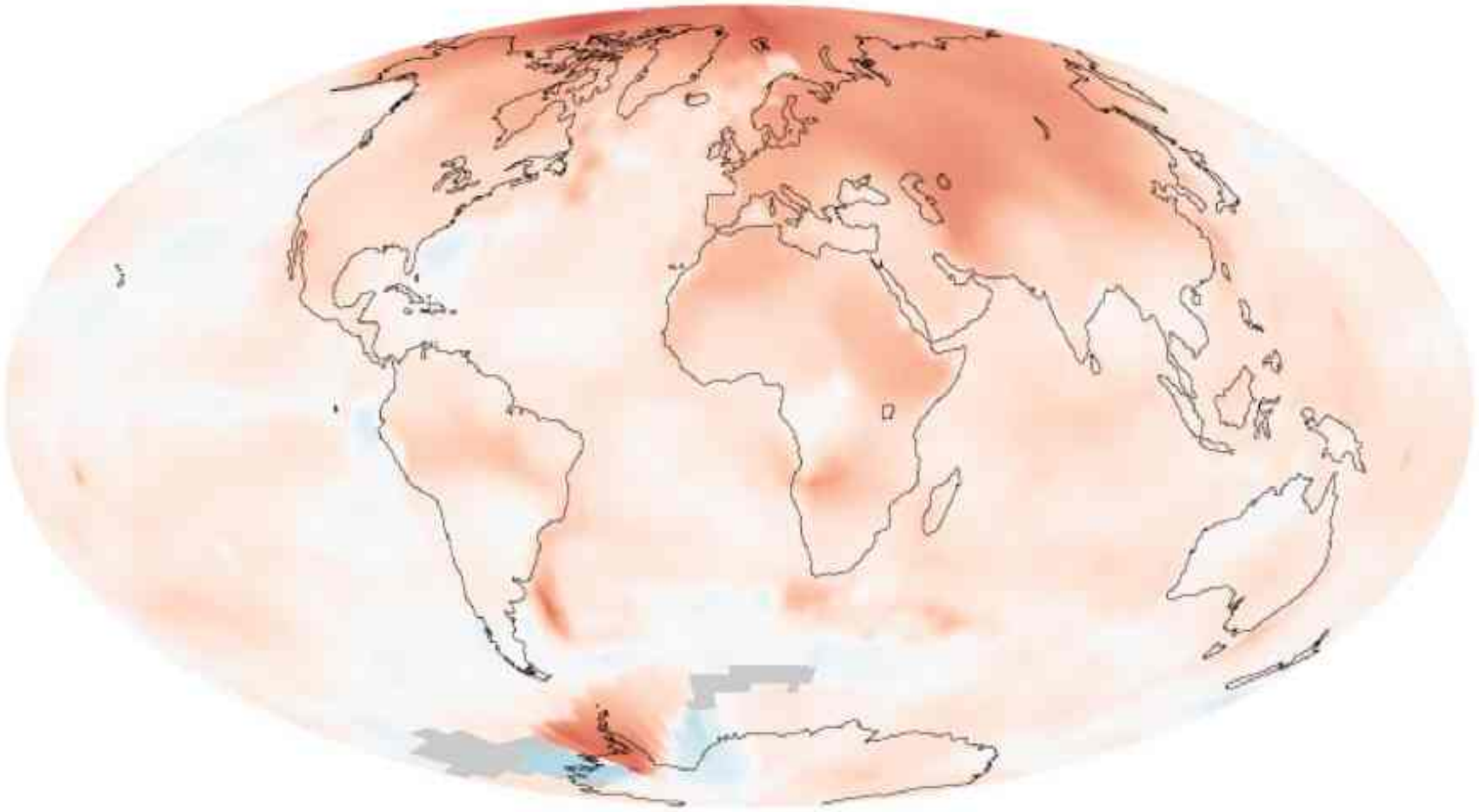

Temp. anomaly (°C)
+0.5
+0.0
-0.5
-1.0
Atmospheric CO₂ (PPM)
360
340
320
300
280
260
Population (billions)
6
5
4
3
2
1
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year



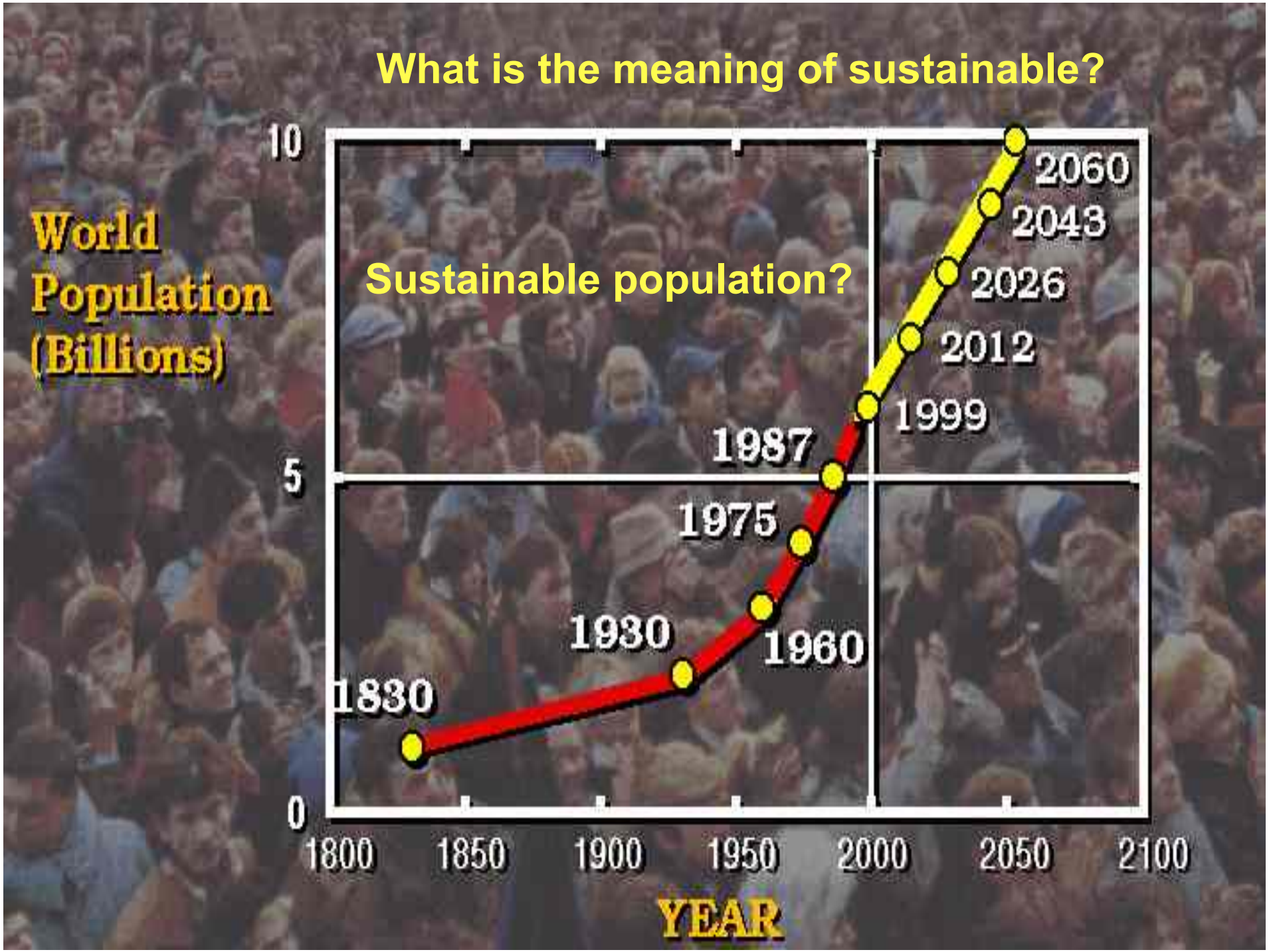
Temperature Anomaly °C

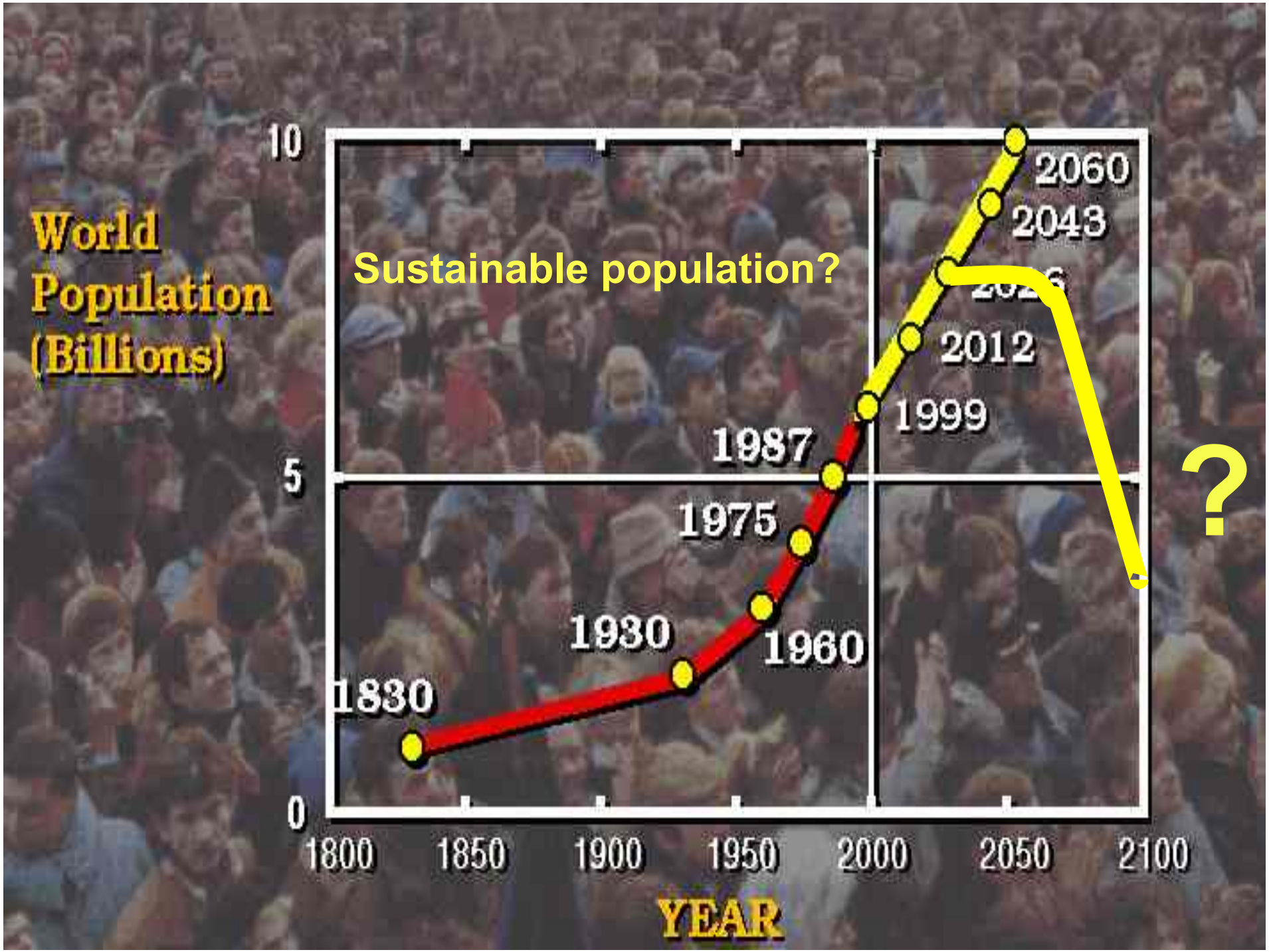
Data from NASA/Goddard Space Flight Center
James Hansen, Goddard Institute of Space Studies
Robert B. Schmunk, Scientific Visualization Studio

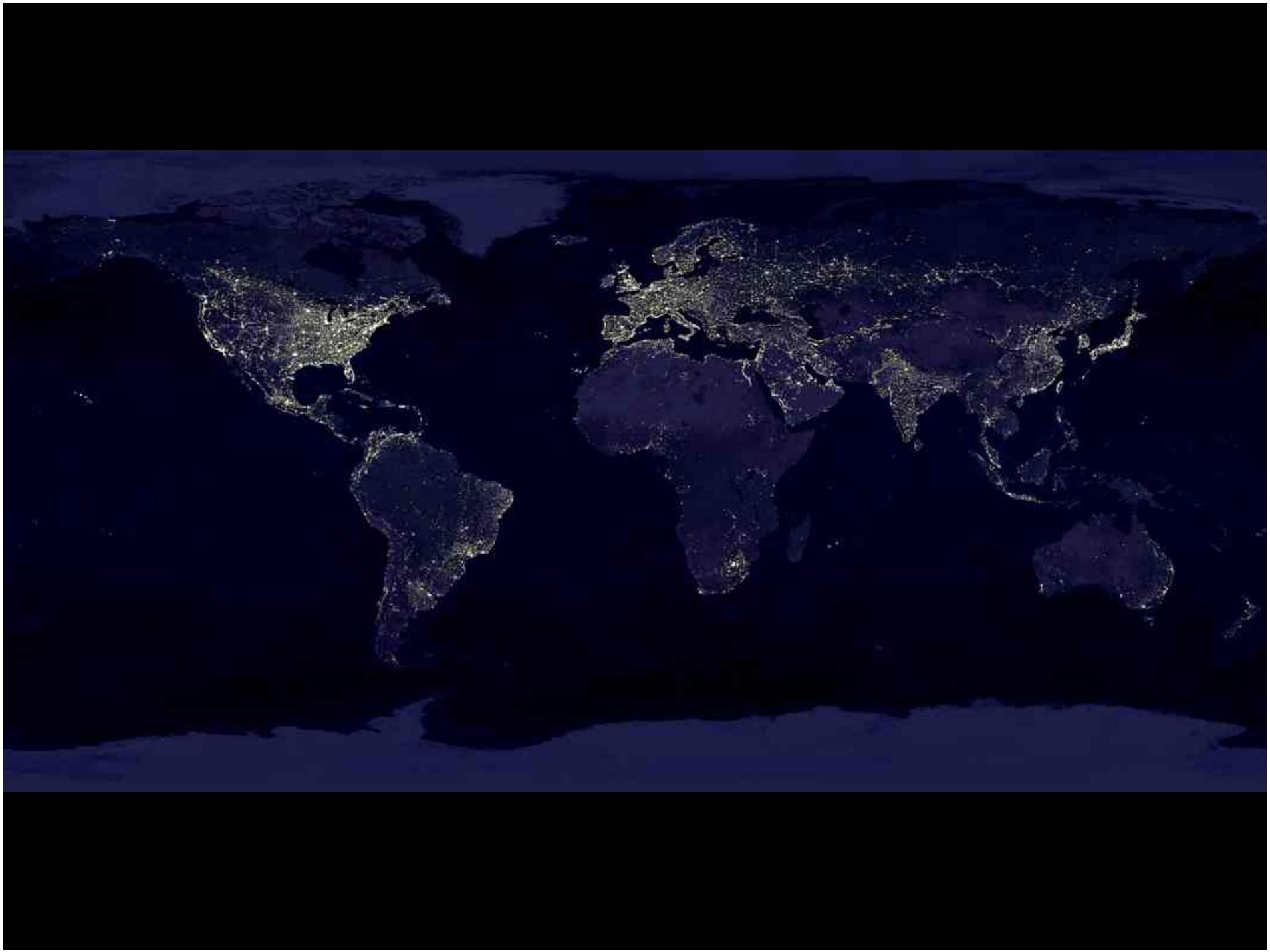
The warmest decade on record…

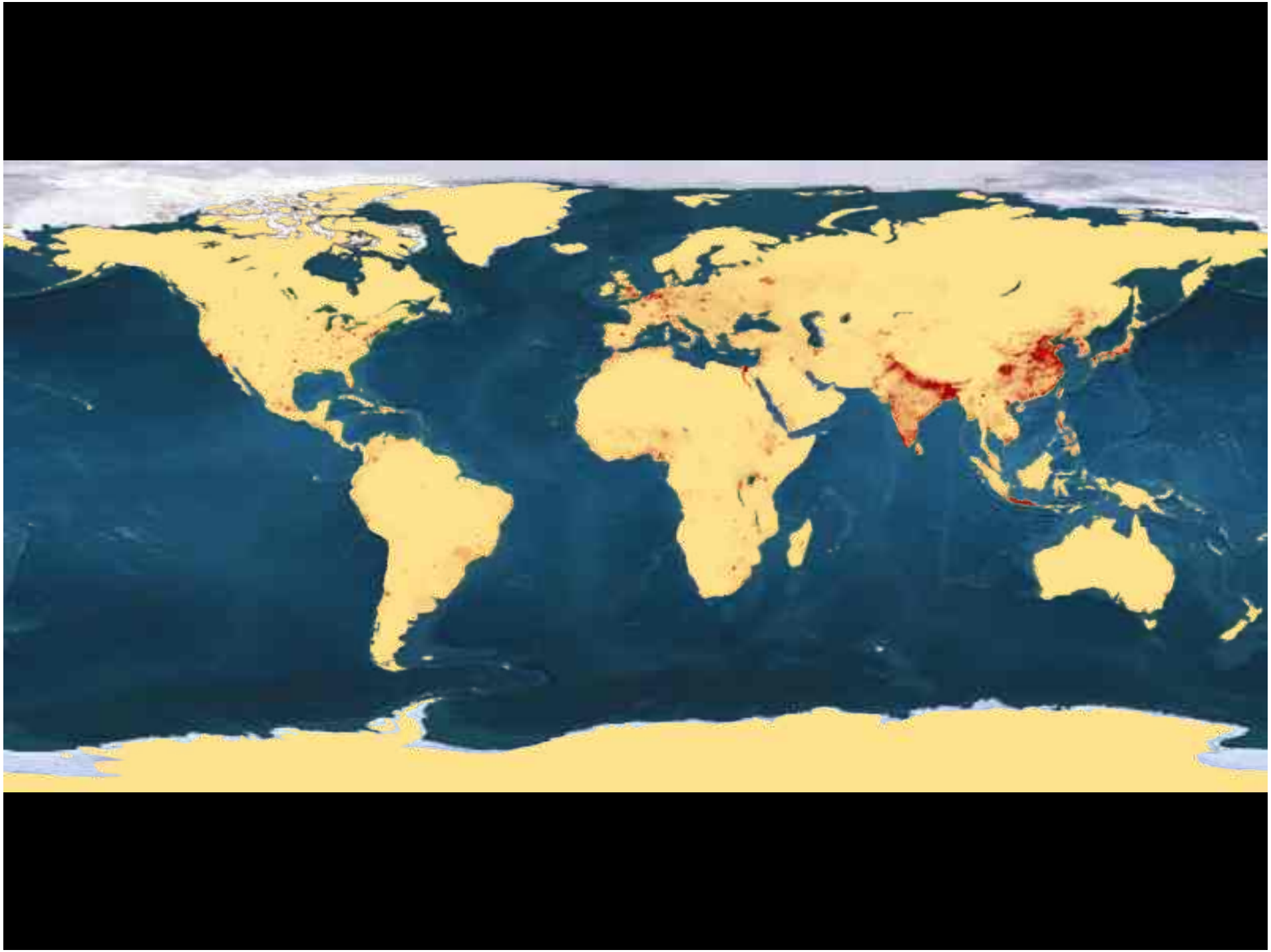


DATA from GISS
Avg: 2000-2009
1951-1980

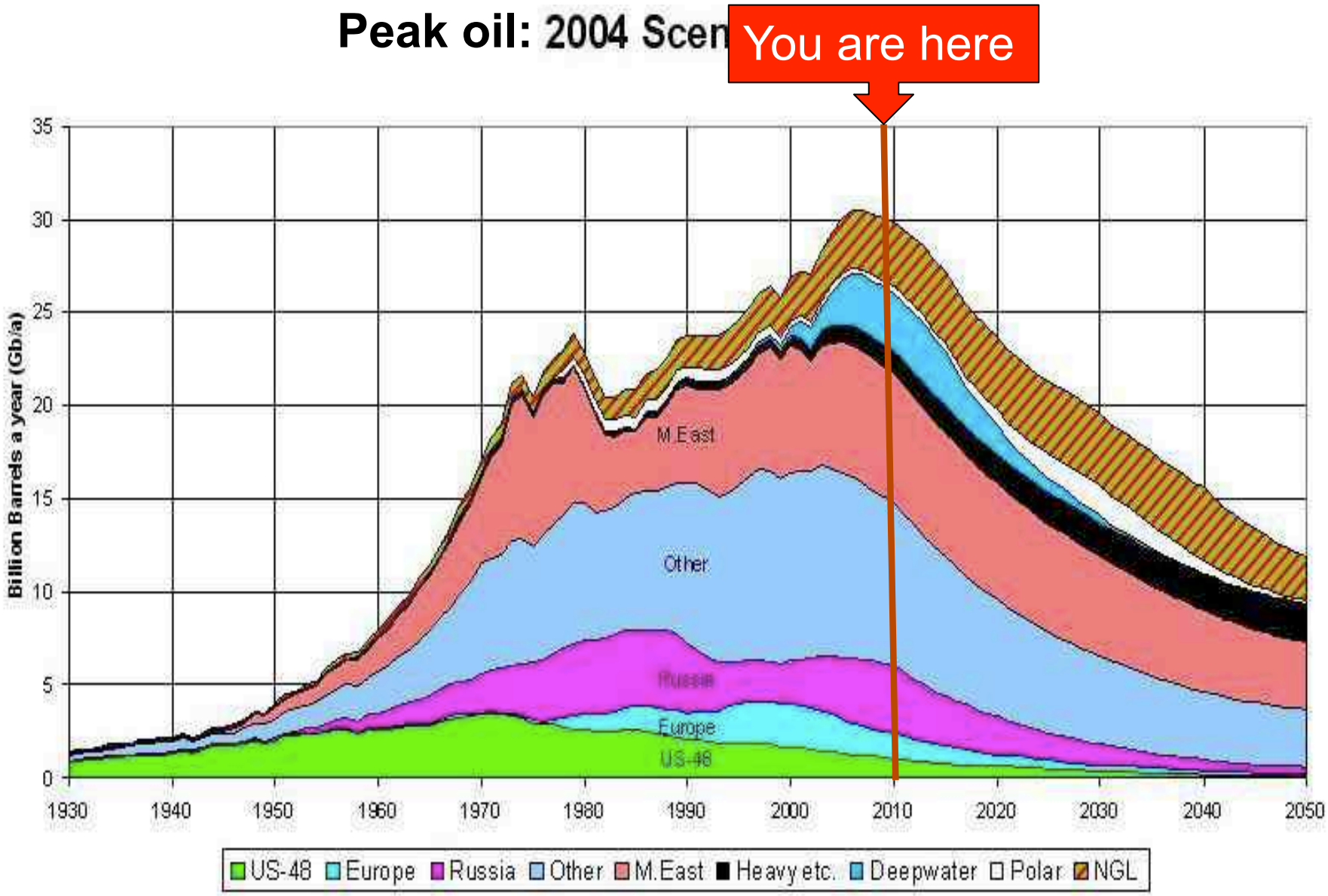

What is the meaning of sustainable?
Sustainable population?
World Population (Billions)
10
5
0
1830
1930
1960
1975
1987
1999
2012
2026
2043
2060
1800
1850
1900
1950
2000
2050
2100
YEAR

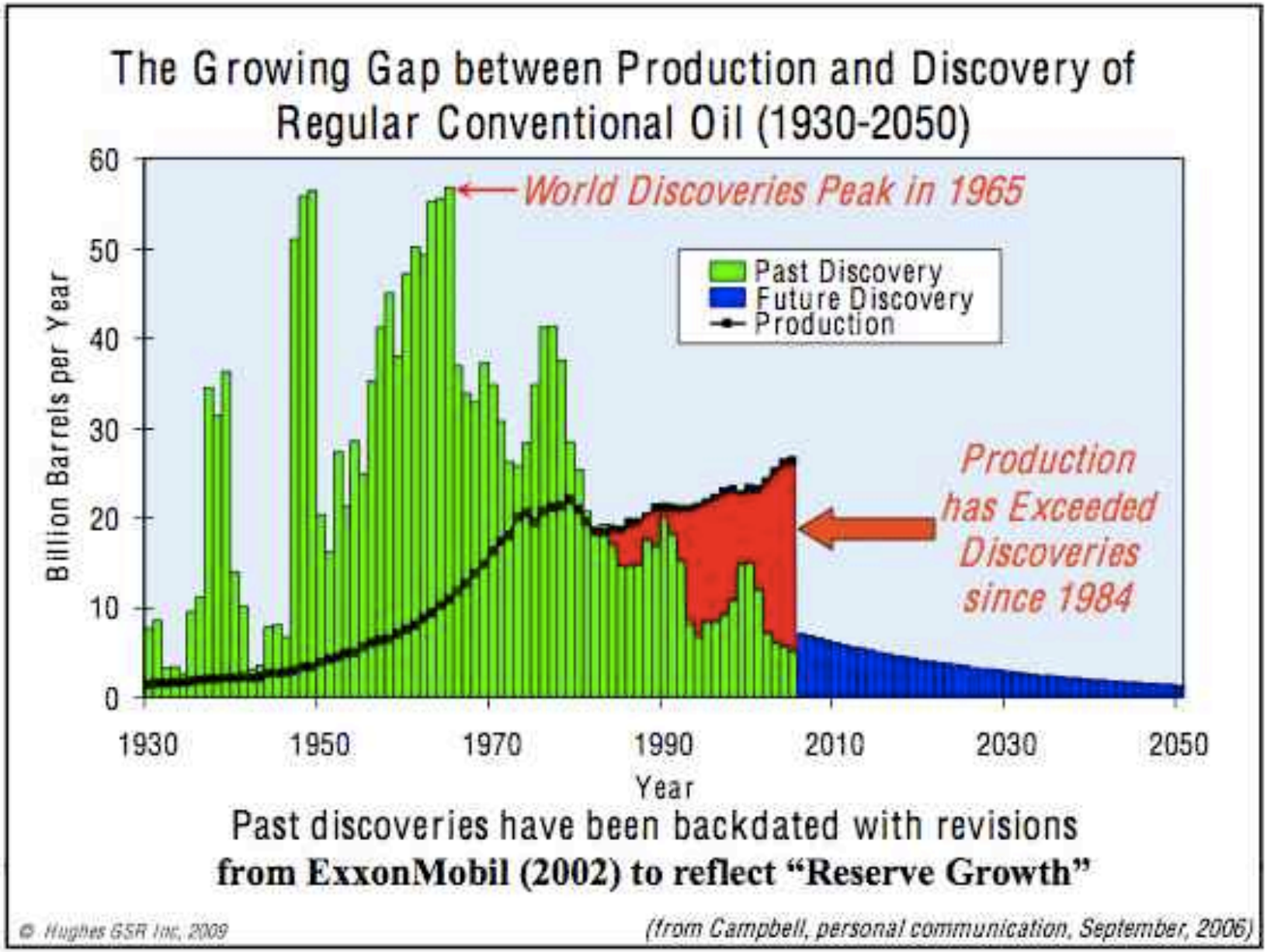

World Population (Billions)
10
5
0
Sustainable population?
2060
2043
2012
1999
1987
1975
1960
1930
1830
?
1800
1850
1900
1950
2000
2050
2100
YEAR

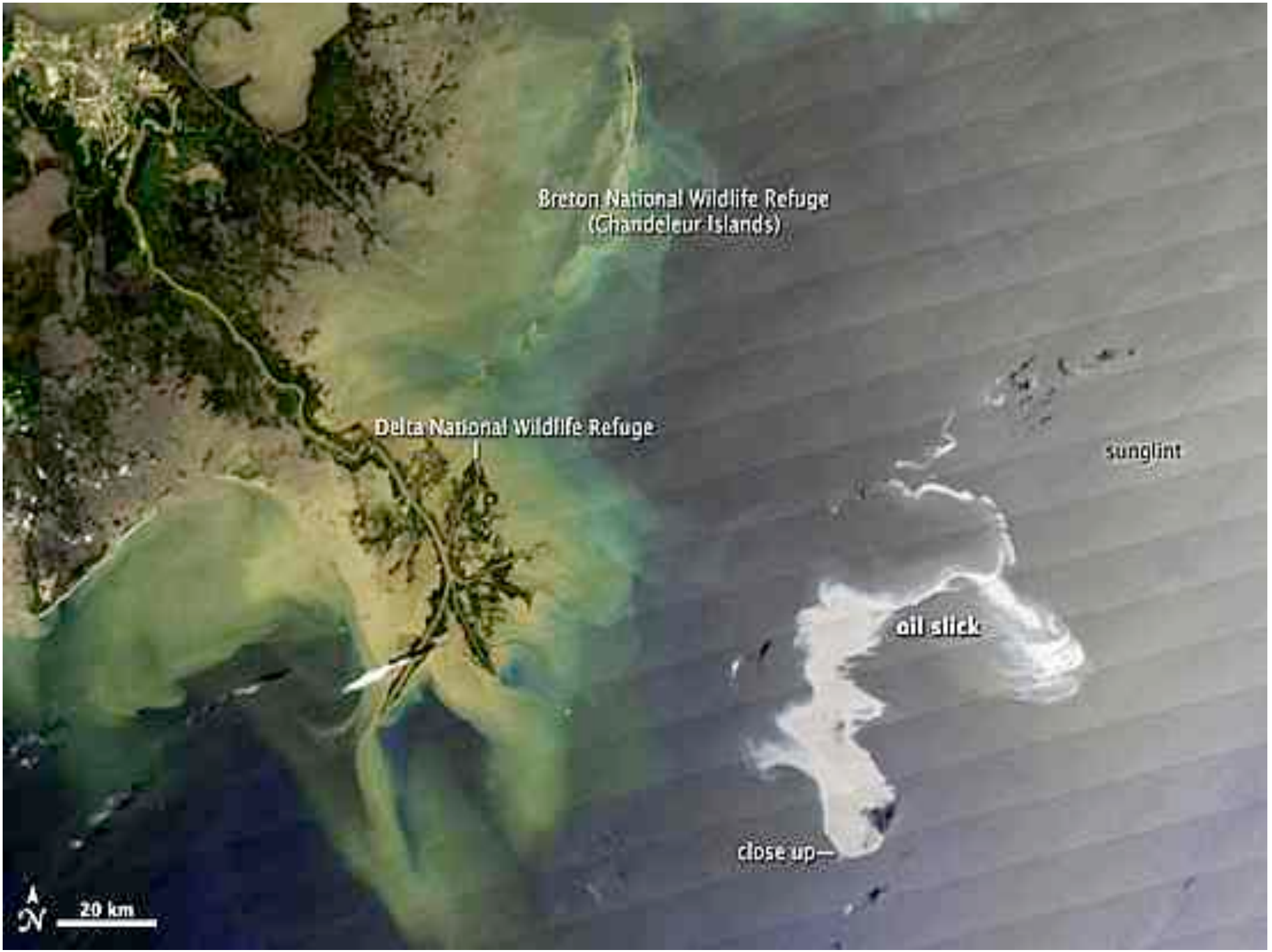


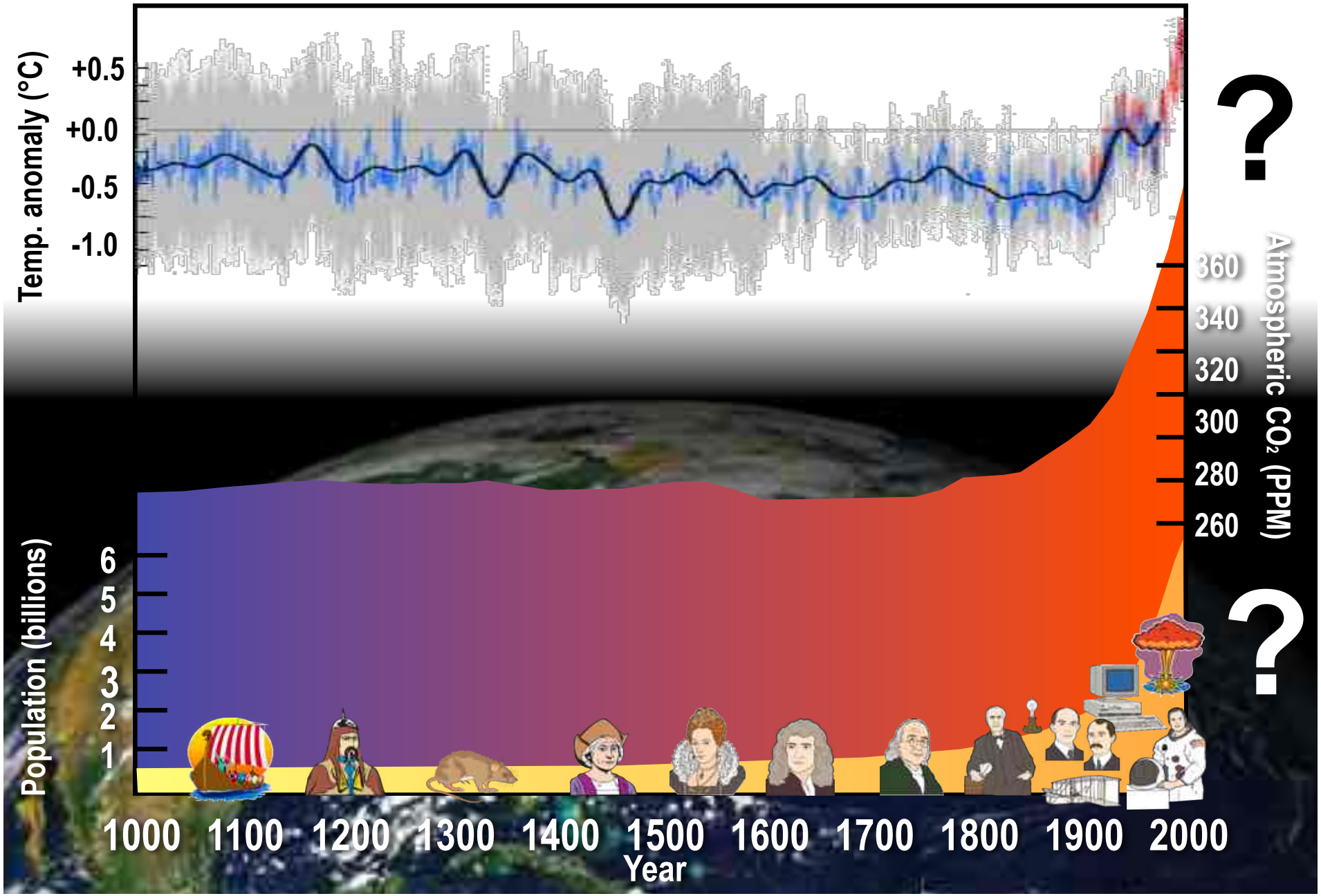


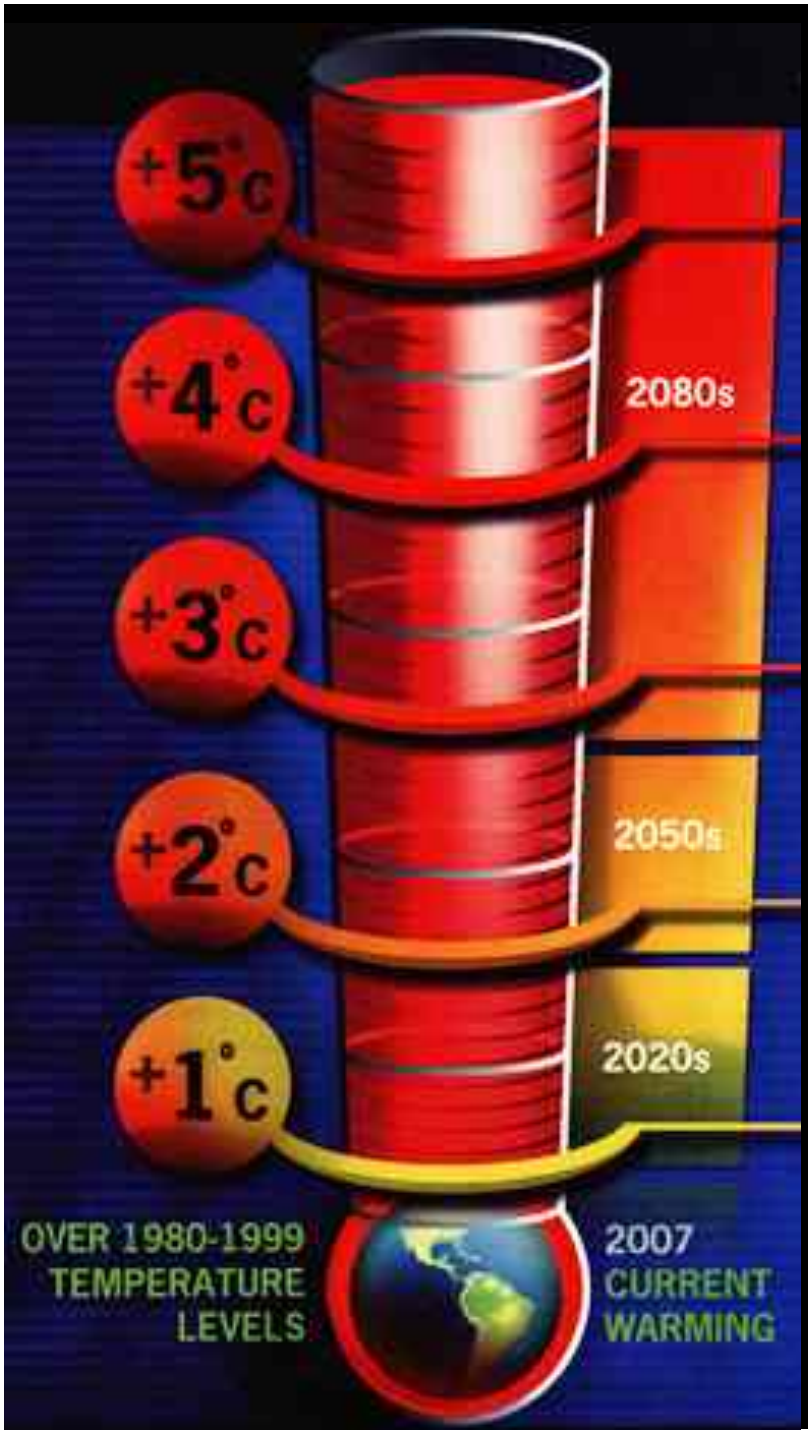
Peak oil: 2004 Scen




The Growing Gap between Production and Discovery of Regular Conventional Oil (1930-2050)
World Discoveries Peak in 1965
Past Discovery
Future Discovery
Production
Production has Exceeded Discoveries since 1984
Billion Barrels per Year
0
10
20
30
40
50
60
1930
1950
1970
1990
2010
2030
2050
Year
Past discoveries have been backdated with revisions
from ExxonMobil (2002) to reflect "Reserve Growth"
© Hughes GSR Inc, 2009
(from Campbell, personal communication, September, 2006)


Breton National Wildlife Refuge
(Chandeleur Islands)
Delta National Wildlife Refuge
sunglint
oil slick
close up—
N
20 km


Temp. anomaly (°C)
+0.5
+0.0
-0.5
-1.0
?
Atmospheric CO_2 (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

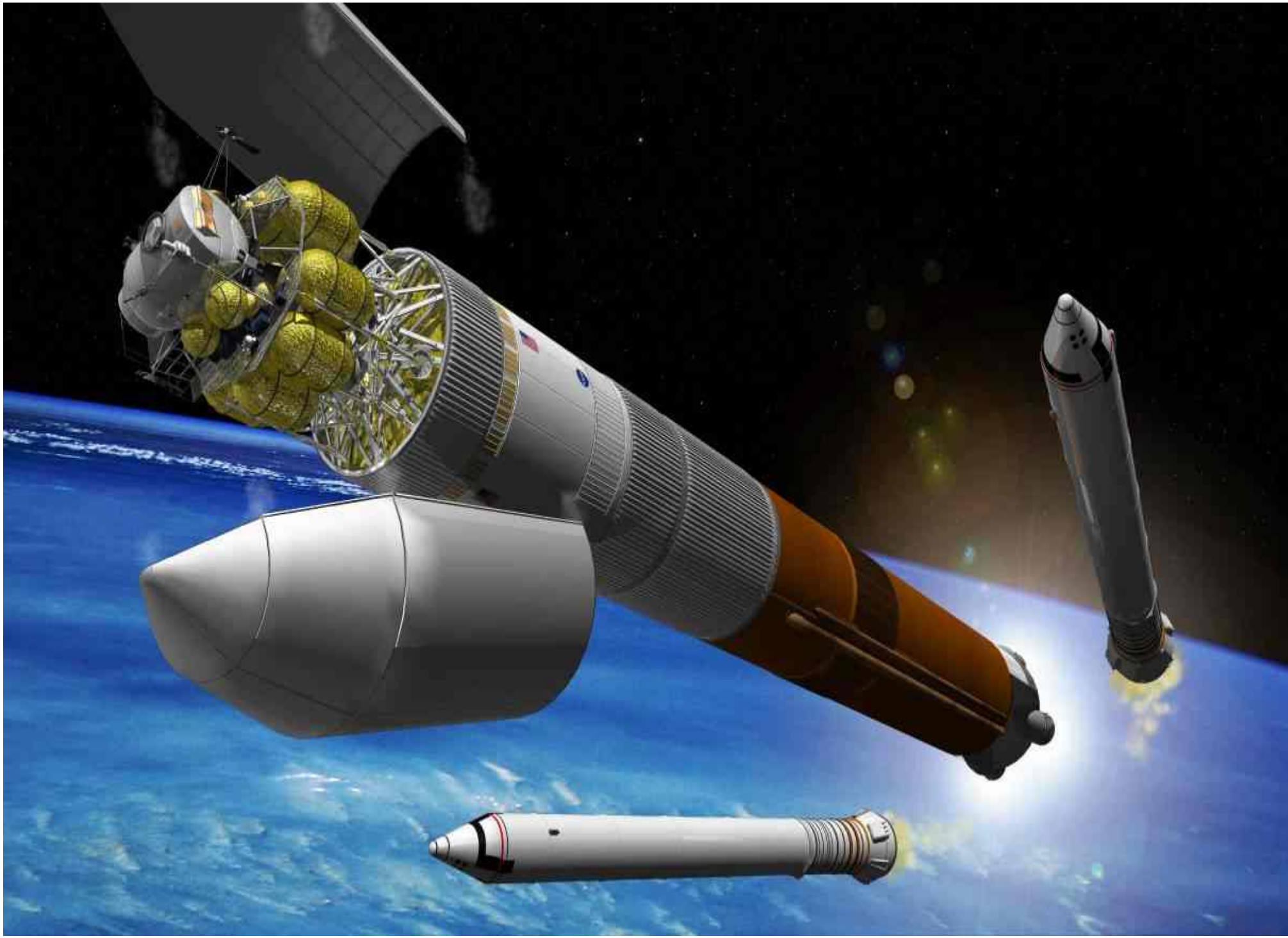
Food?

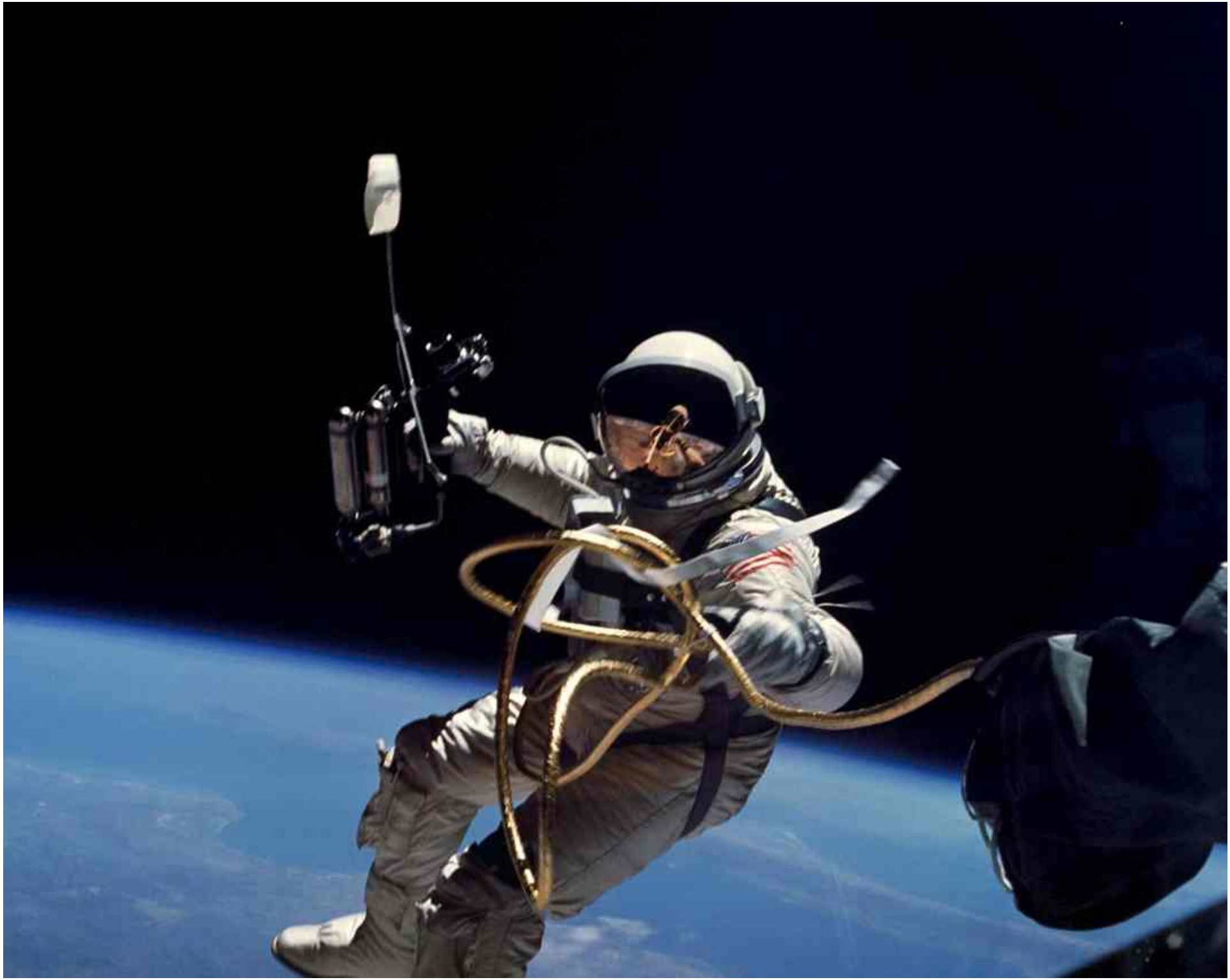
} Temp rise 0.7°C
Weather patterns, wildfires,
floods/droughts

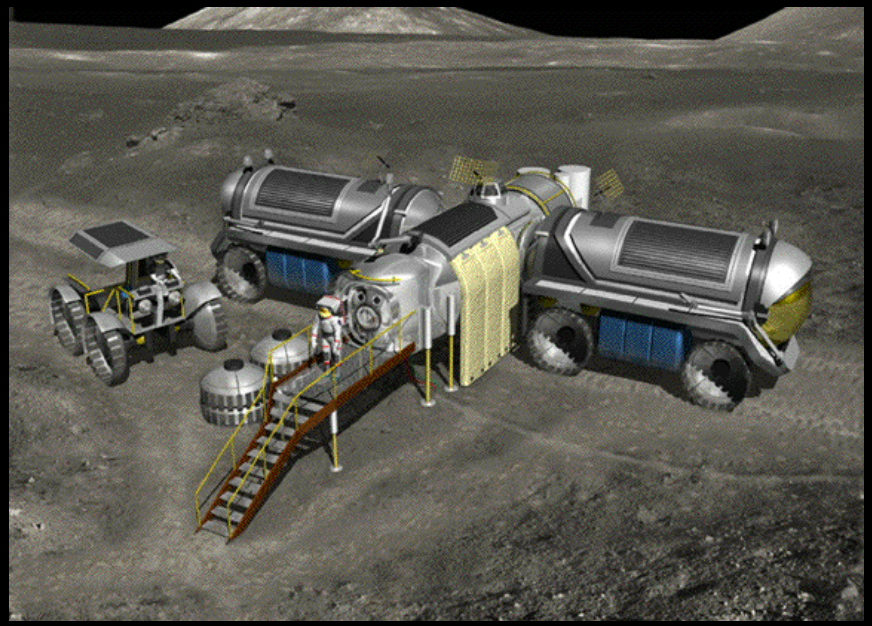
Food?

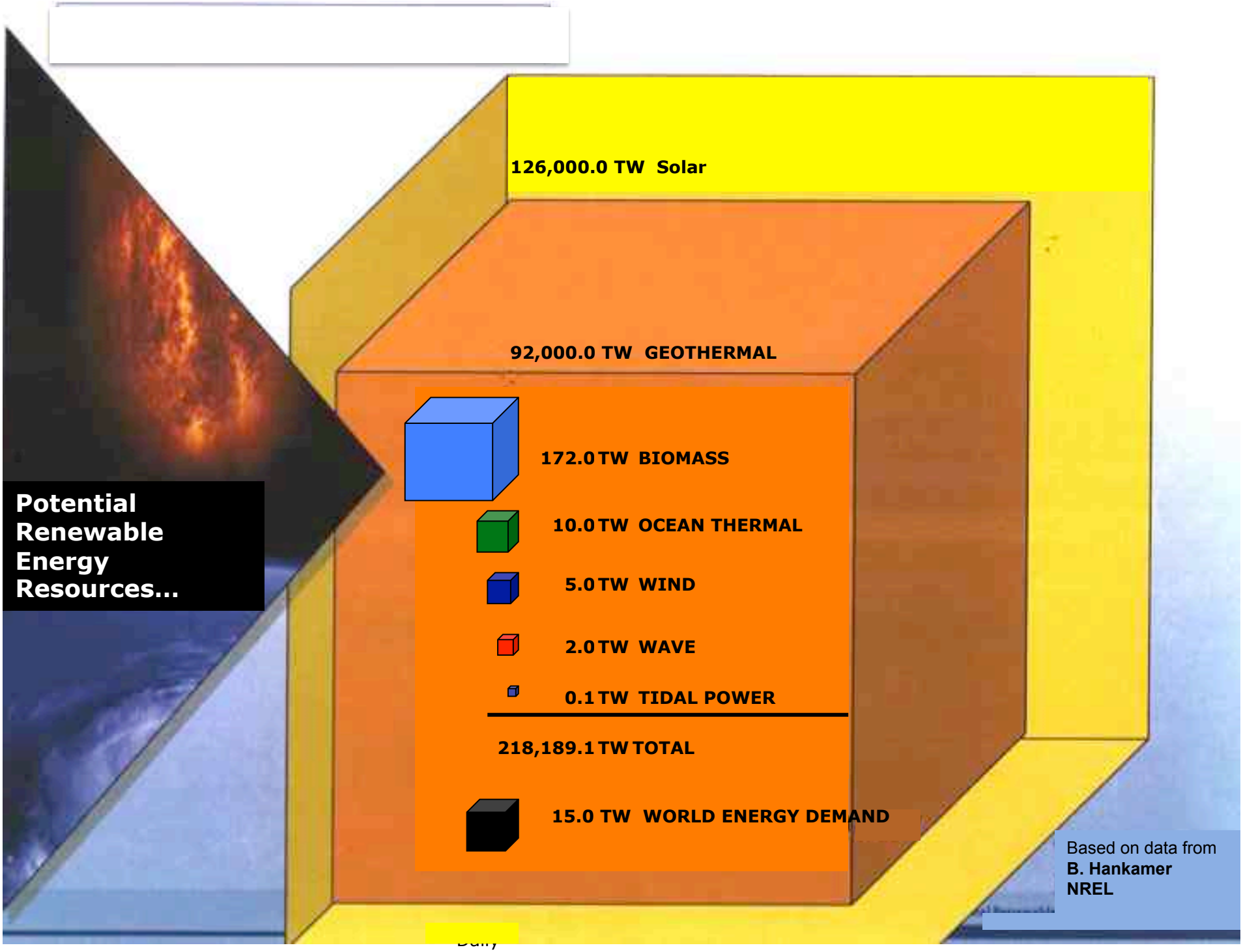
T. Root, Stanford


Sustainability?
Population
Affluence
Species
Technology








Potential Renewable Energy Resources...
126,000.0 TW Solar
92,000.0 TW GEOTHERMAL
172.0 TW BIOMASS
10.0 TW OCEAN THERMAL
5.0 TW WIND
2.0 TW WAVE
0.1 TW TIDAL POWER
218,189.1 TW TOTAL
15.0 TW WORLD ENERGY DEMAND
Based on data from
B. Hankamer
NREL

Are biofuels the answer?

Only if they do not use:

- agricultural land
- freshwater
- fertilizer

Feasible, affordable, scalable, sustainable…

NOW!


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

How **green** are biofuels?

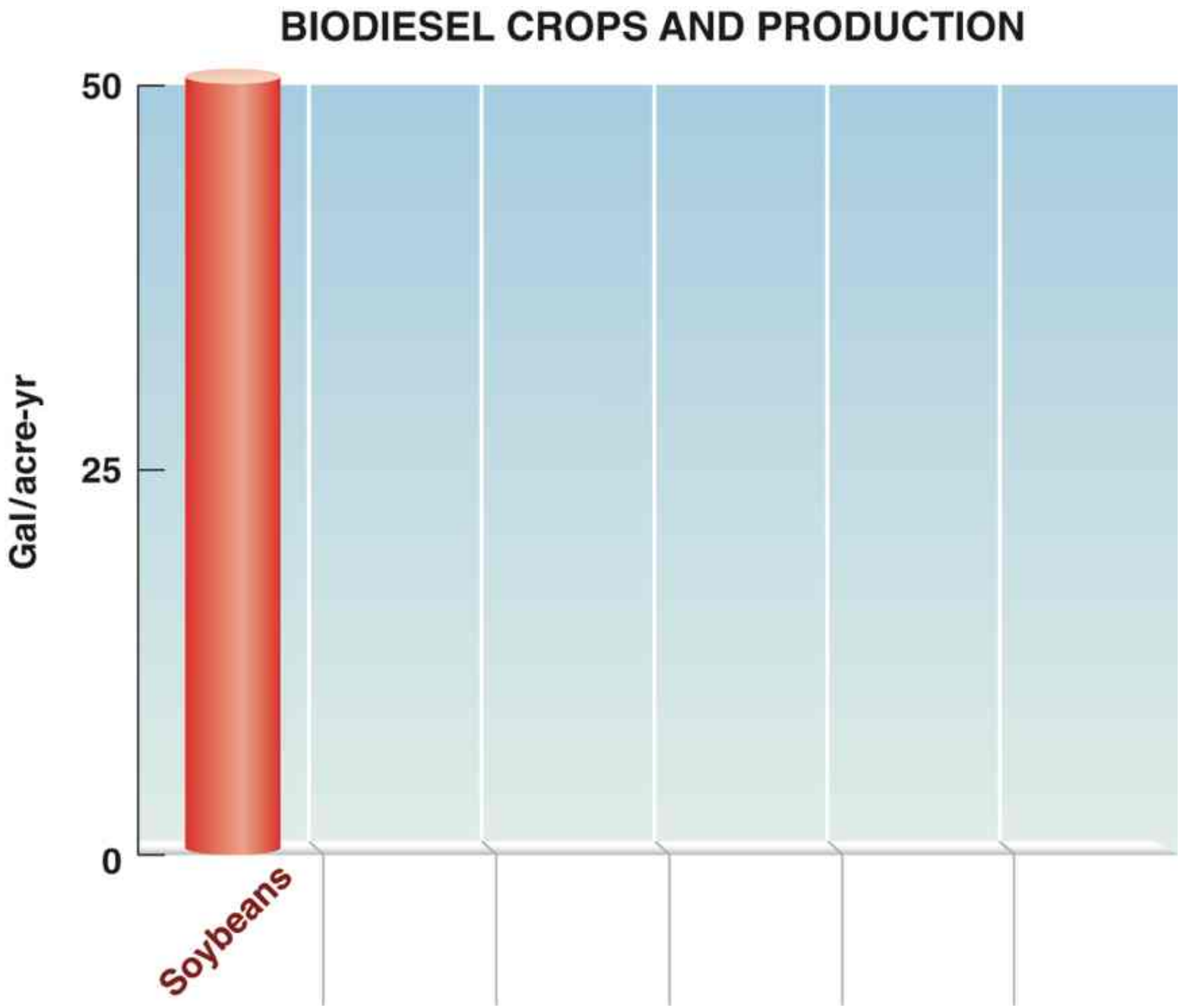
	Corn	Sugar Cane	Switch Grass
Product			
GHG output*			
Water			
Fertilizer			
Pesticide			
Energy			
US crop land/ half demand			

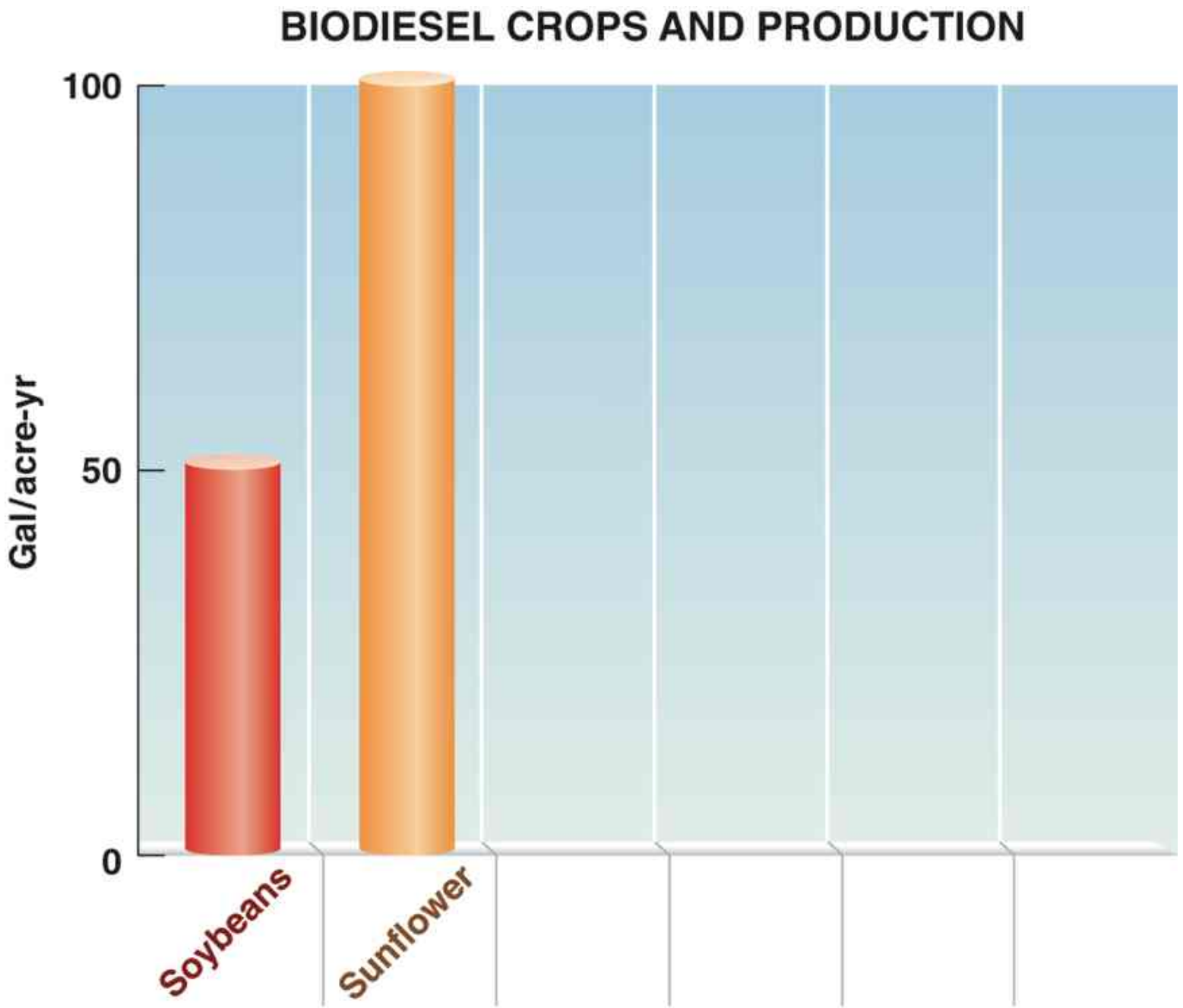
*CO_2 kg/MJ: Growing, harvesting, refining, burning fuel (cf., gas=94)

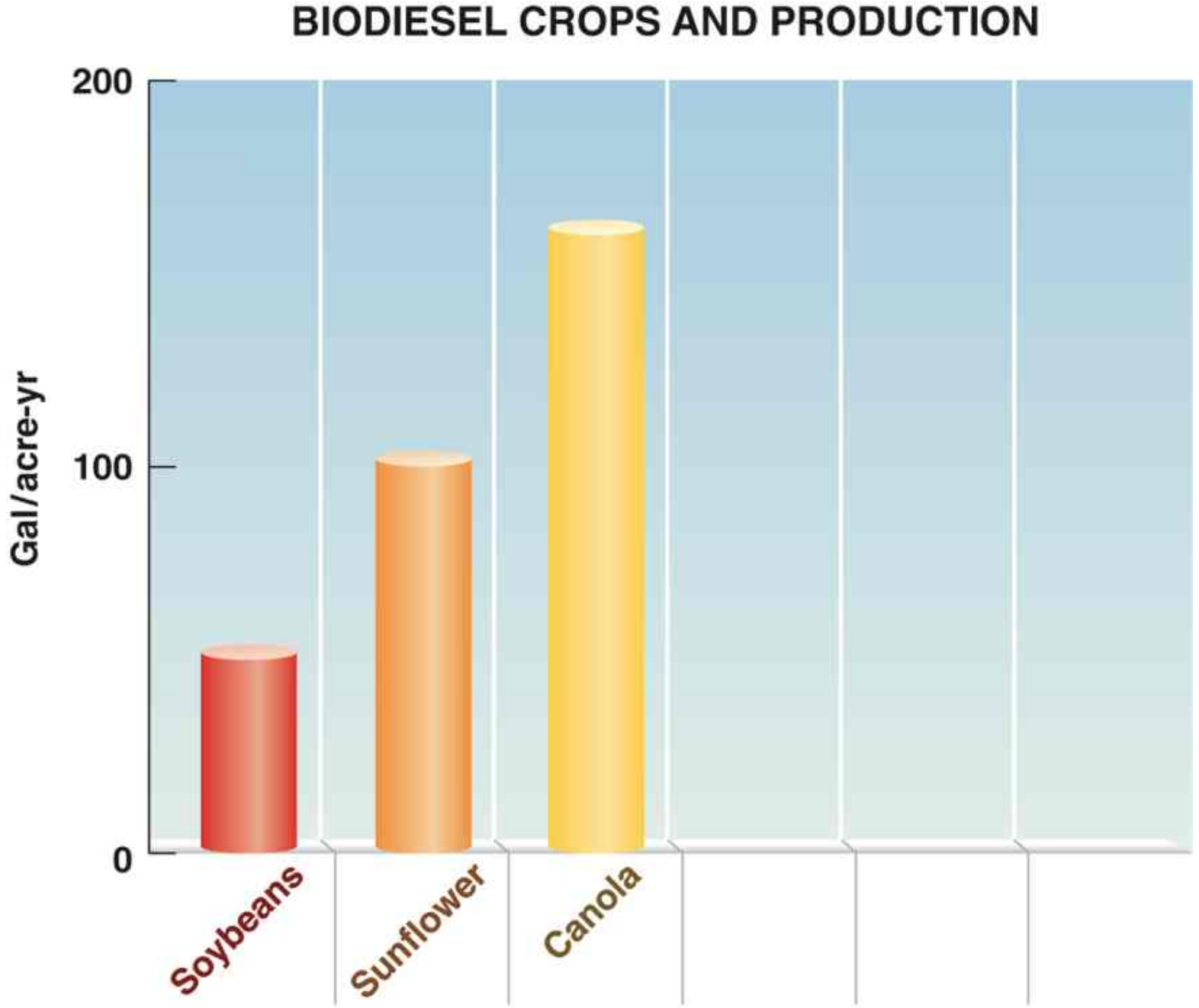
The problem with biodiesel…

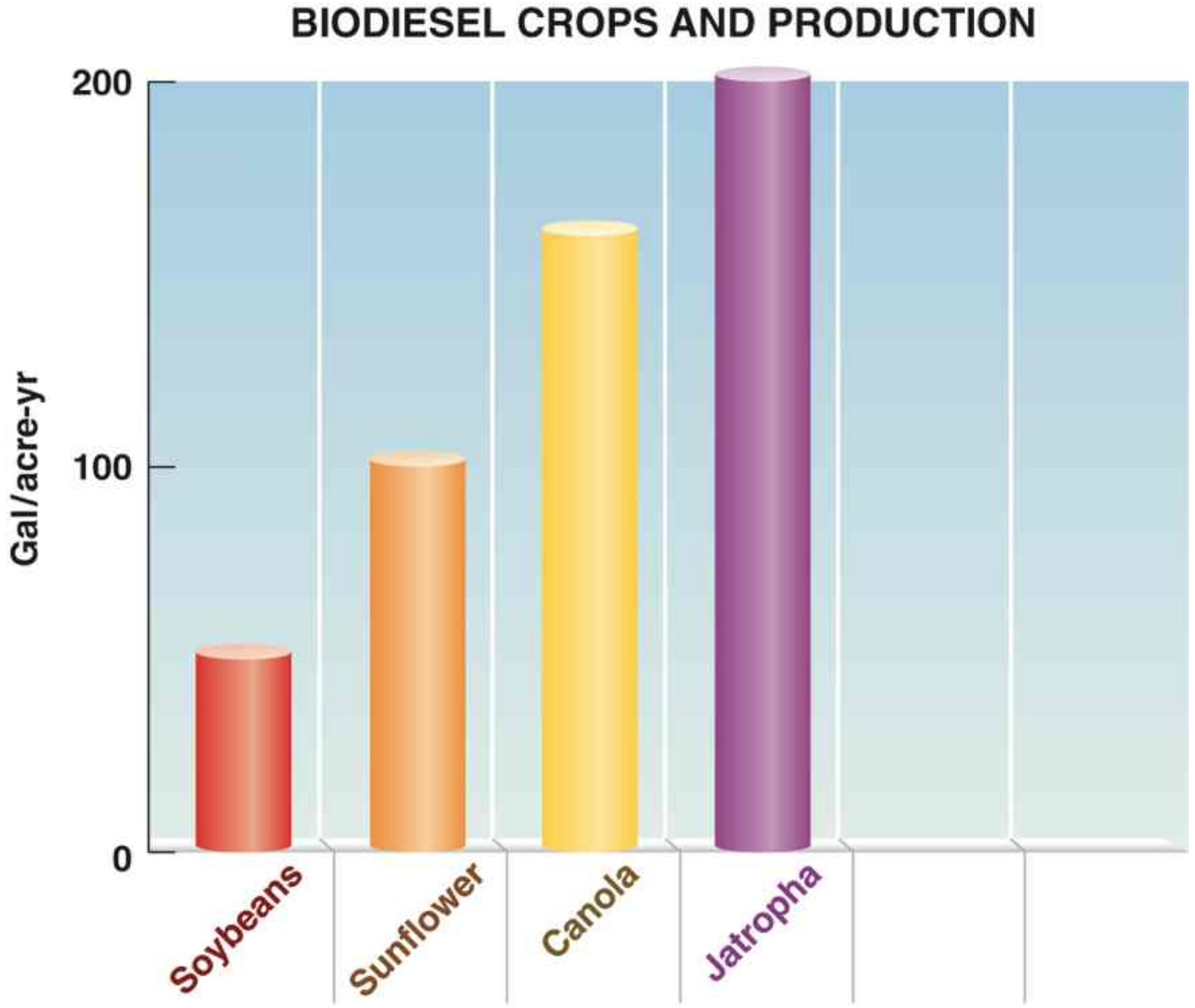
	Wood Residue	Soybeans	Rapeseed, Canola
Product	Ethanol, biodiesel	biodiesel	biodiesel
GHG output*	N/A	49	37
Water	low	HIGH	HIGH
Fertilizer	low	low-med	med
Pesticide	low	med	med
Energy	low	med-low	med-low
US crop land/ half demand	150 -250%	180-240%	30%

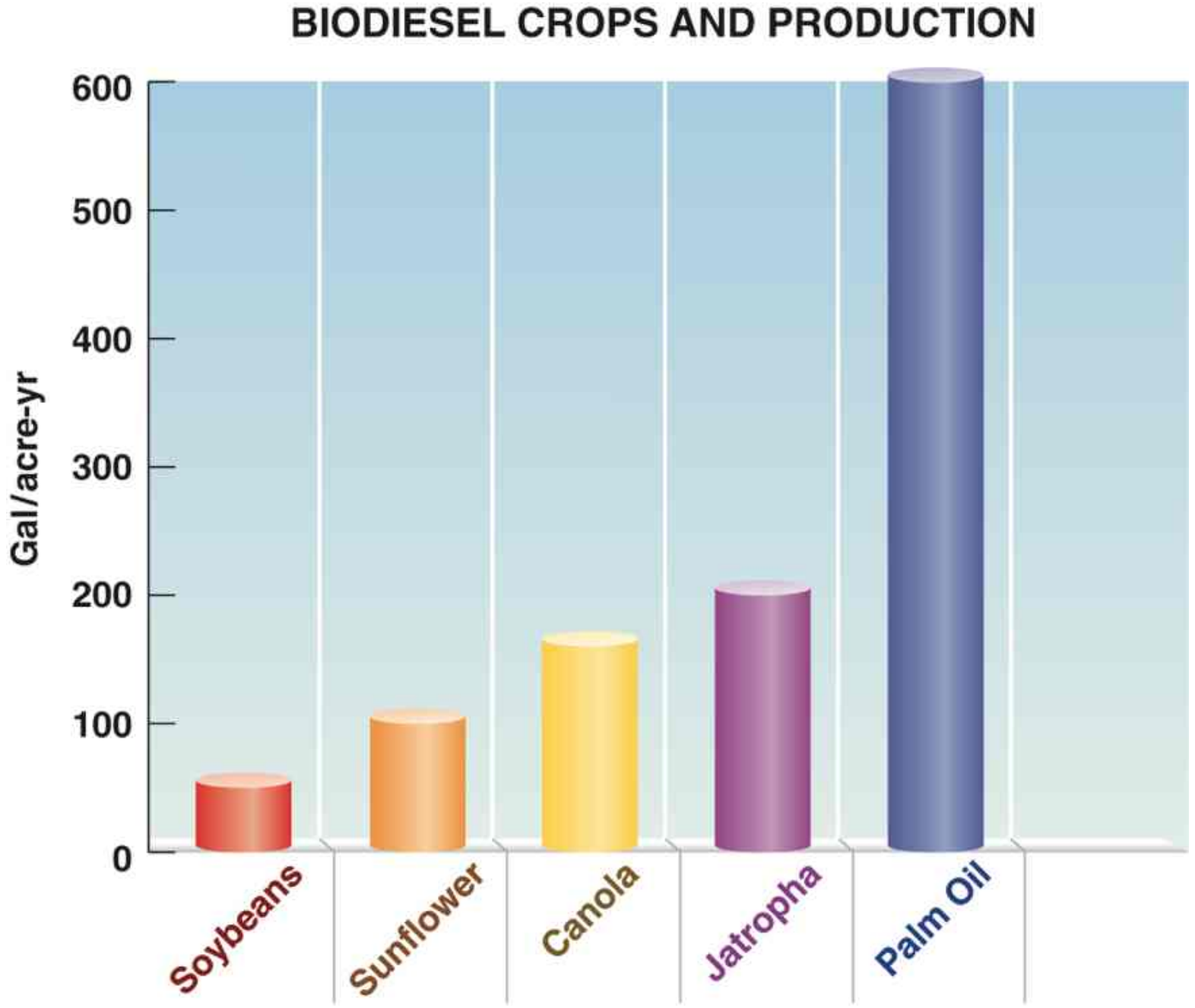
*CO_2 kg/MJ: Growing, harvesting, refining, burning fuel (cf., Diesel=83)

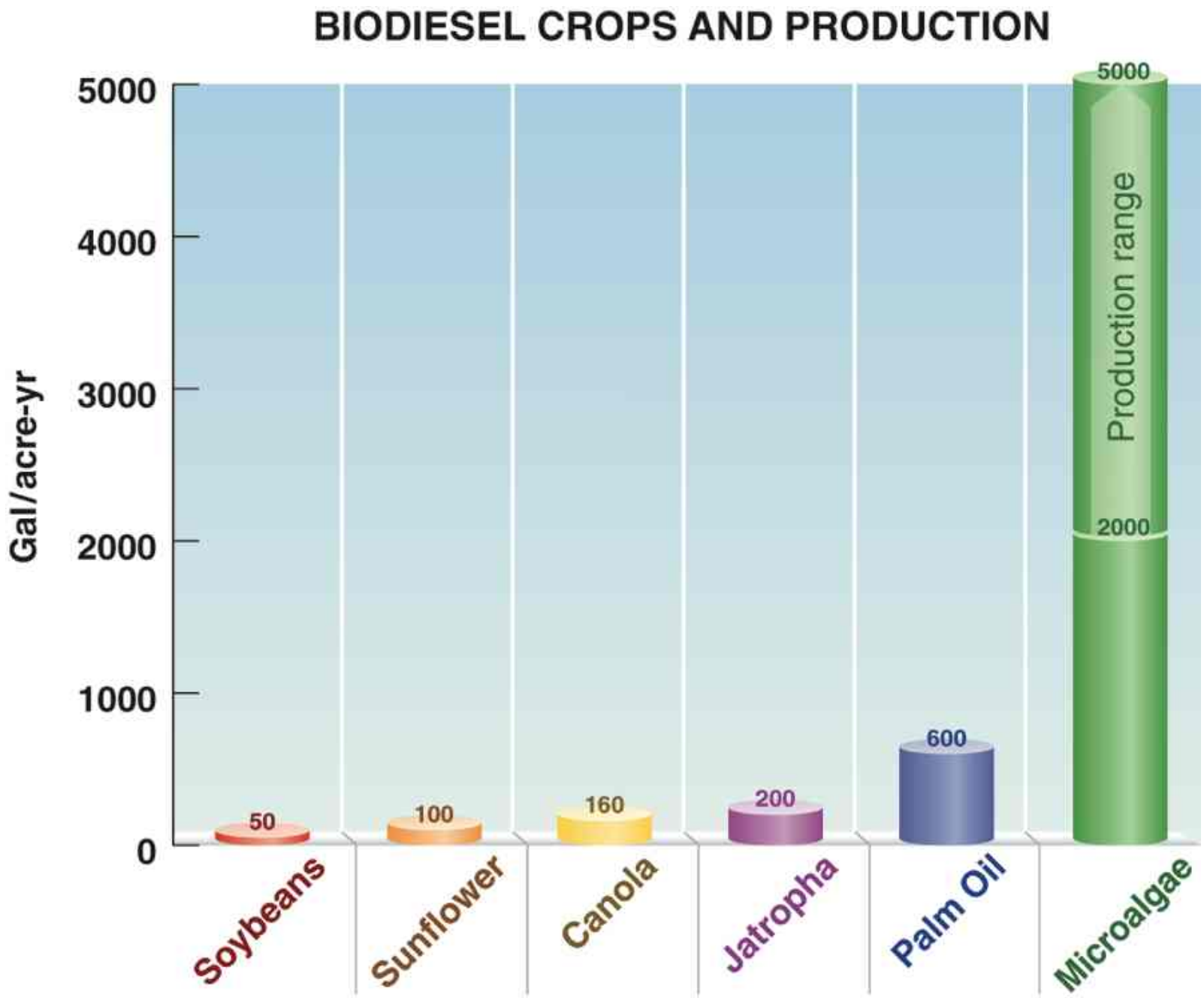

BIODIESEL CROPS AND PRODUCTION
50
25
0
Gal/acre-yr
Soybeans

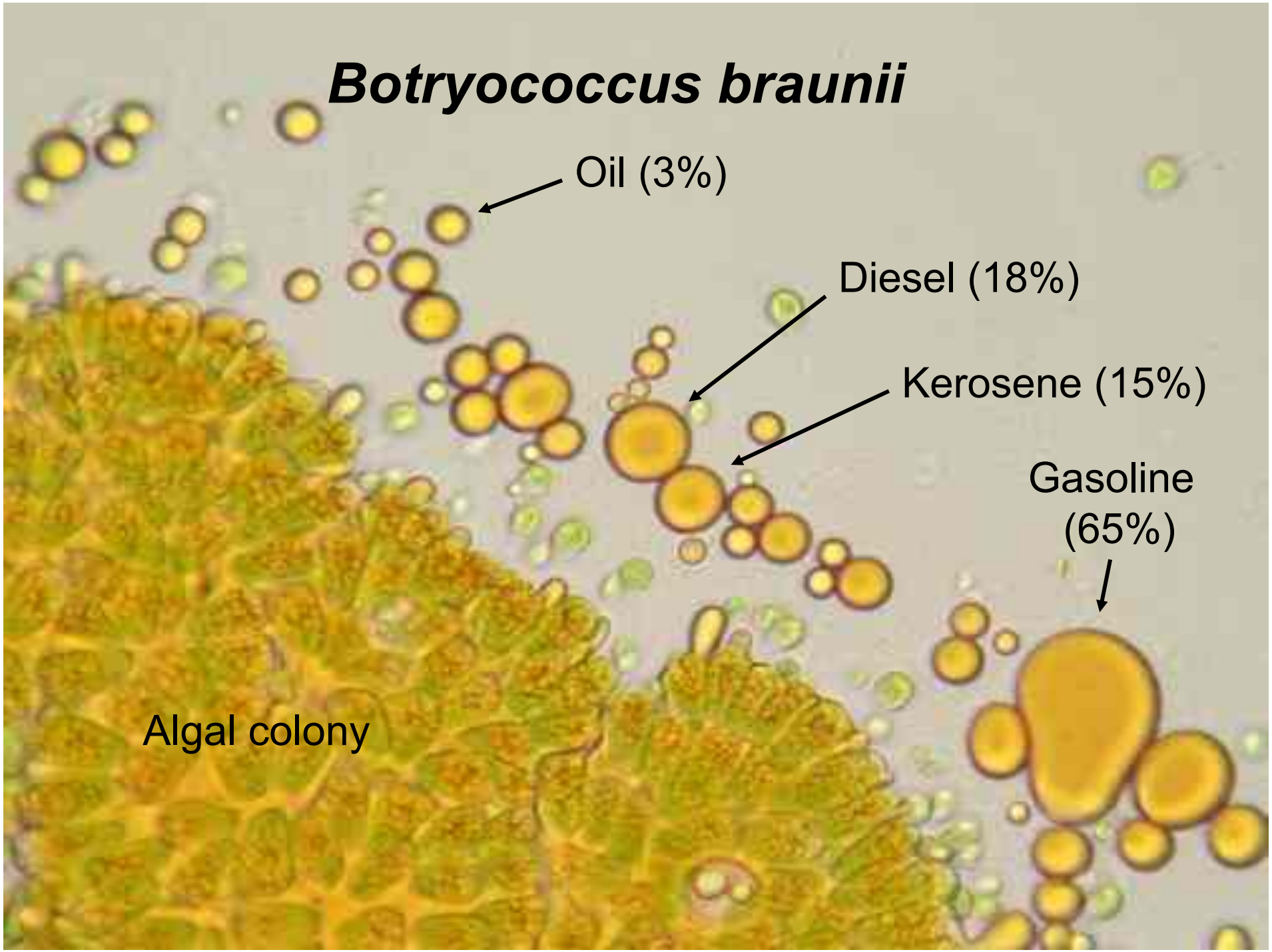

BIODIESEL CROPS AND PRODUCTION
100
50
0
Gal/acre-yr
Soybeans
Sunflower


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

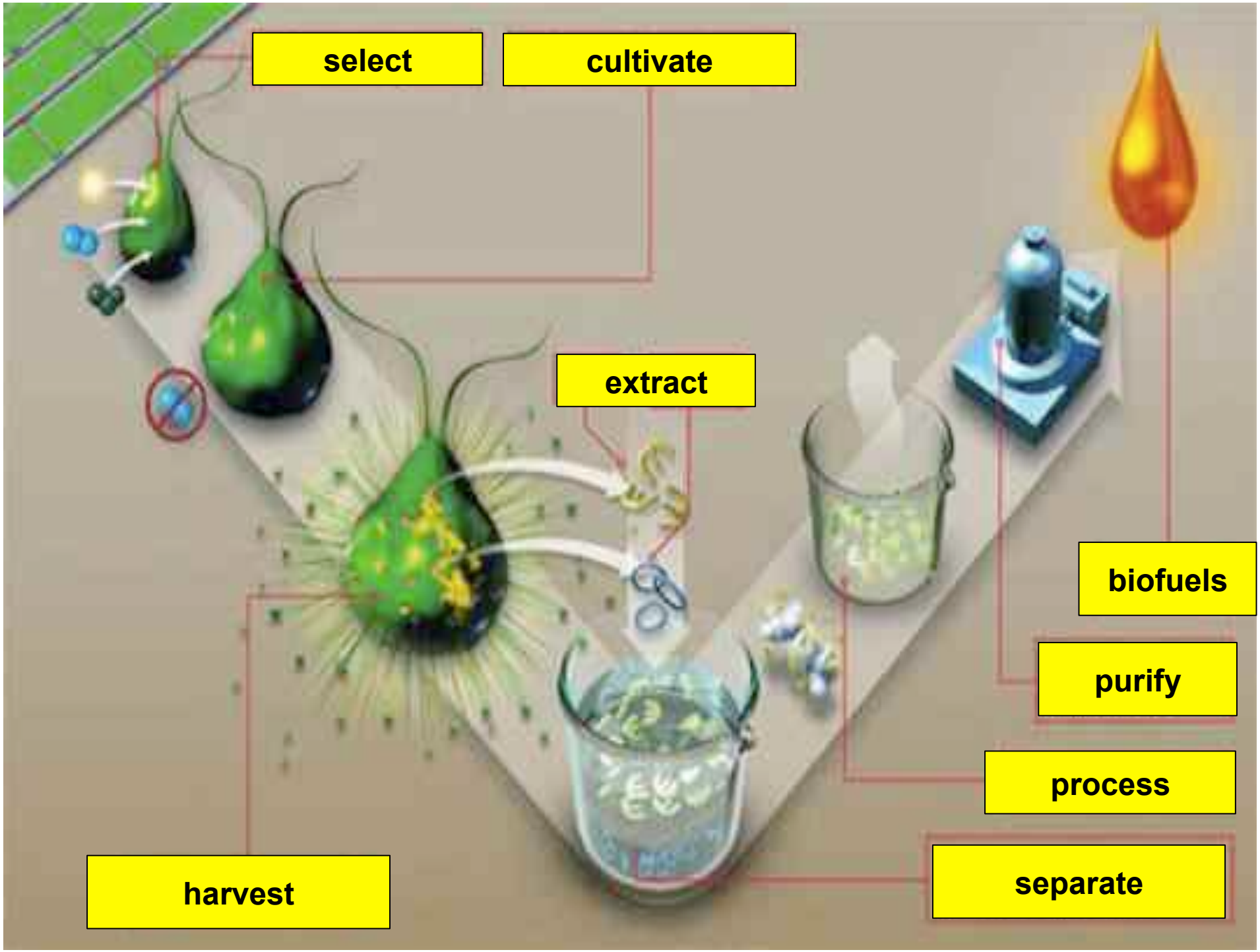

Botryococcus braunii
Oil (3%)
Diesel (18%)
Kerosene (15%)
Gasoline (65%)
Algal colony


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

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


select
cultivate
extract
biofuels
purify
process
separate
harvest

Algae cultivation systems on land…

Open circulating ponds (raceways)

Closed bioreactors

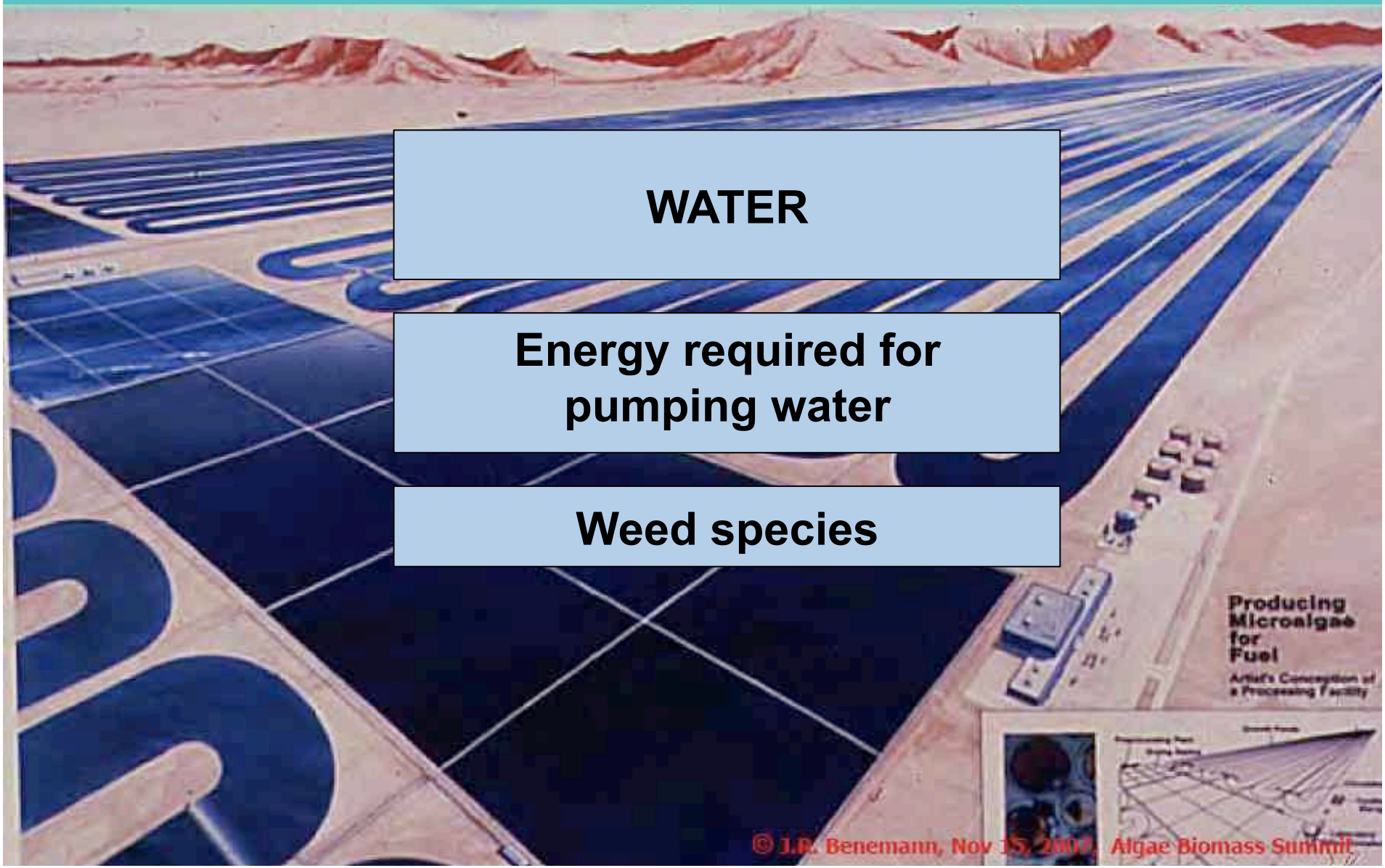

Cyanotech, HI


Yaeyama, Japan

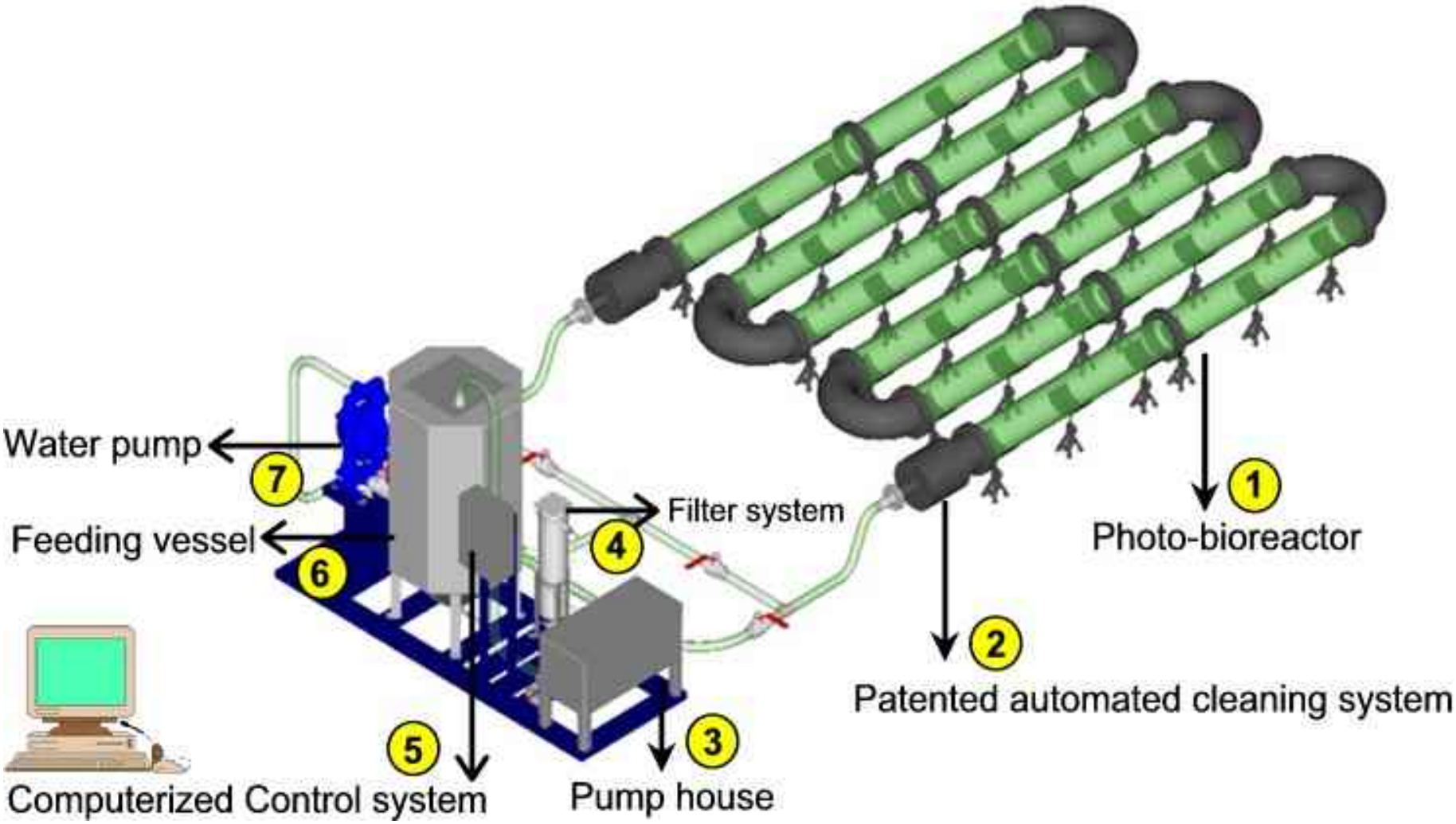

Aquacarotene, Australia


NBT/Seabiotics, Israel

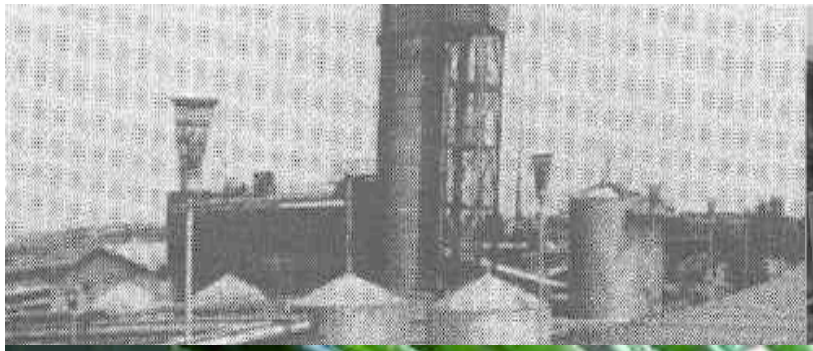
What's wrong with this picture?



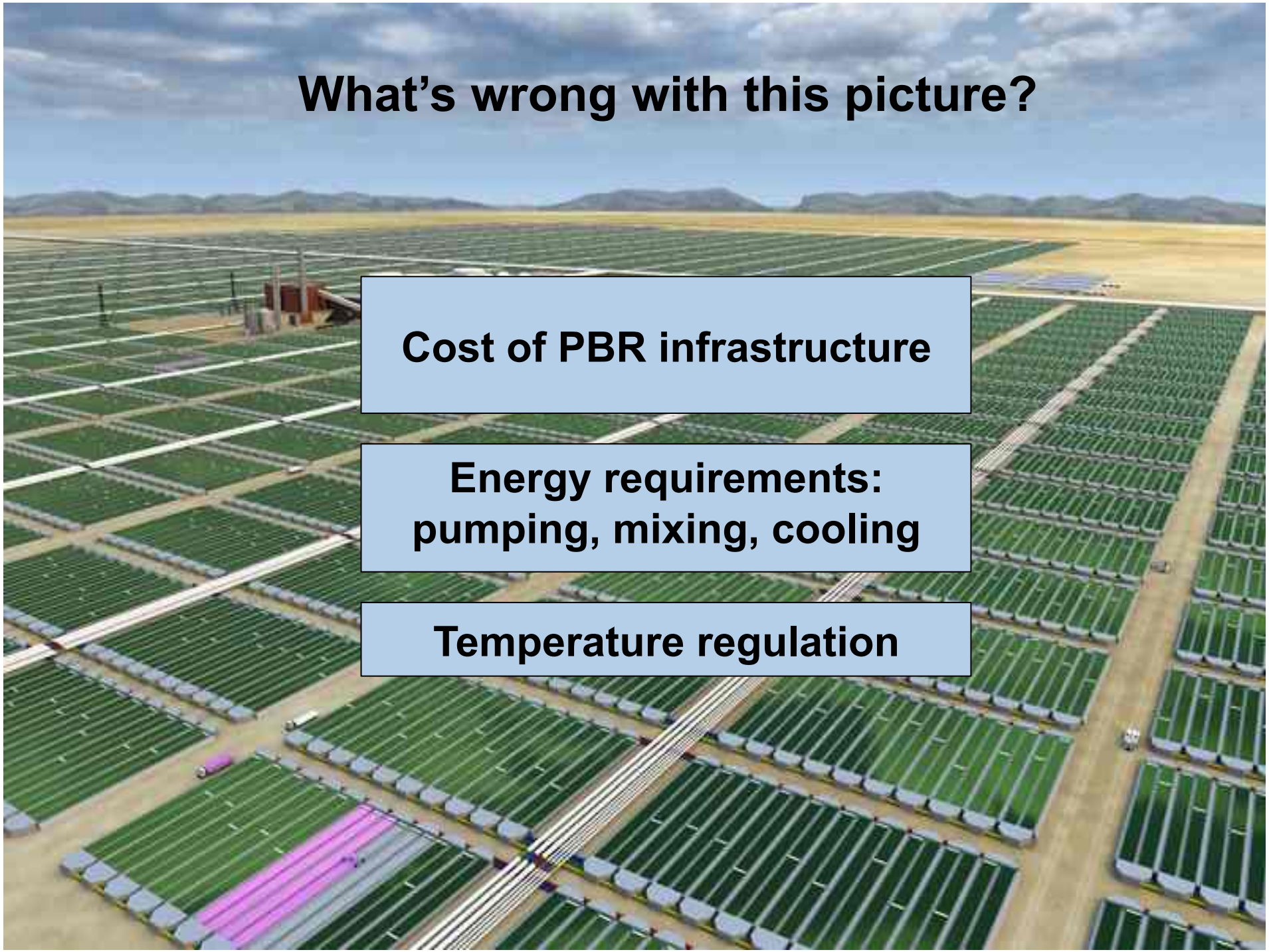
Bioreactor



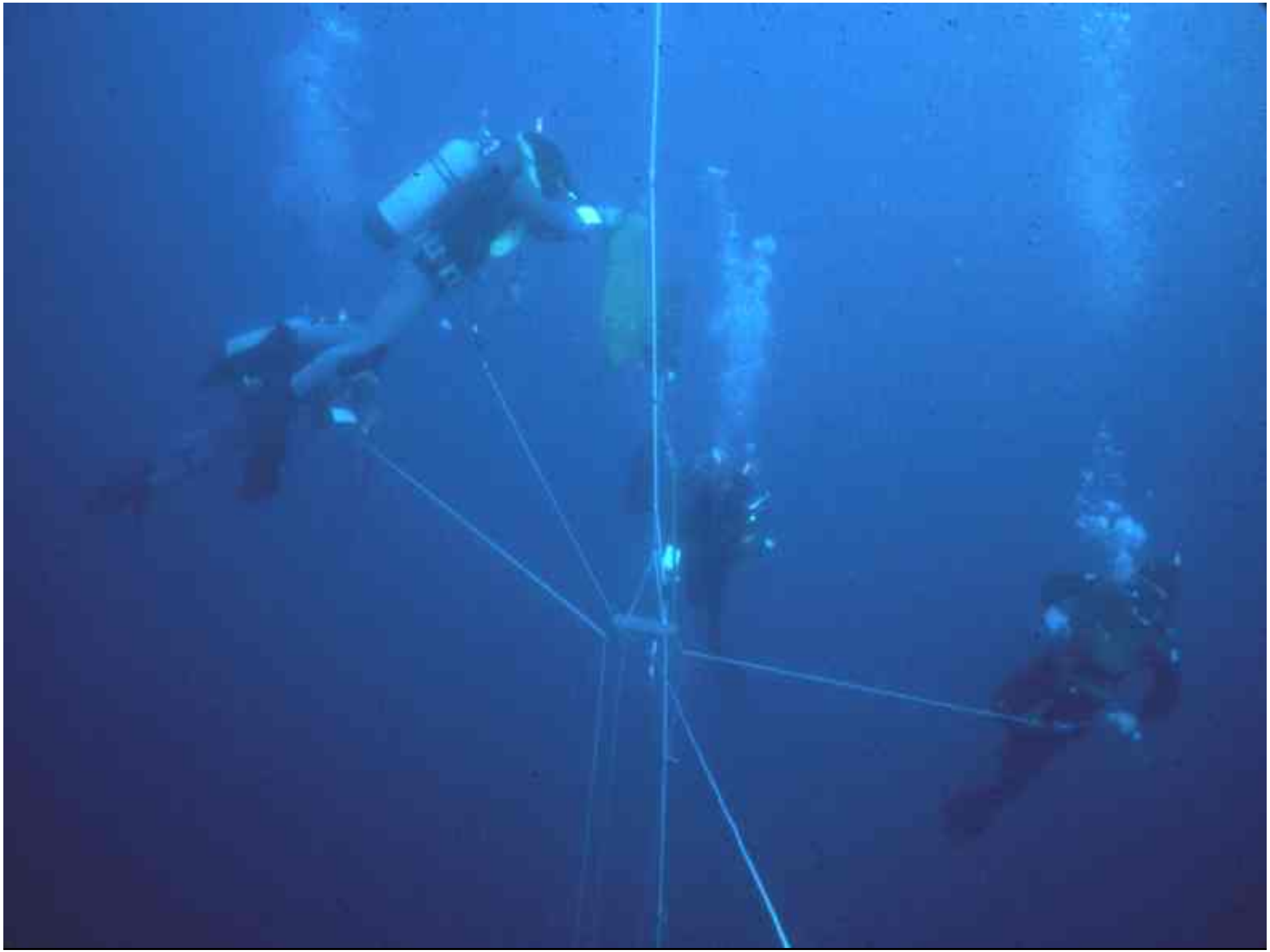
Algal Bioreactor

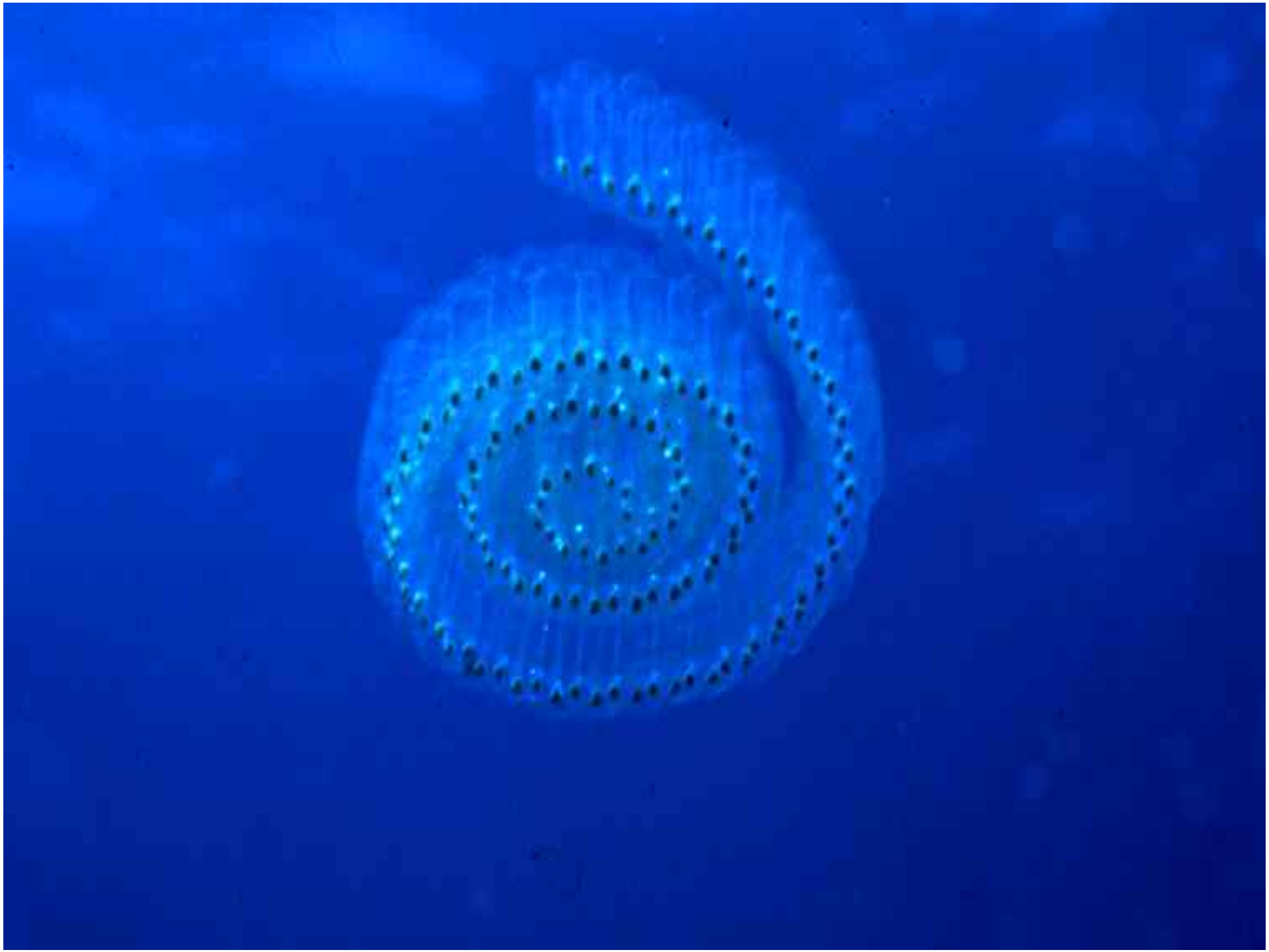


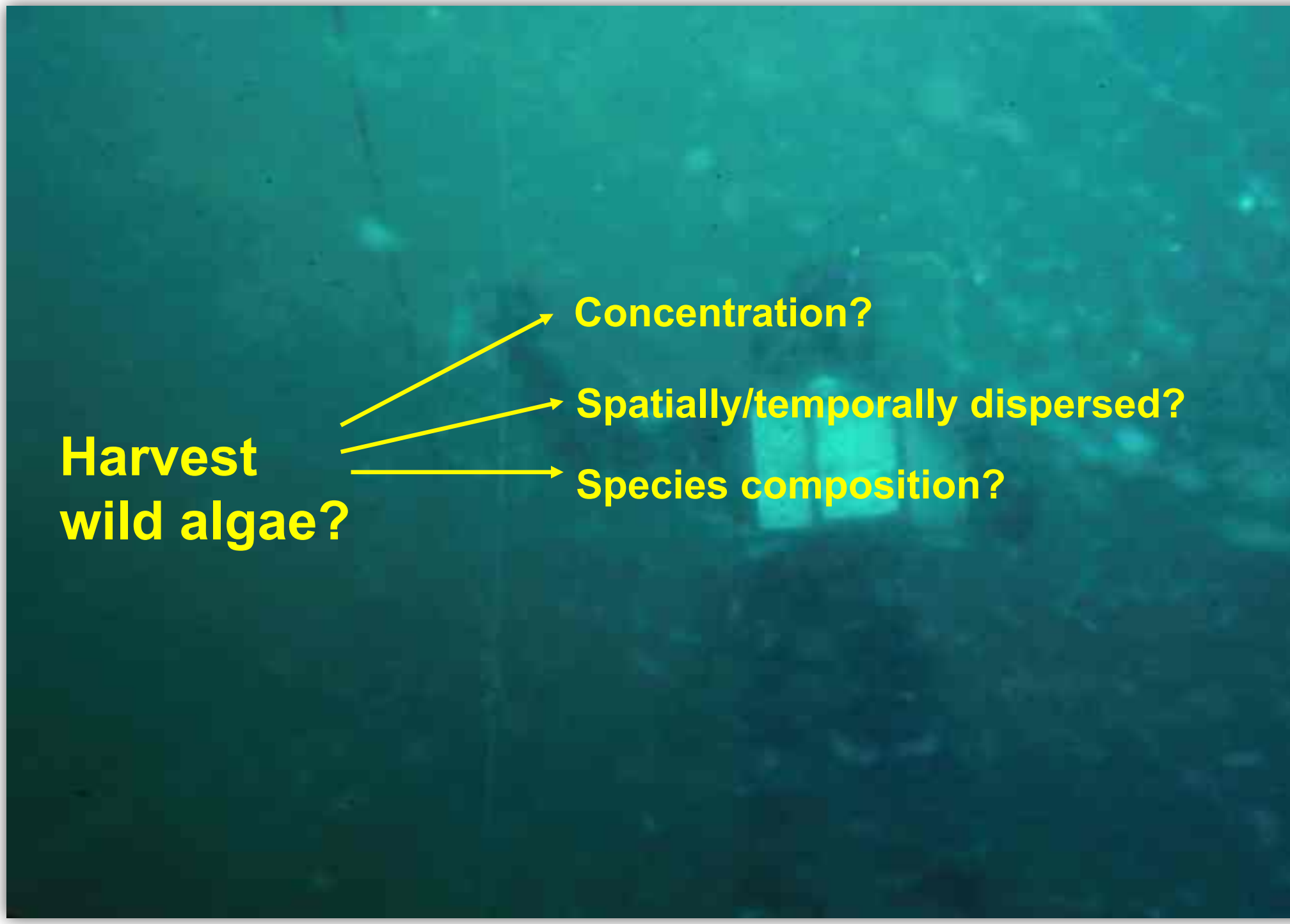

www.bioenergy-noe.org
Vertigro Energy, Texas
Subitec, Germany
NovaGreen, Germany
www.nerc.ac.uk


What's wrong with this picture?
Cost of PBR infrastructure
Energy requirements: pumping, mixing, cooling
Temperature regulation


What about collecting wild
algae from the ocean?

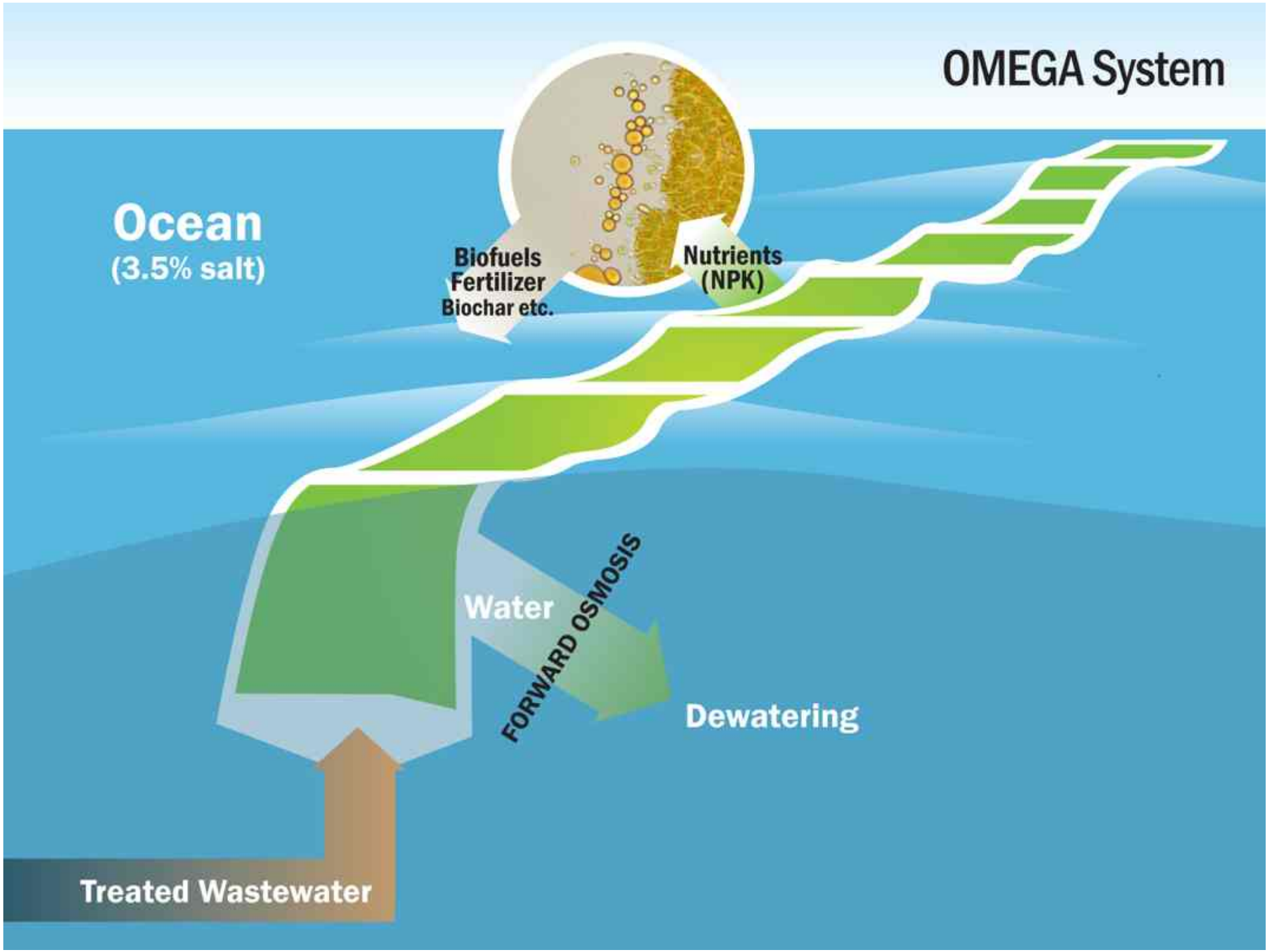





Harvest
wild algae?
Concentration?
Spatially/temporally dispersed?
Species composition?

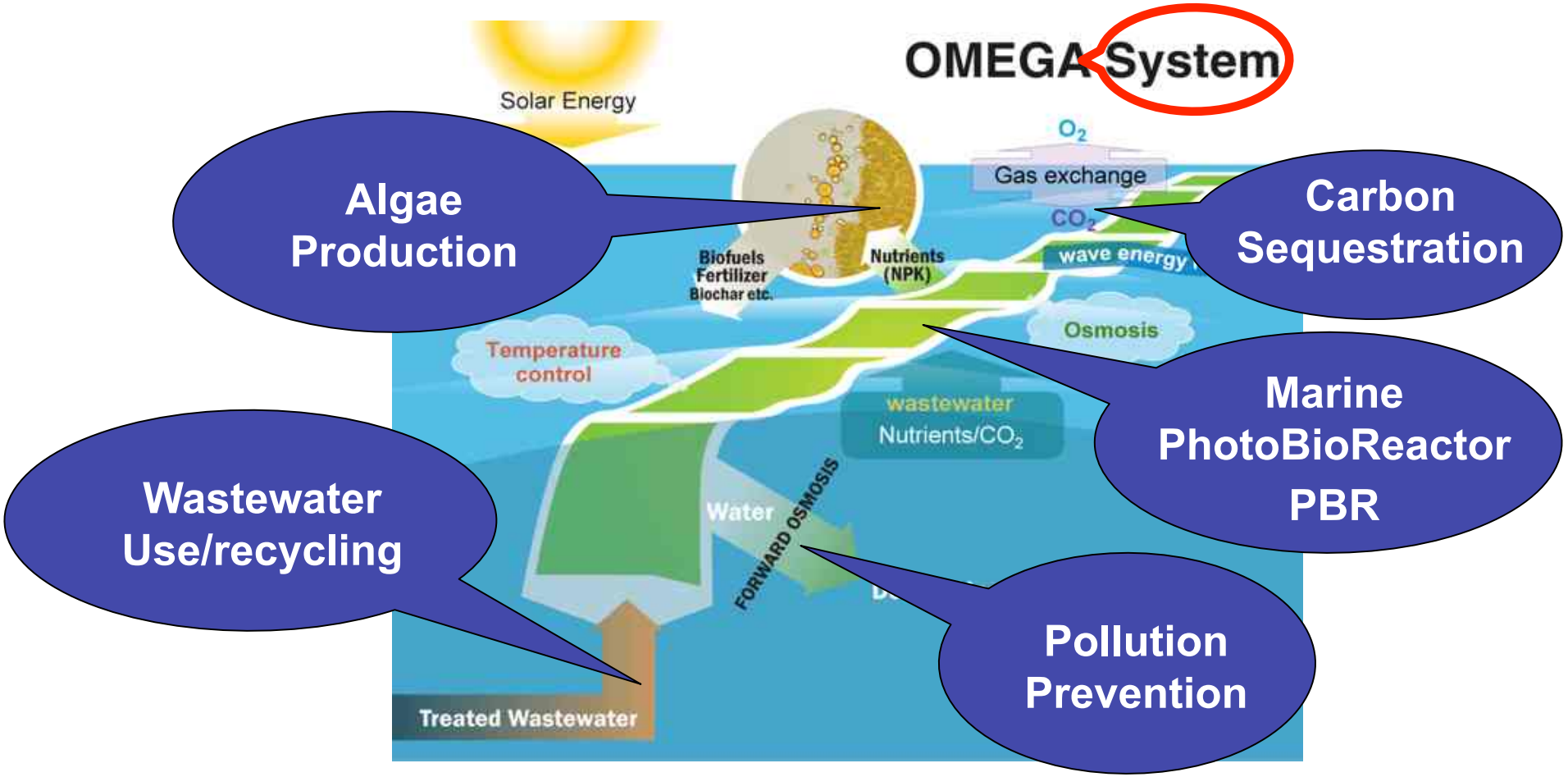

What about growing algae
in the ocean?

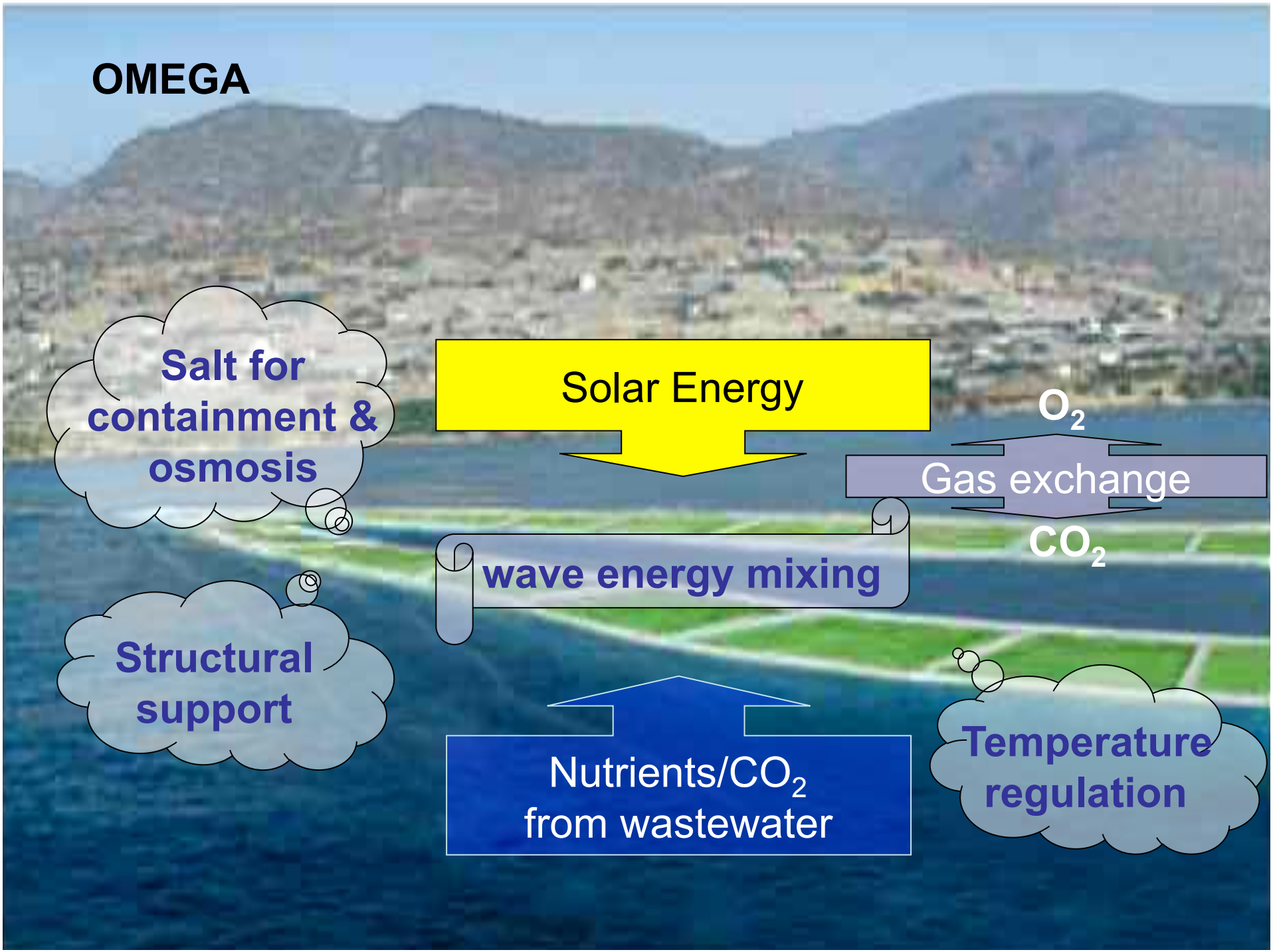

O ffshore
M embrane
E nclosures for
G rowing
A lgae

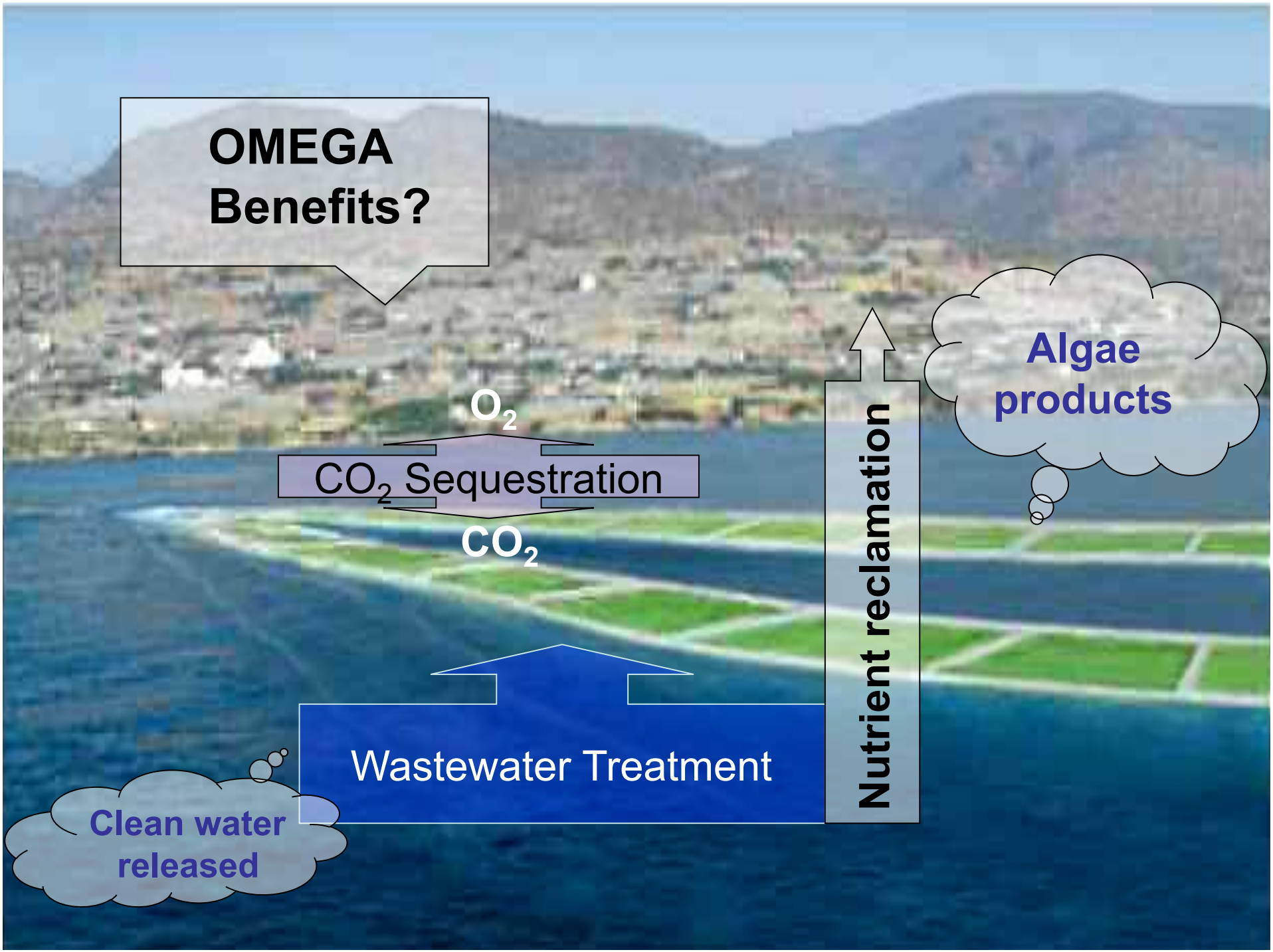

OMEGA System
Ocean
(3.5% salt)
Biofuels
Fertilizer
Biochar etc.
Nutrients
(NPK)
Water
FORWARD OSMOSIS
Dewatering
Treated Wastewater

What is OMEGA?

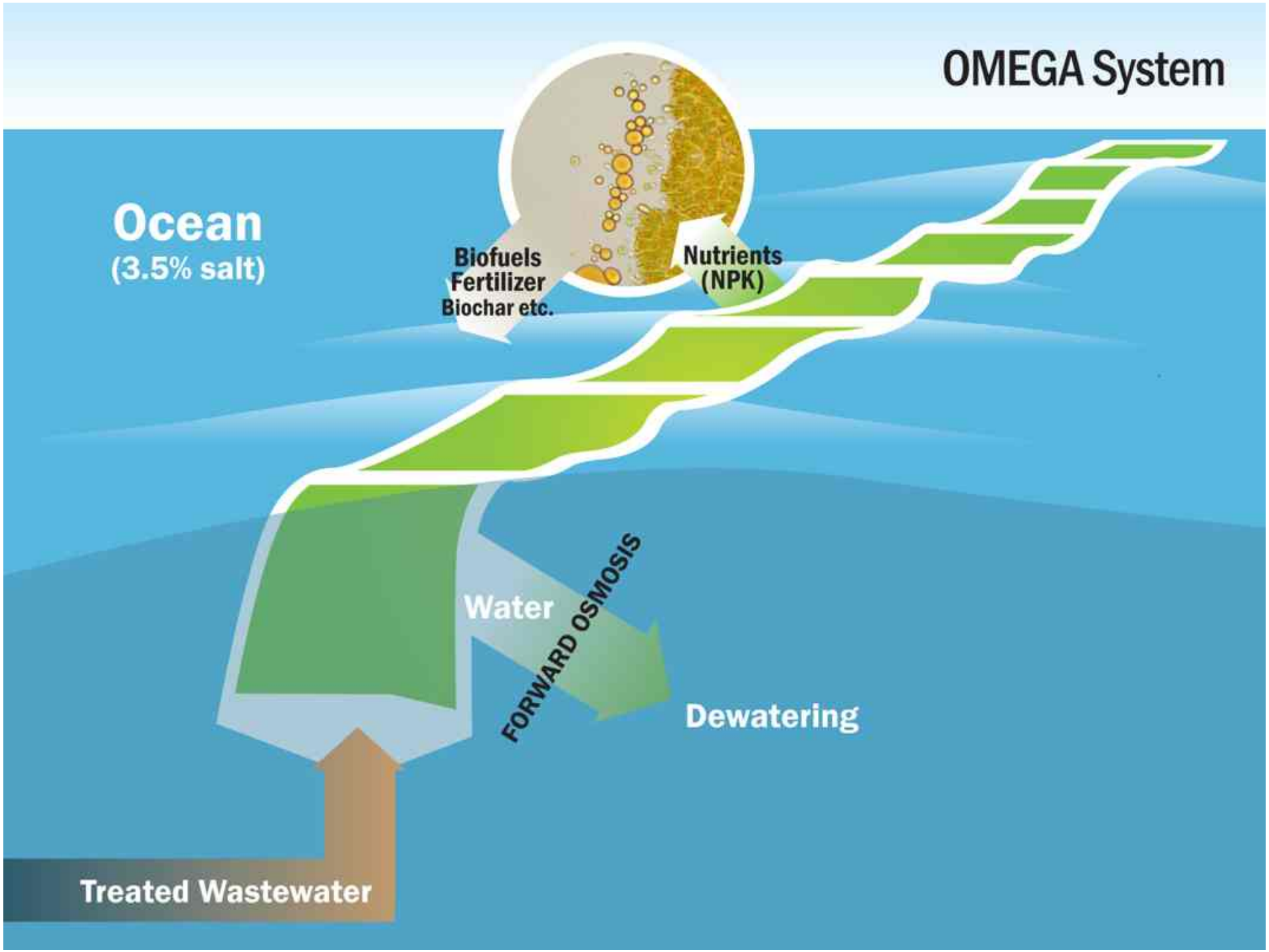
Offshore Membrane Enclosures for Growing Algae

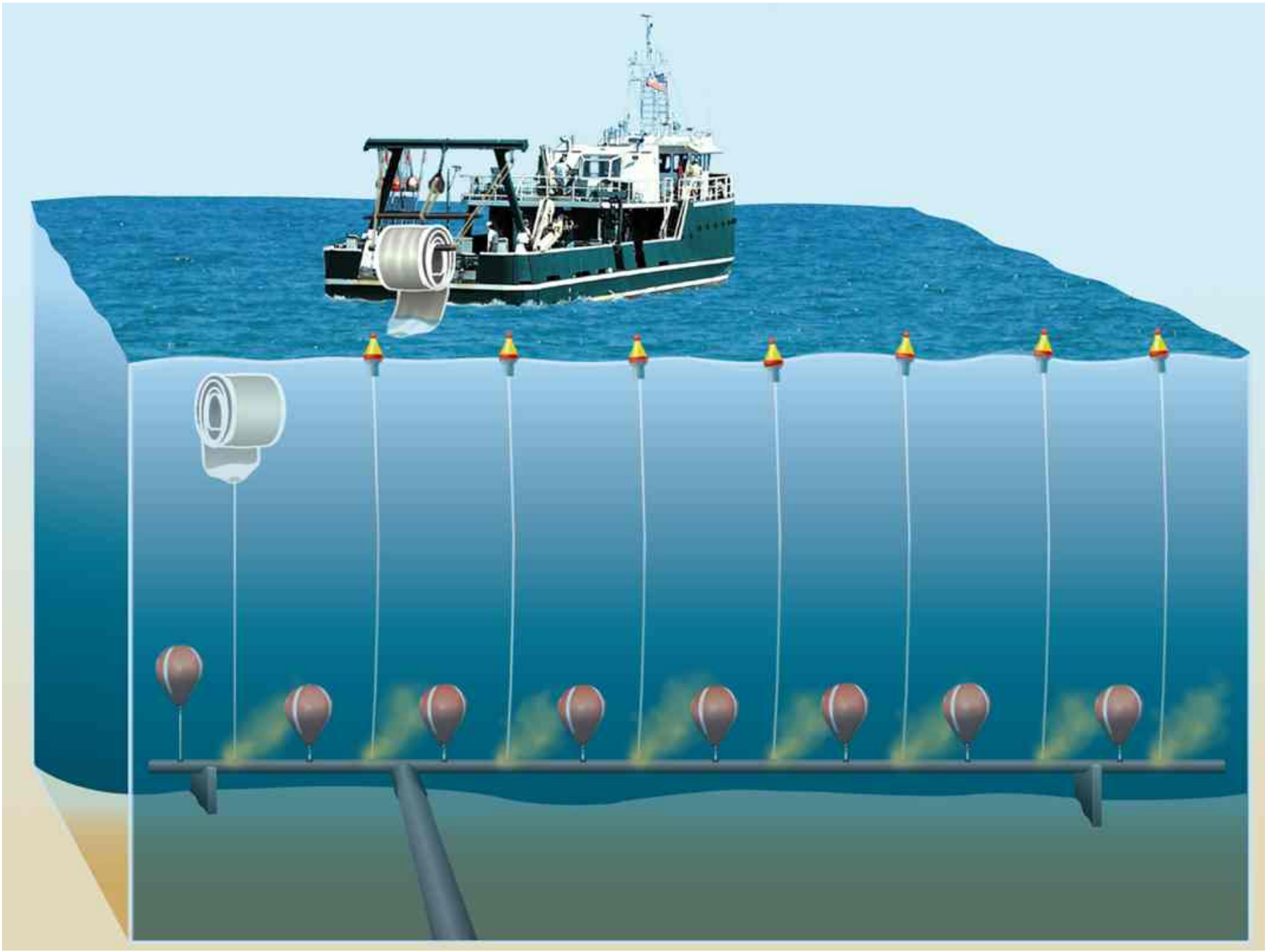


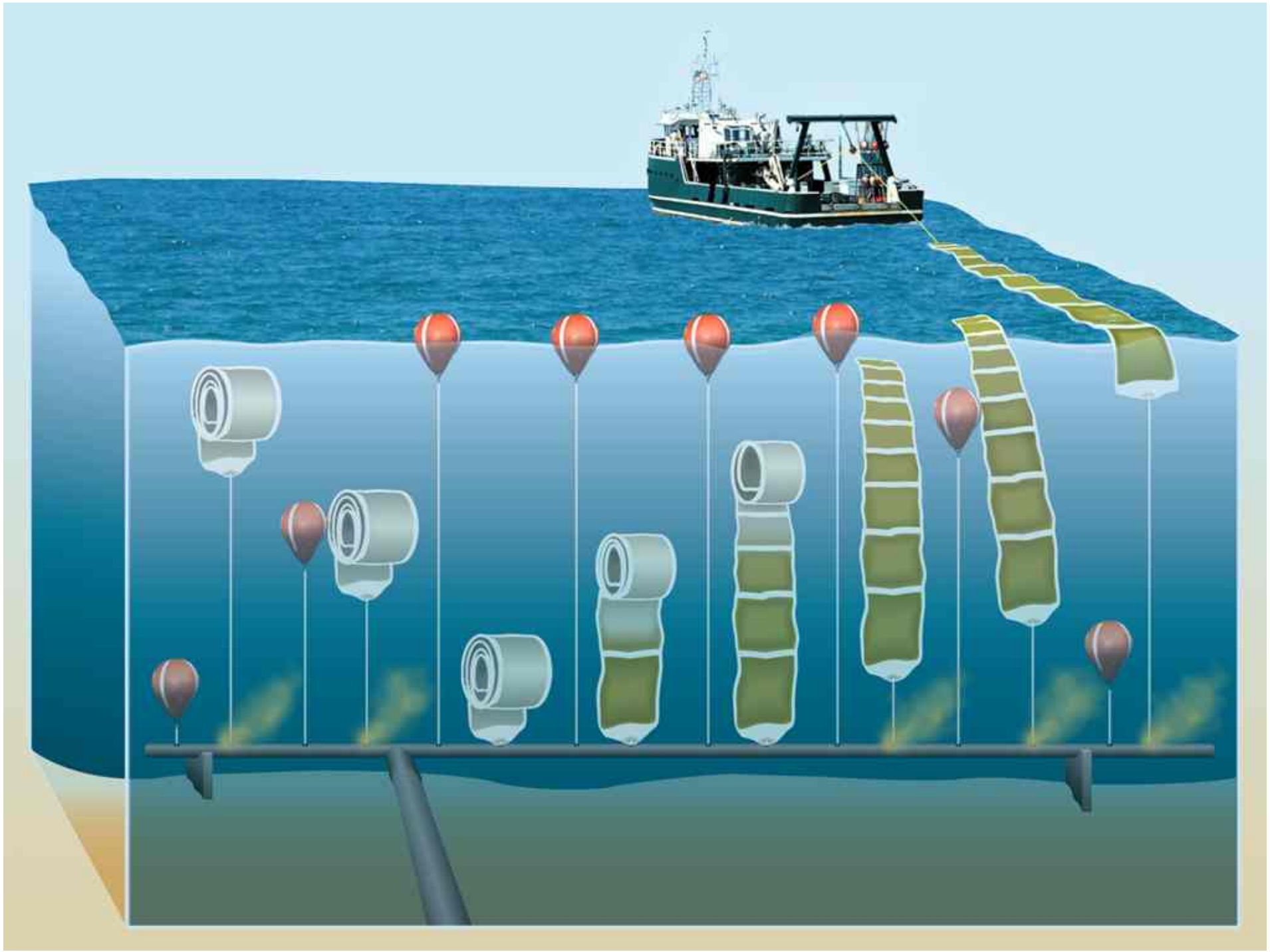

OMEGA
Salt for containment & osmosis
Solar Energy
O_2
Gas exchange
CO_2
wave energy mixing
Structural support
Nutrients/CO_2 from wastewater
Temperature regulation

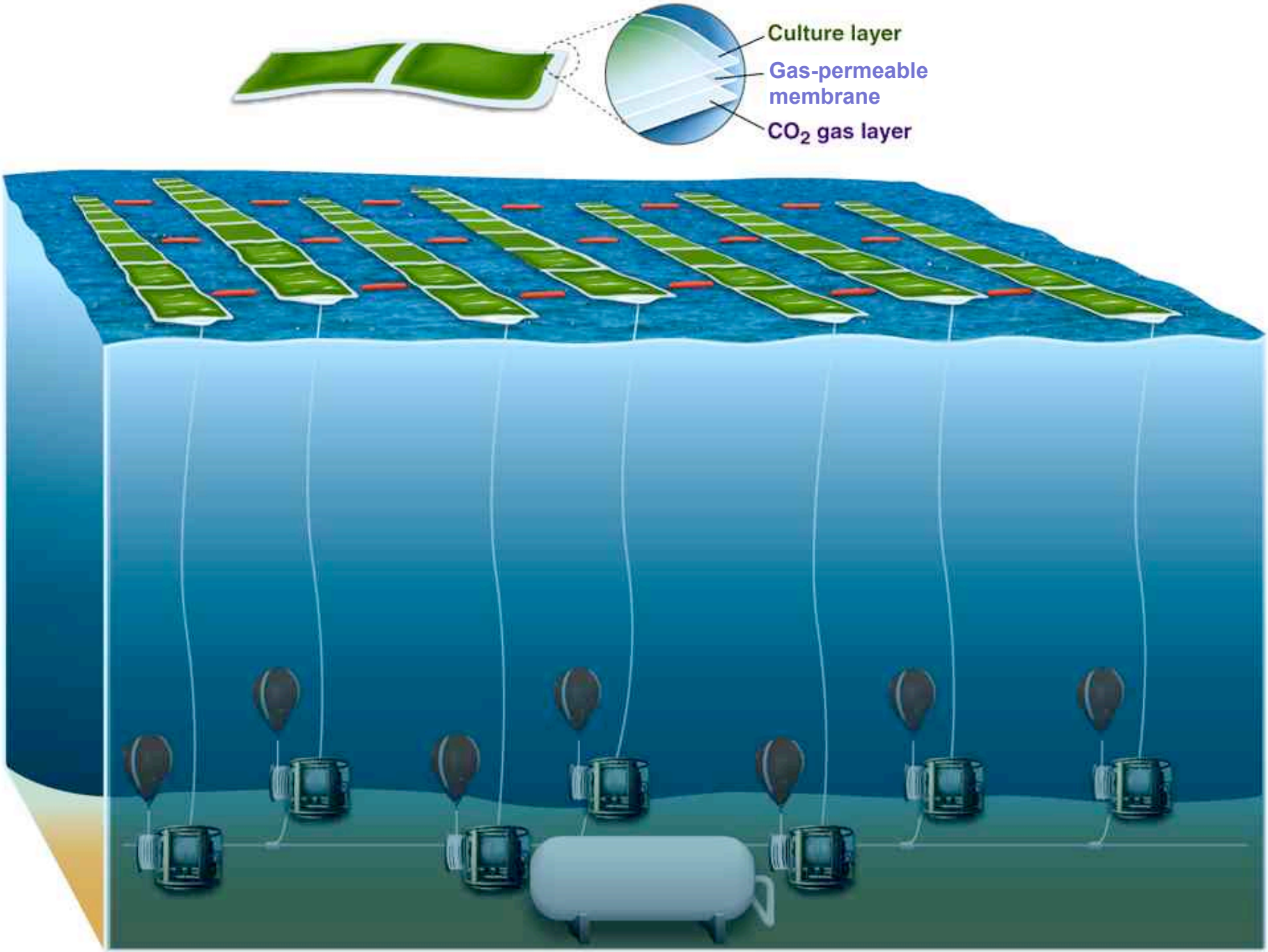

OMEGA
Benefits?
O_2
CO_2 Sequestration
CO_2
Nutrient reclamation
Algae
products
Wastewater Treatment
Clean water
released

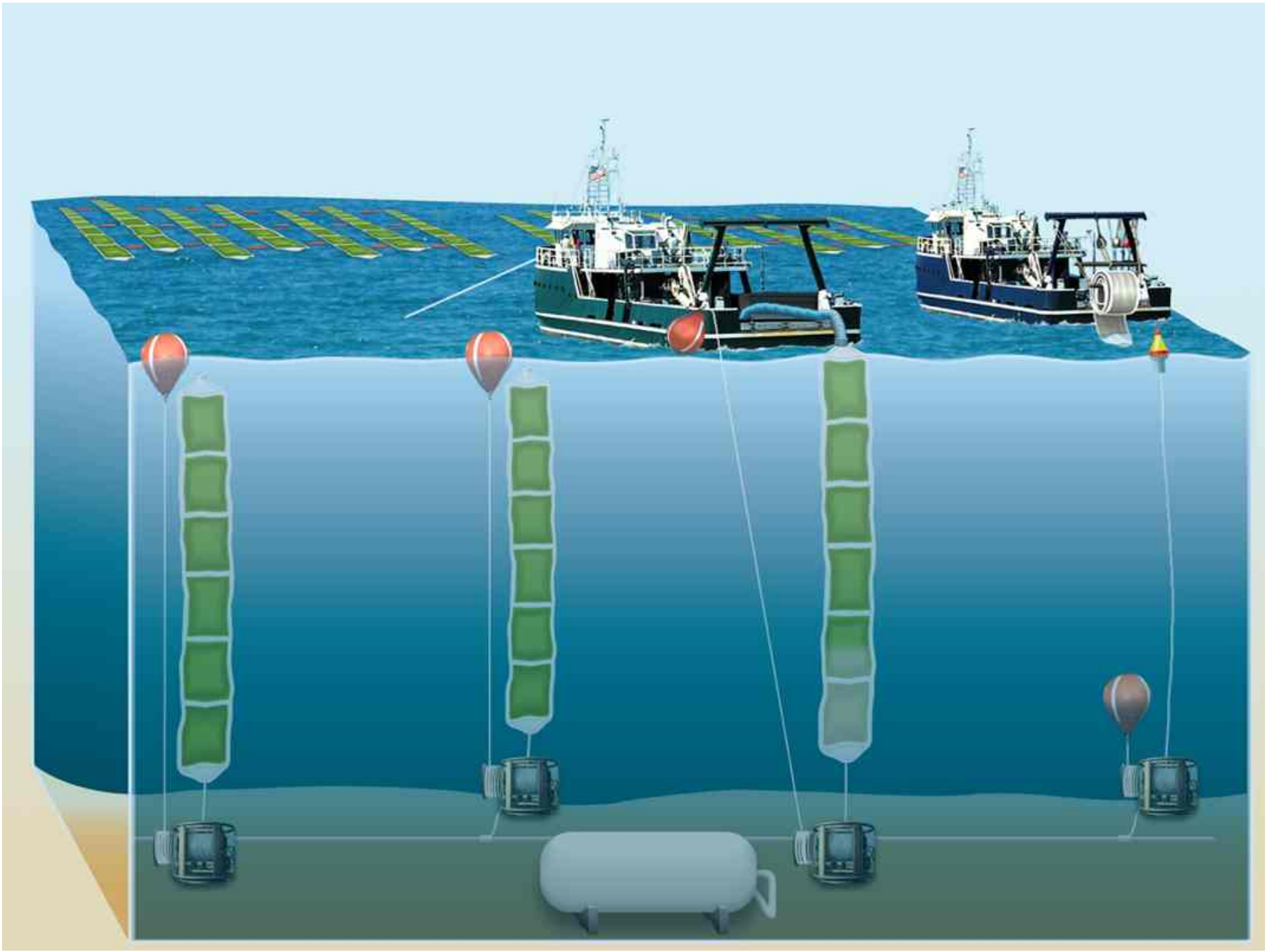
PhotoBioReactor (PBR)

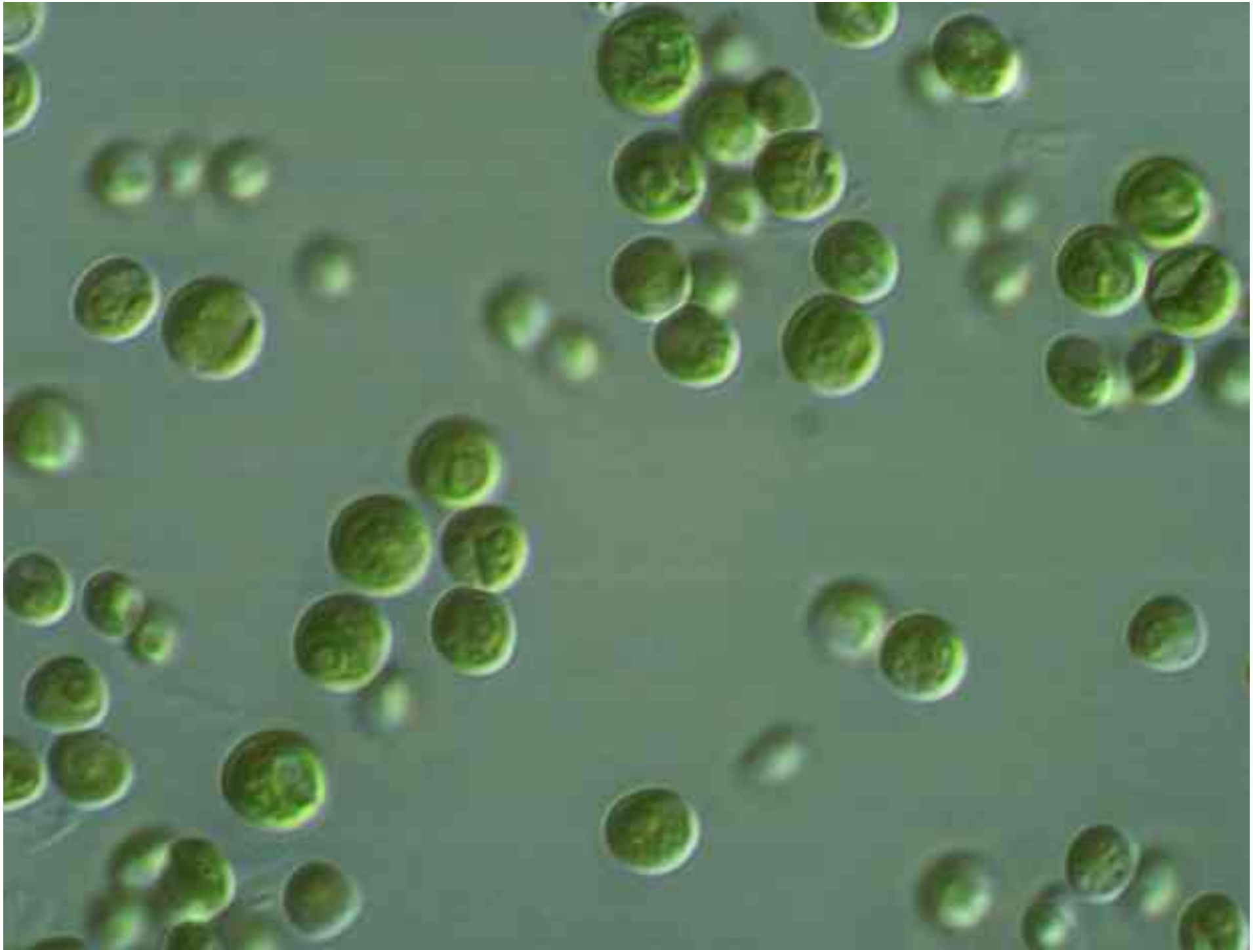

OMEGA System
Ocean
(3.5% salt)
Biofuels
Fertilizer
Biochar etc.
Nutrients
(NPK)
Water
FORWARD OSMOSIS
Dewatering
Treated Wastewater

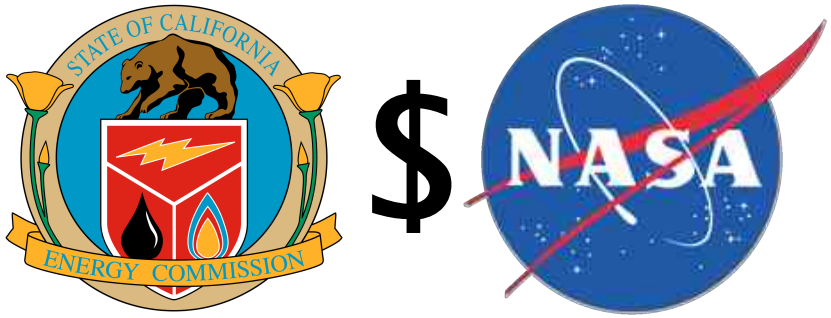





Culture layer
Gas-permeable membrane
CO_2 gas layer






STATE OF CALIFORNIA
ENERGY COMMISSION
$
NASA


Ames Research Center


THE UNIVERSITY OF CALIFORNIA
1868
UC SANTA CRUZ


CALIFORNIA POLYTECHNIC STATE UNIVERSITY
1901
DISCERE FACIENDO


ARTS


Growth is an Imperative
We are Relationship Based
JACOBS
People are Our Greatest Asset


SETI INSTITUTE


SCRIPPS INSTITUTION OF OCEANOGRAPHY
UCSD


HTI
Hydration Technology Innovations


SCHOOL OF MINES
1874
COLORADO


RESOURCES AGENCY
CALIFORNIA
DEPARTMENT
FISH & GAME


NREL
National Renewable
Energy Laboratory


UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY


SFPUC
WATER
HETCH HETCHY
WATER & POWER
CLEAN WATER


BCI

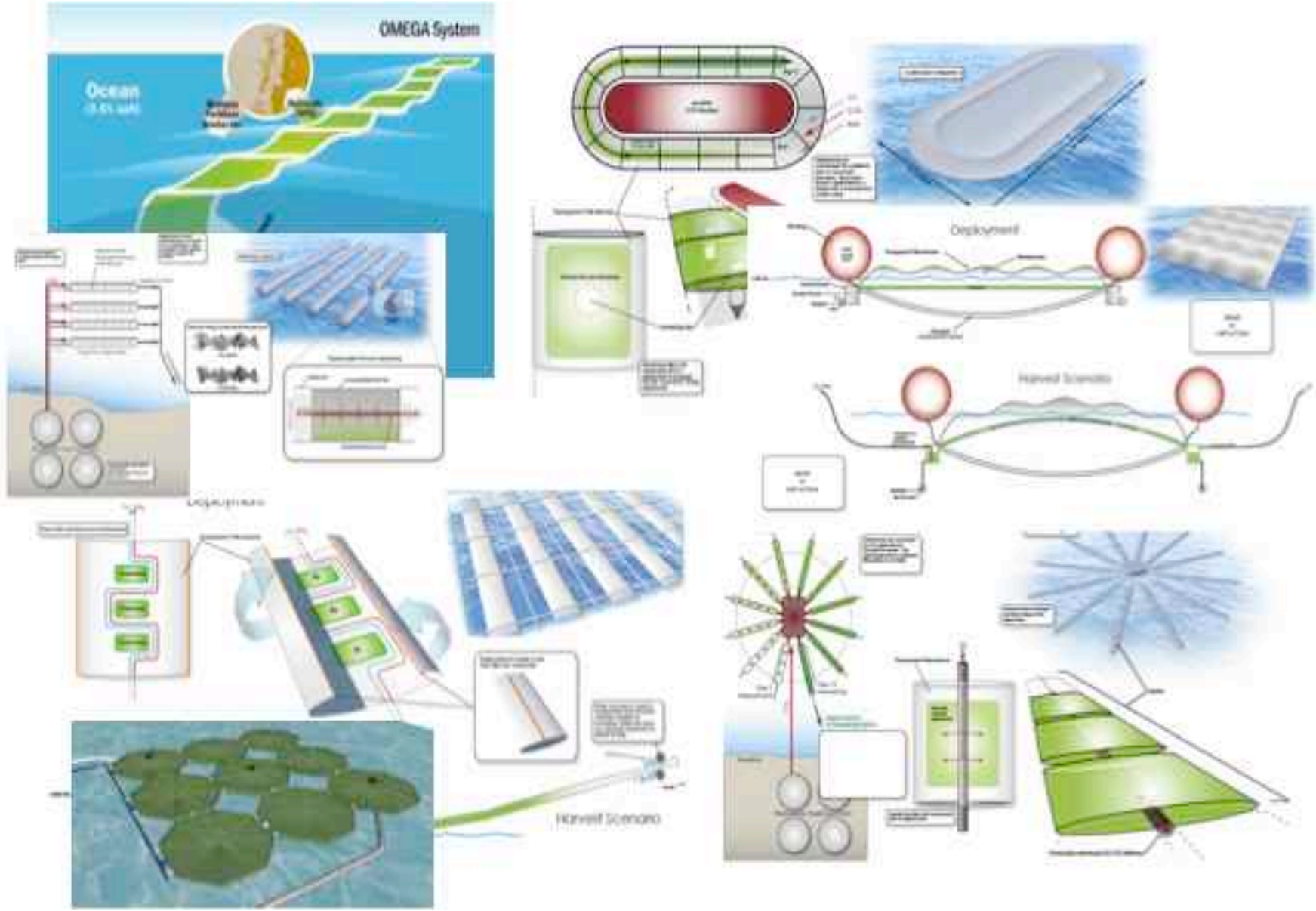

WESTECH
an employee-owned company

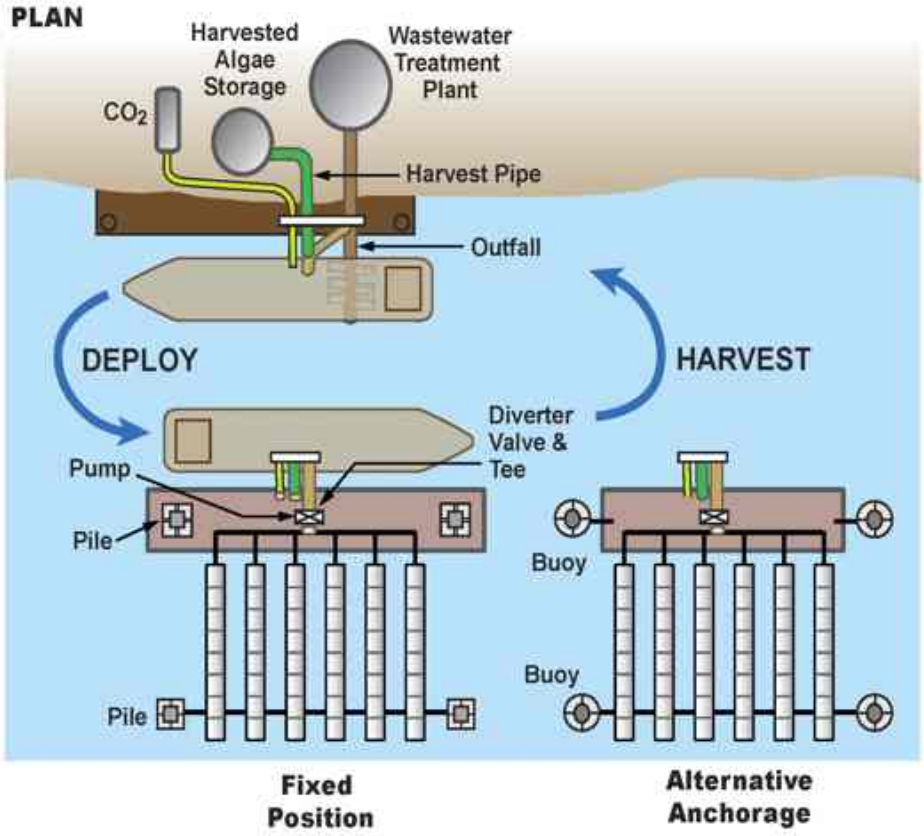

EIMCO
WATERTECHNOLOGIES

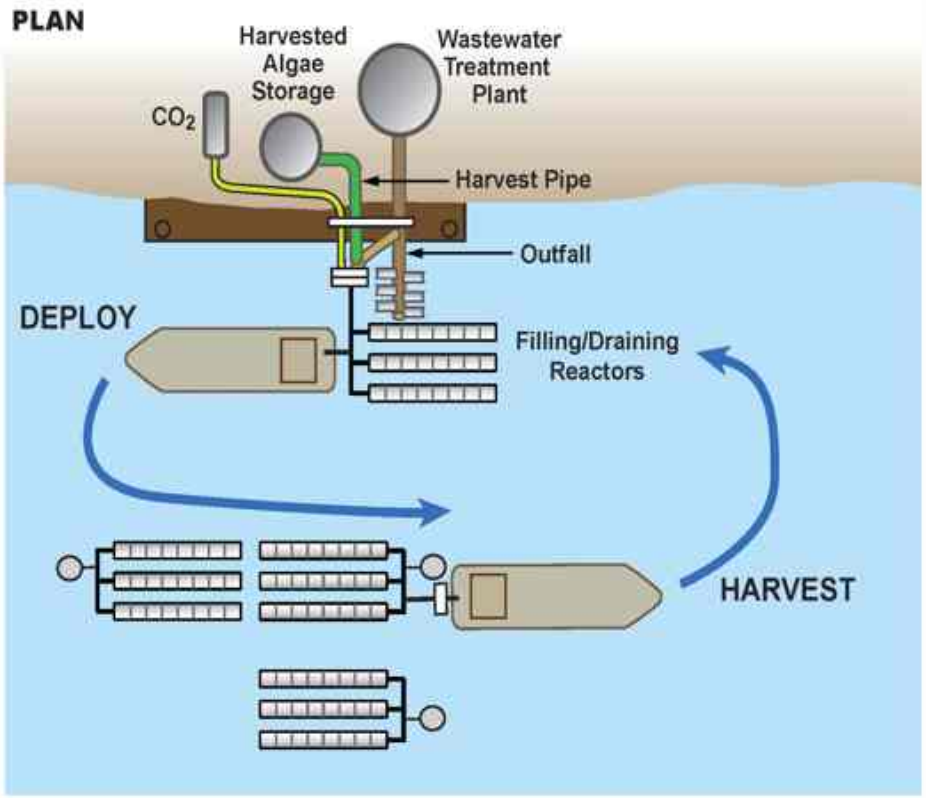

SIEMENS
Water Technologies

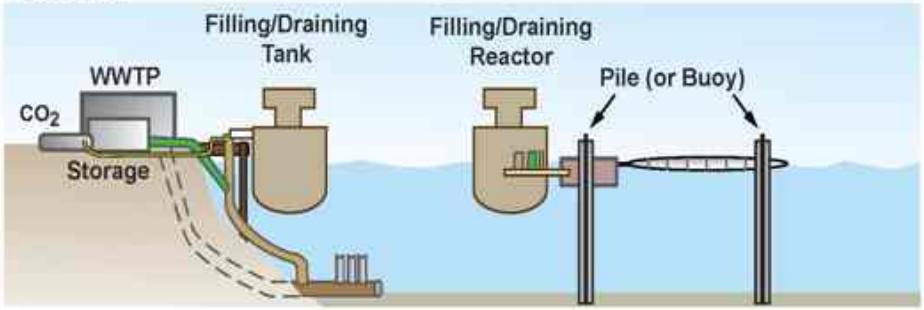

SRI
International


uop
A Honeywell Company

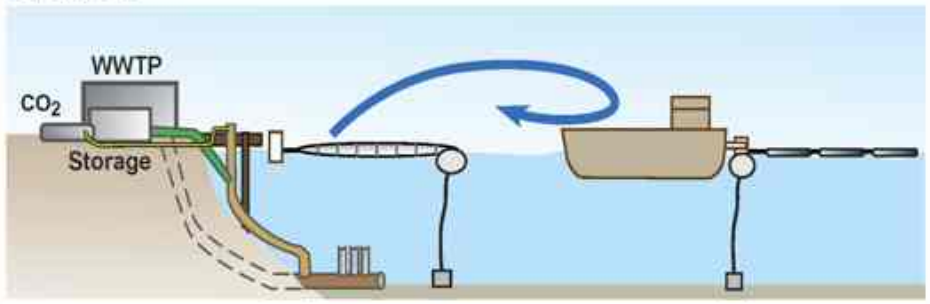

OMEGA System
Ocean
Deployment
Harvest Scenario



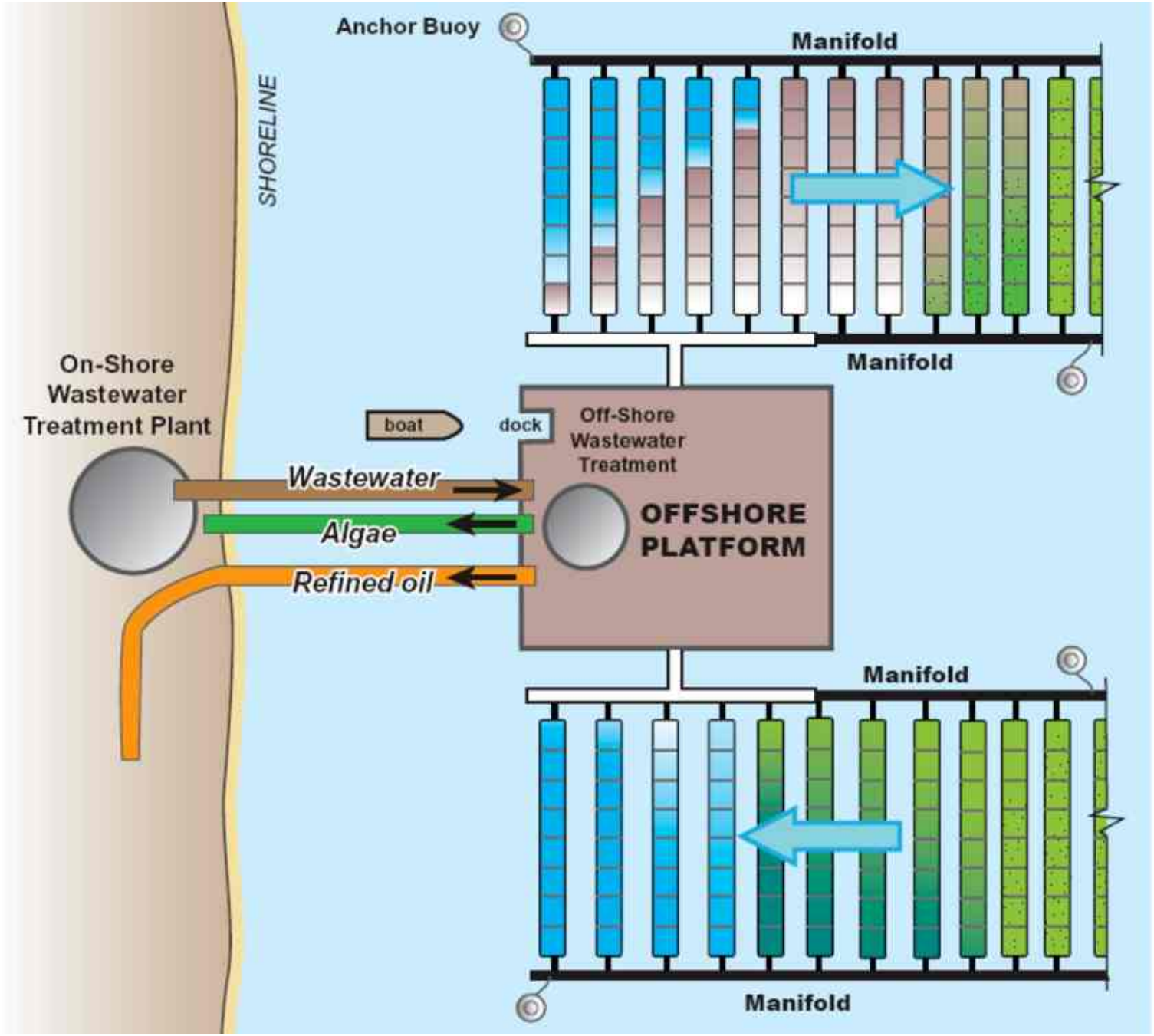


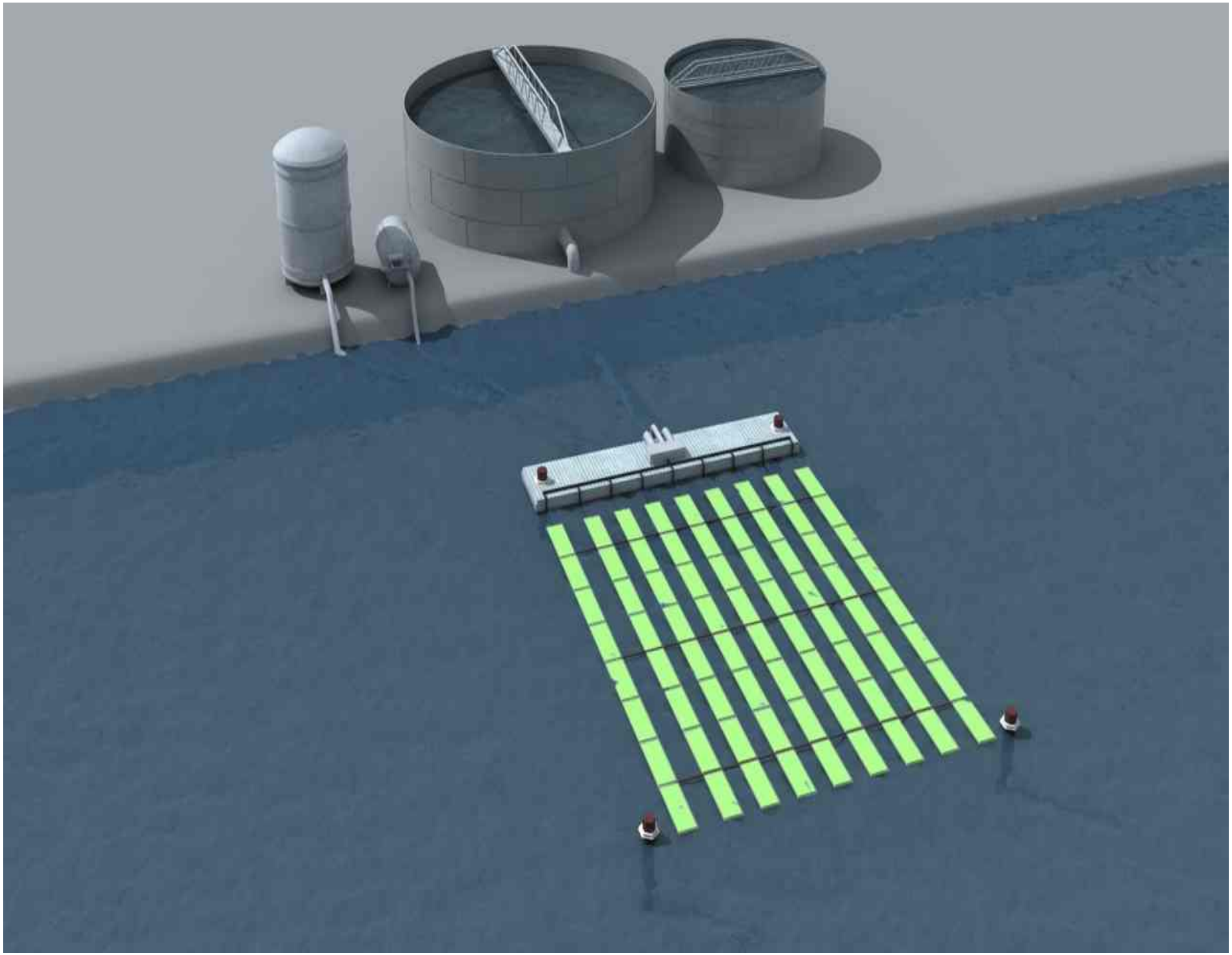


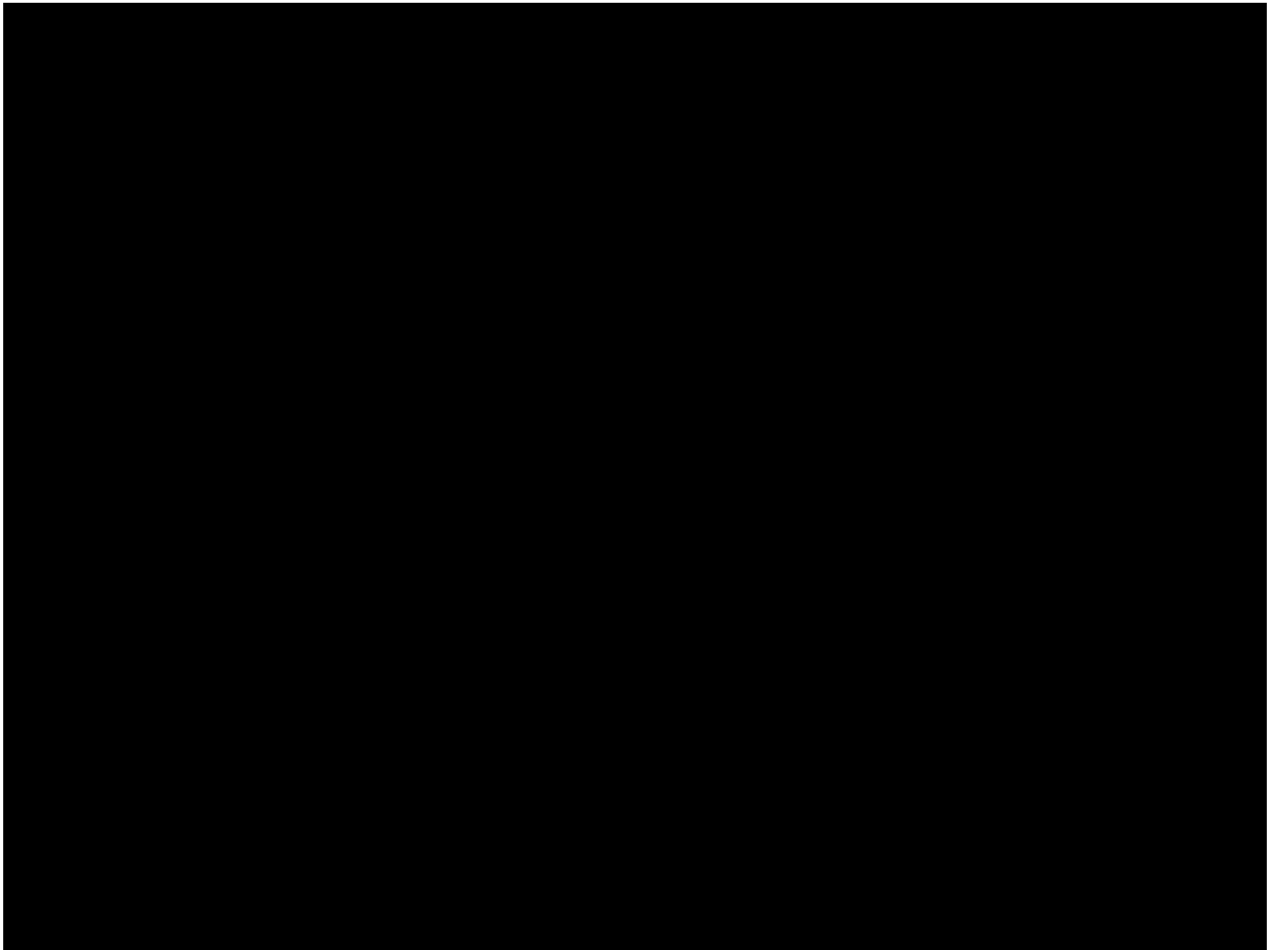
SCHEMATIC: NOT TO SCALE



SCHEMATIC: NOT TO SCALE

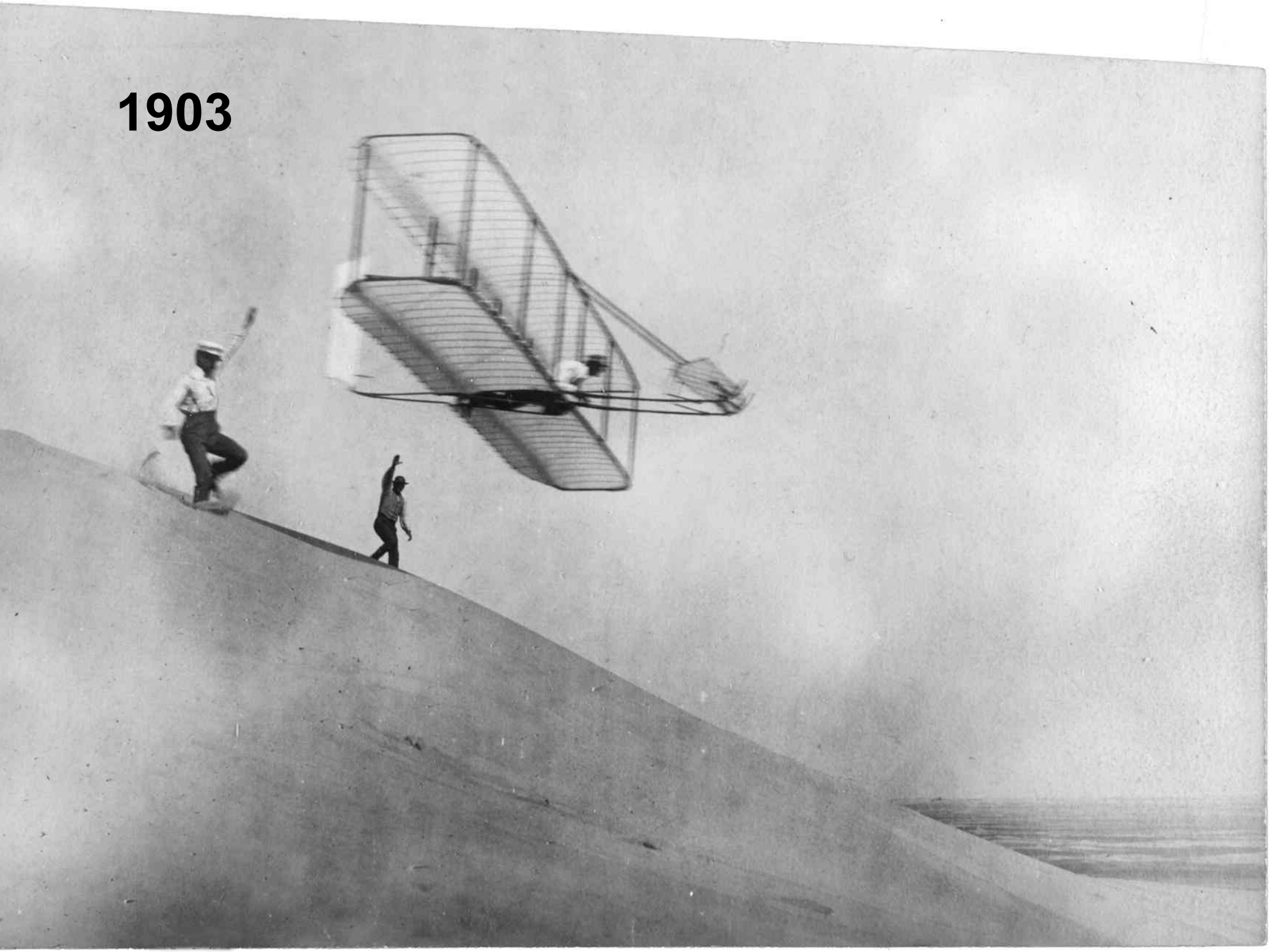

Anchor Buoy
Manifold
SHORELINE
On-Shore
Wastewater
Treatment Plant
boat
dock
Off-Shore
Wastewater
Treatment
Wastewater
Algae
Refined oil
OFFSHORE
PLATFORM
Manifold
Manifold
Manifold

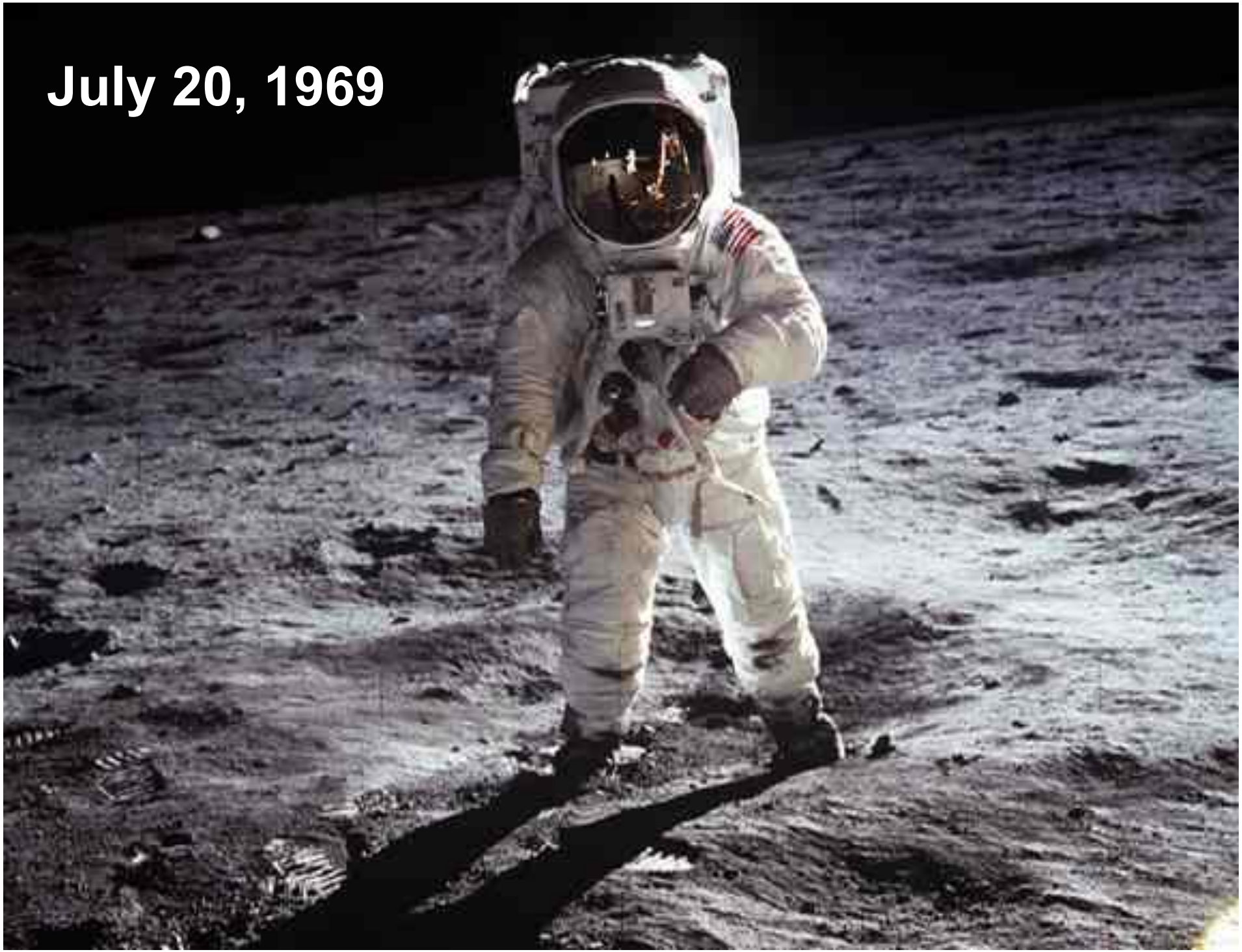


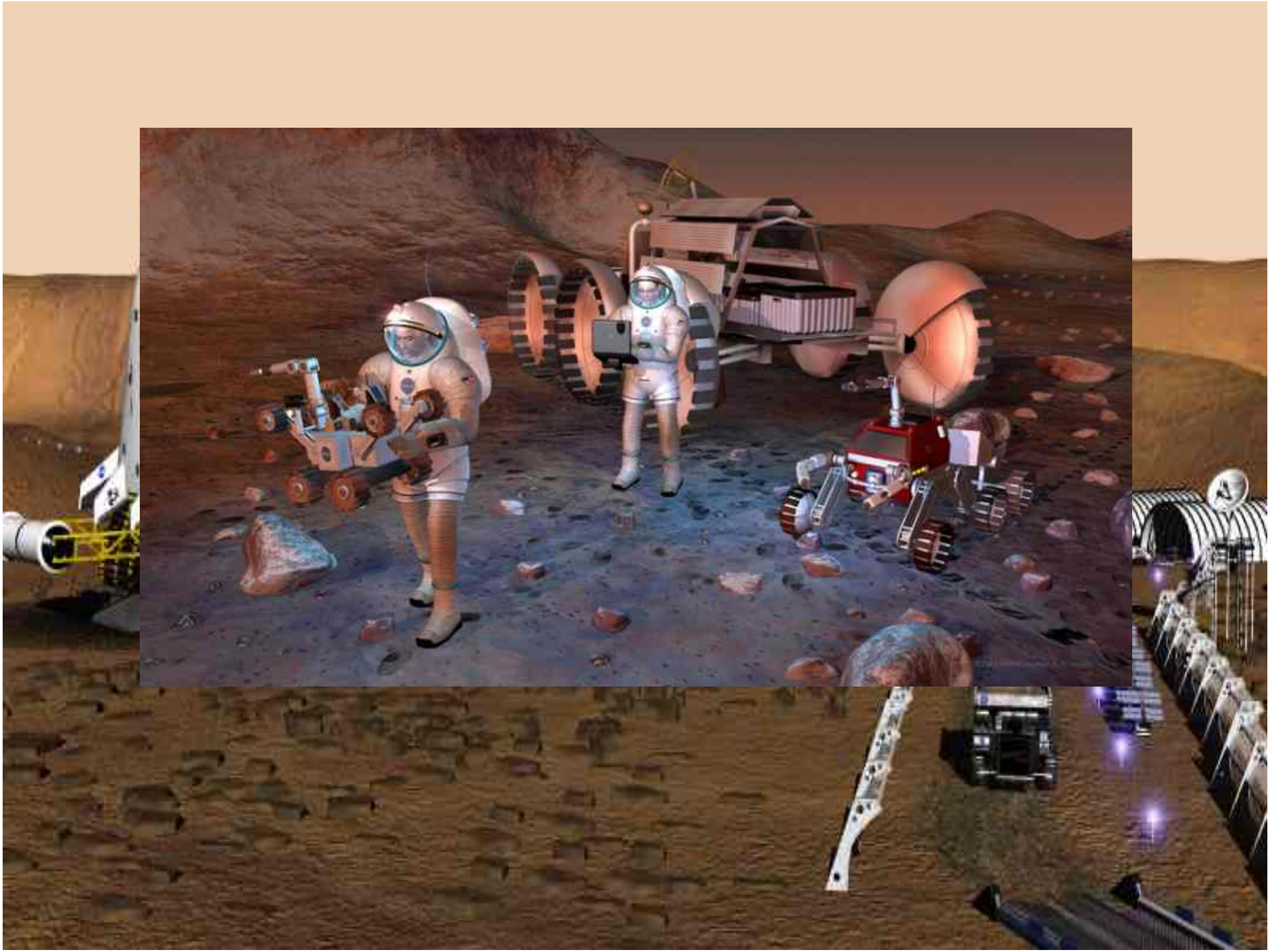



How realistic is OMEGA?

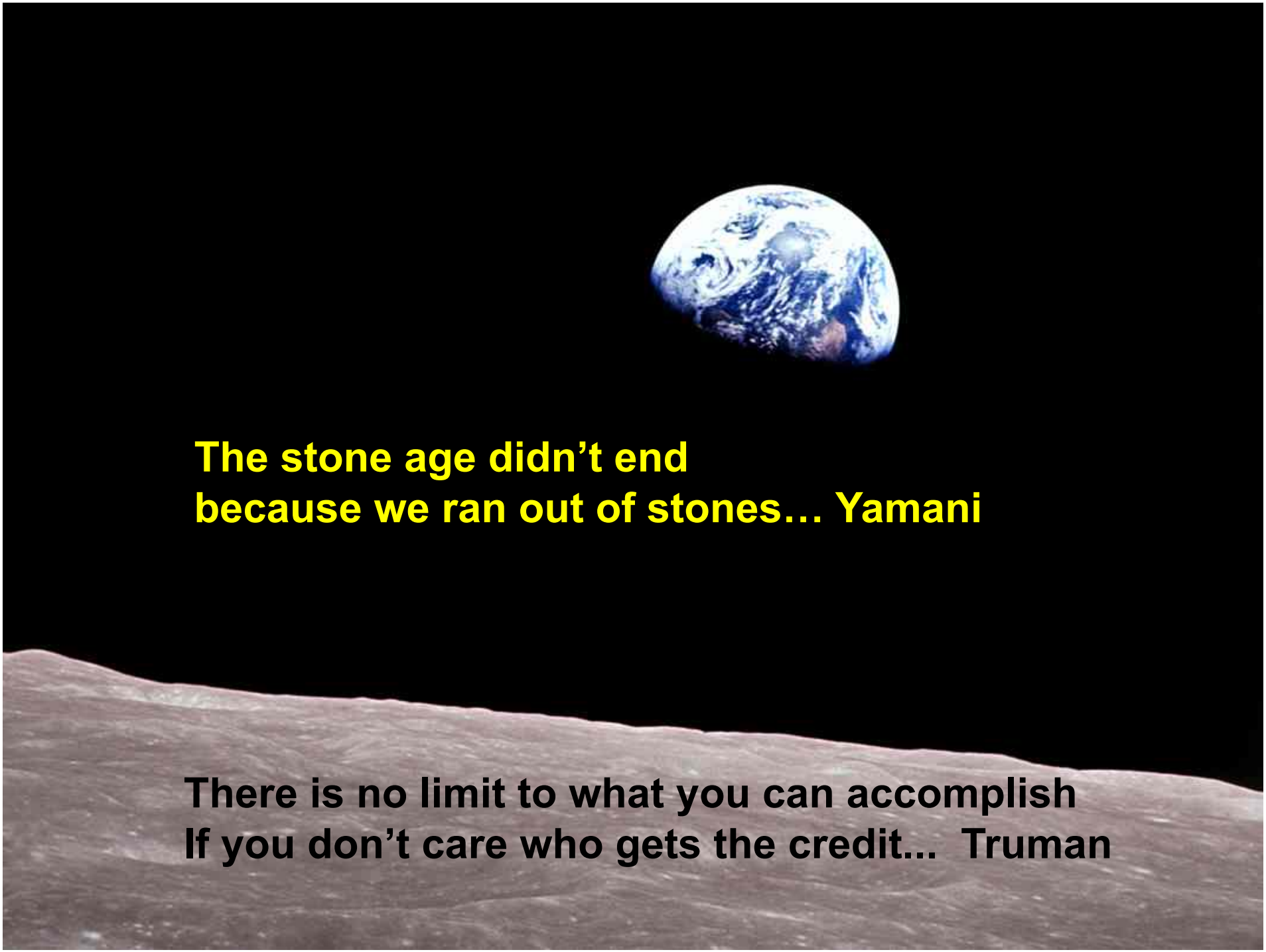

Challenges for OMEGA
• Biology
• Engineering
• Economics
• Environment

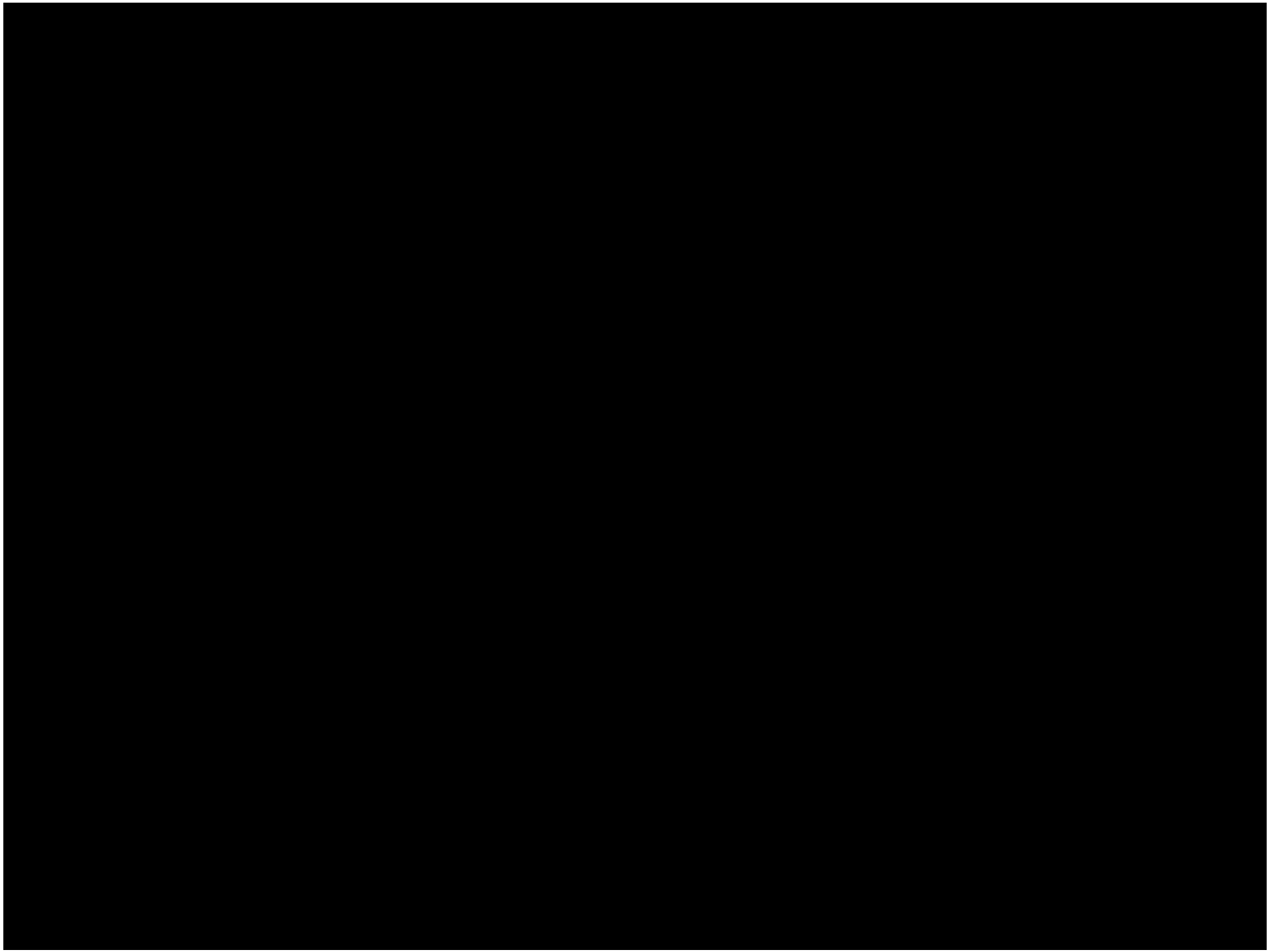

1903


July 20, 1969




Sustainability?
Population
Affluence
Species
Technology
Our Future?

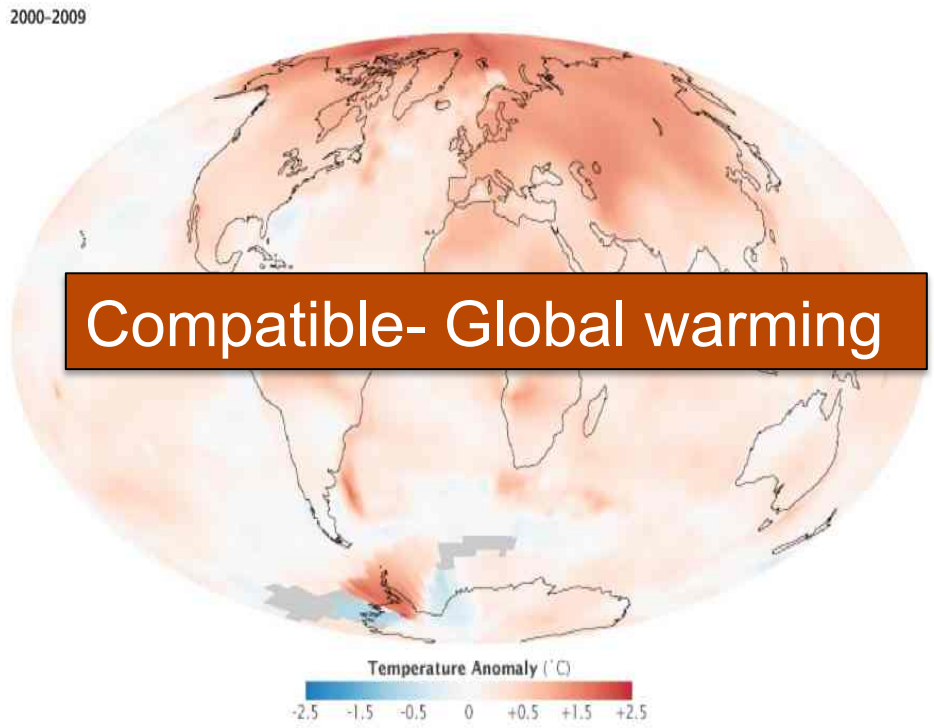

The stone age didn't end
because we ran out of stones… Yamani
There is no limit to what you can accomplish
If you don't care who gets the credit... Truman



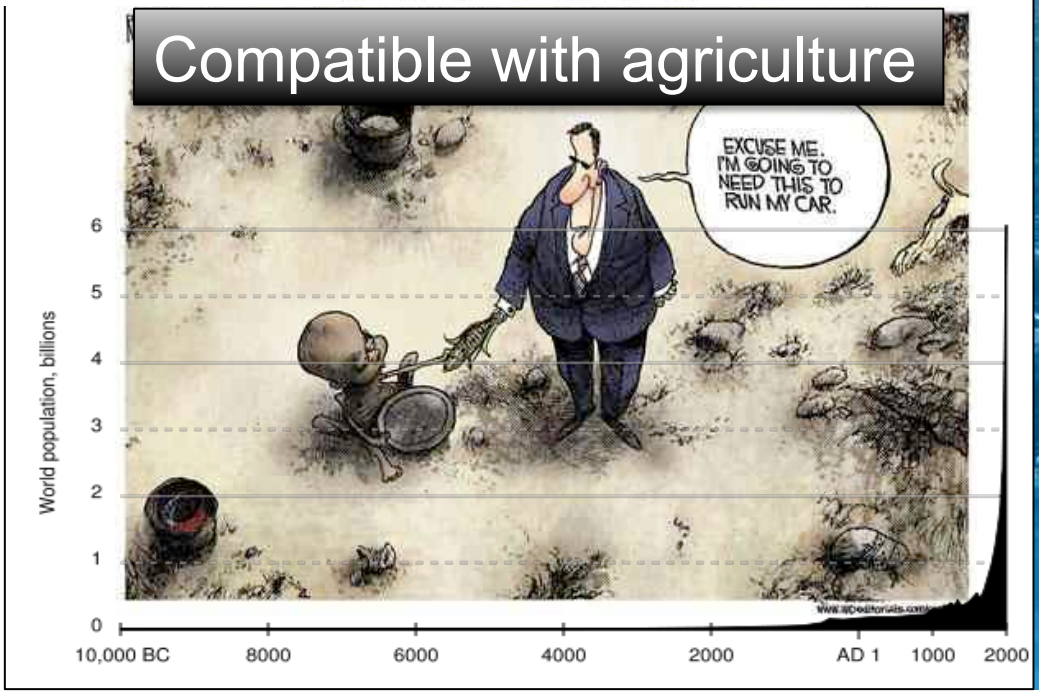
"…what we really want is for things to stay the same…

but get better."

Sydney J. Harris



Compatible- Global warming



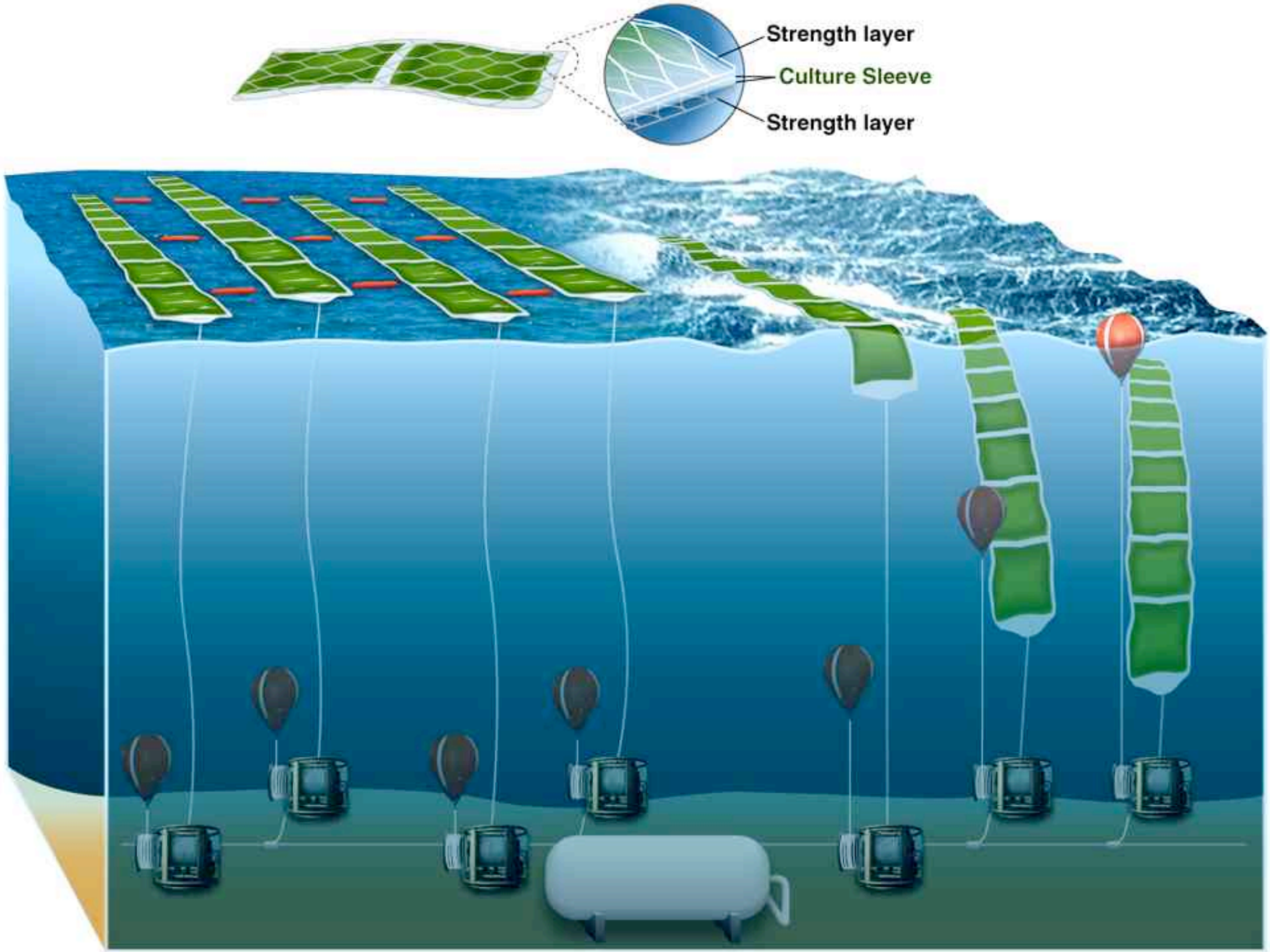
Compatible with agriculture

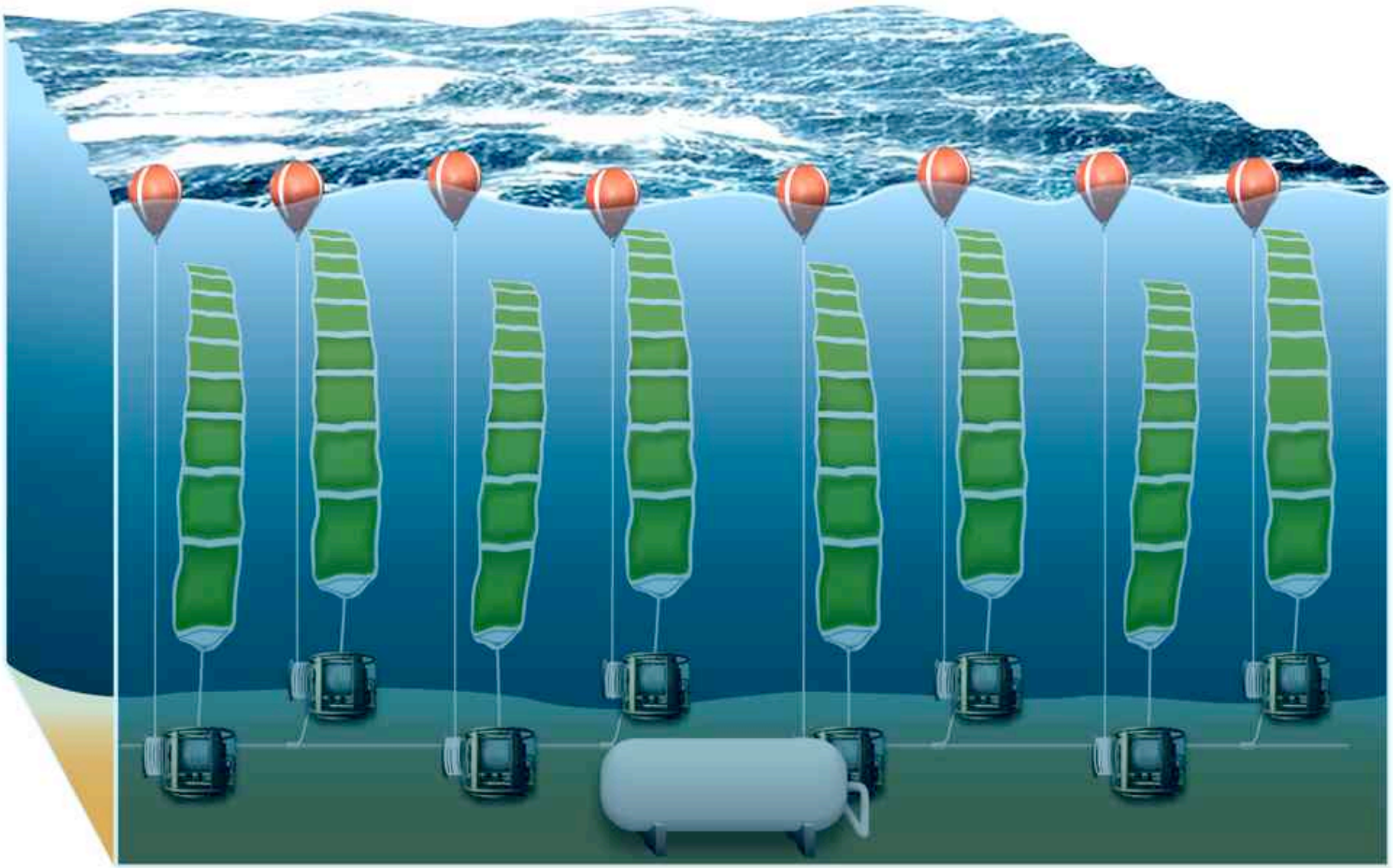
Drop-in fuel

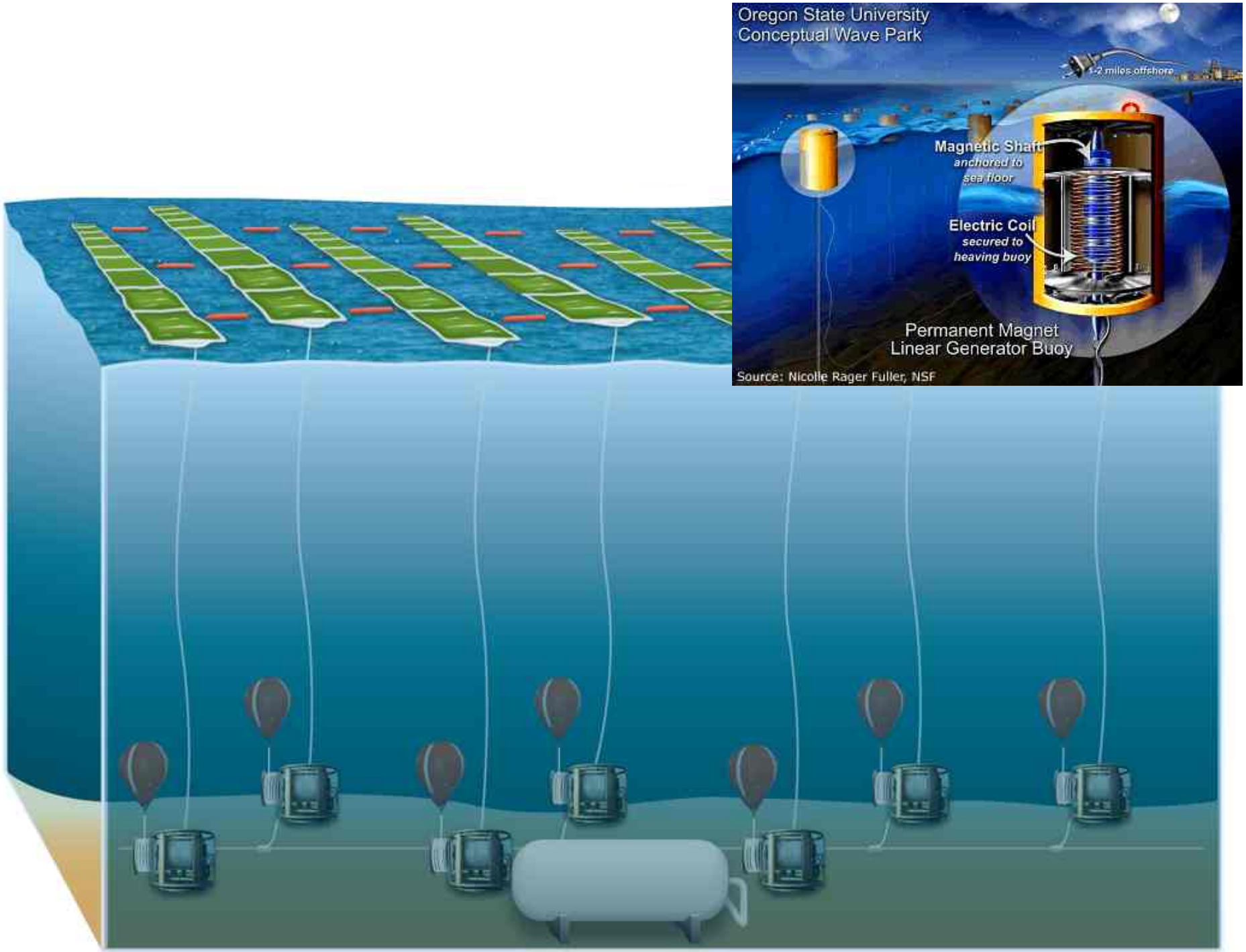

Are we up to the engineering challenge?

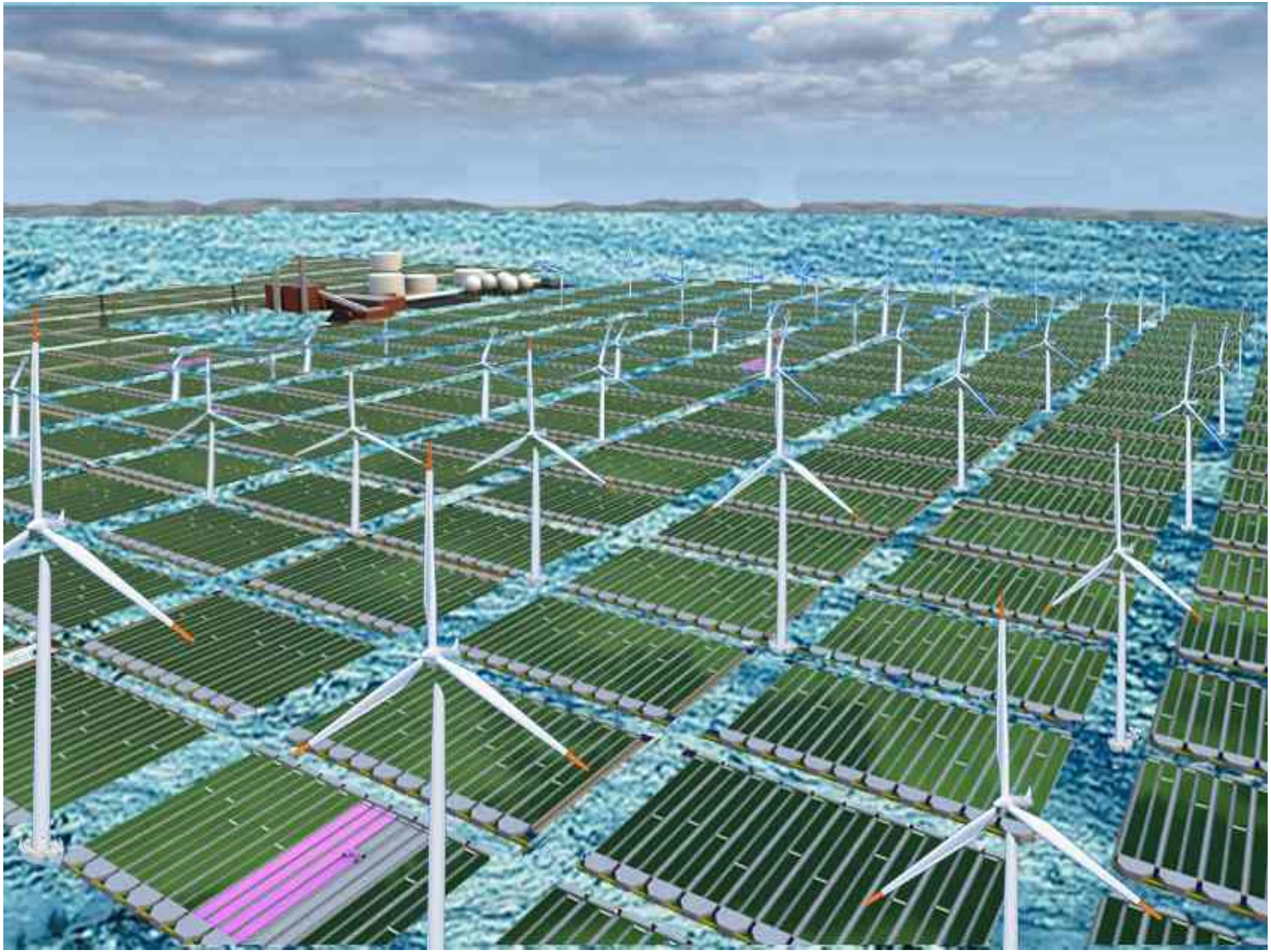

TEN

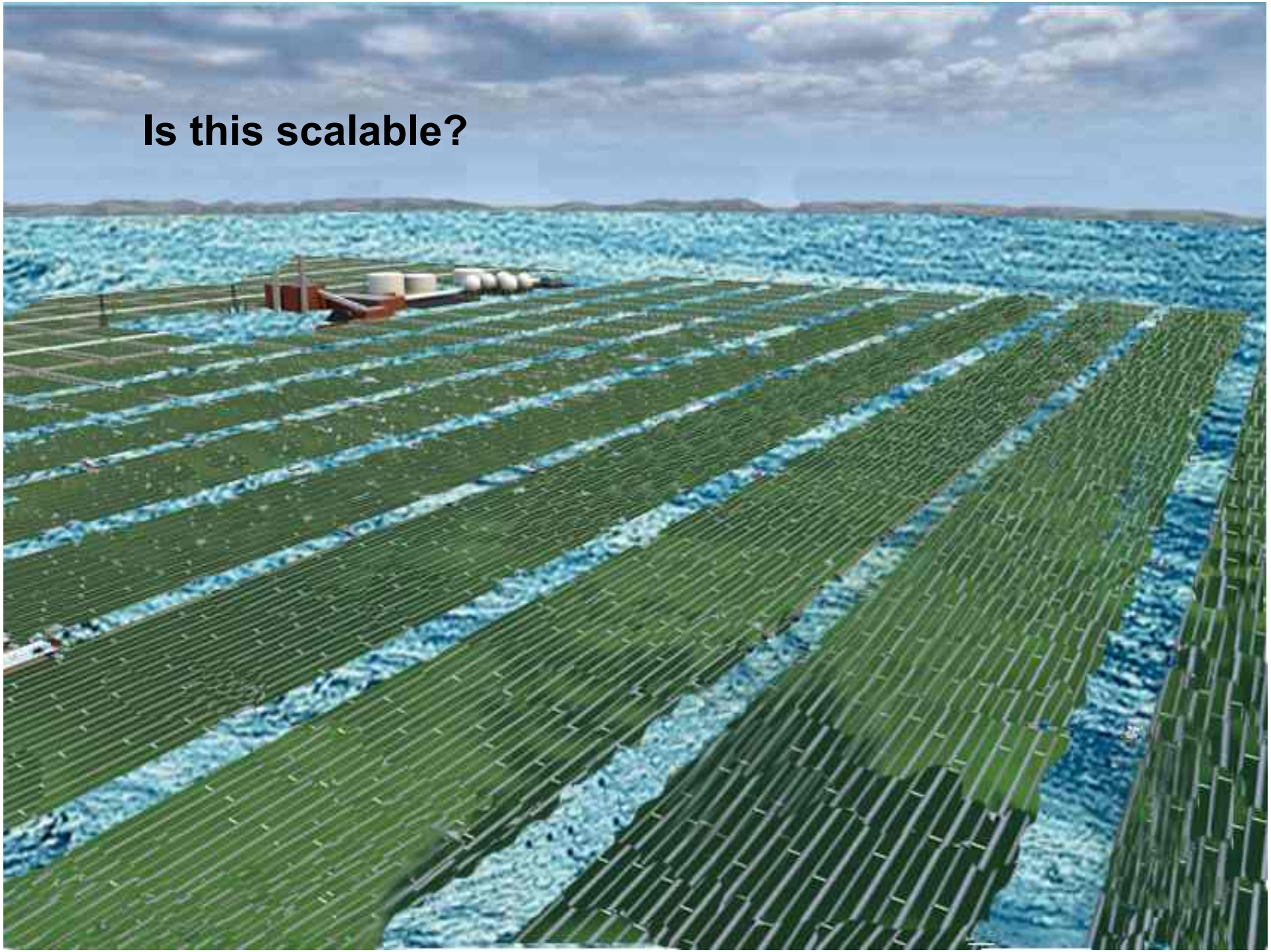

TEN REAL ESTATE


Strength layer
Culture Sleeve
Strength 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



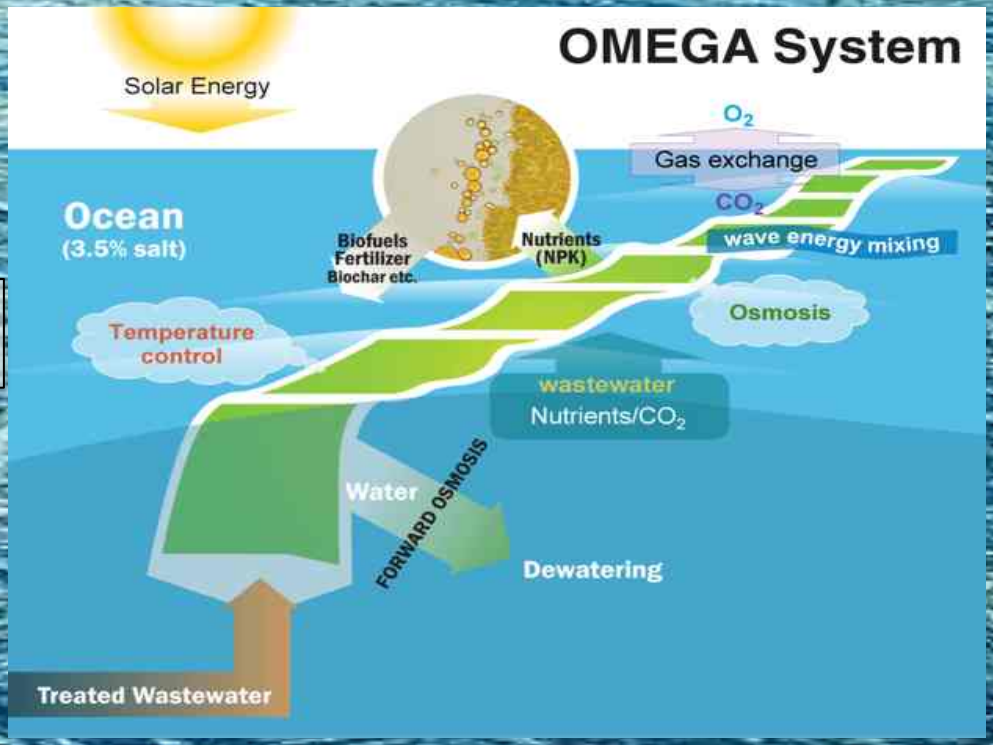

Is this scalable?

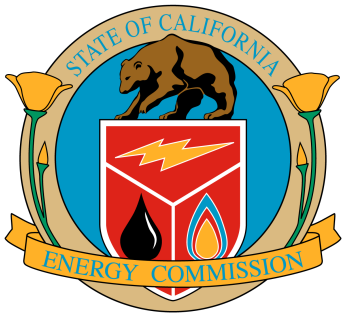

Jan Parker 2006

NASA OMEGA

Demonstration Project

Ecology of Technology




STATE OF CALIFORNIA
ENERGY COMMISSION


NASA


Ames Research Center


URS


UC SANTA CRUZ


DISCERE FACIENDO


ARTS


JACOBS
People are Our Greatest Asset


SETI INSTITUTE


SCRIPPS INSTITUTION OF OCEANOGRAPHY
UCSD


HTI
Hydration Technology Innovations


SCHOOL OF MINES
1874
COLORADO


DYNAMAC
CORPORATION


RESOURCES AGENCY
CALIFORNIA
DEPARTMENT
FISH & GAME


NREL
National Renewable
Energy Laboratory


UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY


SFPUC
WATER
HETCH HETCHY
WATER & POWER
CLEAN WATER


BCI


WESTECH
an employee-owned company


EIMCO
WATERTECHNOLOGIES


SIEMENS
Water Technologies


SRI
International


uop
A Honeywell Company

- OMEGA MOVIE

A challenge and a call to action…

Failure is not an option…

There are challenges growing algae on land…

1: Open circulating ponds (raceways)

2: Closed photobioreactors (PBRs)

Sources of biodiesel…

	Wood Residue	Soybeans	Rapeseed, Canola	Algae
Product	Ethanol, biodiesel	biodiesel	biodiesel	biodiesel
GHG output*	N/A	49	37	-183
Water	low	HIGH	HIGH	Low?
Fertilizer	low	low-med	med	Low?
Pesticide	low	med	med	Low?
Energy	low	med-low	med-low	HIGH?
US crop land/ half demand	150 -250%	180-240%	30%	1-2%?

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

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…


ALGAE
Powering the future of aviation?
Paul Steele Executive Director ATAG

Algal Biomass Organization
www.algalbiomass.org

Claim that algae will address:

- **climate change**
- **energy independence**
- **growth of a green economy**

ALGAL BIOMASS ORGANIZATION

ABO Platinum Members

AIR NEW ZEALAND

bionavitas

BOEING

The Mitchell Family Corporation

UOP A Honeywell Company

Raytheon

Virgin atlantic

Wilson Sonsini Goodrich & Rosati

ABO Corporate Members

Air Transport Association

AURORA BIOFUELS

ALG Advanced Lab Group

Battelle The Business of Innovation

BC hydro FOR GENERATIONS

BELLONA

Bioalgene

bioprocessalgae

Biolight

BYRNE & Company Limited

Canadian Pacific Algae Inc.

Continental Airlines

DAF

EPRI

EndicottBiofuels, LLC A Cleaner Alternative

FedEx Express

Fredrikson

General Atomics

GreenPower conferences

Harris Group Inc.

IATA

Imperium renewables

Kent Bio-Energy

Kimberly-Clark Corporation

kuraray

LiveFuels

MARTEK life enriched.

Mortenson construction

MTU Aero Engines

NESTE OIL

OriginOil

PetroAlgae

Philadelphia Renewable Energy

REG

Renewed World Energies

Sapphire Energy

SIEMENS

solazyme

SRS A UTC Company

STOEL RIVES LLP

SYNTHETIC GENOMICS

Targeted Growth, Inc.

USBIOFUELS

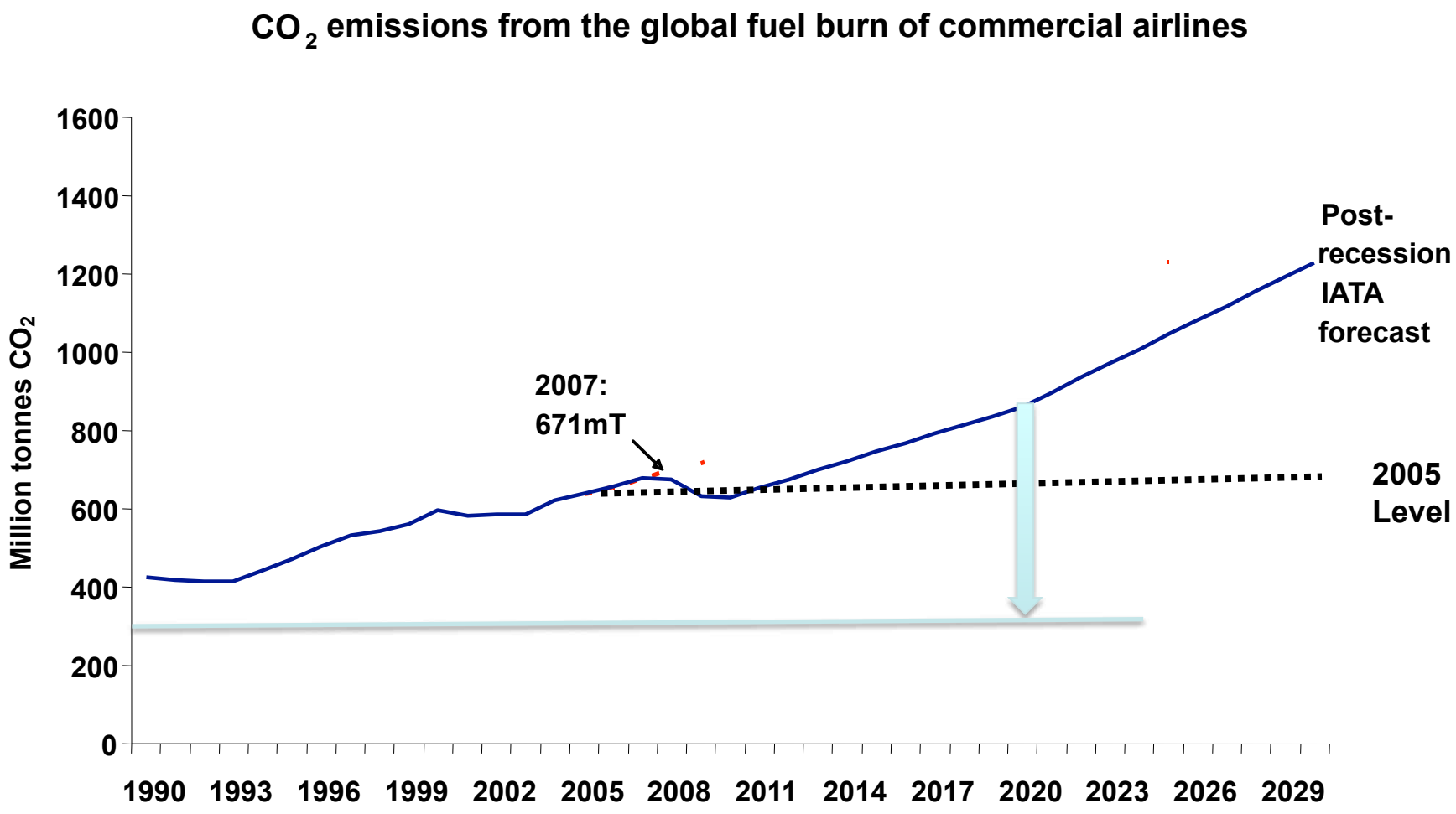
WM WASTE MANAGEMENT

ABO Supporting Organizations

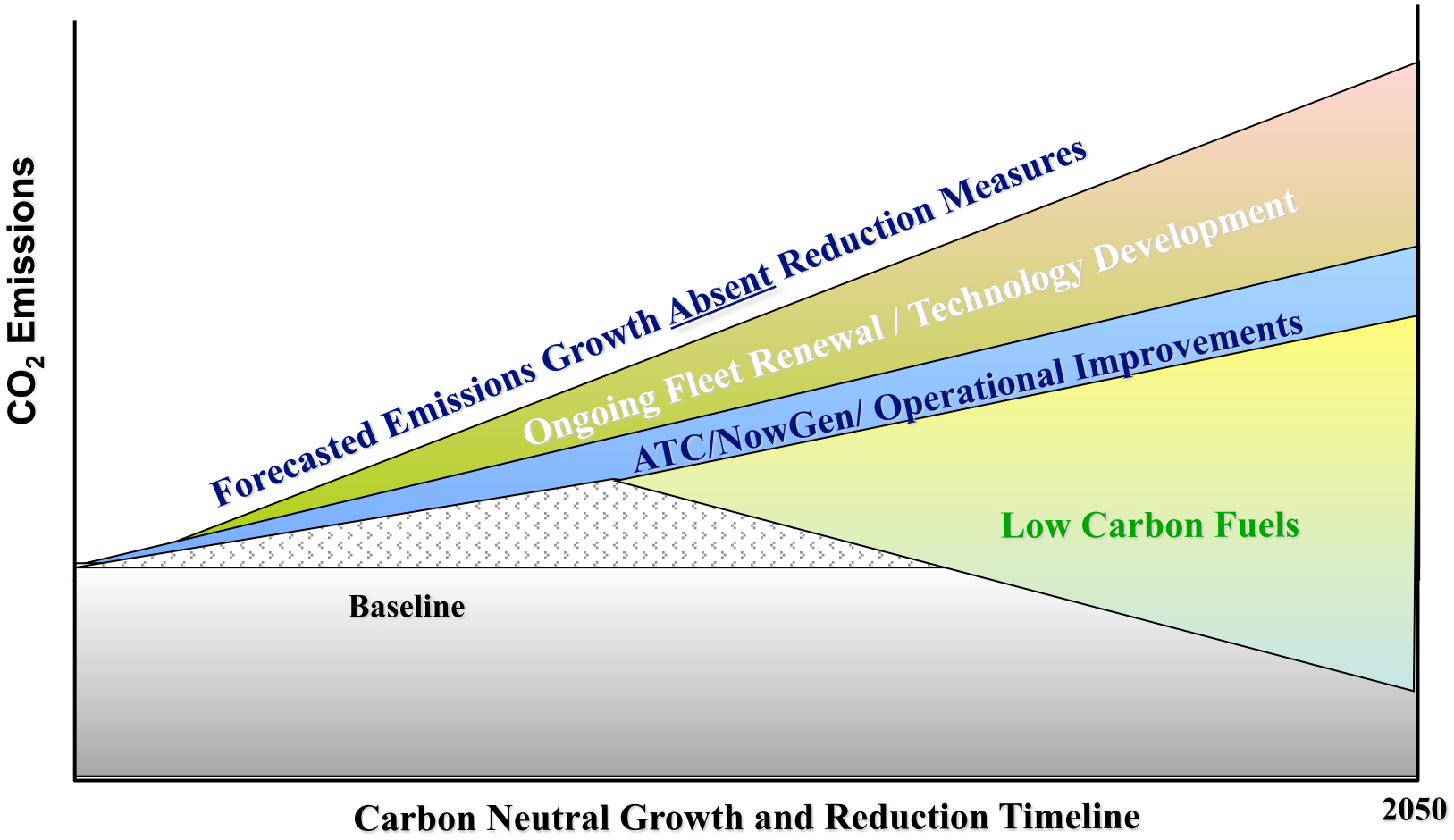
Bio BIOTECHNOLOGY INDUSTRY ORGANIZATION

Phycological Society of America

The aviation emissions challenge



How do we limit aviation's CO_2?



Biofuels for aviation to date:

Carrier	Aircraft	Partners	Date	Biofuel	Blend
virgin atlantic	B747-400	Boeing, GE Aviation	23 Feb 08	Coconut & Babassu	20% one engine
AIR NEW ZEALAND	B747-400	Boeing, Rolls-Royce	30 Dec 08	Jatropha	50% one engine
Continental Airlines	B737-800	Boeing, GE Aviation, CFM, Honeywell UOP	7 Jan 09	Algae with Jatropha	50% one engine
JAL	B747-300	Boeing, Pratt & Whitney, Honeywell UOP	30 Jan 09	Camelina, Jatropha and Algae blend	50% one engine
KLM	B747-400	GE, Honeywell UOP	23 Nov 09	Camelina	50% one engine
jetBlue	TBA	Airbus, IAE, Honeywell UOP	TBA	TBA	TBA


EXIT

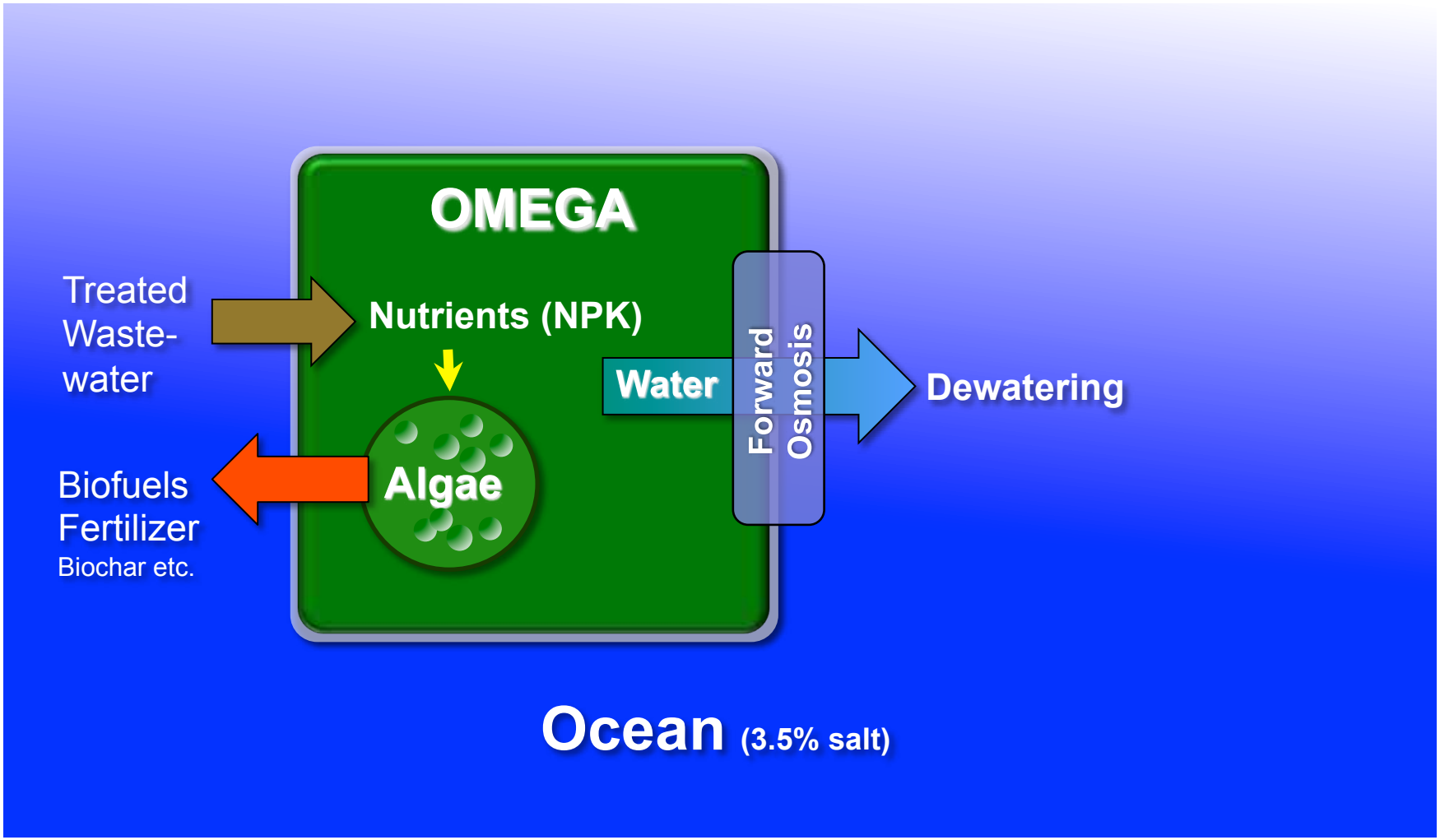

STRIKE TEST

Is this true?

How do you know?

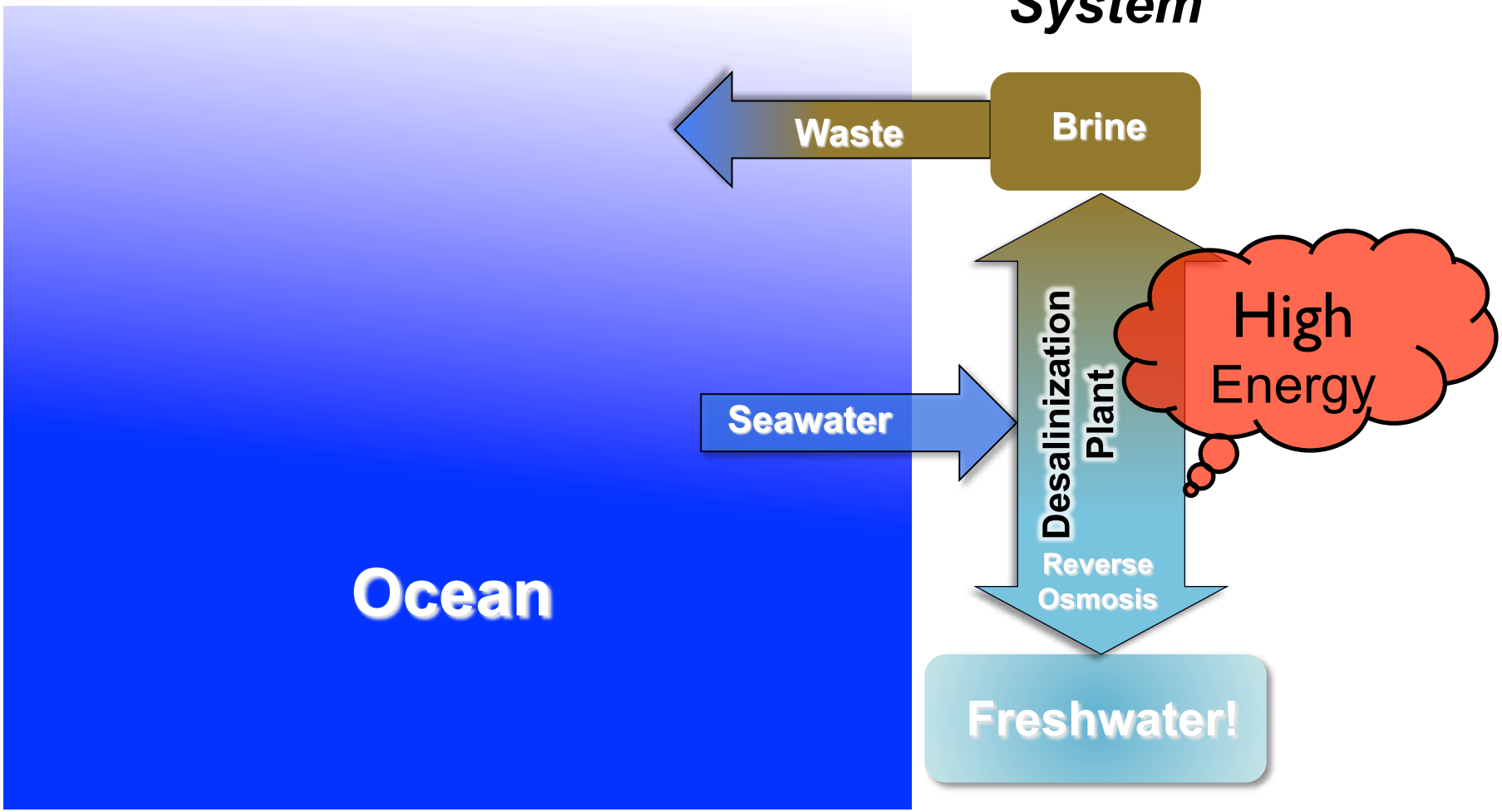
Why should I care?

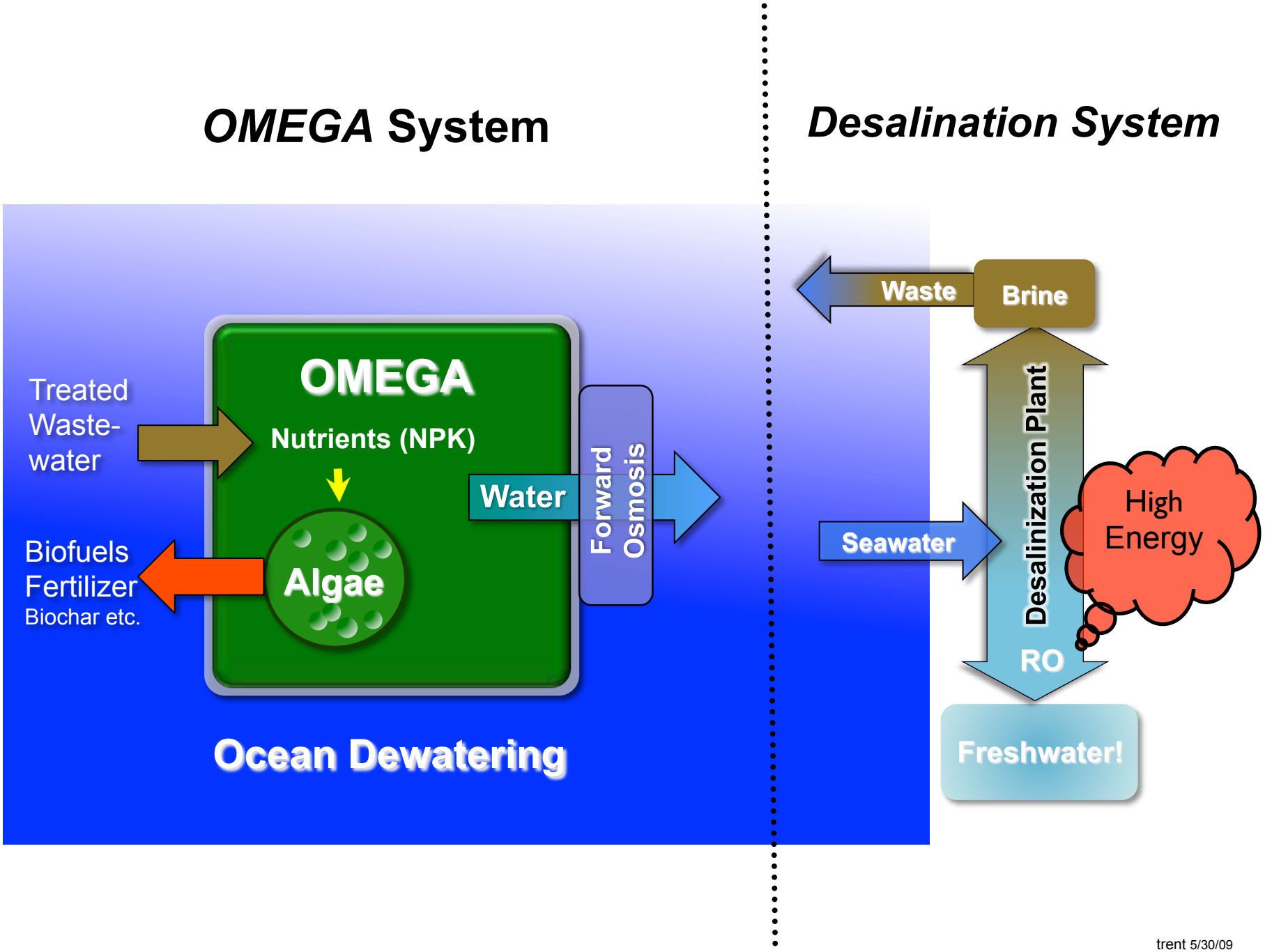
OMEGA System



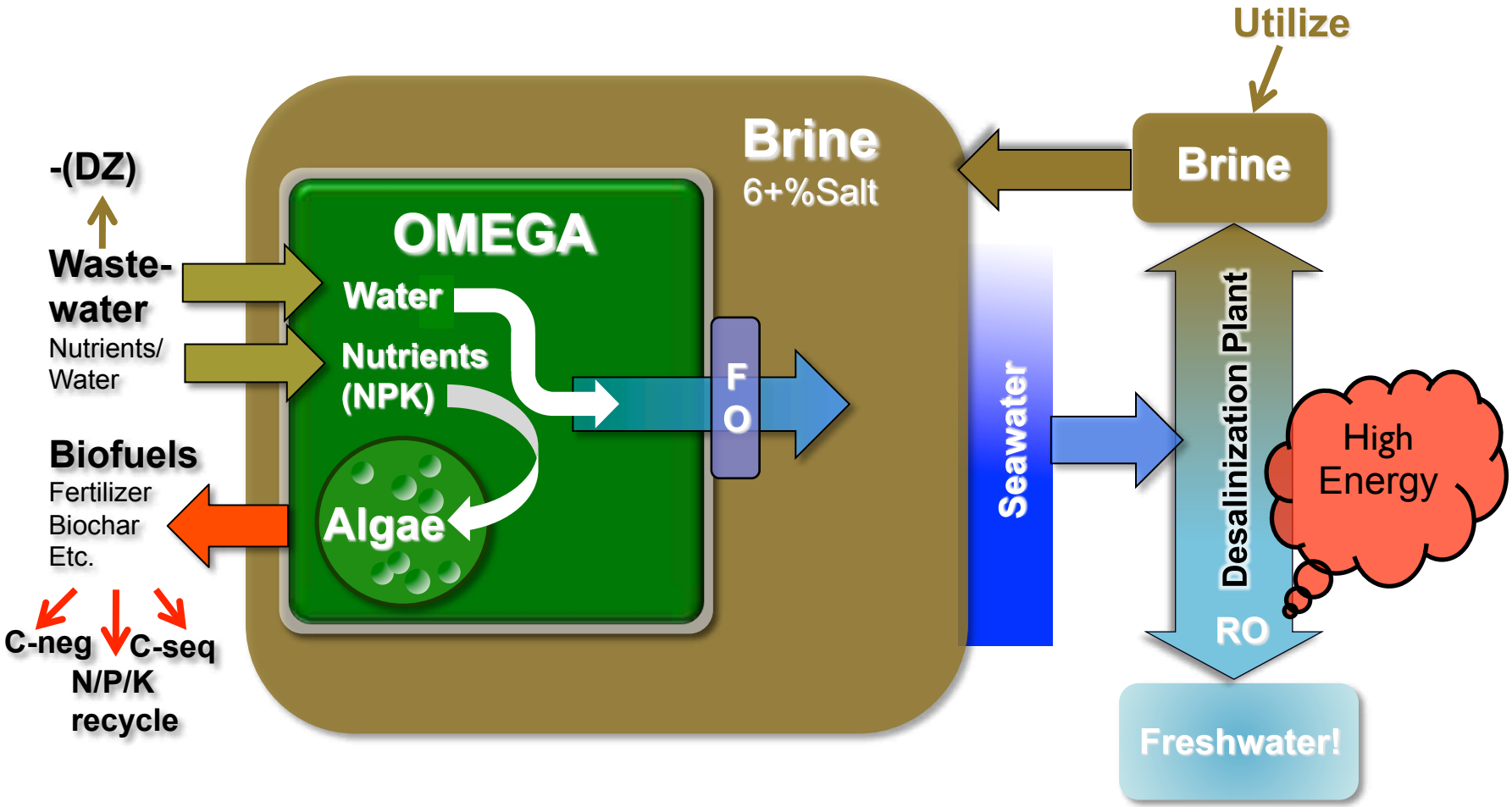
What about the water?

Desalination System

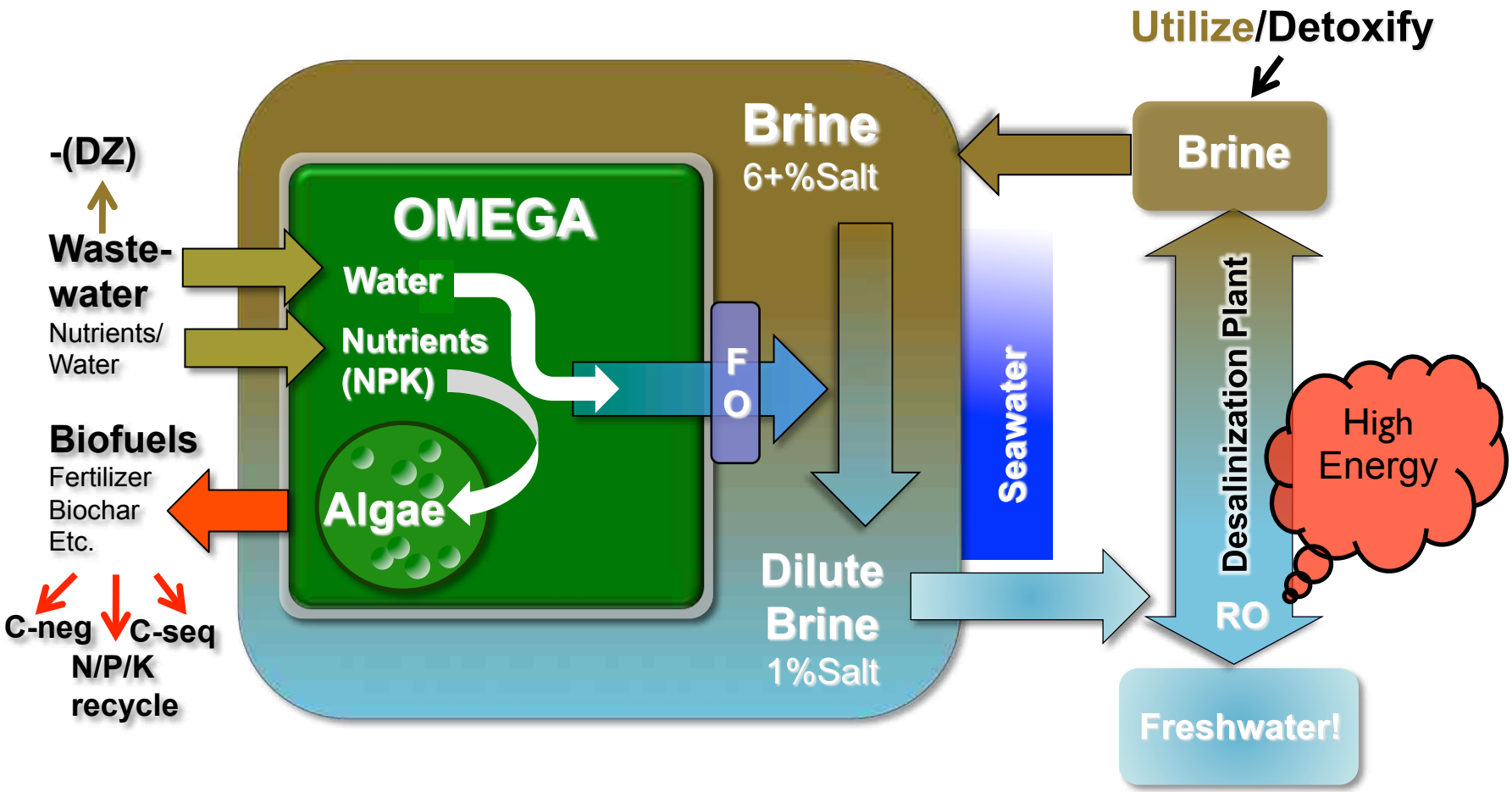



OMEGA System
Desalination System
Treated Waste-water
OMEGA
Nutrients (NPK)
Water
Forward Osmosis
Biofuels
Fertilizer
Biochar etc.
Algae
Ocean Dewatering
Waste
Brine
Desalinization Plant
RO
Seawater
High Energy
Freshwater!

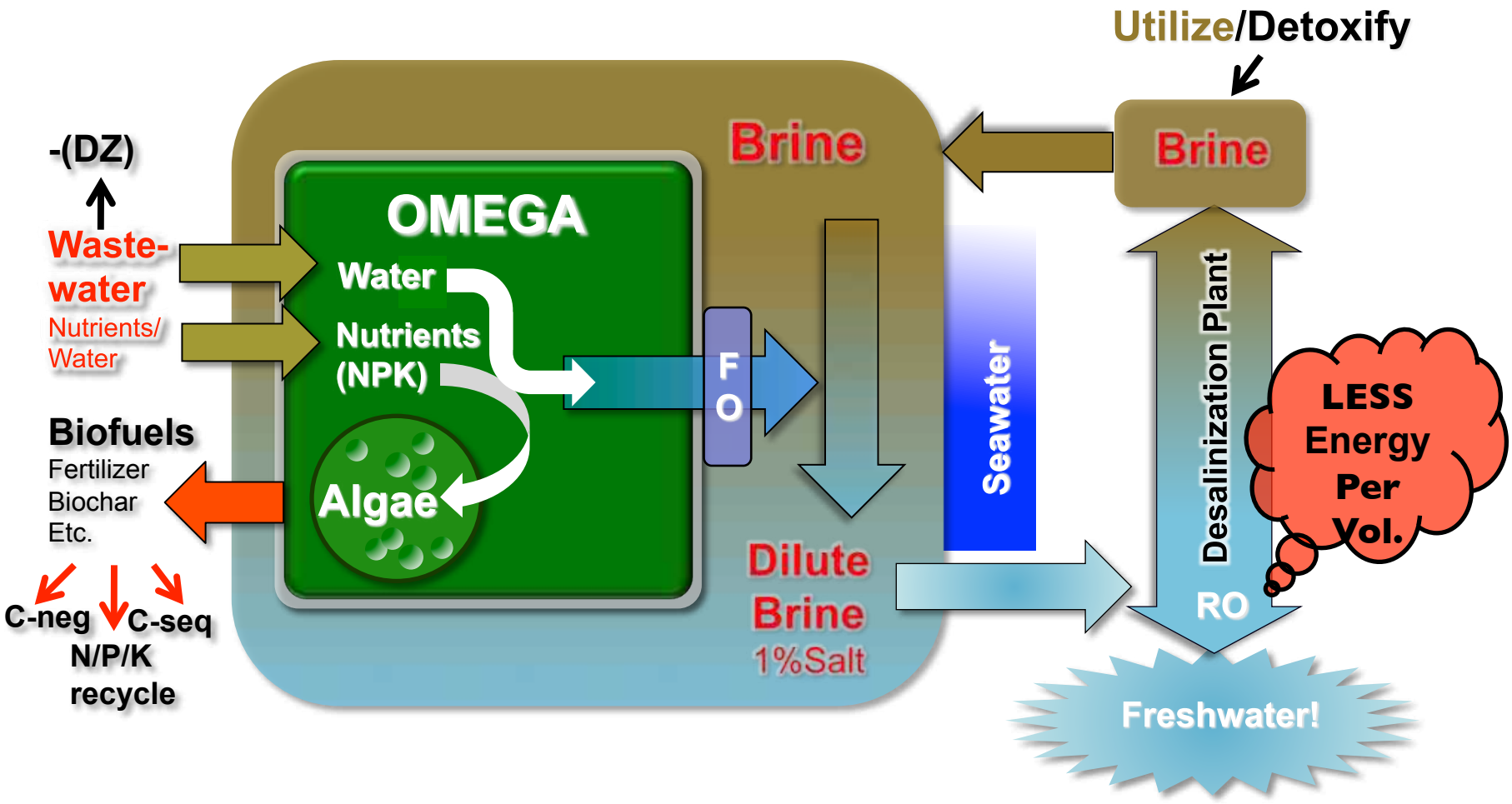
Desalgae System (OMEGA + Desalination)



Desalgae System (OMEGA + Desalination)

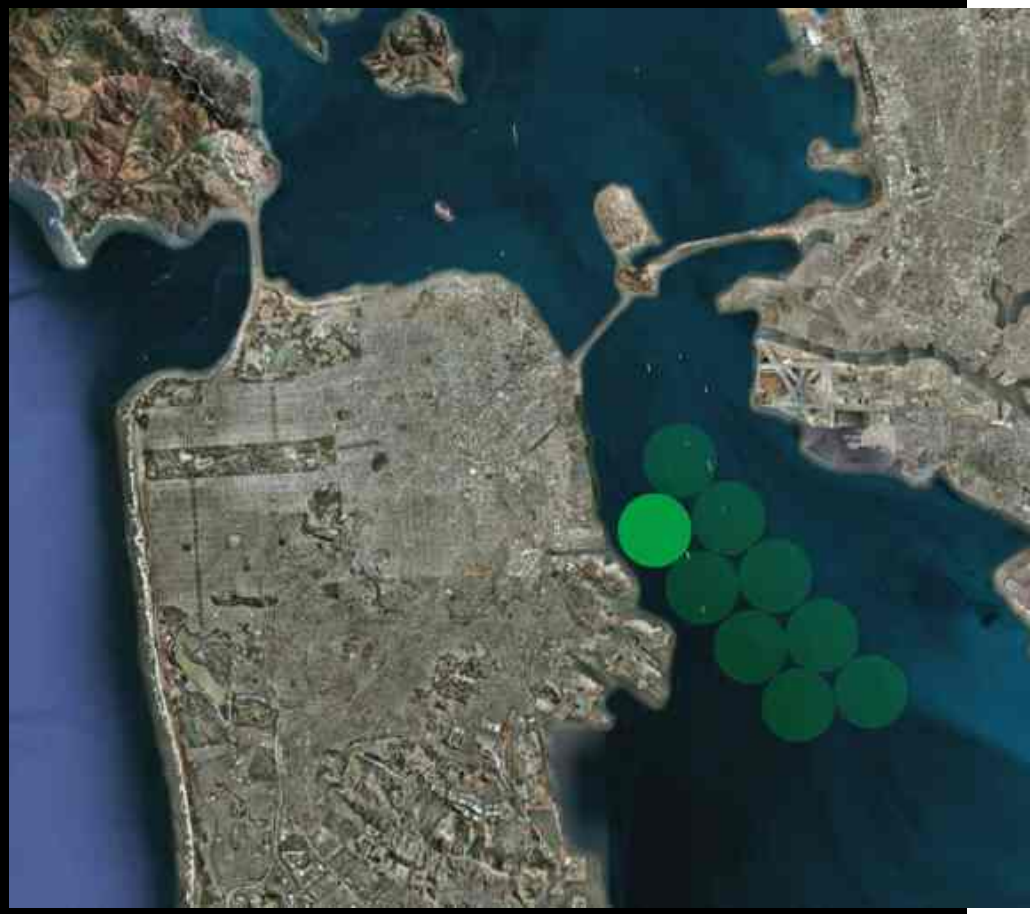


Desalgae System (OMEGA + Desalination)

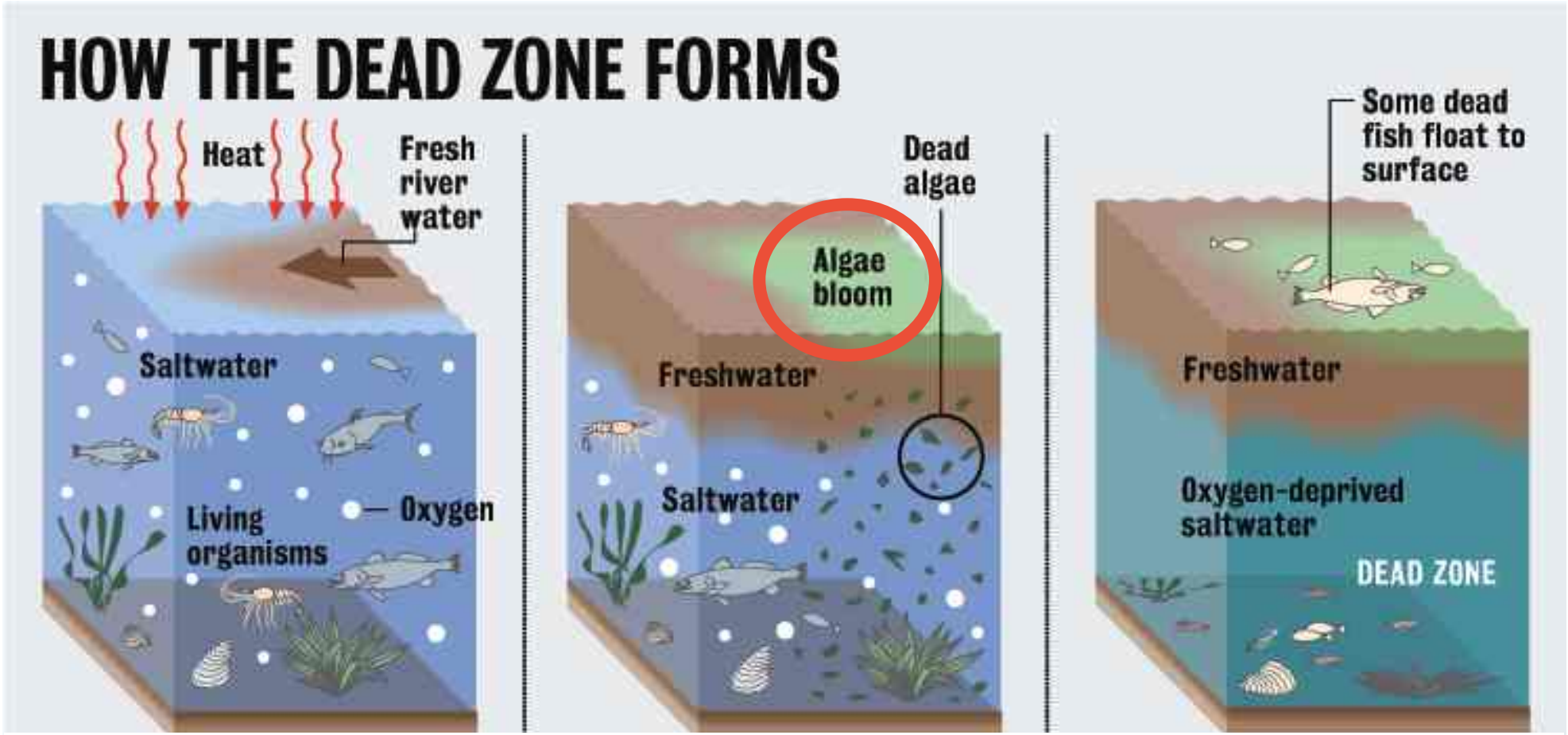


Example: San Francisco

67 MGD, 80% of SF WW
20 g/m^2/day algae growth



- Minimum size
  - N-limited @ 9 mg/L
  - 28 tons dry biomass/day
  - 2.3 MG biofuel/yr
- Maximum output
  - Water-limited
  - 1 g/L algae yield
  - 254 tons dry biomass/day
  - 20 MG biofuel/yr
  - Capture all CO_2 from 32 MW PP



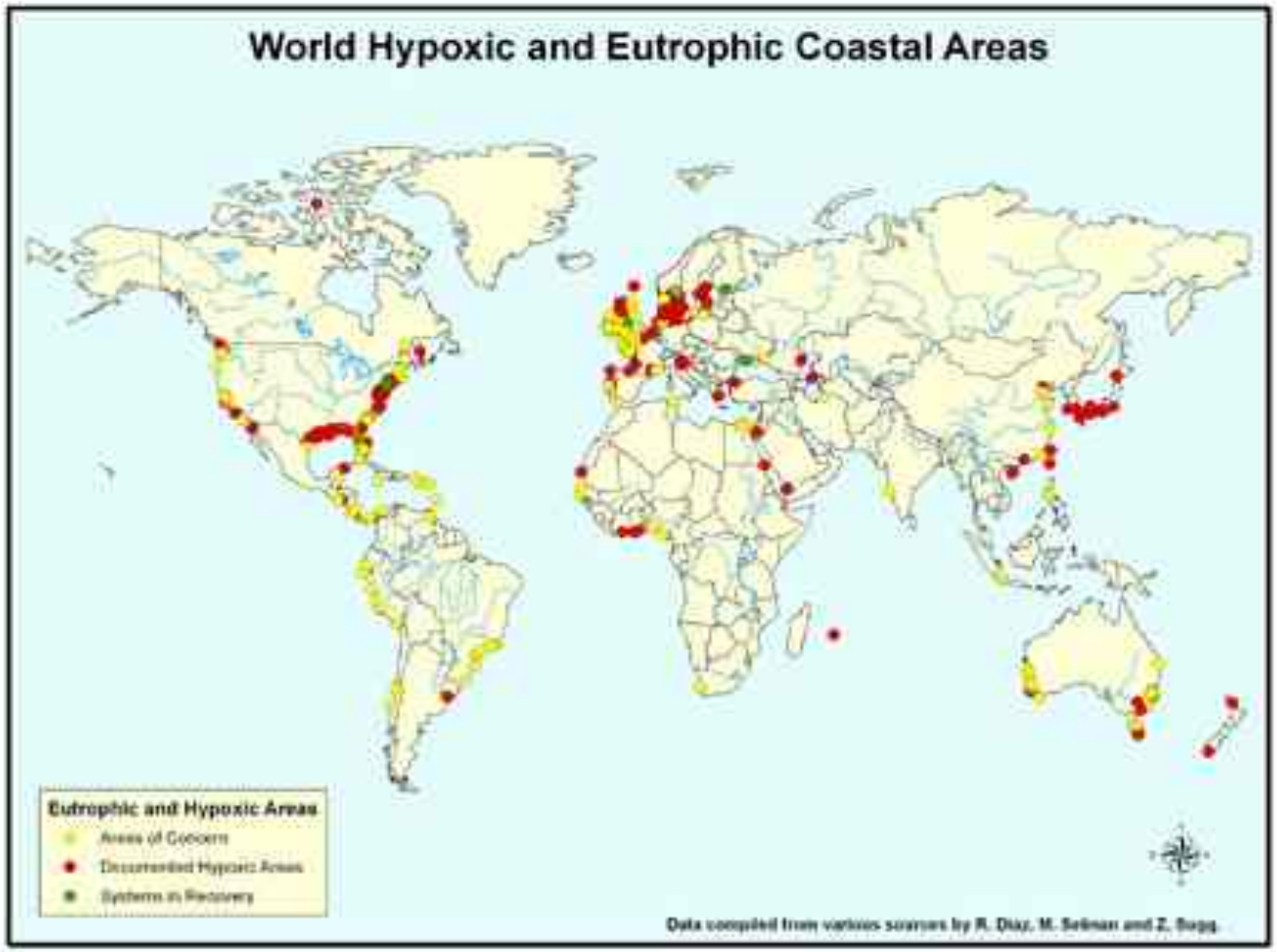
Fertilizer runoff

Stratified water column

Suffocation

Remediating Dead Zones

Dead Zones 2008



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