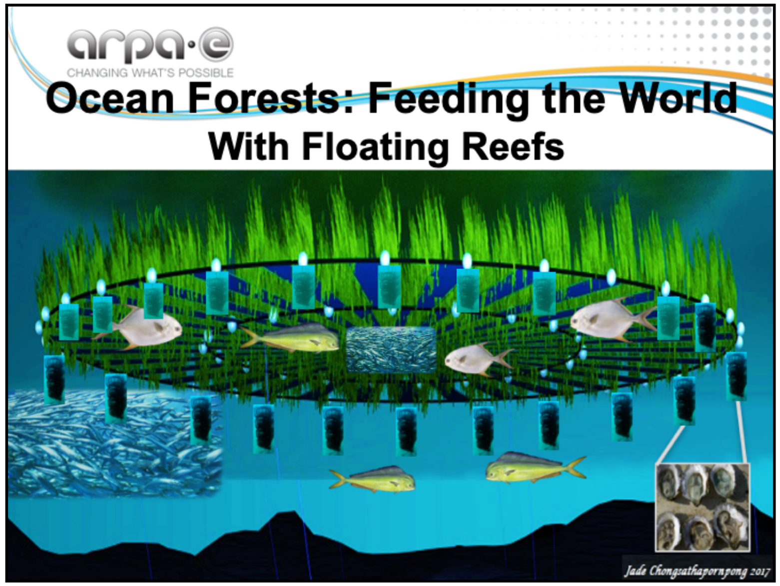
Ocean Forests: Feeding the World with Floating Artificial Reefs



The U.S. Department of Energy Advanced Research Projects Agency for Energy (ARPA-E) funded our team to grow seaweed-for-biofuel inexpensively and sustainably. We also found a way to feed the world with shellfish and finfish grown on huge floating flexible reefs without using fishmeal and while simultaneously growing seaweed.

I'm Kelly Lucas, Director of the Thad Cochran Marine Aquaculture Center, Gulf Coast Research Laboratory, at the University of Southern Mississippi.

I will :

- Introduce our team
- Explain our aquacultural revolution
- Describe how nutrient cycling sustains the revolution
- The features of the reef designed for the Department of Energy
- Benefits of the revolution and the
- Economics

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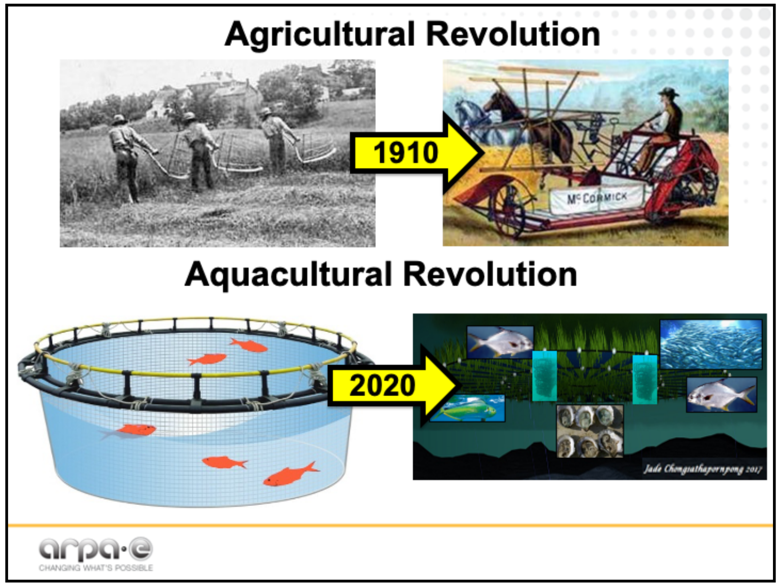
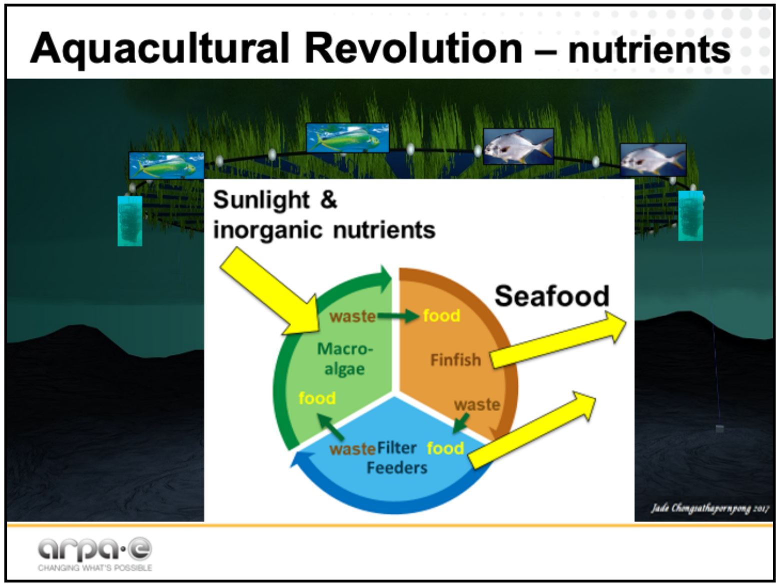
arpa·e
CHANGING WHAT'S POSSIBLE

USM assembled a large interdisciplinary team to address the oceanography and structural engineering in a push to grow seaweed-for-energy. Biologists, ecologists, aquaculture specialists, etc., were inspired by our wastewater engineer to realize we had a potential aquacultural revolution.



Agriculture was revolutionized with synthetic nitrogen growing more plants, increased mono-culture farm size, and more machines.

Aquaculture is revolutionized with recycled inorganic nutrients growing more plants, increased biodiversity and size (more a forest than a farm or feedlot), and more machines.



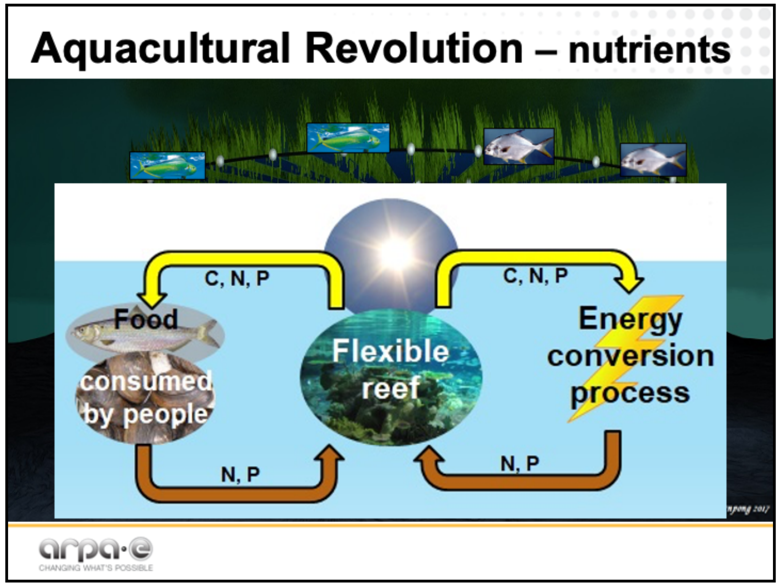
Natural reefs, and our floating flexible reef, contain an intricate food and nutrient chain, simplified in this diagram. There are dozens of tasty human food products on every reef. Good ocean forest reef management practices can recycle human-provided nutrients into a pound of finfish, shellfish, lobster, and the like 365 days per year per person. Good reef management involves:

One. If nutrient exports and imports don't match, bad things happen.

Two. If the nutrients are too concentrated in time or space, bad things happen.

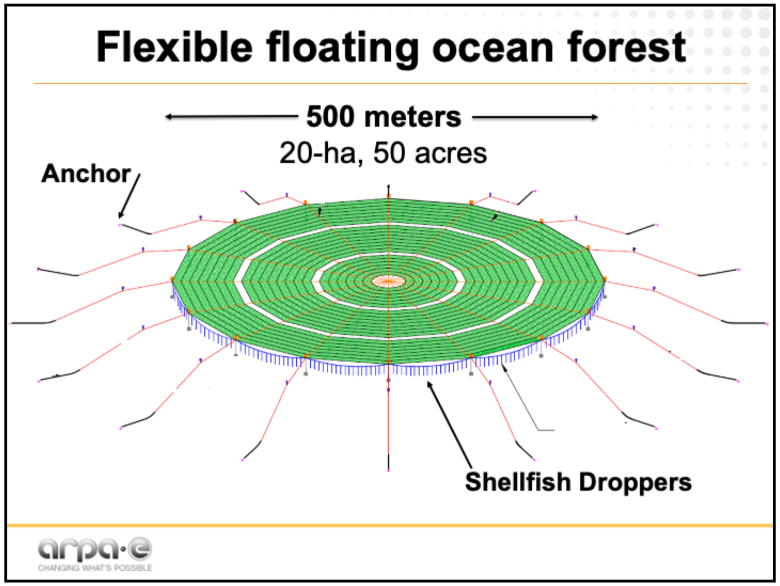
Three. But if you supply more nutrients, you can export more food.

Four. If you supply inorganic nutrients, photosynthesis will increase their food value **for free!** Actually not completely free. You have to install and maintain a reef!



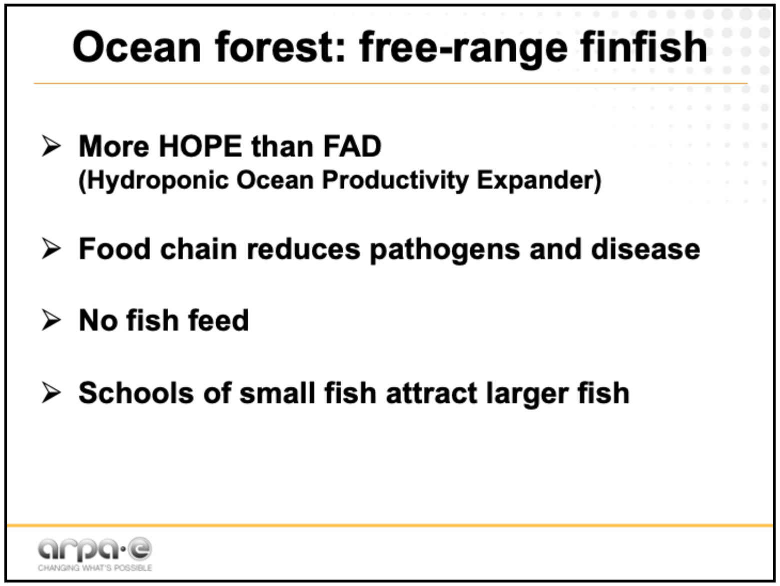
The previous slide showed how that the aquacultural revolution can sustainably feed the world without synthetic fertilizers. But what about the Department of Energy's interest, fueling the world with biofuels?

Conveniently, all the processes that convert wet seaweed to energy at less than 400 degrees Celsius produce ammonia, phosphate and micronutrients as by-products. That means we can operate both loops on the same ocean forest reef. A "Feed the world" loop and a "Fuel the world" loop. The "Fuel" loop will be cycling ten to a hundred times the biomass and nutrients of the "Food" loop, if seaweed satisfied global demand for both food and fuel.



This is the Spiderweb, a depth adjusting reef we have developed for the Department of Energy. The green area provides a substrate for growing seaweed, finfish shelters, and hanging shellfish. The substrate is normally 2 to 6 meters deep when growing *Gracilaria Tikvahiae* in the Gulf of Mexico. If a storm approaches, the entire structure submerges to at least 40 meters deep. The system is designed for seafloor depths between 50 to 100 meters.

All the components of the Agricultural Revolution are here. In addition to operating with more nutrients, we envision a new machine for autonomous mowing and harvesting of our perennial *Gracilaria*. The reef is larger than current aquaculture systems. We will have many crops growing simultaneously, a form of fast, continuous crop rotation. Unlike the agricultural revolution, the reef is definitely not a mono-culture farm. It more resembles a multi-culture forest populated by free-range fish.



Our flexible reef is more HOPE than FAD. HOPE stands for "Hydroponic Ocean Productivity Expander". Because of the primary productivity boost, you can be sure HOPE will be increasing fish stocks and biodiversity.

With all that space, the products are not crowded. They move in the densities for which they are adapted. Pathogens and disease microbes are more likely to be eaten before they can infect another seafood product.

Many of us have been looking for more sustainable sources of fishmeal, including dried seaweed. But, why go to the expense of growing, harvesting, drying, transporting, blending, and feeding seaweed? Why not let the finfish, crabs, mussels, abalone, etc. do what they evolved to do … find their food in the reef ecosystem? However, we may use some less desirable product as chum to attract and harvest finfish.

The reef ecosystem can be managed as a nursery and an adult final destination for the most valuable finfish. *Maybe we could put radio frequency ID chips in baby tuna and have agreements to share income from wherever and whenever they are harvested.*

Flexible floating ocean forests

Benefits

- Restorative aquaculture
- Sustainable – reef-to-reef production
- More habitat
- Climate change – no freshwater, acidification …
- Safer automatable harvesting, more profit

Challenges

- Climate change – warmer water, bigger waves …
- Less concentrated for harvest – LEDs
- Expense of floating flexible reef
- Difficulty managing dozens of species – turtles and marine mammals eating products

The Aquacultural Revolution can restore ocean health and biodiversity. Friends of the Ocean can become our allies. Our desire for jobs, food, and profit aligns with maintaining a biodiverse and healthy reef. Plus, by recycling nutrients, we have the holy grail of sustainability – cradle-to-cradle manufacturing. More accurately: reef-to-reef production.

More natural reefs can become marine sanctuaries, if the existing fishing interests can have a flexible floating ocean forest offering more production than the marine sanctuary. The ocean forest might be positioned to maintain higher pH in the sanctuary. The sanctuary would "stock" the managed forest.

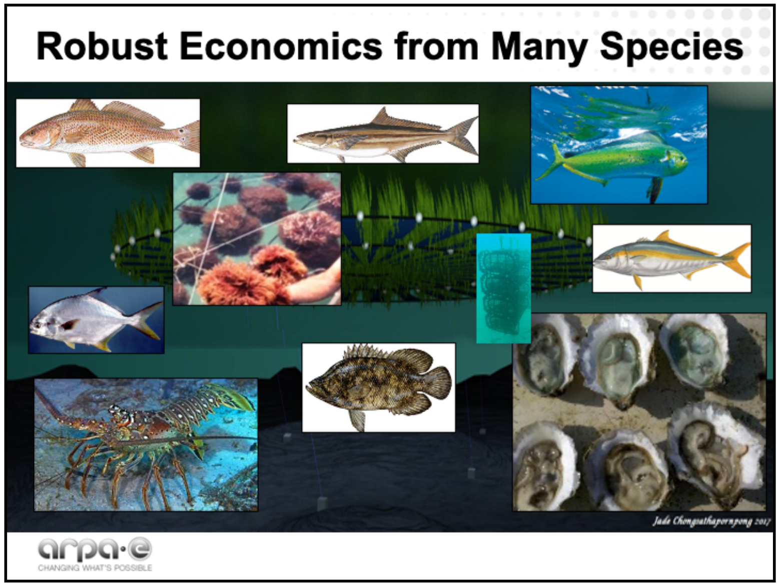
Of course there are some unknowns and challenges. Fish grow smaller in warmer water or migrate toward the poles. Waves will be larger.

But most challenges are of the kind humanity can overcome with practice and innovation. For example, Cobalt Intelligence is using lights to aggregate fish.

This is a photo in a *National Geographic* article about managing natural reef resources. A town in Mexico's Baja California manages the abalone harvest from their natural reef so well they can afford to educate their children and send them to college.

If a managed natural reef can provide that much wealth, consider what should be possible on our artificial reefs with their benefits of:

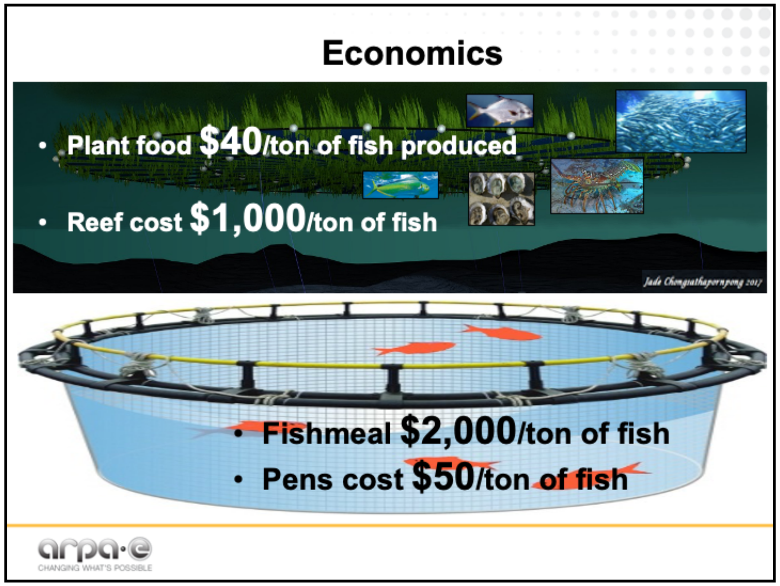
- Ideal depth for maximum sunlight, independent of seafloor depth;
- Ideal substrate for attached plants and animals (not too soft or sandy for dense sealife);
- Ideal wave energy, never too strong because we can submerge;
- Ideal nutrient supply and distribution, as we will learn in the next slide.



The system allows reef owners to grow a suite of products appropriate for an ocean forest. In the Gulf of Mexico, our products might include:

- *Gracilaria*
- Oysters hanging in cages
- A wide variety of finfish
- Not pictured potential species include: scallops, mussels, barnacles, sea cucumbers, crabs, octopus, and more …

The finfish will hide in the structure when young and hang out in the shade as they become larger. Occasional swarms of small finfish are likely to attract large fish, such as tuna.



If we buy ammonia to start our ocean forest operation before recycled nutrients are available, the economics are like renewable energy. That is a high initial cost for the structure followed by low annual cost.

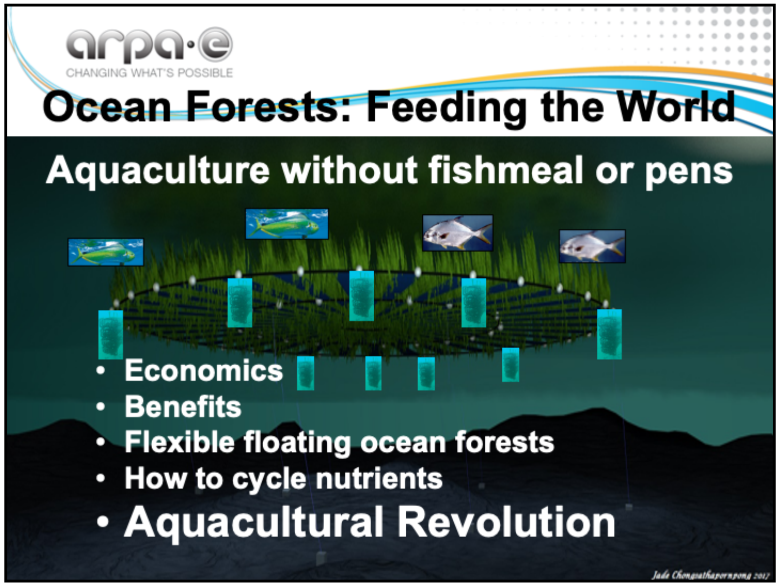
The $40/ton of fish for the plant food is based on supplying nitrogen as ammonia at 1.5 times the current cost of ammonia. The cost assumes only 50% of the supplied nitrogen gets into a fish product. Our fish products include finfish, shellfish, mollusks, crustaceans, seaweed, … everything that will grow over, in, and around our floating flexible reef.

The $1,000/ton of fish for the structure is based on our techno-economic analysis prepared for the U.S. Department of Energy Advanced Research Projects Agency-Energy. The reef is built for 20-year service life while surviving hurricanes in 50 to 100-meter seafloor depths in the Gulf of Mexico, so it is pricey.

Bottom line: Fish products from a flexible floating reef will cost about half as much as products from pens.
Optional additional text
A thousand people provide sufficient nutrients to grow about 700 wet tons of seaweed per 20-hectares of reef per year. Allowing for the difference in protein density, about half that seaweed productivity would give about 150 wet

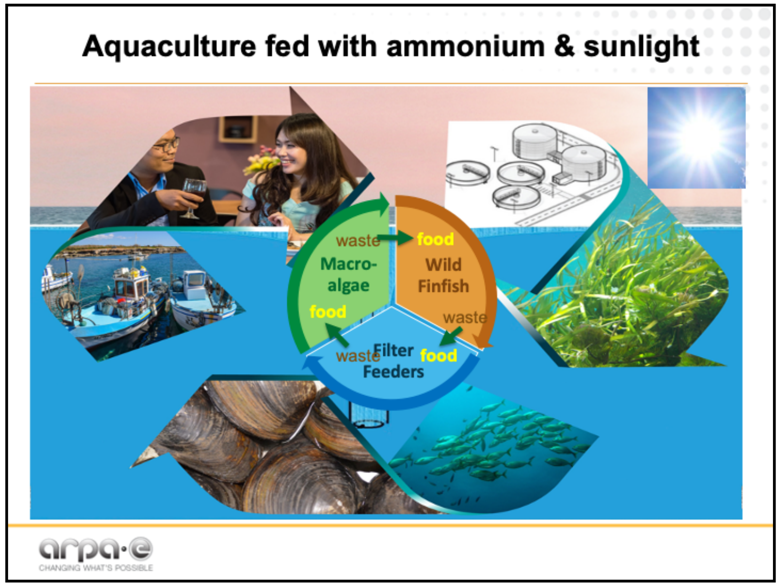
tons of non-seaweed high-value seafood. At $1 per wet kilogram, we'd have $15 million per year at the dock from one of our 20-hectare reefs.

Our Department of Energy research suggests the first 5-pack of reefs, custom designed for the location, will cost about $20 million installed. They would have 100-ha of reef area and occupy about 1,000-ha of seafloor area. We estimate 15,000 wet tons of seafood worth $15 million per year from the 5-reef array.



In conclusion:

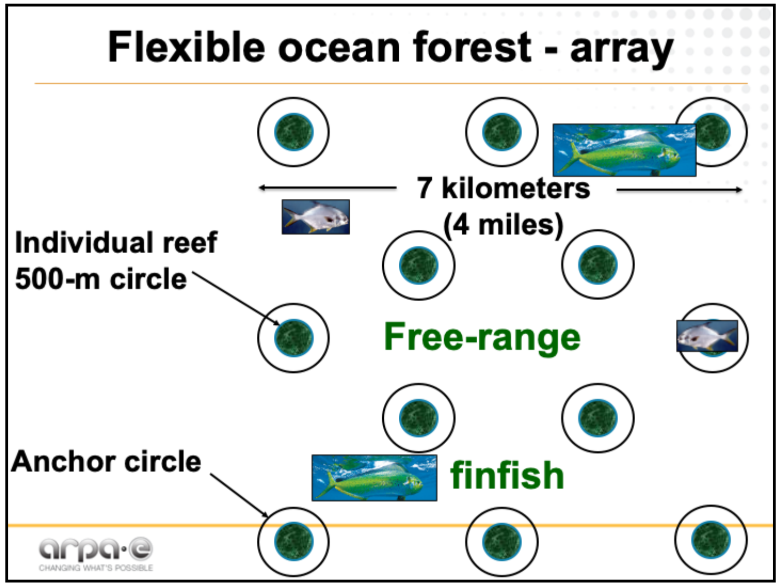
- The economics favor ocean forestry
- The sustainable social and environmental benefits favor ocean forestry
- Every coastal community can have their own flexible ocean forest
- Nutrient recycling favors this approach
- Everyone in this room can help bring about an **aquacultural revolution**!!



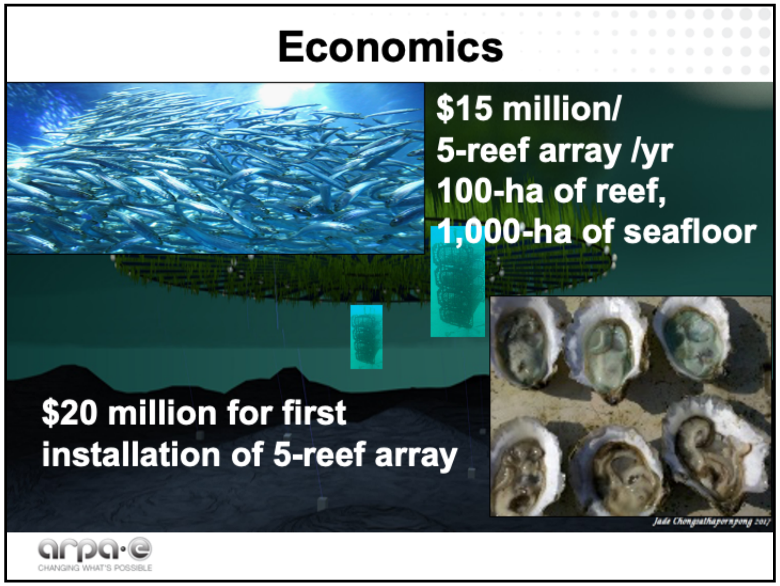
This slide to answer questions about the food-human waste-food recycling loop or the concept of reef-to-reef production.

We can increase the output of the ocean forest aquaculture ecosystem using the outer recycling loop. This outer loop is what makes ocean forestry a completely different kind of Aquaculture, a significant move beyond Integrated Multi-trophic Aquaculture. In the upper right you see the seaweed using sunlight to produce food for fish and shellfish in the lower figures. The people in the upper left eat the fish and shellfish and produce plant nutrients, which are then pasteurized and recycled to feed the seaweed. Aquaculture becomes **reef-to-reef production**, which is the holy grail of sustainability usually expressed as **cradle-to-cradle manufacturing**.

Nutrient recycle from people is unnecessary in some locations. For example, our first few structures may use the excess nutrients from the Gulf of Mexico dead zone, cleaning it up.



Use this slide for questions about area, scale, and the practicality of free-range finfish. The concept:
Permits are granted by the seafloor area occupied by the anchors or the watch circle of the structure. If we pack the Spiderweb structures tight with 10 meters clear between anchors, then five 20-ha reefs would occupy about 100-ha of seafloor. (More seafloor in deeper water.) But why not adjust the permit laws so that five 20-ha reefs are allowed (or required to occupy not less than) 1,000-ha? The requirement comes with ownership of the free-range fish within the 1,000-ha seafloor area. This slide shows an example with a dozen reefs. Any finfish caught or sea cucumbers grown on the 16 square miles (nearly 5,000-ha area) on or above the seafloor would be the property of the permit holder. With lots of room to grow, ocean forestry fish can obtain a market premium as “wild-caught.” Perhaps even a new category as “organic ocean forest wild-caught.”



Use this slide for questions about nutrients, production and costs.
A thousand people provide sufficient nutrients to grow about 700 wet tons of seaweed per hectare per year. Allowing for the difference in protein density, about half that seaweed productivity would give about 150 wet tons of non-seaweed high-value seafood. At $1 per wet kilogram, we'd have $15 million per year at the dock.

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