DESIGN OPPORTUNITY

FUTURE VISION (SCOTLAND/UK)

1. Government cracks down on unsustainable food production (harmful fishing and aquaculture). Retailers are made to emphasise environmental impact of food production.
2. Aquaculture is made more sustainable and diverse thanks to new legislation and innovation efforts.
3. UK aquaculture industry can only grow by moving aquaculture sites to FOWFs.
4. Byproducts from harmful aquaculture such as agrochemicals, effluent, lice, fish feed, and dead fish are removed from the sea.
5. Planned FOWFs are funded by profits from integrated aquaculture systems instead of taxpayer
6. Scotland meets renewable energy targets.

FUTURE VISION (GLOBAL)

1. Sustainability becomes top priority.
2. Growing world population eats much less meat and switches to healthier seafood protein.
3. Global aquaculture industry continues to rapidly expand while becoming sustainable.
4. Aquaculture provides majority of worlds seafood.
5. Strain on wild fishes and marine environments is greatly reduced.
6. Fisheries are closely monitored and only licensed to be fished when proven to be sustainable.
7. The ecosystem and seabed within dead zones have a chance to regrow and repopulate.
8. Aquaculture industry continues to grow in developing countries and is combined with FOWF where appropriate.
9. Combined FOWFAC sites provide decentralised food and power to remote communities.
10. Renewable energy sources provide most of the worlds electricity.

STAKEHOLDER ENGAGEMENTS

OFFSHORE WIND ENERGY:
As FOWFs are in their infancy, this aspect of the project relied heavily on professional advice to make up for the lack of information and research online.

CATAPULT Offshore Renewable Energy: Jude Ugwu, Project Manager. John Walker, Project Engineer. Robert Proskovics, Project Engineer.

Vestas: Keith Forsyth, Head of Procurement.

SCOTTISH AQUACULTURE/FISHING:
Scottish salmon is highly controversial at the moment, so combatting this was essential. As well as this, it was important that the final system stayed within the fishing sector.

Loch Duart: Sonja Brown, Head of Technical.

Euan Myles, lifelong fisherman & professional photographer.

ENVIRONMENTAL CONSIDERATIONS:

GSofA: John Thorne, Sustainability Coordinator.

Ian Cowan, Environmental Law Consultant.
Dr Raeanne Miller, Marine Ecologist.

INNOVATION & TECHNOLOGY:
Recent years have shown huge efforts to make salmon farming more ethical. Identifying & utilising proven technologies to their best potential was an important factor in optimising the system.

stingray: Anders Fjellvang, Field Operations Manager.

DEEP TREKKER: Jordan Ninaber, Inside Sales Representative.

HIE Highlands and Islands Enterprise / Iomairt na Gàidhealtachd 's nan Eilean: David Howie, Head of Innovation & Technology.

HUMAN FACTORS:
Testing could not be carried out at offshore sites, so someone with experience in designing for these environments was crucial.

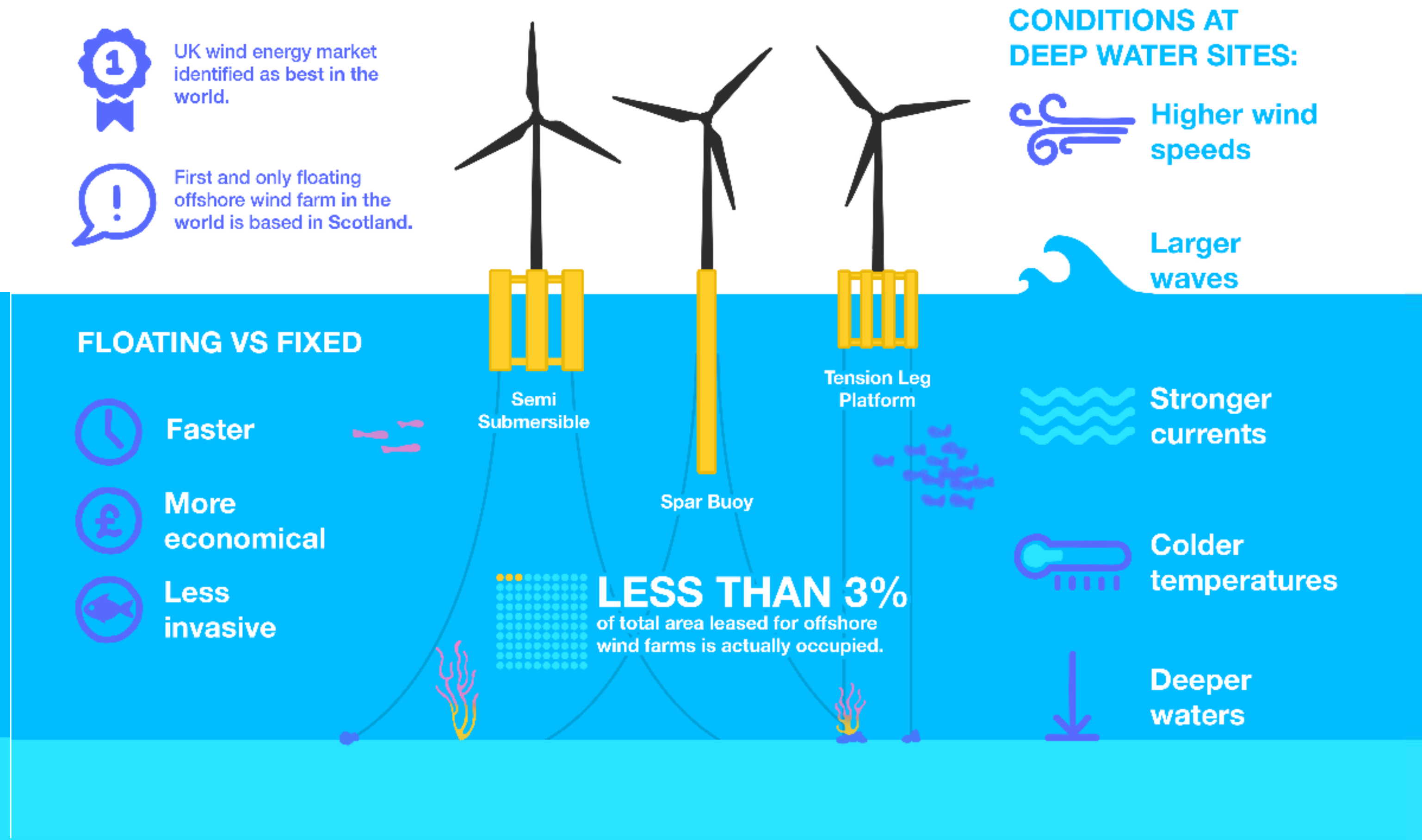
Ron McLeod, Independent Human Factors Consultant (former Head of Human Factors at Shell).

MATERIALS SELECTION:

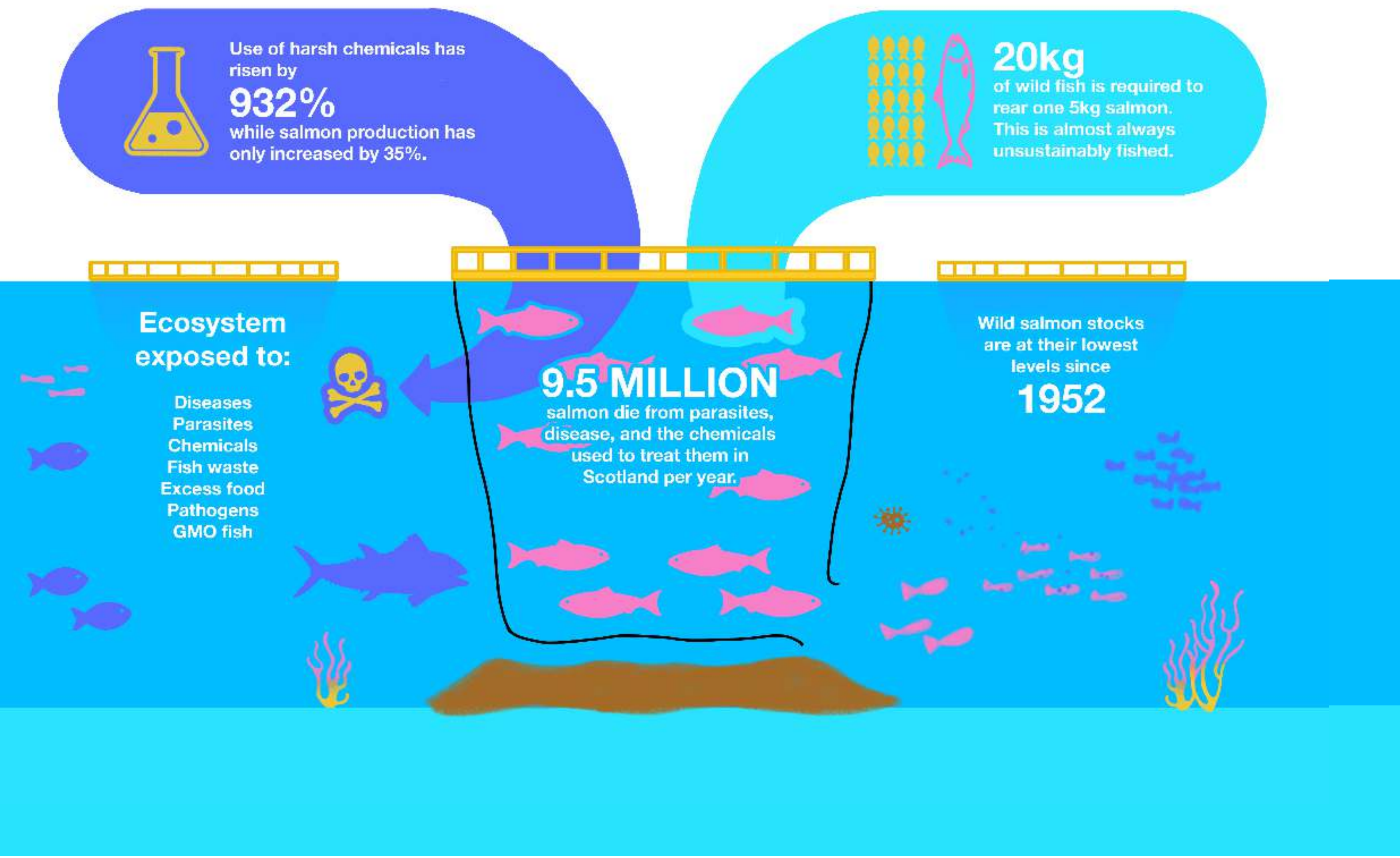
University of Glasgow: Dr Philip Harrison, Senior Lecturer.

KNOX W&J KNOX: Julie Macdonald, Knox Marine.

SCOTTISH OFFSHORE FLOATING WIND ENERGY



SCOTTISH SALMON AQUACULTURE



IMPORTANT INSIGHTS

FARMED SALMON CASE STUDY

Densely packed fish enclosures in areas with very little water flow lead to horrendous consequences for not only the farmed salmon, but the surrounding environment too: excess food attracts thousands of wild fishes which are subsequently passed on lice, diseases and harsh chemicals from the farmed salmon.

DISEASES & PARASITES:

UNNATURAL BEHAVIOUR. DEFORMITIES. AND DEPRESSION:

FISH FIRST, NOT PROFIT

Salmon were considered as the primary user of the system, with the user requirements relating to their wellbeing. These included proper monitoring, natural conditions, and chemical free parasite control.

"Fish farming at present is purely aimed at making money in the short term... these firms aren't fishermen, they are business people making money, it just happens to be fish..."

"Need to be wary of replacing one industry with another."

"We need to feed 7.7 billion people, so is it the case of least worst as best option?"

John Thorne, Sustainability Coordinator at GSA

"Wastes would disperse much more widely (at offshore locations) with much less, if any, impact on the sea-bed."

"...I think the industry could become a lot more sustainable."

"...there is now very little local employment."

"Images of a wild sea environment would probably be equally marketable."

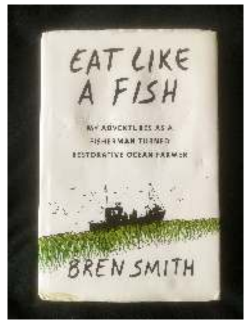
Ian Cowan, Environmental Law Consultant

"The biggest (floating offshore wind energy) markets going forward are in the North Sea..."

Keith Forsyth, Head of Procurement at Vestas

CLOSED VS EXPOSED

One of the most important decisions was which kind of salmon enclosure was the most environmentally friendly choice. Through research; stakeholder engagement; and concept evaluation, it was decided that the **most ethical choice was exposed farming.** This was because the power consumption and drawbacks to the farmed fish were too great when in closed-containment, and that many of the environmental problems regarding inshore fish farming could be alleviated by **more dispersive sites, higher flow rates, and better cage construction.**



BOOK: EAT LIKE A FISH

Bren Smith, an aquaculture celebrity famous for pioneering vertical ocean farming, discusses in great detail his insights regarding kelp & oyster farming in his autobiography 'Eat Like A Fish.' His sustainable farming methods were a big inspiration for the project.

PRODUCT DESIGN BRIEF

WHAT?
Utilising the empty space within the area of sea leased for floating offshore wind farms (FOWFs) for sustainable aquaculture.

WHERE?
Scottish waters considered suitable for FOWFs in the Scottish Govt's Offshore Sectoral Marine Plan.

WHO?
The Scottish Govt., Wind Farm Developers, Aquaculture Companies, Fishermen, Boatyards, Salmon.

WHY?
1. 40 million tonne extra seafood requirement predicted by 2030.
2. Worldwide fishery production has stabilised, so aquaculture alone can supply this.
3. Lack of UK inshore fish farming sites has necessitated the move to offshore sites.
4. Less than 3% of the area of sea leased for FOWFs is actually occupied by floating foundations/turbines.
5. UK wind energy market identified as best in the world.

WHEN?
Now: the first and only FOWF is off the coast of Scotland and industry is expected to grow rapidly as it is faster, more economical, and less invasive to install.

CONCEPT DEVELOPMENT

CONCEPT

Combining salmon, mussel & kelp farming to create a sustainable, closed loop aquaculture system suitable for use at floating offshore wind farms (FOWFs).

PROCESS OVERVIEW

GENERATION & EVALUATION:
Concepts were generated based on the 'must/should/could' analysis, which acted as a PDS for the system.

INTERIM & REDESIGN:
The 'jellyfish' concept presented at the interim was developed into a more functional and viable final product through a number of technical and environmental feasibility studies.

MUST/SHOULD/COULD (PDS)

MUST:
- Resist the harsh conditions at FOWF sites.
- Keep lice counts low and prevent infestations.
- Feed fish sustainably.
- Deal with waste effectively.
- Reduce salmon chemical exposure.
- Monitor fish health and diseases.
- Present equal feeding opportunities for fish.
- Encourage swimming to boost fish health.

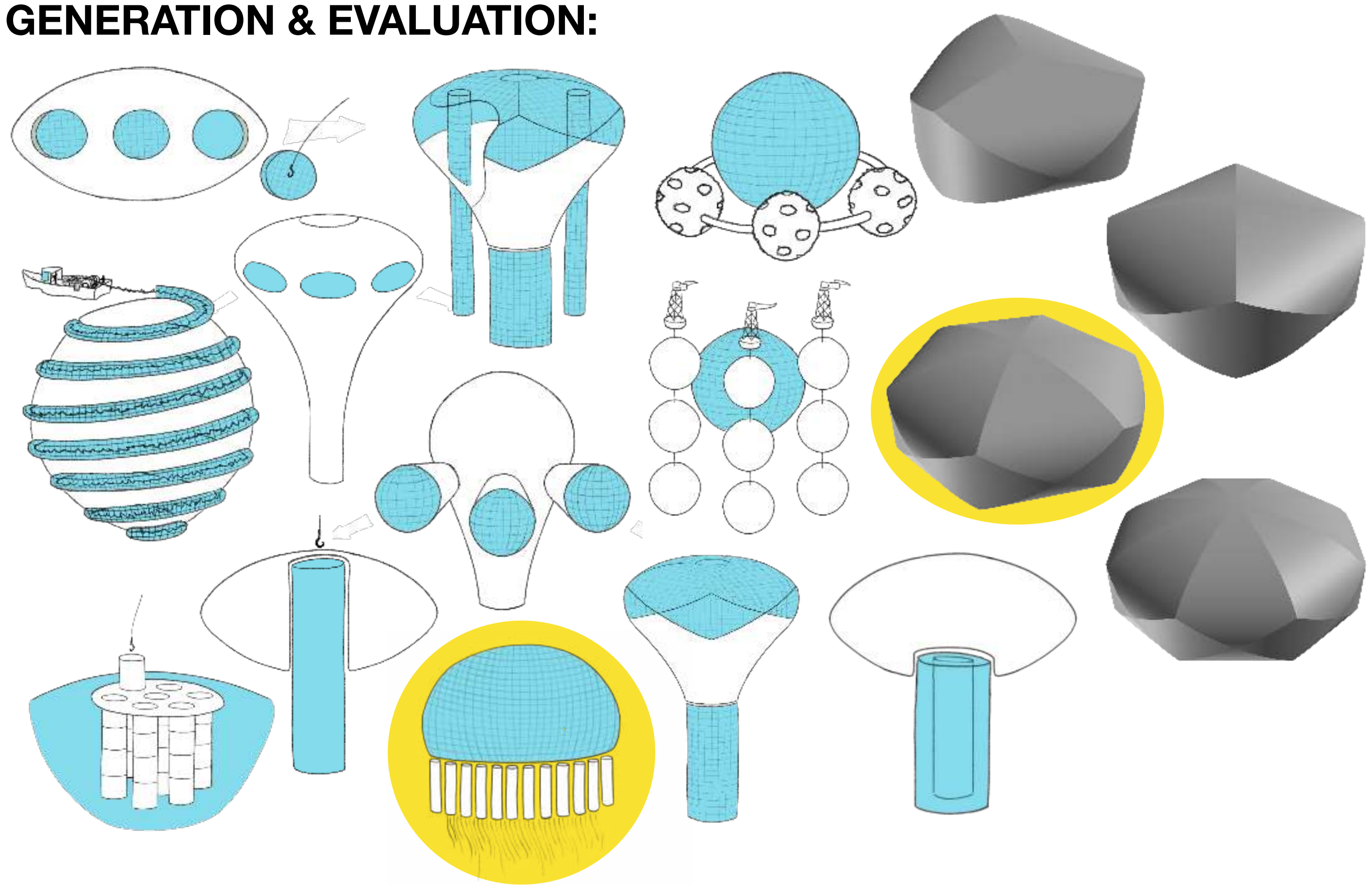
MUST NOT:
- Interrupt wind energy production, operation, or maintenance.
- Damage surrounding fish populations and ecosystem.

SHOULD:
- Be powered by renewable sources.
- Be able to connect to all three types of floating foundation.
- Be able to connect to the foundations in-situ.
- Enhance surrounding marine protected area.

COULD:
- Utilise existing floating substructures to drastically reduce costs.
- Combine other types of aquaculture (shellfish, algae, etc).
- Be fully automated/remotely controlled.

INTERIM:

GENERATION & EVALUATION:

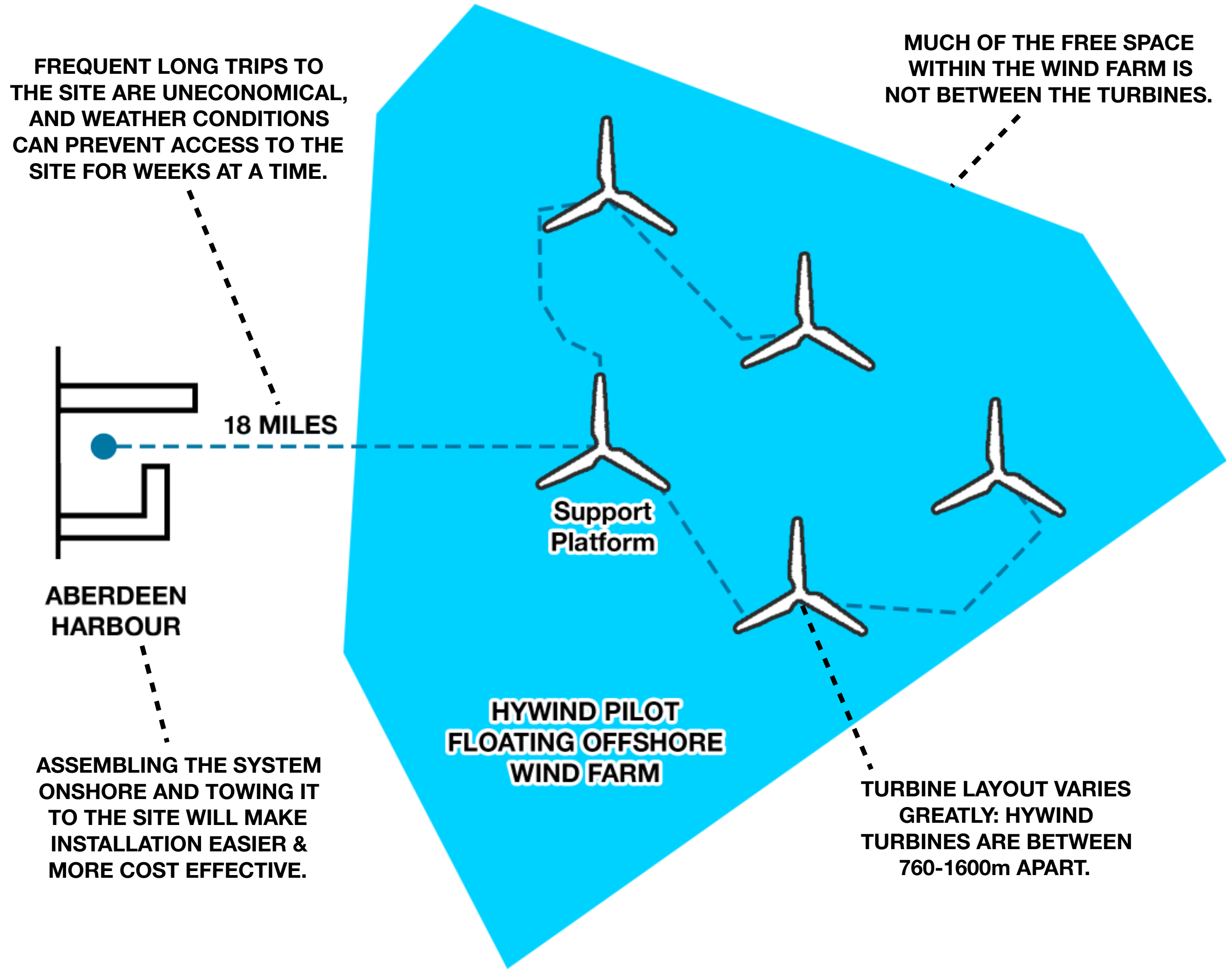


REDESIGN & DEVELOPMENT:

PROCESS OVERVIEW

CASE STUDY: HYWIND SCOTLAND

As the world's first and only FOWF, Hywind Scotland was used as a case study when considering the user journey, layout, and product lifetime.



DESIGN LOAD CASES

To ensure the system could handle the conditions at FOWF sites, three load cases based on 10 years of buoy data gathered at 168 and 200m (as well as additional assembly and towing load cases) were used in calculations when designing the frame.

Load Case	Design Load Case 1	Design Load Case 2	Survival Load Case
Conditions	Normal operation	Extreme operation	Extreme non-operation
Wind speed	10.2 m/s	11.4 m/s	45 m/s (500-yr)
Sig. wave height	2.7 m	8.0 m (50-yr)	12 m (500-yr)
Current speed	0.23 m/s	0.30 m/s	0.55 m/s

CONDITIONS MATCHUP

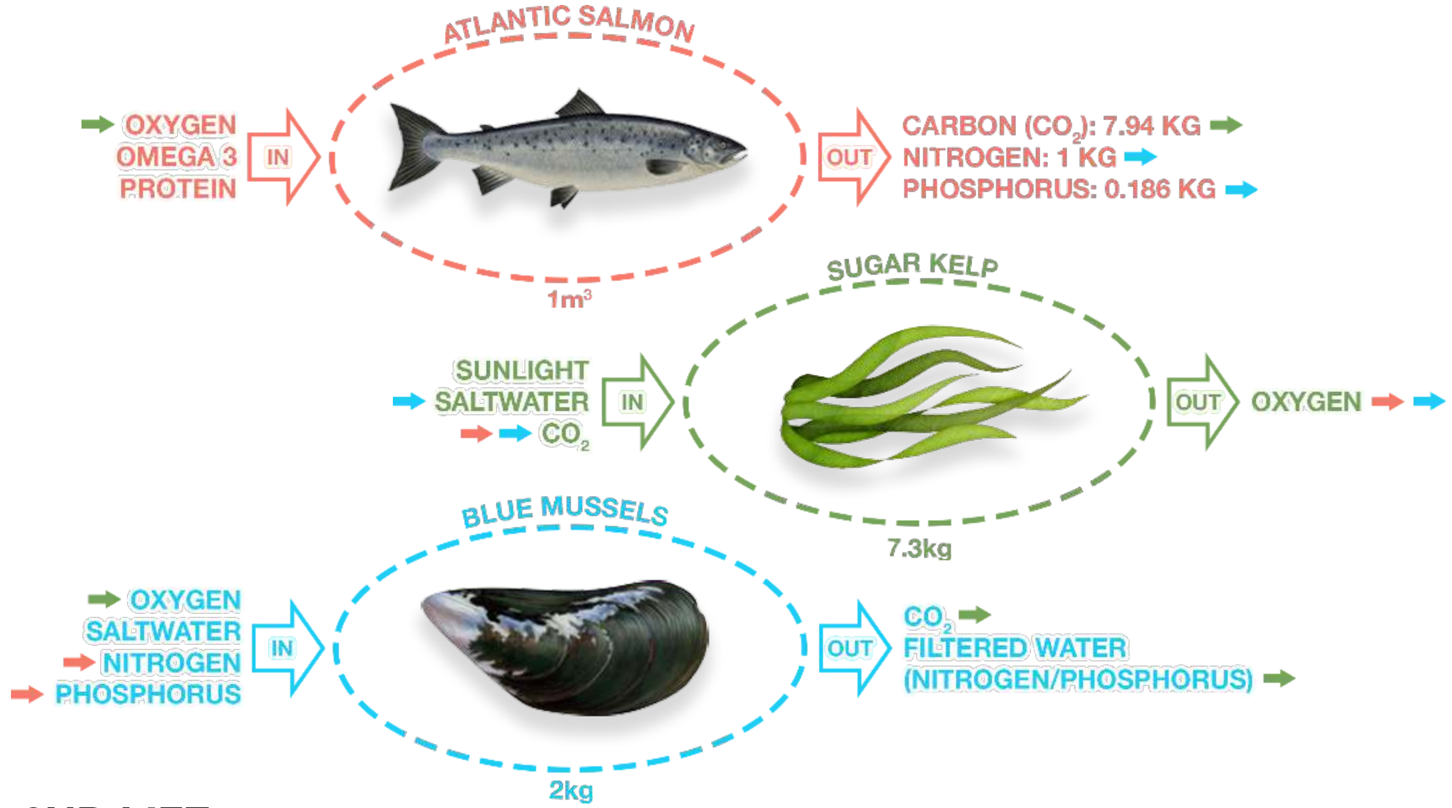
Conditions in waters considered suitable for FOWFs in the Scottish Govt's Offshore Sectoral Marine Plan were investigated and compared to the living conditions of viable farmed species.

FUNCTION ALLOCATION

Moving aquaculture offshore meant a complete redesign of typical inshore farming methods. The required work was thought of as functions, with inputs (such as required skills, fish feed, etc) as constraints. Alternative automated/remote means of carrying out the functions were investigated and formed the basis of the system design.

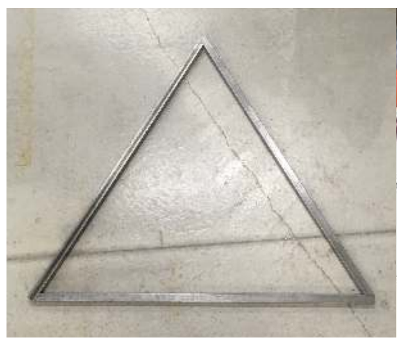
MINIMUM SALMON:MUSSEL:KELP RATIO

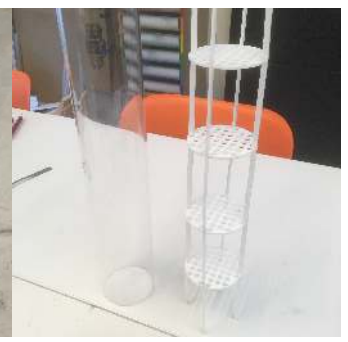
Proving the environmental aspect of the concept meant calculating the approximate amount of mussels & kelp required at any one time to offset the amount of harmful carbon, nitrogen & phosphorus produced by one cubic metre of salmon over the course of a farming cycle.



2ND LIFE

To maximise the environmental benefit beyond its aquaculture life, opportunities for repurposing the system were investigated and implemented into the design.

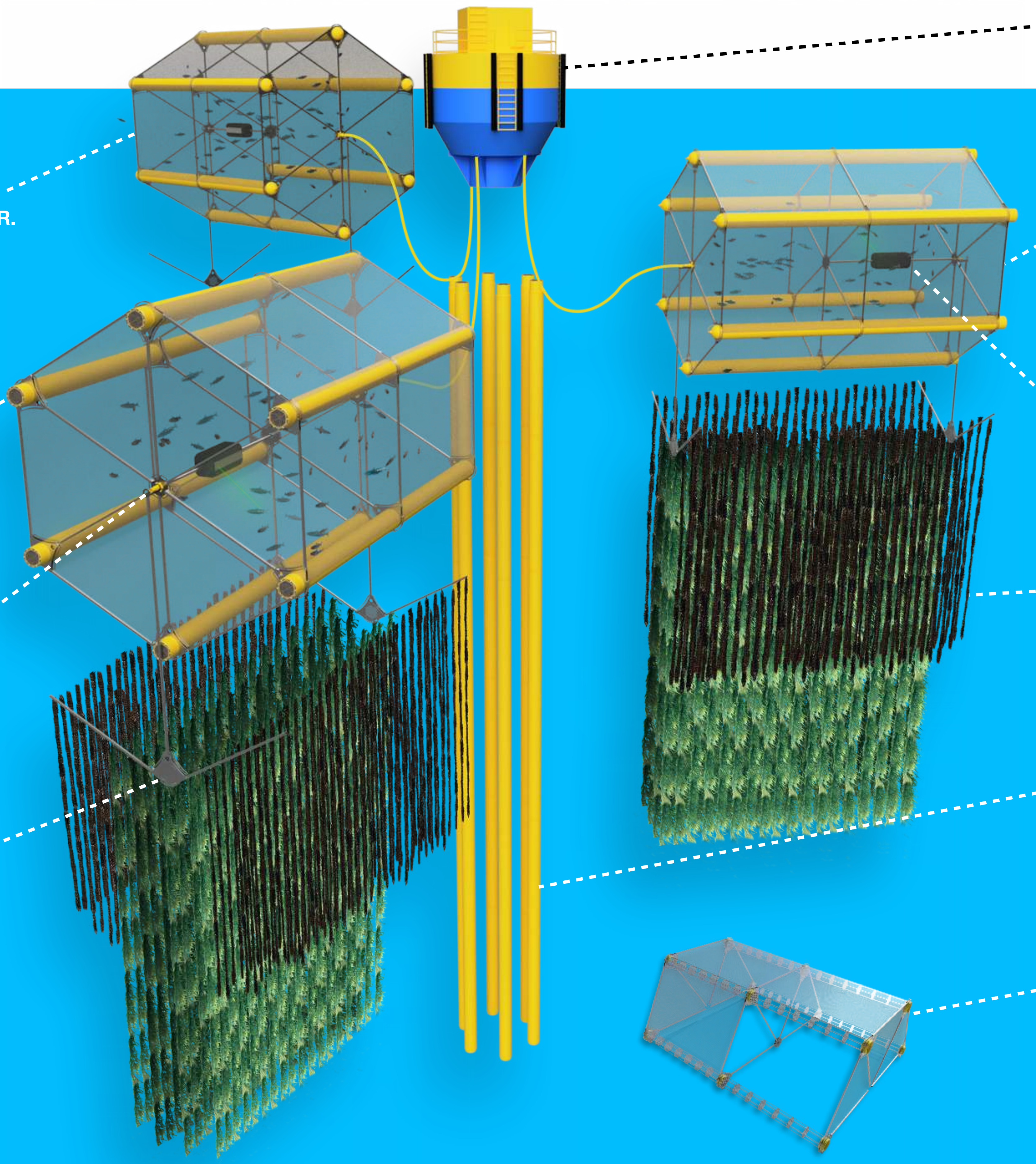

1x1x1m frame for net testing.


Ballast stability prototype.

DESIGN / BUILD / ~~TEST~~

To prove the concept would perform as expected, several integral parts of the system were prototyped for physical testing. However, due to COVID-19, these tests were not carried out and assumptions based on professional advice were instead made.

PRODUCT OVERVIEW



SUPPORT BUOY:
PROVIDES AIR, FEED, POWER, AND COMMUNICATIONS TO THE SYSTEM.

AUTOMATED/REMOTE:
OPERATES SUBMERGED TO AVOID SEVERE WEATHER AND LICE LAYER. RISES TO SURFACE AND ROTATES IN GOOD WEATHER TO EXPOSE BIOFOULING TO UV RAYS, PREVENTING BUILDUP.

BALLAST SYSTEM:
PUMP-ABLE BUOYANCY SYSTEM WHICH ALLOWS THE ENCLOSURE TO SUBMERGE, SURFACE, AND ROTATE IN THE WATER FOR OPERATION & MAINTENANCE.

HUB/BUSH:
ACTS AS AN AXLE SO THAT THE ENCLOSURE CAN ROTATE INDEPENDENTLY FROM THE HANGING FRAME. ALSO TRANSLATES AIR TO BALLAST TANKS OVER ROTARY JOINT.

HANGING FRAME:
KEEPS KELP AND MUSSELS AWAY FROM WAVE ENERGIES AND PREDATORY BIRDS. CAN ALSO ROTATE TO BE HARVESTED FROM THE SURFACE USING A BOAT WINCH.

SCALABLE STEEL FRAME:
DESIGNED TO WITHSTAND THE EXTREME WEATHER CONDITIONS AT FLOATING OFFSHORE WIND FARM SITES AND ADAPT TO ANY SIZE.

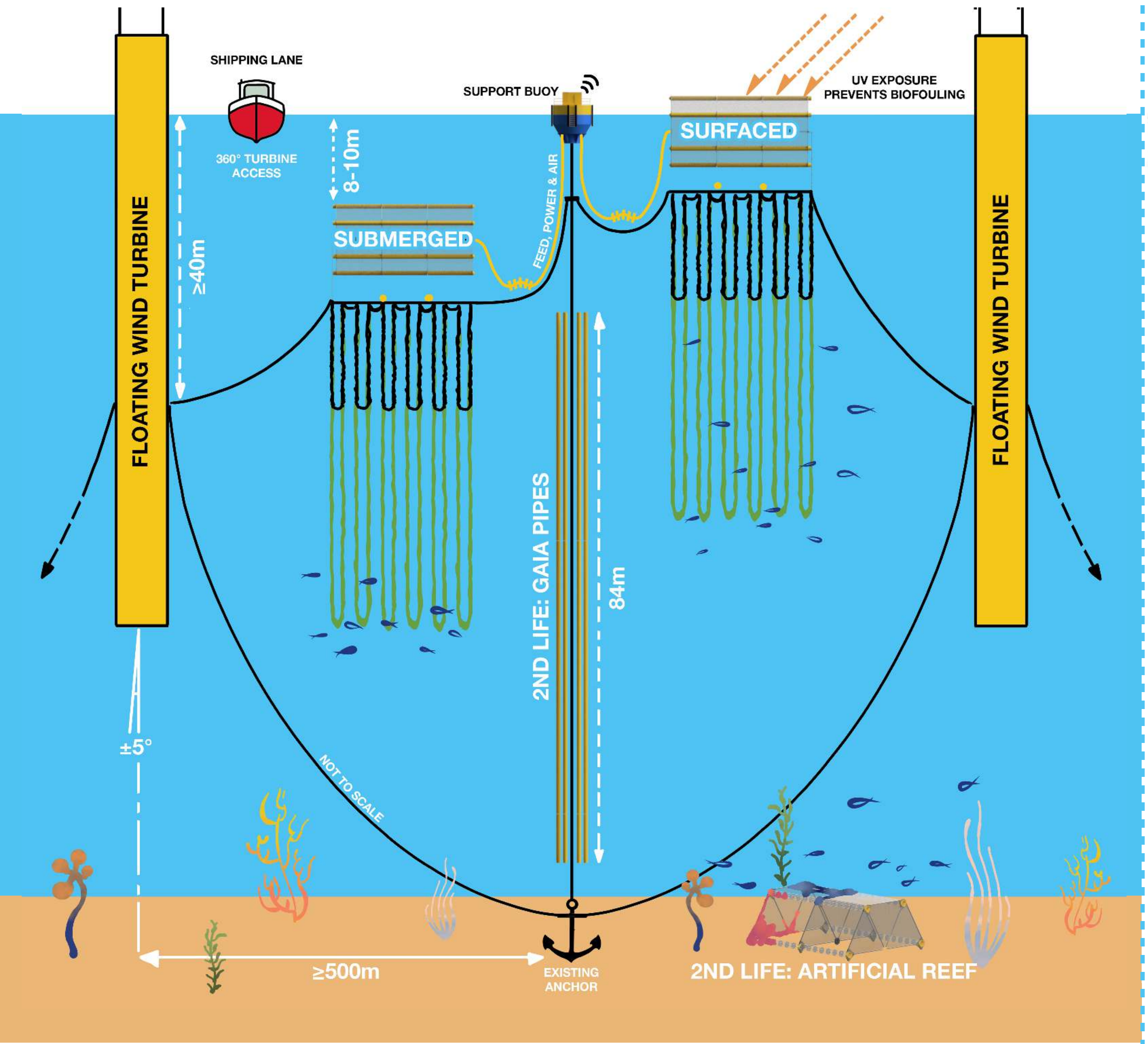
STINGRAY SYSTEM:
TARGETS AND DESTROYS LICE WITH LASERS WITHOUT THE NEED FOR HARMFUL CHEMICALS. ALSO USED TO MONITOR, COUNT, AND GRADE FISH WITHOUT REMOVING THEM FROM THE WATER.

MUSSELS/KELP:
REMEDIATES SURROUNDING WATER BY REMOVING EXCESS CARBON, NITROGEN, AND PHOSPHORUS.

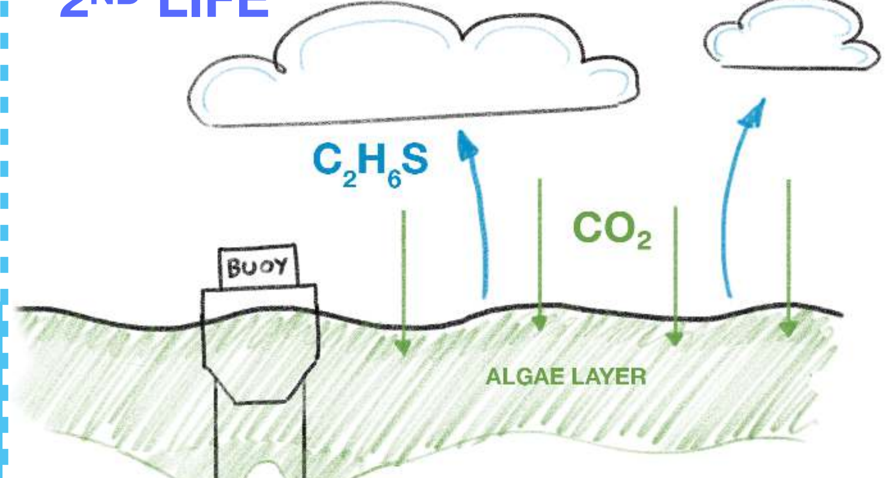
UPWELLING PIPES:
REPURPOSED BALLAST TANKS FIGHT CLIMATE CHANGE AND BOOST KELP AND MUSSEL GROWTH BY PUMPING NUTRIENT AND ALGAE RICH WATER TO THE SURFACE; DRAWING IN CO_2 AND ASSISTING CLOUD FORMATION.

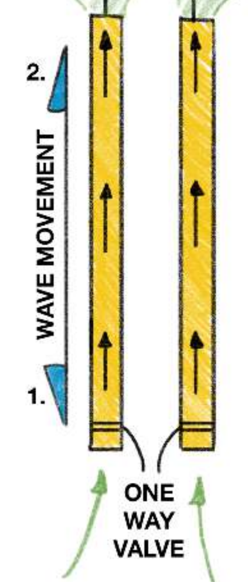
ARTIFICIAL REEF:
ENCLOSURE IS SUNK AT THE END OF ITS LIFE TO PROVIDE HABITAT FOR MANY SPECIES, CREATING A HEALTHIER MARINE ENVIRONMENT.

LAYOUT



2ND LIFE





GAIA PIPES: HOW DO THEY WORK?

1. PIPE MOVES DOWN: VALVE OPENS, NUTRIENT FILLED WATER FILLS PIPE.

2. PIPE MOVES UP: VALVE CLOSES, NUTRIENT FILLED WATER IS PUSHED TO THE SURFACE.

ALGAE LAYER DRAWS DOWN CO_2 WHICH CAUSES CLIMATE CHANGE.

NUTRIENT FILLED WATER BOOSTS NEARBY KELP & SHELLFISH GROWTH.

C_2H_6S IS EMITTED BY THE ALGAE LAYER. THIS IS A CHEMICAL WHICH AIDS CLOUD FORMATION; BLOCKING SUNLIGHT & UV.

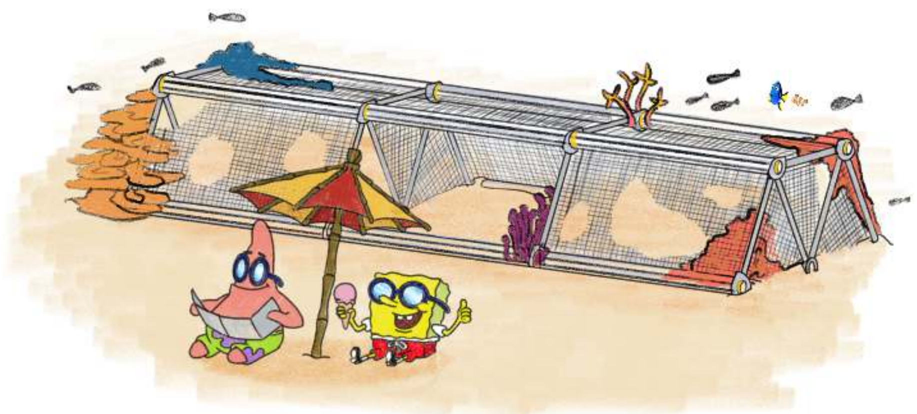
ARTIFICIAL REEF: WHAT ARE THE REQUIREMENTS?

✓ STABLE (EVEN IN LARGE STORMS).

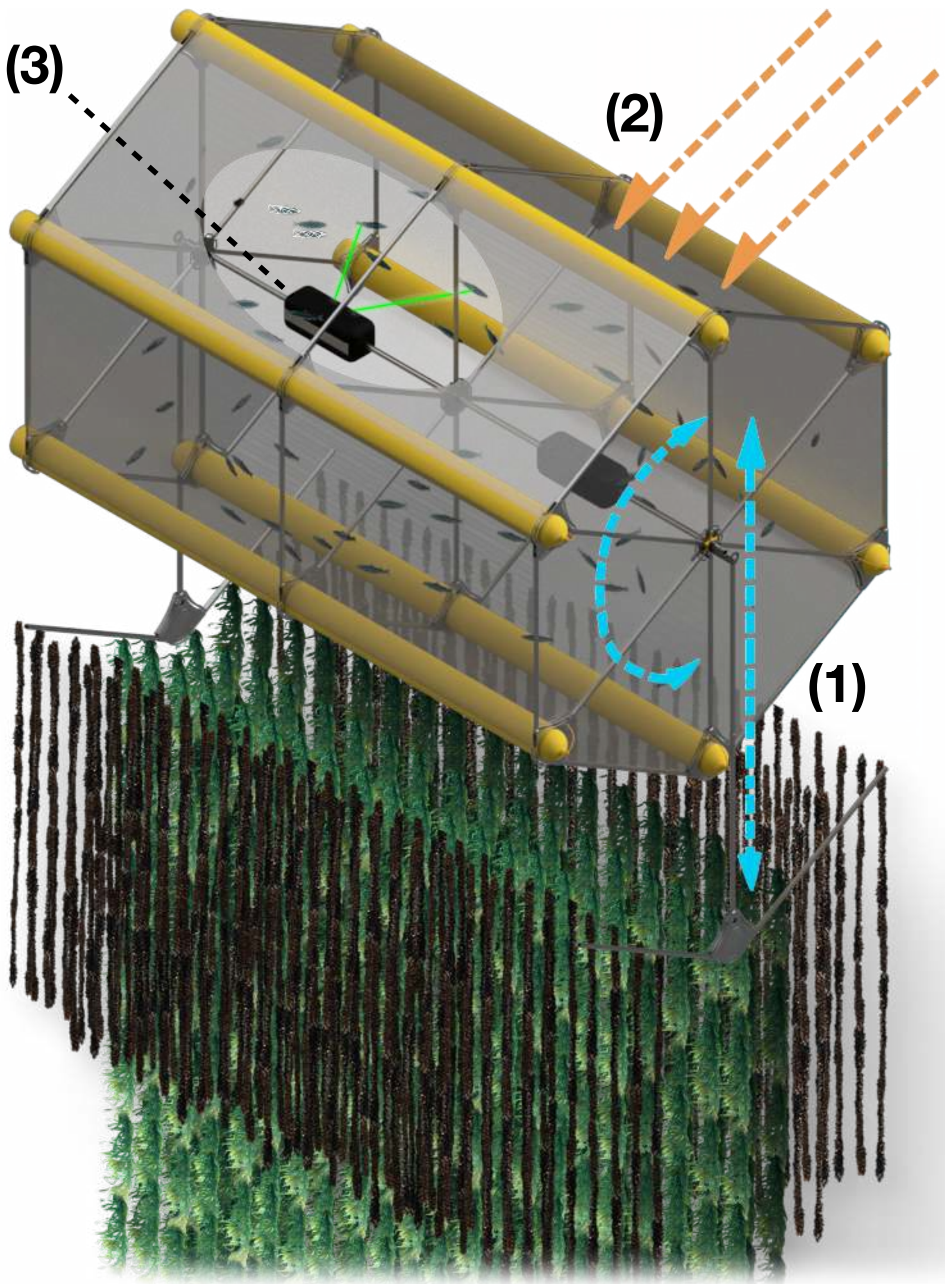
✓ BUILT FROM LONG LASTING, NON TOXIC MATERIALS.

✓ DESIGNED WITH STRUCTURAL COMPLEXITY (FOR FISH ETC.).

✓ DESIGN WITH SURFACE COMPLEXITY (FOR CORALS & SPONGES TO ATTACH TO.



USER JOURNEY

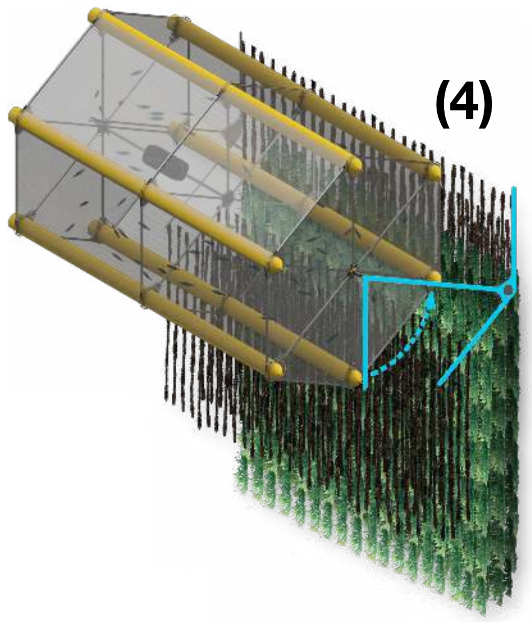


PRODUCT LIFETIME

AUTOMATED FEATURES:

THE ENCLOSURE IS SUBMERGED 8-10 METRES UNDERWATER DURING NORMAL OPERATION TO AVOID THE MOST SEVERE WAVE ENERGIES AND LICE LAYER. AT LEAST EVERY TWO WEEKS, THE ENCLOSURE SURFACES & ROTATES **(1)**, REMOVING UNWANTED BIOFOULING BY EXPOSING IT TO UV RAYS **(2)**.

FISH ARE MONITORED, GRADED, AND RID OF LICE CHEMICAL-FREE USING THE STINGRAY LICE LASER SYSTEM **(3)**. FEEDING IS CONTROLLED REMOTELY VIA CELLULAR MODEM ON THE SUPPORT BUOY.

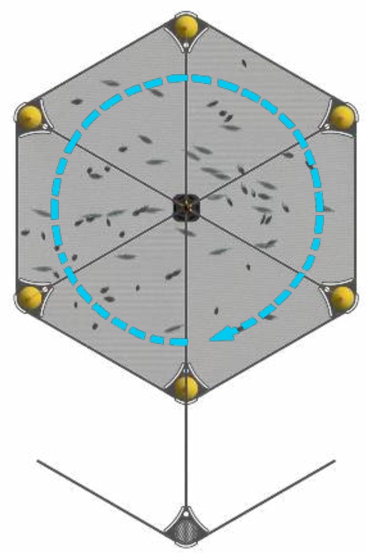


OPERATION & MAINTENANCE:

ALL O&M, INCLUDING HARVESTING OF SHELLFISH/ KELP **(4)**; REPLACING DAMAGED PARTS; MORT RETRIEVAL & ADDITIONAL CLEANING CAN BE DONE FROM THE SURFACE WITHOUT THE NEED FOR OFFSHORE DIVERS VIA THE ROTATING ENCLOSURE.

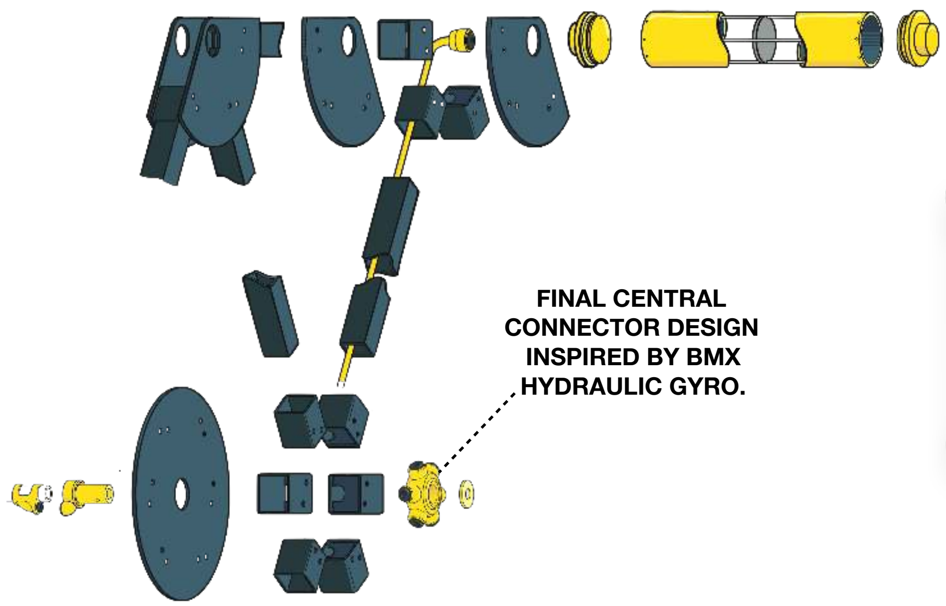
TO KEEP JOBS WITHIN THE SECTOR, O&M IS BASED AROUND FISHERMEN'S EXISTING SKILLS & EQUIPMENT:

- NETS ARE TIED TO THE FRAME
- HARVESTING OF KELP & SHELLFISH IS DONE USING A WINCH.

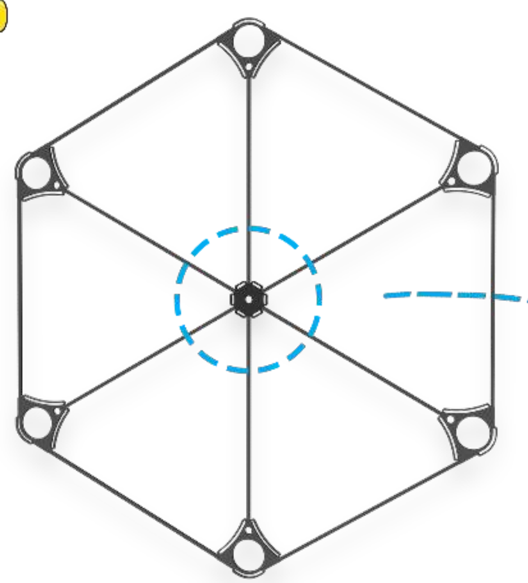


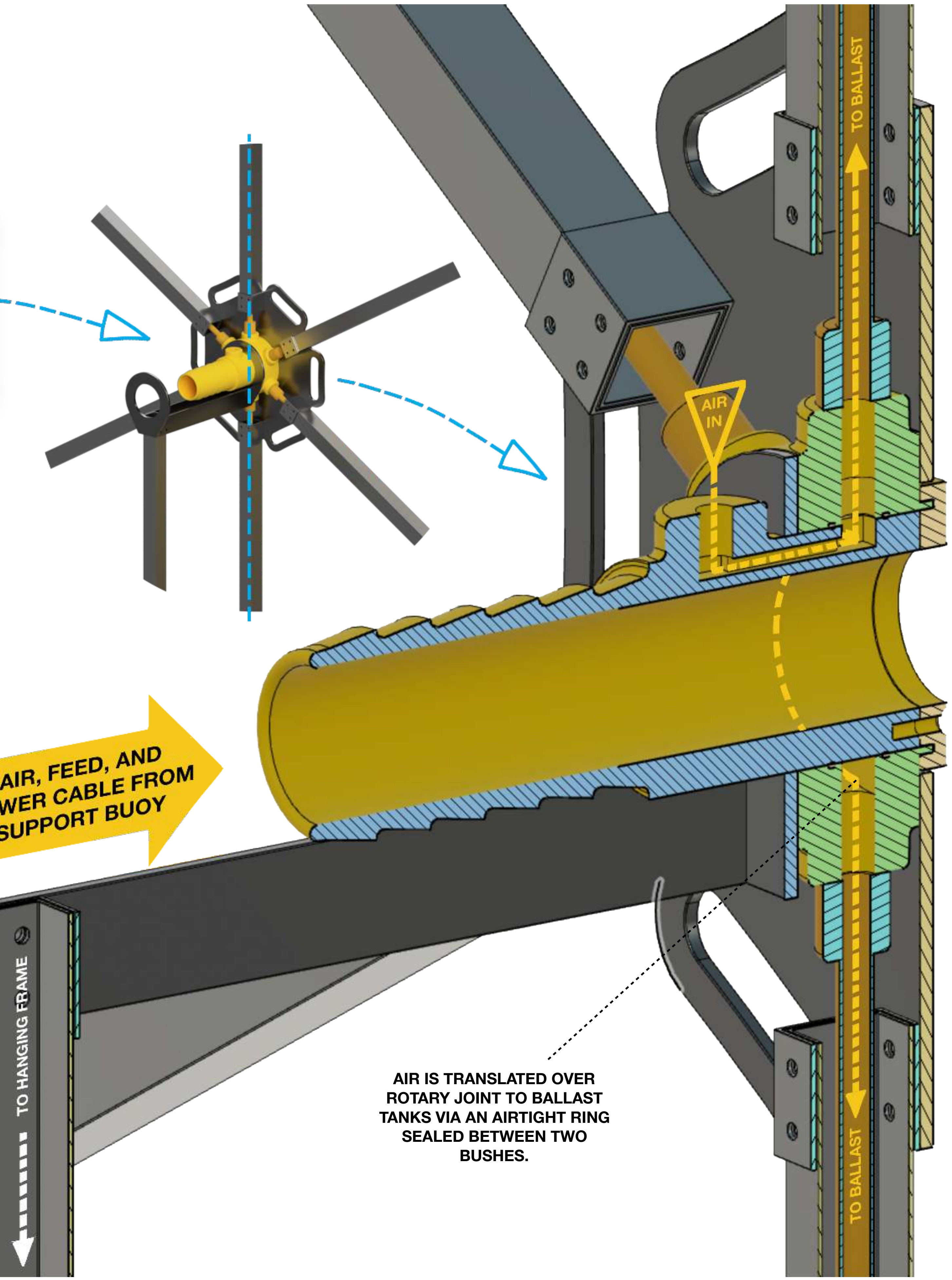
FRAME & HUB DEVELOPMENT

ASSEMBLY CONCEPT:

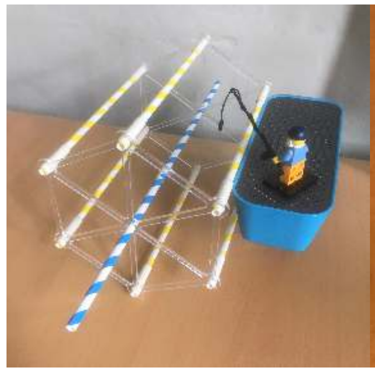


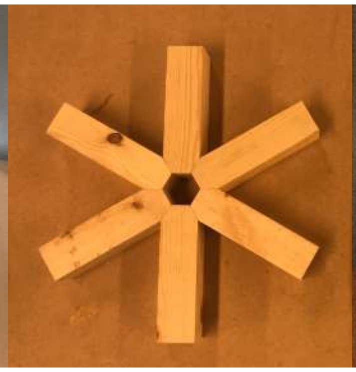
HUB SECTION VIEW:

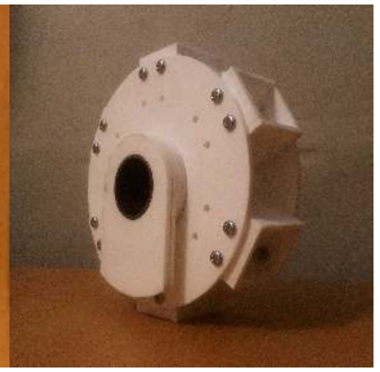




PROTOTYPING:


User journey prototype.


Hub mk1 prototype.


Hub mk2 prototype.

MATERIAL SELECTION

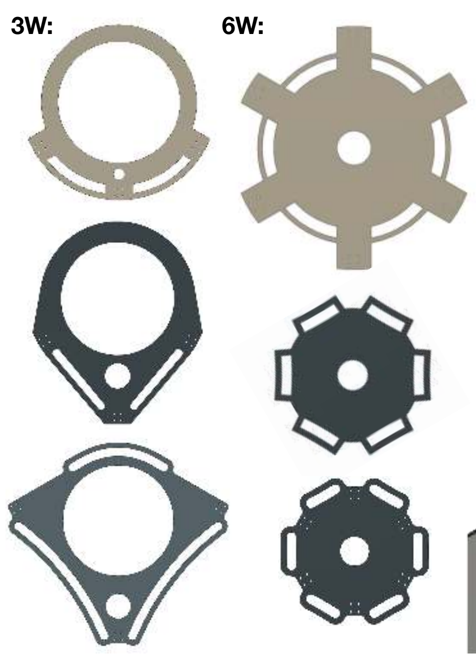
REQUIREMENTS:

- Resistance to corrosion by seawater.
- Resistance to corrosion by UV.
- Withstand load case water velocities.
- Manufacturing: ability to cut, drill, weld.
- Serviceability: ability to carry out NDT.
- Reliable life expectancy in seawater of minimum 36 months.
- Ability to withstand hazards during transportation, assembly, and operation.
- Materials/material combinations must not electro-degrade.
- Components/raw materials must be readily available.

SELECTED FRAME MATERIAL:

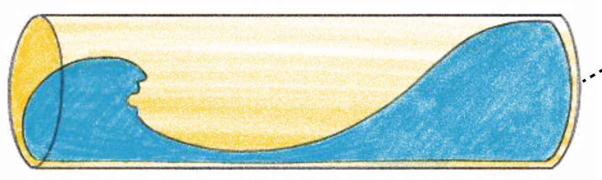
Coated S355 Carbon Steel.

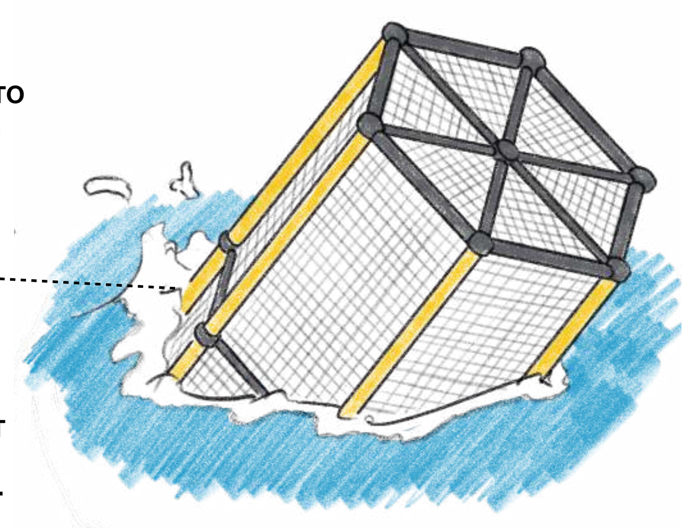
CONNECTOR 3D DEVELOPMENT:



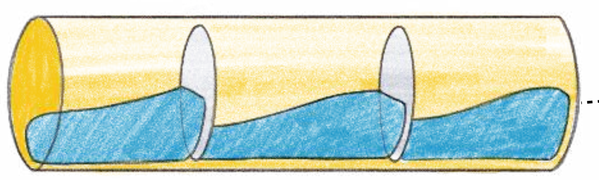
BALLASTS & BAFFLES

WITHOUT BAFFLES:



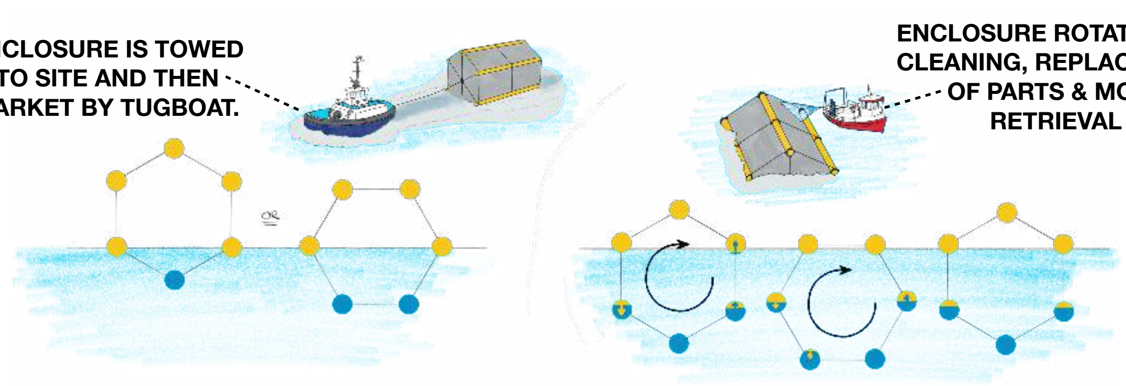


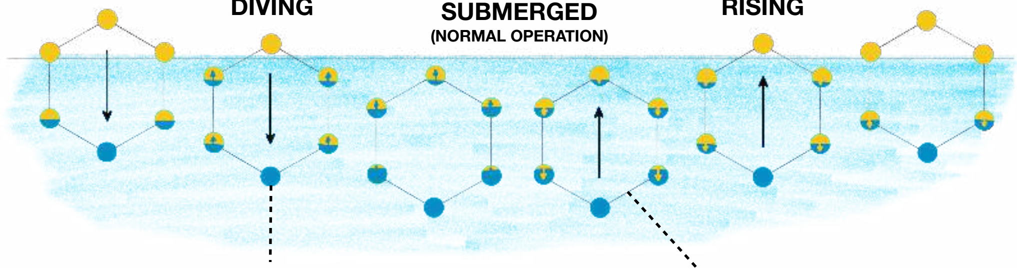
WITH BAFFLES:



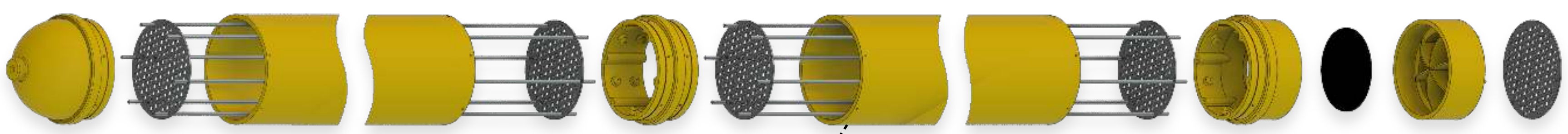
TOWING:

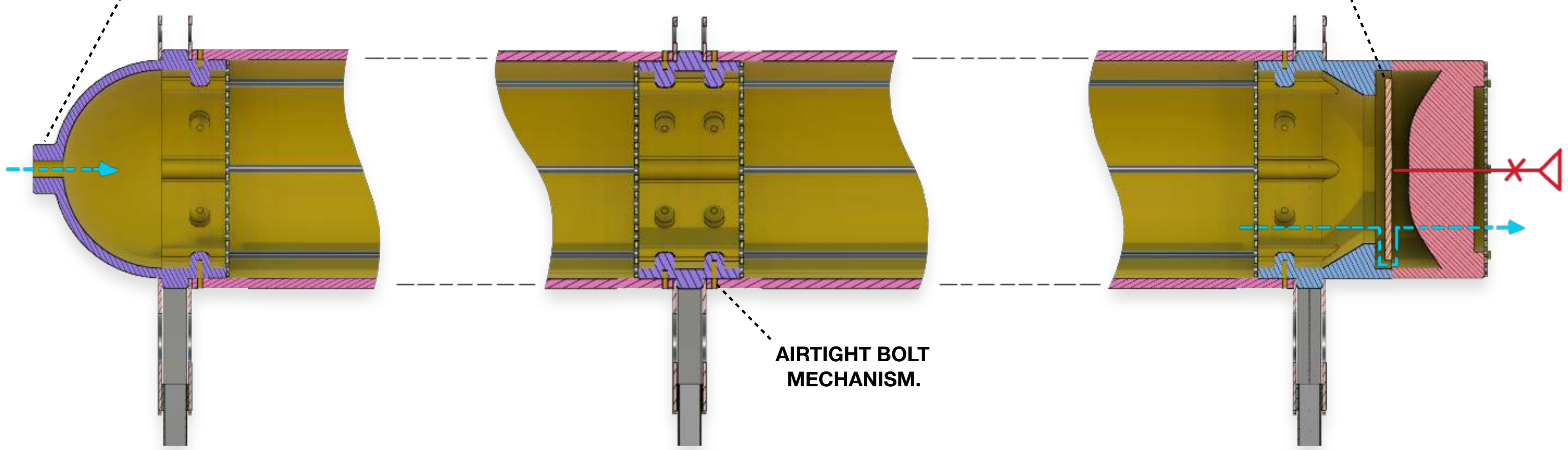
ROTATION:



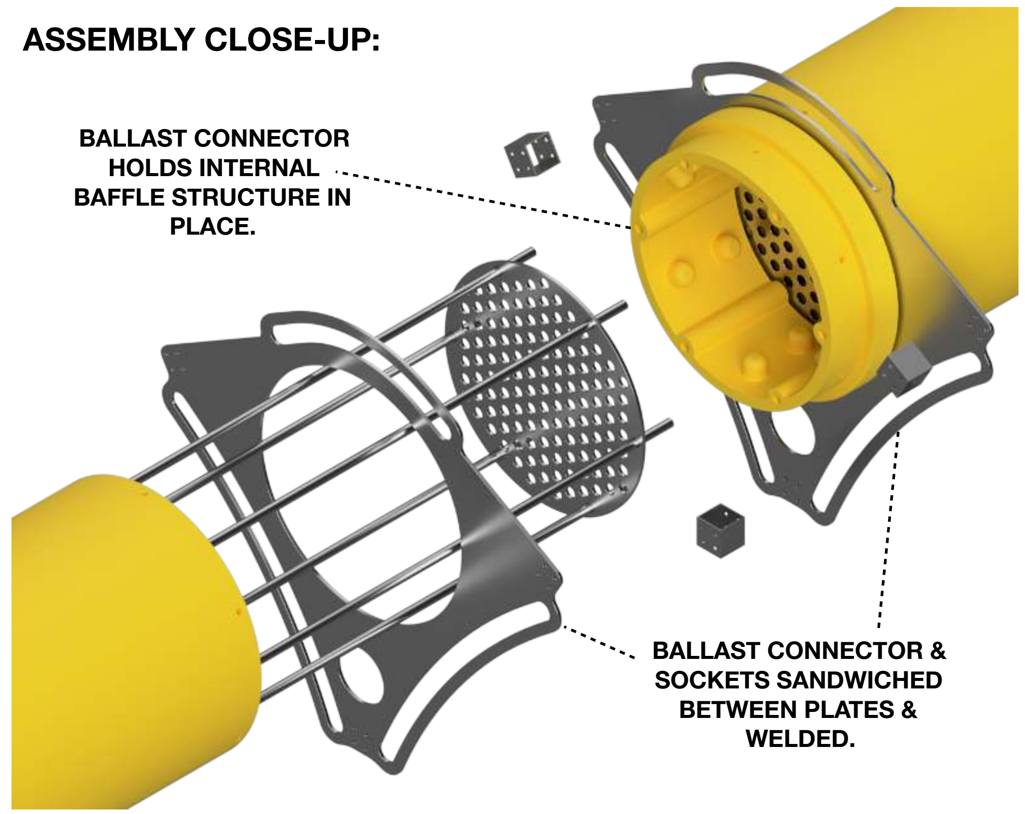


BALLAST TANK/INTERNAL BAFFLE STRUCTURE:

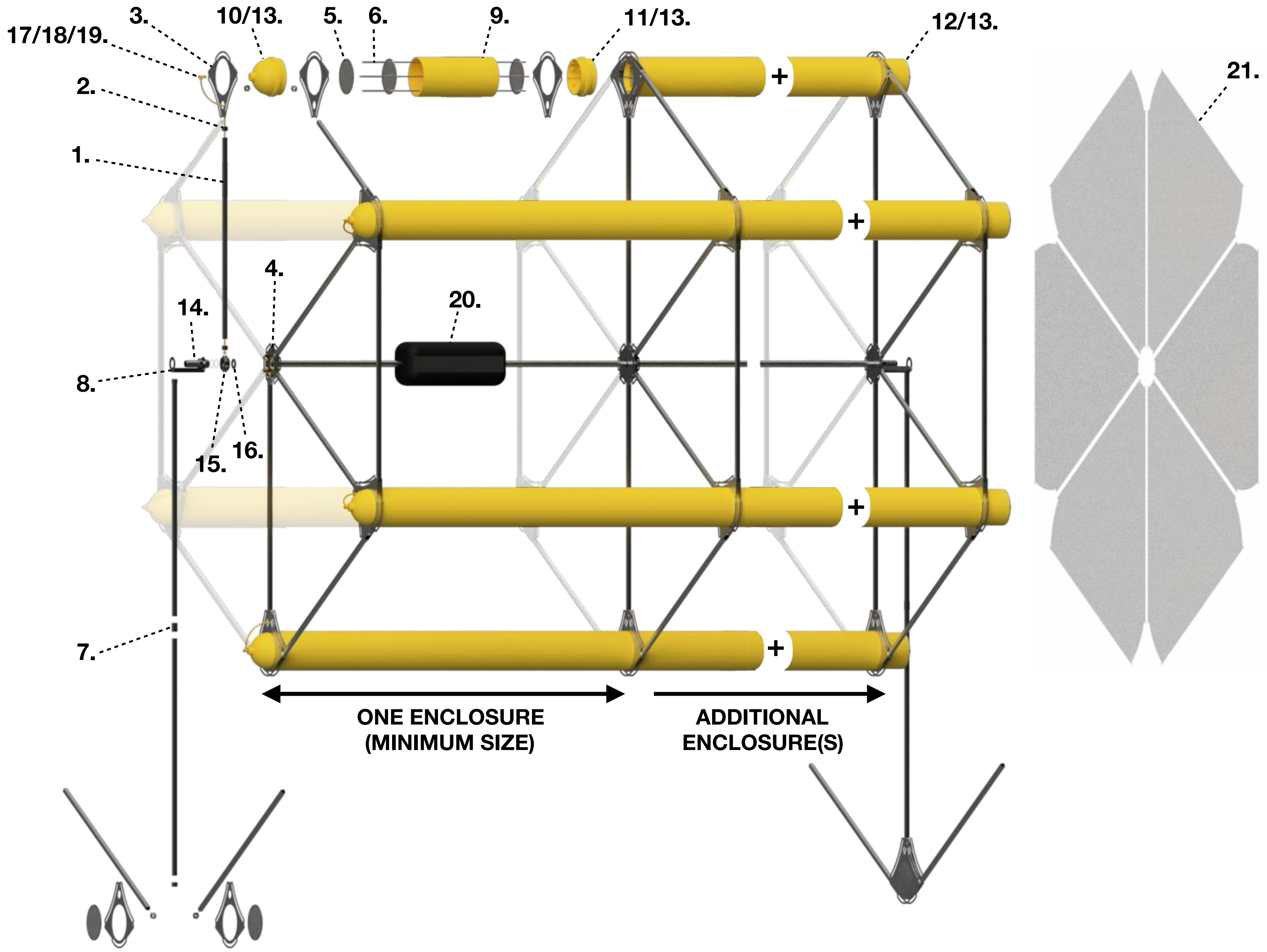




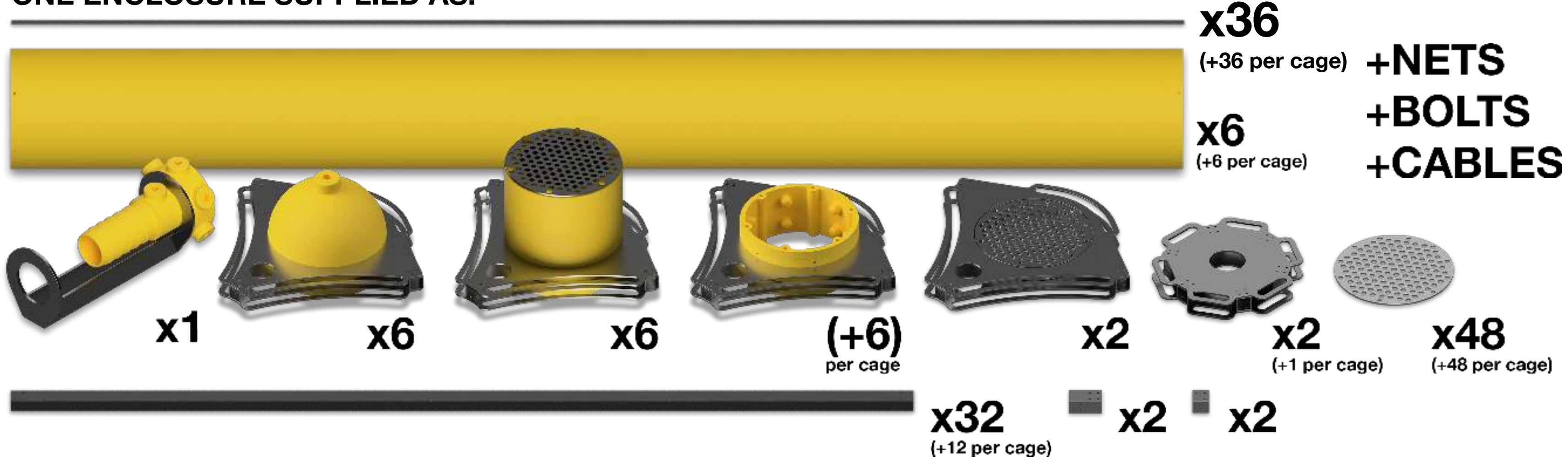
ASSEMBLY CLOSE-UP:



ASSEMBLY, PARTS & MANUFACTURE



ONE ENCLOSURE SUPPLIED AS:



FRAME SUB-ASSEMBLY:
All Hot-Formed S355 Carbon Steel.

1. Strut (4.3m):
70x70x3.2 mm Square Hollow Section.
Cut to length & holes drilled.
2. Socket:
80x80x3.6 mm Square Hollow Section.
Cut to length & holes drilled.
3. Three-Way Connector Plate:
6mm Sheet.
Laser cut, holes drilled & prepped for welding.
4. Six-Way Connector Plate:
6mm Sheet.
Laser cut, holes drilled & prepped for welding.
5. Baffle:
6mm Sheet (using circle cut from Three-Way Connector).
Holes drilled.
6. Baffle Holder (7m):
6mm diameter. Cut to length.
7. Double Socket:
80x80x3.6 mm Square Hollow Section.
Cut to length & holes drilled.
8. Hanging Frame Connector:
6mm Sheet.
Laser cut, holes drilled & welded.

BALLAST SUB-ASSEMBLY:
All HDPE (excl. diaphragm & seals).

9. Tank (7m):
660x30mm pipe. Extruded & holes drilled.
10. Inlet:
Cast & seal added.
11. Connector:
Cast & seals added.
12. Outlet (Check Valve):
Diaphragm & baffle inserted, housing ultrasonic welded, seal added.
  12a. Housing:
  Cast.
  12b. Diaphragm:
  Cast & vulcanised rubber.
13. Seal:
Extruded & vulcanised rubber.

BUSH SUB-ASSEMBLY:
All Nylon (excl. seals).

14. Inner Bush/Pipe Connector:
Cast & holes drilled. Valve screwed in.
15. Outer Bush:
Cast & holes drilled. Valves screwed in.
16. Bush Cap:
Cast & holes drilled.

MISCELLANEOUS:

17. Three-Way Solenoid Valve
18. Level Sensor.
19. HDPE Air Hose.
20. Stingray Lice Laser & Fish Monitoring System.
21. Heavy-Duty 25 mm Square Mesh Polythene Netting.

NOT SHOWN:

Support Buoy
M5 x 30mm Carbon Steel Bolts.
M15 x 30mm Carbon Steel Bolts.

ASSEMBLY:

Required skills & equipment for assembly are based on a boatyards existing facilities & workforce:

Skills:
- Steel welding.
- Engine/generator servicing (support buoy).
- Spraying.
- Marine plumbing & freshwater systems.

Facilities:
- Workshop
- Pillar crane (≈20 tonne).
- Spray booth.