New technologies to achieve net-zero emissions by 2050 and pre-industrial CO2 levels by 2150

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Diagram of processes involved in restoring the world’s climate to pre-industrial levels while supporting UN Sustainable Development Goals. Credit: OceanForesters

As humanity struggles to limit ever-rising temperatures, it also seeks to address growing poverty, disease and hunger across the world. Our team has designed an approach to address both issues in a way that is practical, economical, and effective, relying on three newly demonstrated technologies.

The world faces multiple crises affecting basic human needs for food, shelter and health, while at the same time maintaining aspirations for education and meaningful work. Crises affecting food and shelter, such as droughts, floods, groundwater depletion, diminished glaciers/snowpack and sea-level rise are exacerbated by increasing greenhouse gas concentrations. Health issues such as pandemics and increasing ranges of disease-transmitting organisms are also intensified by climate change.

Human needs and climate crises require finding interconnected opportunities addressing these interrelated challenges. Indeed, Pope Francis has issued a call to "...bring the whole human family together to seek a sustainable and integral development…" The 2015 Paris Agreement recommends "rapid reductions" of greenhouse gases be achieved "on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty."

Our team found interconnected opportunities with two approaches addressing human and climate issues. The two approaches update our 2012 proposal to grow more seaweed to simultaneously solve the problems of feeding the world, fueling the world and reversing climate change. We discovered these approaches during our work on the U.S. Department of Energy Advanced Research Projects Agency-Energy (ARPA-E) MARINER Program. The program's goal was to reduce the cost of growing macroalgae for biofuel.

Figure 1 shows how wastes, biomass, and fossil fuels are employed by the three newly demonstrated technologies: (1) building floating flexible fishing reef ecosystems with nutrient recycling achieving many Sustainable Development Goals, such as producing a half-billion tonnes of seafood per year; (2) Allam-Fetvedt Cycle (Allam Cycle) power plants efficiently producing both electricity and sequestration-ready CO_2; and (3) advances in hydrothermal liquefaction transforming any type of biomass into high quality biocrude oil.

During our MARINER work, we found that growing shellfish and fish close to seaweed improves the growth and potential yield of all three. In fact, farming annual mono-crops, or even dual-crops, in the ocean is sub-optimal. The best seaweed productivity is a perennial crop as part of a complete ecosystem that is managed as forests are managed. Perhaps as many as 30 species of fish, shellfish, crustaceans and others can be harvested, leaving the 100 ecosystem-supporting species. It's best to harvest a little macroalgae every week or so (as opposed to one to three harvests per year).

The permanent artificial reefs can be placed at any seafloor depth while floating at the ideal depth for the seaweed species. With ideal depth for sunlight and nutrient recycling, each reef can be even more productive than are natural reefs. This Total Ecosystem Aquaculture is a proposed program for the U.N. Decade of Ocean Sciences for Sustainable Development (2021-2030).

Co-author Antoine de Ramon N'Yeurt, a senior marine biologist at the University of the South Pacific in Fiji, has investigated marine ecosystems across many tropical islands of the Pacific and Indian Oceans. He says, "I have looked at the productivity and biodiversity of natural coral reefs and I realize that artificial seaweed reefs could be even more productive and thriving ecosystems. A scientifically designed mixture of seaweed and shellfish would uptake excess nutrients while attracting sustainable eco-communities of fish, crustaceans, sea cucumbers and their myriad associated microbial communities. This system could restore fishing jobs and natural habitat, helping island and coastal nations throughout the world not only to feed themselves, but export food to help feed humanity."

Allam cycle electrical plants make electricity with zero emissions whether burning coal or biofuels, allowing no gases to escape. The result could be the ending of dangerous pollution from power plants, yielding great health benefits while capturing all the carbon dioxide for sequestration. And if they burn trash, plastic, crop residues or other dry biofuels, the process is carbon negative, resulting in high net carbon removal. The company 8 Rivers currently has a working plant in Texas demonstrating that the technology is ready for commercialization.

Then we looked at the World Bank analysis of the 2 billion tons of waste generated by humanity every year. We saw that only a small fraction is recycled; most is either dumped in landfills, which emit climate-harming methane, or dumped in trash heaps that often catch fire, emitting dangerous air pollution. Too much waste, especially plastic, finds its way into the ocean, harming turtles, fish and birds. The economics of hydrothermal liquefaction (see page 13 in our paper and pages 22-27 in our Supplemental Material) have improved to support commercial-scale conversion of organic wastes, mixed with some plastics, into high quality biocrude oil. The biocrude oil can replace bunker fuel or be refined to make biodiesel and bio-gasoline at prices comparable to fossil fuels by applying the waste disposal fees to the production costs. By the time waste is fully used, the process economics should support using purpose-grown macroalgae.

Our analysis found that the world could achieve net-zero emissions by 2050, even with substantial fossil fuel use. In fact, a tax on fossil fuels could be used to pay for removing the trillions of tonnes of previously emitted CO_2. The International Panel on Climate Change (IPCC) 1.5

degrees C report projects nearly 3 trillion excess tonnes of CO_2 in the atmosphere and oceans (see the right side of Figure 2) if net zero emissions are achieved by 2050.

We put all this analysis into an Excel spreadsheet with 24 interlinked tabs that estimate the amount of waste and biomass of many kinds available globally. Combined with the three technologies and the estimated demand for energy, we were able to calculate how to remove all of the excess CO_2. Removing excess CO_2 will bring global air and water temperatures and ocean pH back to pre-industrial levels. Climates and ocean currents will more slowly stabilize and eventually return to pre-industrial conditions. Many species extinctions will be avoided.

Our spreadsheet (Supplemental Material in the zip document) allows countries and communities to choose a suitable balance using variations of low bio-electricity and high biofuels (for current vehicles) or high bio-electricity and low biofuels (to supply electric vehicles). The spreadsheet is designed so anyone can plug in estimates for their region and see the outcomes in terms of quantities, costs, and carbon sequestration amounts.

Figure 2: Our paper's calculations superimposed on the IPCC 1.5ºC projections. Both our low and high bio-electricity alternatives show much more carbon removal than the IPCC each year in order to return CO_2 levels to pre-industrial levels of about 300 ppm. Credit: OceanForesters calculations superimposed on Figures SPM 3a and SPM 1c from IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]

Figure 2 graphs possible emissions from both our approaches. Allam Cycle plants are only economical with dry fuels, such as trash, plastic, and crop residues. Some islands do not have sufficient quantities of dry biomass, but have access to Total Ecosystem Aquaculture reefs that could grow abundant seaweed biofuel that could make oil in hydrothermal liquefaction plants.

ARPA-E required us to have a path to market for our macroalgae-grow-harvest technology. That requirement inspired us to phase the three technologies for a path to full scale. We suggest roughly this order:

1. Grow up to 500 million tonnes/yr of seafood worth about $1 trillion/yr on permanent flexible floating reefs. While growing seafood, refine equipment for growing macroalgae for biofuel.
2. Produce 20 million barrels/day of biofuel from solid waste worth $0.3-0.7 trillion/yr. While processing trash, refine the process to use purpose-grown macroalgae economically.

3. Scale to produce more biocrude oil from macroalgae than current fossil oil.
4. Scale up to sequestration of 28 to 38 billion tonnes/yr of CO_2, which could restore pre-industrial CO_2 levels by 2140-2170. At full scale, our carbon dioxide removal costs are projected at $26 per tonne of CO_2. That is less than one-third of cost estimates for bioenergy with carbon capture and sequestration with pre-2019 technology or the projected cost of direct air-capture removal.

The climate window of opportunity is rapidly closing. Action is needed now. Starting on our path to scale appears immediately economically viable, even without a carbon fee/tax.

We look forward to ongoing dialogues with scientists, engineers, political decisionmakers and communities to "bring the whole human family together" with "sustainable and integral development." The more perspectives, the better. For action opportunities involving the ocean, please participate in the U.N. Decade of Ocean Sciences for Sustainable Development (2021-2030).

This story is part of Science X Dialog*, where researchers can report findings from their published research articles.* Visit this page *for information about ScienceX Dialog and how to participate.*

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