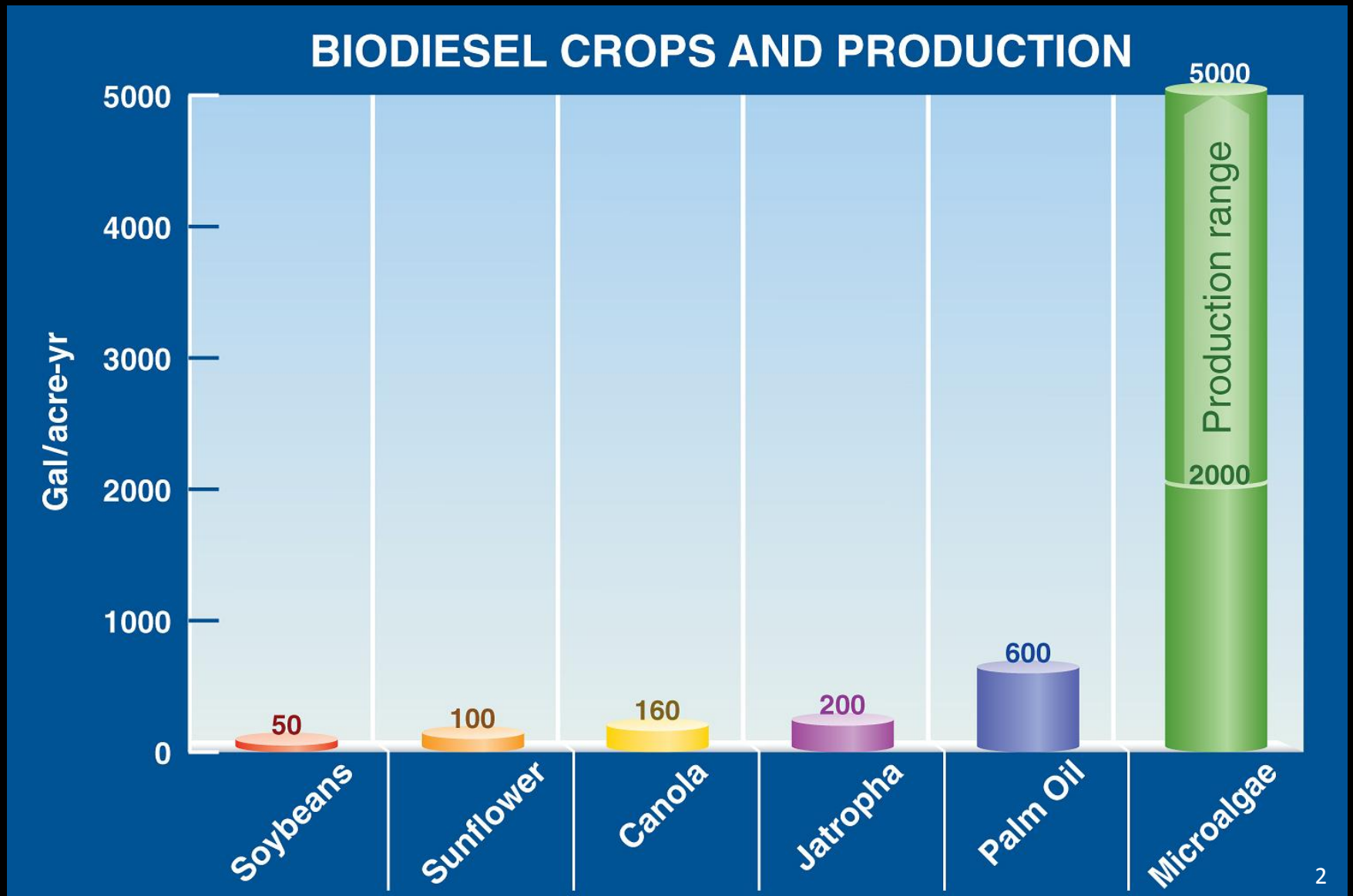
OMEGA

Offshore Membrane Enclosures for Growing Algae


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

Current State of the Art

Open circulating ponds (raceways)

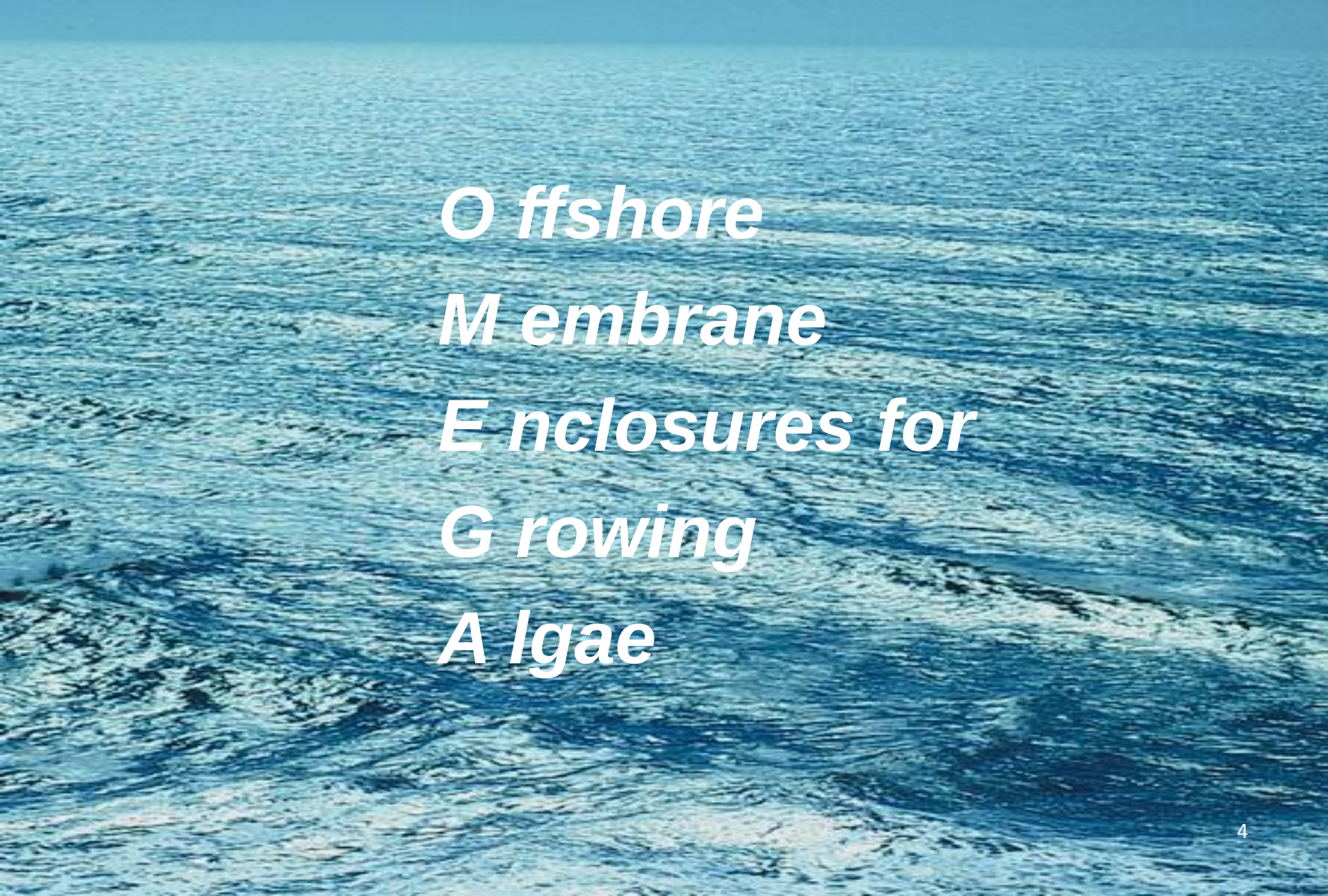
Limitations:

- **Water**
- **Energy demand for pumping**
- **Weed species**

Closed bioreactors

Limitations:

- **Infrastructure cost**
- **Energy demand: pumping, mixing, cooling**
- **Temperature regulation**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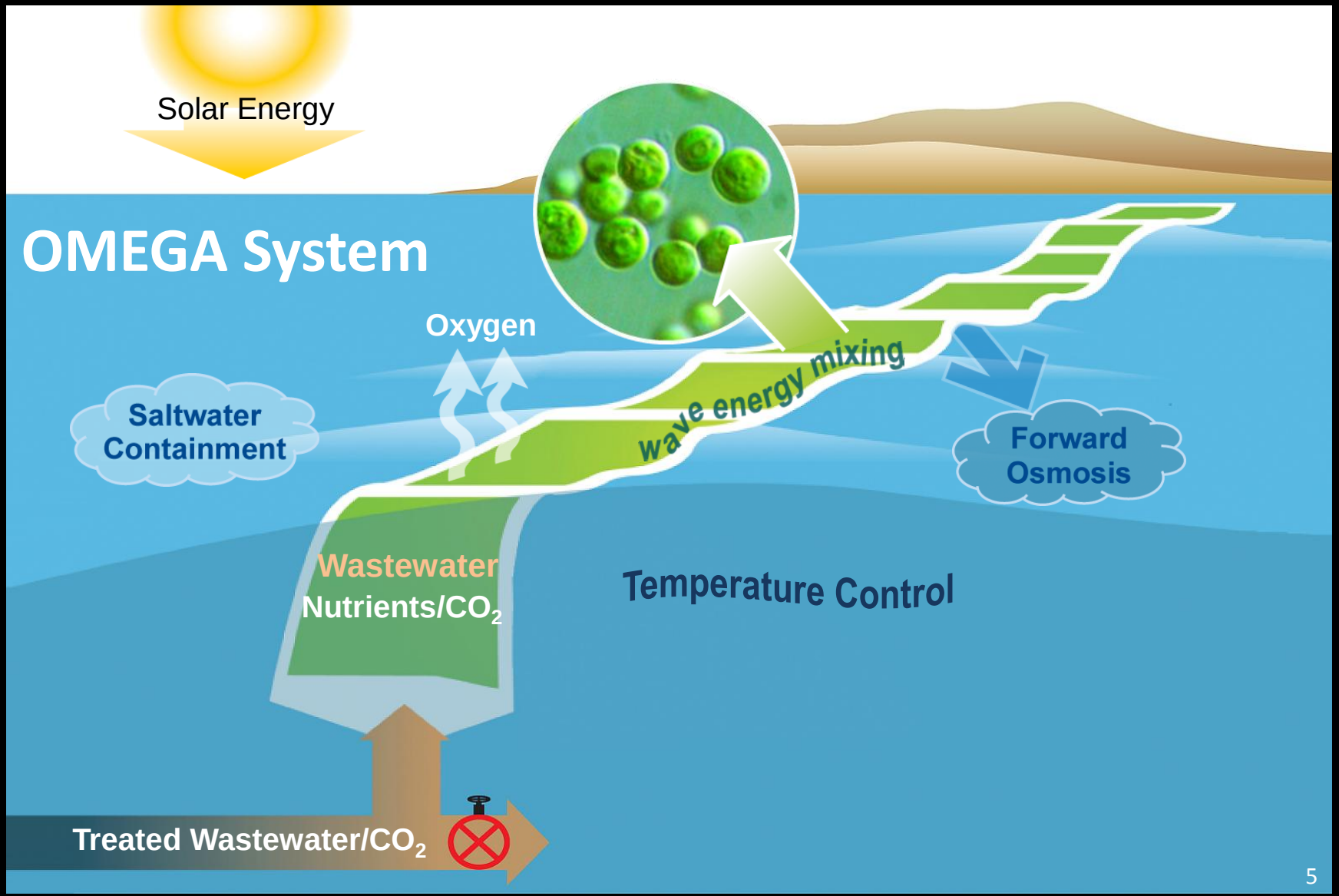

Solar Energy
OMEGA System
Oxygen
Saltwater Containment
wave energy mixing
Forward Osmosis
Wastewater
Nutrients/CO_2
Temperature Control
Treated Wastewater/CO_2

OMEGA Project Objectives

- Design, develop and build an algal cultivation system that utilizes and treats wastewater and is sufficiently scalable to be relevant for biofuels
- Deploy and operate an OMEGA pilot system for repeated algal growth cycles
- Develop protocols to maintain the OMEGA system under various conditions in marine environments
- Evaluate the OMEGA return on investment for both energy, economics, and perform a complete life-cycle analysis to determine its impact on the environment
- Develop partnerships with DoD, DoE, and/or Industry to transition and implement large scale OMEGA projects

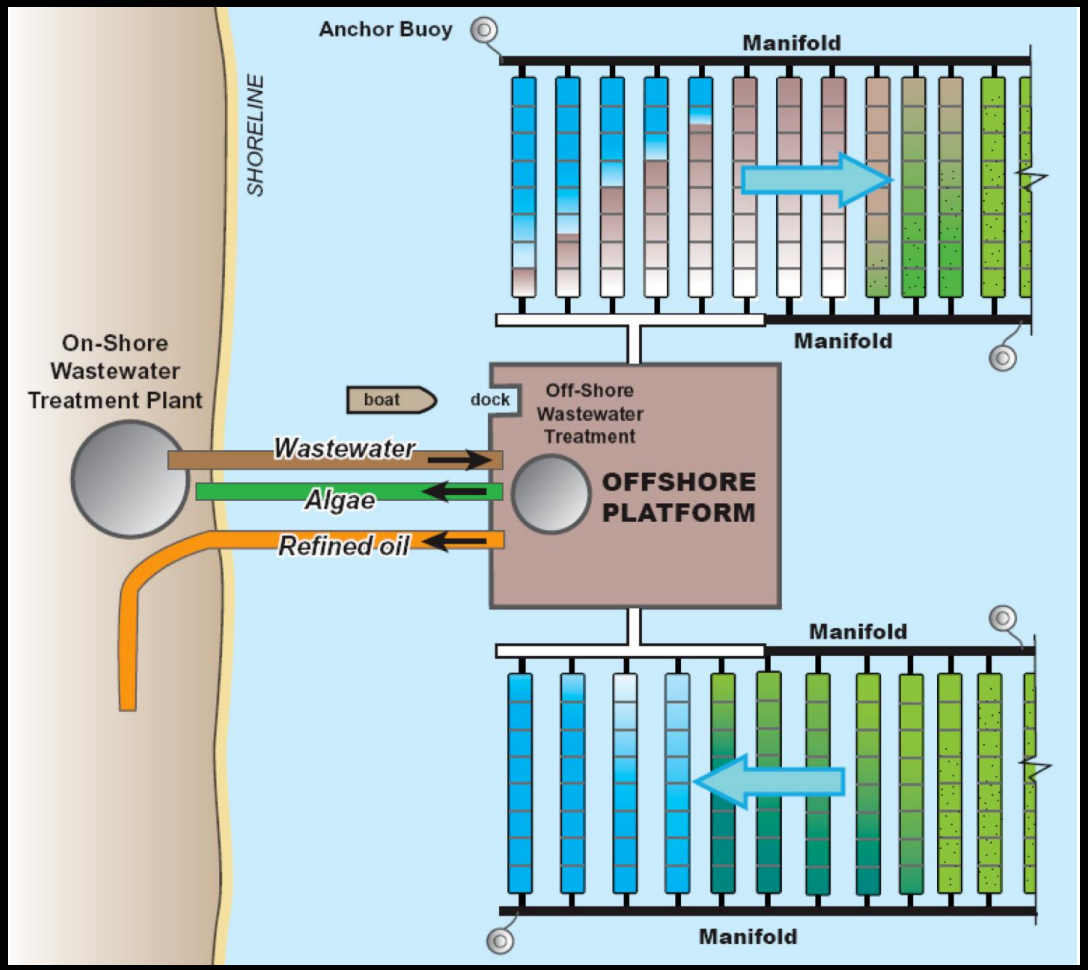
Project Deliverables

- Technology development for “ocean-going” photobioreactor (OMEGA)
  - Design, build and test OMEGA prototypes, lab and pilot scale systems
- 35% detailed design of commercial-scale OMEGA system to PDR level
- Systems analyses for commercial-scale OMEGA system
  - Productivity (aviation fuels, food, fertilizers) & services (WW treatment, CO2 sequestration)
  - Returns on Investments (economics & energy)
  - Life cycle and cost benefit analyses
  - Greenhouse gas emissions reduction analyses
- Technology transfer to U.S. Navy, DOE, & private sector

Accomplishments to Date

- Concept of Operations
- PBR process design
- Material selection for PBR module
- PBR module concept design
- PBR module structural considerations
- Infrastructure design

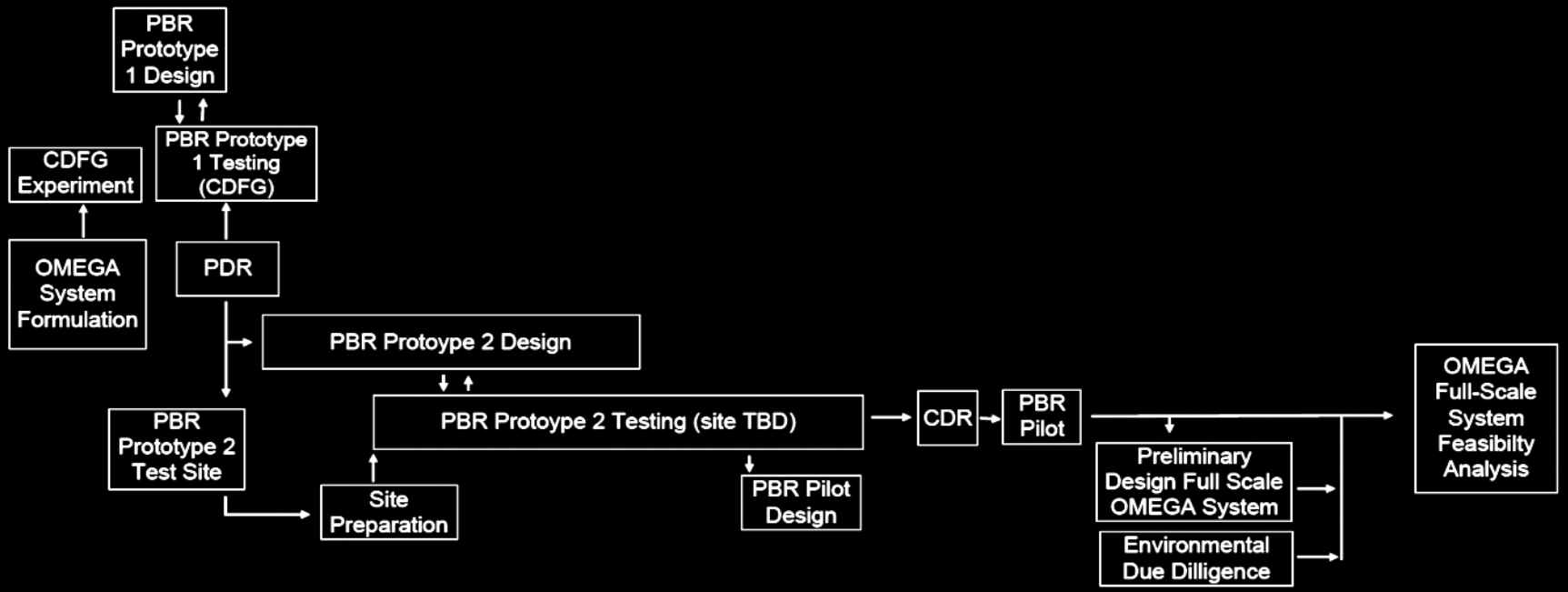
OMEGA Concept of Operations



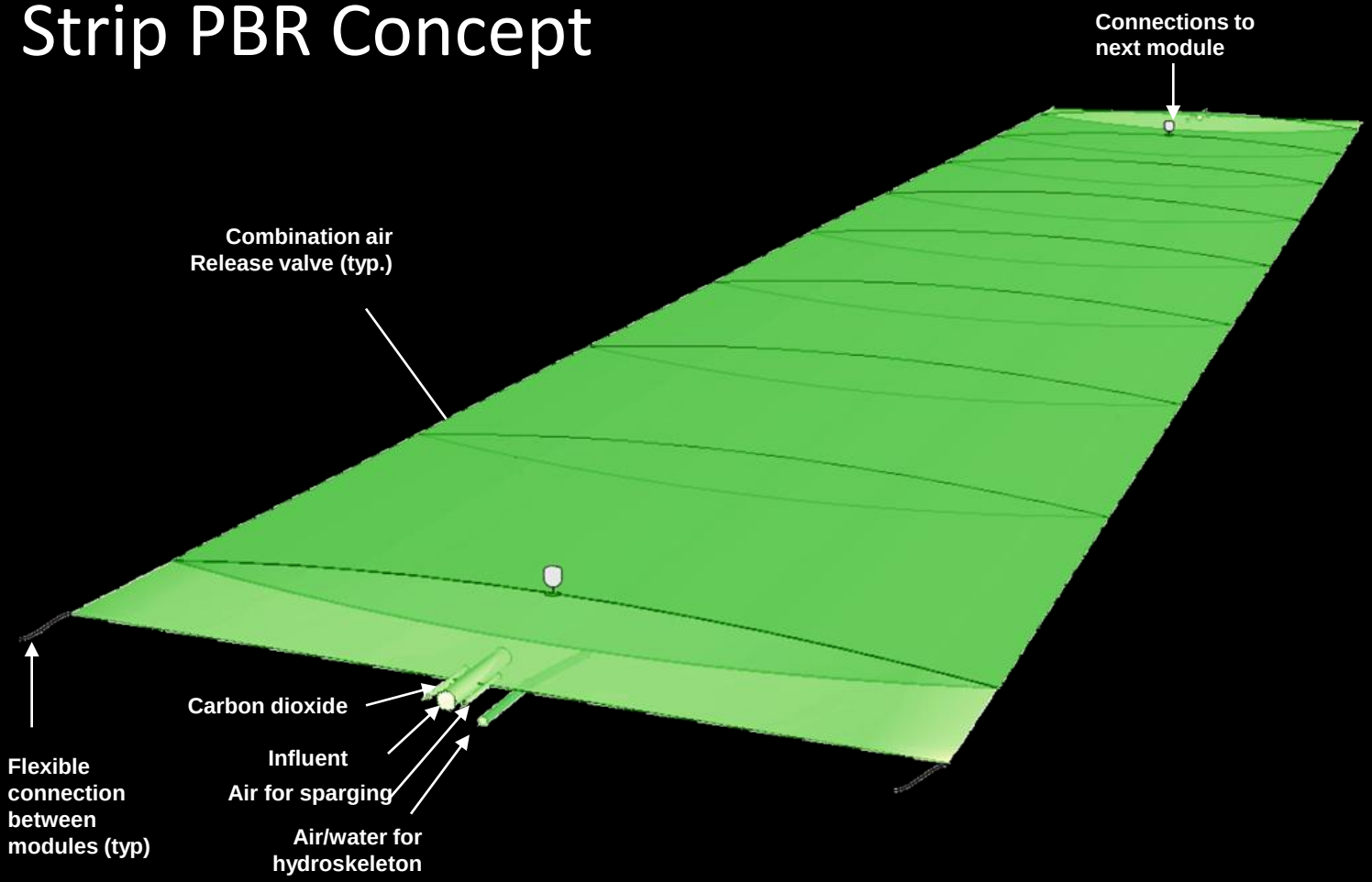
Baseline PBR Design

- Primary material: Polyethylene (HDPE and LLDPE)
  - PAR transmittance, UV resistence
  - Structural considerations
- Batch or Continuous modes of operation
  - Wastewater for water, carbon, nutrients, and trace elements
  - Internal recycle loop for nutrients
  - Control dissolved oxygen
  - Use carbon dioxide in flue gas to provide pH control and supplemental carbon
- Forward Osmosis membranes for dewatering
  - Dewater at a rate to concentrate nutrients for optimal biomass growth
- PBR concepts are Strips or Cellular < 21,000 liters

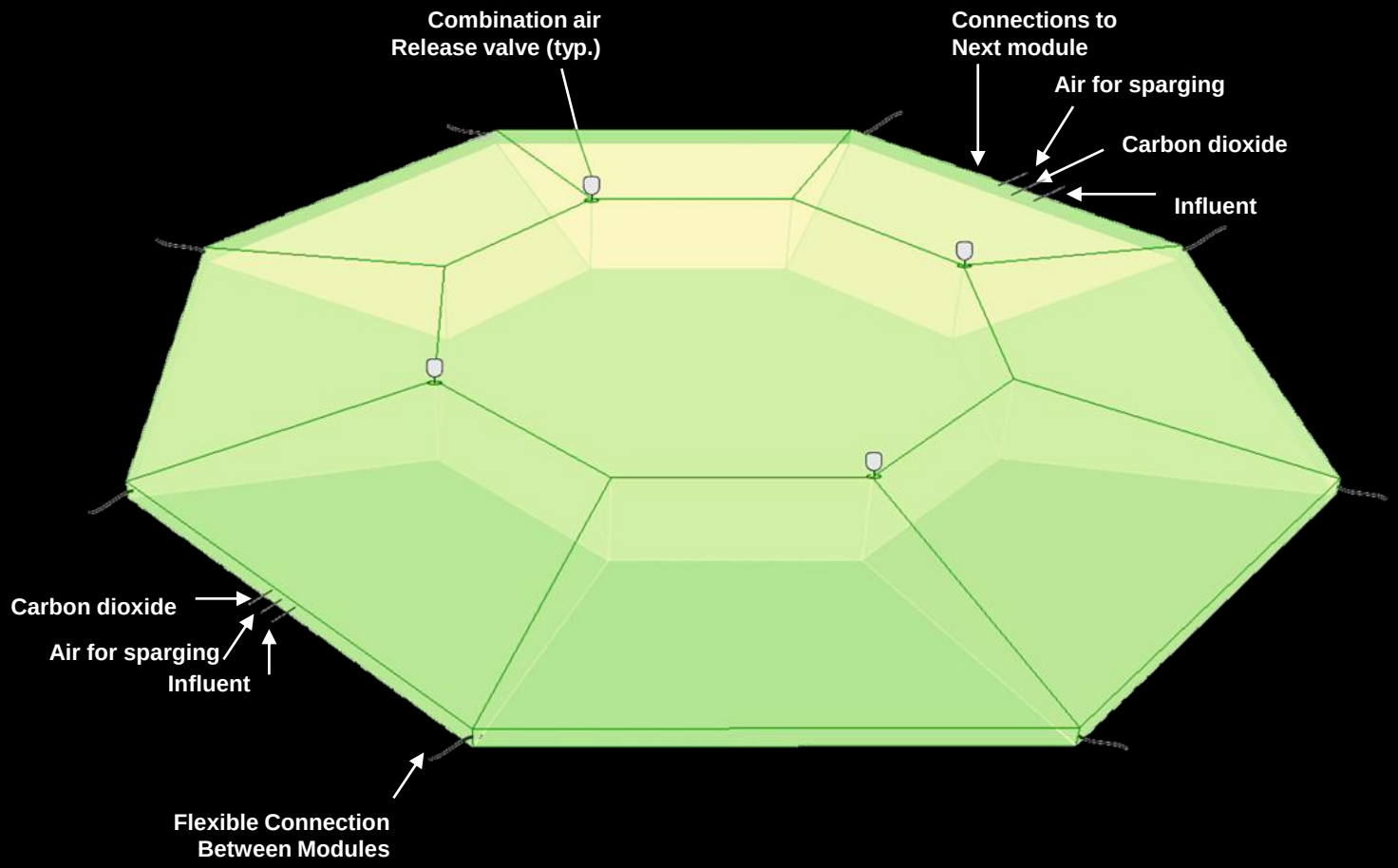
OMEGA Project Timeline



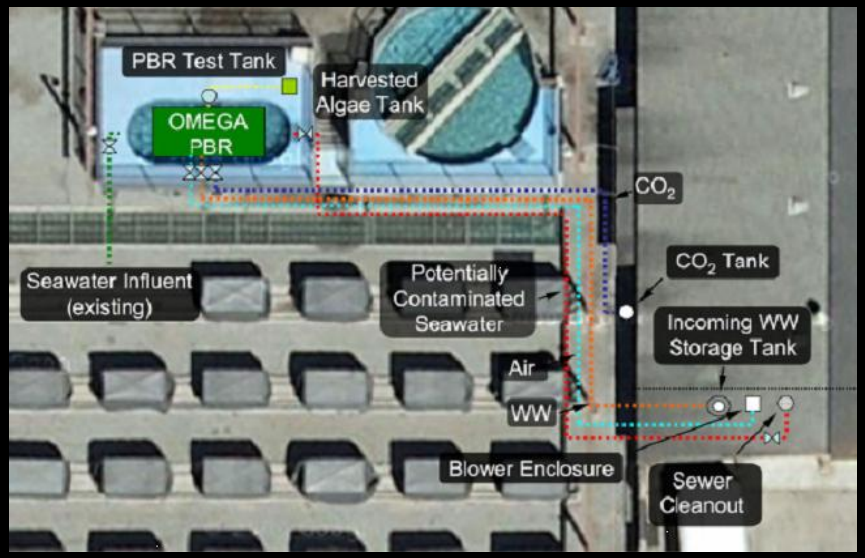
Strip PBR Concept



Cellular PBR Concept



Santa Cruz Site (CDFG)



Process Performance:

- Mixing intensity and duration
- Nutrient removal efficiency
- Effects of batch mode of operation vs. continuous mode of operation

Module Development:

- Determination of locations for ports in PBR for process control & monitoring
- Filling and harvesting methods
- Placement of air, CO_2 and FO membranes

What's Next

Q3 – Q4 FY10

- OMEGA PBR Prototype Testing
- CA Department of Fish & Game (CDFG) Facility

Q1 – Q2 FY11

- OMEGA Pilot-Scale PBR Prototype Testing
- Wastewater Treatment Facility (To be selected)

Q3 – Q4 FY11

- CDR
- OMEGA Pilot Test (final PBR design)
- Wastewater Treatment Facility and/or wave tank facility

Q1 – Q2 FY12

- Preliminary design of full-scale OMEGA system
- Perform feasibility assessment

Contra Costa Site Option

SF Site Option

Pilot-Scale Test Objectives

- Continue prototype PBR module tests:
  - Algae growth with wastewater and flue gas
  - Wastewater treatment
- Build larger systems to determine how OMEGA modules will be assembled in place and/or deployed
  - Filling, incubating, mixing, harvesting, and refilling to repeat the cycle
  - Productivity, rates and efficiencies in both batch and flow-through systems
  - Structural integrity and basic handling
- Design logistics plan for OMEGA pilot test
- Collect data on PBR and sub-system performance for FE model and hydrodynamic model
- Down select a final PBR Module Design for OMEGA Pilot test

OMEGA Points of Contact

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Back Up Charts

Sites Considered for PBR Design

- Selected Two Sites
  - Estuary – Near Treasure Island in San Francisco Bay
  - Ocean – Santa Monica Bay near Hyperion Wastewater Treatment Plant
- Rationale for Site Selection
  - Possible Full-Scale Deployment Locations
  - Broad Range of Conditions

PBR Enclosure Structural Studies

Approach

- Assumed a “Generic” PBR Module, since actual design has not been selected
- Calculated loading for Hyperion (Santa Monica Bay) and Treasure Island
- Performed Preliminary Structural Analysis
- Assumed PBR size, e.g. 10’ x 100’, 10’ x 1000’
- Determined Factor of Safety (FS) = Failure Load or Stress divided by Applied Load or Stress
- Acceptance Criteria
  - FS = 2
  - Lower FS may be allowed for Extreme Events

PBR Enclosure Structural Studies

- Use external conditions from Treasure island and Hyperion as boundary conditions
- Structural analysis
  - Drag force
  - Anchorage
  - Buoyancy
  - Impact and inertial Loading
- Equipment Anchorage
- Internal Stability

Boundary Conditions for PBR Designs

- Site selections represent real-life off shore conditions
  - Treasure Island in San Francisco Basin: 0.5 miles from water water outfall of EBMUD WWTP
  - Santa Monica Bay: Hyperion WWTP

Conditions		Hyperion	Treasure Island
Wind (mph)	Nominal	7.5	12.8
	Summer max		28.0
	Winter storm	62	60.0
Current, knots	Up-coast	1.46	2.2
	Down-coast	1.94	3.3
Wave, ft	Nominal	6-10 (8-12 sec)	0.5 (<1.5 sec)
(Wave period, sec)	Extreme	>16 (17 sec)	1–4.5(<2 sec)