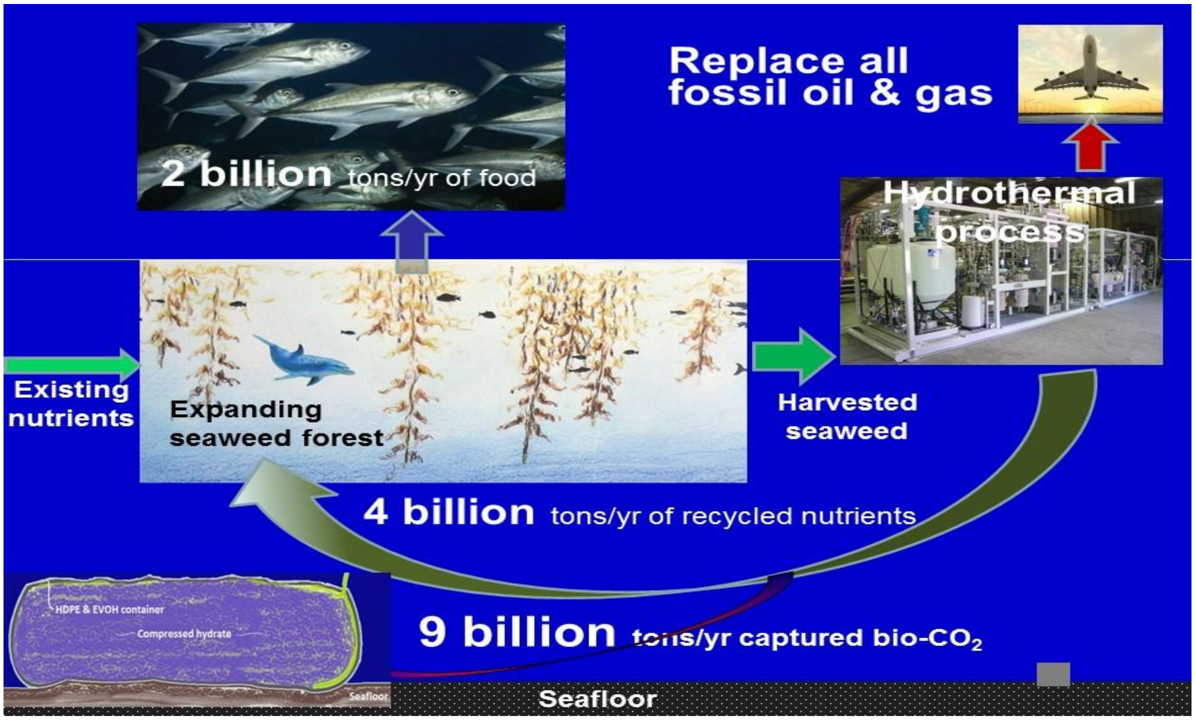
Big Picture Resilience via Ocean Forests

Topic Solution Summary

Build managed ocean seaweed ecosystems (Ocean Forests) in steps:
1. Integrate coastal defense with food-water-energy producing ecosystems by 2030
2. Recover 90% of "waste" resources by 2040
3. Grow more food with less fresh water than 10 billion people need by 2050
4. Replace 100% of global oil and gas demand by 2060
5. Eliminate excess ocean acidity by 2100
6. Reduce atmospheric CO_2 concentration below 350 ppm by 2200

In the big picture, sustainability and robust structures provide mediocre resilience at best. Civil Engineers can be heroes providing awesome resilience with multi-use structures that preemptively return greenhouse gases to pre-industrial levels. First Civil Engineers design resilience into coastal structures and migrate waste treatment toward resource recovery. Then they continue the steps to Ocean Forests and global food-water-energy-climate resilience.

Ocean Forests involve:
a) Solar powered photosynthesis, mostly in macro-algae (seaweed)
b) Infrastructure to grow and harvest the seaweed and other seafood
c) Local infrastructure to separate the non-food harvest into energy and nutrients
d) Local infrastructure to distribute nutrients to grow more seaweed
e) Global infrastructure to recover energy separated from nutrients so that the nutrients from agricultural runoff and digested food return to agriculture and Ocean Forests
f) Infrastructure to separate and permanently store two trillion tons of CO_2 produced by anaerobic digestion, hydrothermal processing, and methane combustion



Submission and Supporting Evidence

Big Picture Resilience

Resilient infrastructure continues service through extreme events, changing loads, and changing needs. In the big picture, scientists are identifying the kinds of events, loads, and needs engineers can expect over the next few decades and centuries. These include:

- More droughts and floods, less snow, more and then less glacier runoff, and groundwater is already depleted.
- Sea level is rising. Storm intensity, surge, and waves will be larger.
- Rivers, lakes, and oceans are warming. Warm water holds less dissolved oxygen. Lesser known effects include the eventual extinction of coral reef ecosystems, and toxic microalgae blooms in lakes and oceans[1] like the one which delayed California's 2015 Dungeness crab season.
- Ocean pH is dropping. Lower pH reduces the bioavailability of shell-forming minerals needed by corals, mollusks and myriad microorganisms, likely causing mass extinctions as the entire marine food chain is disrupted.

All of the above changes threaten food, water, shelter, and energy supplies. When food, water, shelter, or energy become unreliable, people migrate as conflicts over suddenly scarce resources erupt in violence. All the above creates an opportunity for Civil Engineers to be heroes by building food, water, shelter, energy and climate resilience into global infrastructure.

1. Integrated Coastal Defense

Coasts have many stakeholders making it difficult to agree on what action to take in response to their future situation. The stakeholders might be oversimplified into two opposing viewpoints: x) leave it to nature (don't touch it, don't build on it); or y) protect or increase human return on investment.

Both parties might be brought together with the realizations:

x) It is too late to leave it to nature. Evolutionarily rapid change is accelerating and is already causing habitat damage and species extinctions.
y) Building species diversity-increasing habitat, which yields food, water, shelter, and energy into our coastal investments can provide more protection at less cost, or even payback from new products.

One of four Sustainability Committee entries, "Public-Private Coastal Resilience Innovating," explains the multi-threats to coastal infrastructure and suggests a few tools to sustainably address the threats. In essence, engineers can build invisible breakwaters which calm waves and double as seaweed farms. With the waves calmed, options for resilient coastal land infrastructure increase. The seaweed farms create locally higher pH and locally increased dissolved oxygen.

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[1] "Agencies Collaborate, Develop a Cyanobacteria Assessment Network" *Earth & Space Science News*, Vol. 96, No. 23, 15 Dec 2015

At locations where coral reefs are natural breakwaters, we might lift and condition (raise pH, add oxygen) cool deep ocean water to trigger epigenetic adaptations[2] within coral reefs.

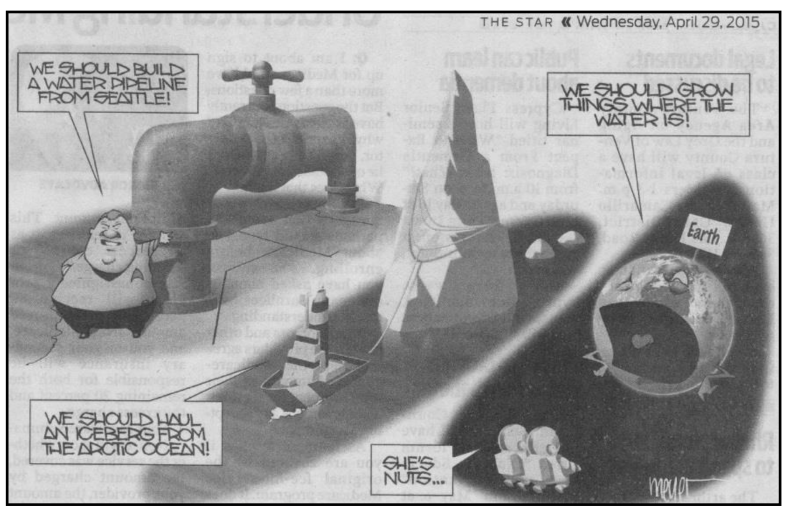
2. <u>Recover waste resources</u>

The Hydrothermal process (HTP) can start as a “waste” system which replaces “treatment” with resource recovery. Humanity can use HTP to concentrate and move energy, nutrients, and metals from places of excess to places of need. For example, recover energy, nutrients, and metals from municipal wastewater, municipal solid waste, dairy farms, mining slag, and ocean dead zones. The feedstock can be any carbon source, including: the above plus, bio-hazard waste, cafeteria or packaged supermarket food waste, used lubricating oil, grass, drugs, old paint, leaves, woodchips, plastics (including Styrofoam), paper, cardboard, food processing waste such as animal parts, etc. Sell the energy and metals. Move the nutrients to land and ocean farms.

HTP separates energy (carbon and hydrogen) from nutrients (phosphates, ammonia, sulfur, potassium, metals). The energy can be either all biogas (60% CH_4: 40% CO_2) or bio-oil and biogas. Phosphates and sulfur precipitate early in HTP. The nitrogen becomes 2% aqua ammonia in clear water output from the HTP. The PRD Tech Ammonia$^+$ Recovery (A^+ R) concentrates the ammonia to dry powder ammonium sulfate or other ammonia products.

The innovation “Complete Resource Recovery” submitted by Mark E. Capron explains how humanity would replace its waste treatment and storage options with recovery operations. Employing HTP with A^+ R on wastes allows near-immediate economic viability. Improving HTP economics improves the economics of growing seaweed directly for energy.

3. <u>Grow more food</u>



Growing seaweed for food and energy is inexpensive, renewable energy-powered, biologic, ocean desalting.

We must first recognize that growing seaweed is virtual water. Virtual water involves growing food in water-rich areas for consumption in dry areas. Whereas current concepts of virtual water deal with the 1% of Earth’s water that is liquid and fresh, seaweed virtual water

[2] Raising deep ocean water to de-stress coral reefs is an important component of Haven Atolls. Haven Atolls is a concept developed by Ocean Foresters for preserving islander and coastal homes and coral reef ecosystems through a millennium of Climate Change.

accesses 97% of Earth's water. See the picture on page 1 of the Sustainability Committee entry "Designing Water Law for Future Innovation."

The dry-matter composition of seaweeds ranges from 10-30% protein, with red and green seaweeds typically higher than browns. Taking an average of 19% protein and 3% lipid, 500 million dry tons of seaweed would produce about 150 million tons of algae protein and 15 million tons of algae oil.

500 million tons of seaweed would represent about 20% of current soy-protein production. Even more dramatic is the potential for lipid replacement; algae oils could represent a 750% increase over current fish oil production. Current price per ton for soy meal is about $550 meaning the protein fraction could be worth about $28 billion. Current price for fish oil is about $1500 per ton, making relatively small percentage of algae oil worth about $15 billion.

Places in need of coastal defense measures sometimes have excess nutrients from agricultural runoff: Chesapeake Bay and Gulf of Mexico. Seaweed production could absorb many of these excess nutrients while producing at least 1,000 tons dry weight of marine plants per square kilometer or 245 million tons dry weight if all of the dead zones were farmed at this modest intensity. Assuming nitrogen content of 3% for dry seaweed, it would absorb 20 tons of nitrogen per square kilometer. Reaching a global level of 500 million tons of seaweed production would assimilate 10 million tons of nitrogen from seawater, equaling some 30% of the nitrogen estimated to enter the ocean from fertilizer use.

4. Grow 100% of global oil & gas demand

With HTP as the energy-nutrient recovery process, seaweed forests over about 3% of world ocean surface could produce enough energy to replace 100% of global oil and gas. The area estimate is interpolated from a calculation by N'Yeurt, et al[3] to grow 100% of 2030 world fossil energy demand[4] when employing anaerobic digestion.

At this scale, the local nitrogen (ammonia/nitrate) recycle would be about ten times current global artificial nitrogen fertilizer production. That is why the key to achieving scale is nutrient recovery, separating the carbon-hydrogen compounds from the nitrogen, phosphorous, potassium, and trace minerals. Other than coastal areas with excess nutrients, most of the ocean surface is a nutrient desert. The necessary nutrients are available from deep water, below 500 meters depth, but only in parts per billion concentrations. Plus, we don't want to divert those deep water nutrients. They are expected to upwell at some distant ecosystem in the natural course of things.

Several aspects of oceans suggest Ocean Forests can increase species diversity while remaining cost effective. That is, Ocean Forests can more resemble tropical rainforests or the waters

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[3] N'Yeurt, A.de R., Chynoweth, D.P., Capron, M.E., Stewart, J.R., Hasan, M.A., 2012. "Negative carbon via Ocean Afforestation." *Process Safety and Environment Protection*, Vol. 90, p. 467-474: http://dx.doi.org/10.1016/j.psep.2012.10.008. More details at http://OceanForesters.org.

[4] 600 quadrillion BTU per U.S. Energy Information Agency's 2010 projection for 2030.

around the Galapagos Islands, completely unlike monoculture farms. Ocean surface area is inexpensive. The ecosystem and transportation to and through it are in three dimensions, moving up, down, and across the average ocean depth of 4,000 meters. Different conditions of pressure, temperature, density, turbidity, etc. are available with tiny energy costs. Wind, waves, tides, and sun offer easily accessed renewable energy to help manage our energy and food producing ecosystem.

Evolving technology suggests Ocean Forests can increase species diversity while remaining cost effective. HTP works with any biomass and even plastics, avoiding the difficulties of growing a specific species with finicky grow-harvest requirements. Autonomous equipment is more easily deployed in water and is improving rapidly. Consider the crown-of-thorns starfish killing robot (COTSbot) which gives COTS a lethal injection. "It is now so good it even ignores our 3-D printed decoys and targets only live starfish."[5] Very similar systems could selectively harvest sea food (sea cucumbers, abalone, sea urchins, red dulse, etc.) from within Ocean Forests.

5 & 6. Decrease atmospheric and ocean CO_2

When HTP is used to produce bio-oil and biogas the actual CO_2 production per ton of biomass is about the same as for anaerobic digestion. The high pressure and temperature of HTP biogas production allow production of pure bio-CO_2 (and pure bio-CH_4) with very little additional capital or energy expense. Because the pure CO_2 is a by-product of the energy production and nutrient recovery, Ocean Forest CO_2 is an order of magnitude less expensive than carbon capture after combustion[6].

There are many ways to store pure CO_2. While "Geologic Storage" in old oil wells, gas wells, and saline aquifers is drawing most of the research money and hype, humanity needs to diversify its options. Solid waste engineers would appreciate the Ocean Forests suggestion: storing CO_2 as a hydrate inside carefully engineered long-lived geosynthetic membranes[7]. Humanity should also explore the economics of locking the Ocean Forests' bio-CO_2 into limestone by reacting it with silicate minerals.

Processes producing food, bio-oil and biogas from seaweed are at the very start of their learning curve. Processes for producing fossil oil and gas continue to increase costs as the "easy" deposits are depleted. At some point, Ocean Forest bio-oil and biogas will be the less expensive and more abundant option. The fossil fuel industry will retire. Humanity might then pay a little more for oil and gas to fund storing legacy CO_2 (CO_2 emitted prior to 2030). The fossil oil and gas industry would not revive because investors will know the Ocean Forest oil and gas industry can cease CO_2 storage to reduce its energy prices.

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[5] Quote from Queensland University of Technology in Australia's Matthew Dunbabin in *Scientific American*, January 2016.

[6] Read "The Carbon Capture fallacy", David Biello, *Scientific American*, January 2016

[7] Capron, M.E., Stewart, J.R., Rowe, R.K. "Secure Seafloor Container CO_2 Storage." OCEANS'13 MTS/IEEE San Diego Technical Program #130503-115. Author's copy at http://OceanForesters.org.