Seaweeds, the coming revolution

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Ignored yet potentially top players in the bioenergy vs. food game.

Ricardo Radulovich

Climate change and bioenergy have placed agriculture and photosynthesis back into the main stage. Besides the opportunities, some looking like cream on top of a glamorous and subsidized market, many questions remain unanswered. These are being addressed by many with a discourse that envisions “a world of clean fuels produced in lush fields by prosperous farmers”(1), forging an energy-independent “bio-economy” based on “multifunctional” agriculture(2). All of this supported by a detailed accounting of biomass sources, including animal dung and coconut husks together with corn and sugarcane(3).

Others, however, are more cautious. New and old problems have been rapidly evidenced by this change in the traditional purpose of agriculture and pressure to expand. Of particular relevance are environmental costs, including deforestation, water and greenhouse gases, energy-efficiency limitations, and food and nutrition issues affecting poor people the most. For example, an OECD-FAO joint panel views biofuel technologies and policies as uncertainties that could dramatically impact food prices(4) (and they have risen), while IFPRI’s models predict that expanded biofuel production will also be accompanied by “a net decrease in the availability of and access to food”, adding that “subsidies for biofuels that use agricultural production resources are extremely anti poor.”(5)

Yet, and save for a brief mention in a recent paper by the Royal Society(6), the main potential player in this bioenergy race, biomass production at sea, is ignored(1,2,3,4,5,7). However, the oceans, the largest active carbon sink in the planet, cover over 70% of its surface area (predicted to grow with rising sea levels), and receive an even larger proportion of photosynthetically active radiation (due to an even larger sea coverage at the tropical and subtropical belts) which goes largely unused for this purpose since, it is estimated, only 50% of the world´s photosynthesis naturally takes place there, mostly through phytoplankton(8)—in other words, to the eyes of an agriculturalist, the oceans should be seen as vast and grossly underutilized fields well provided with insolation and water.

While millenia ago humanity evolved from hunting-gathering into agriculture, the cultivation of the seas had to wait until recent years, when aquaculture, and within it mariculture in something termed the “blue revolution”, entered an exponential phase of growth as its potential begun to unfold (coincidentally with reaching and surpassing the limits of sustainable fisheries).

According to FAO(9), aquacultured production moved from less than a million tonnes in the early 1950s to 59.4 million tonnes, with a value close to 70 billion US$ in 2004. However, 91.5% of this production came from Asia and the Pacific region, while the European region contributed 3.9%, Latin America and the Caribbean 2.3%, North America 1.3%, and the Near East and Africa 1.1%. Of this, 99.8% of cultured aquatic plants, with a market of billions of US$

and million tonnes of seaweed biomass produced per year, come from Asia and the Pacific region, mostly from China, Japan and Korea(10).

Thus, agriculture, based on the systematic use of plants to harvest solar energy, has already evolved to the sea, though not in the Western hemisphere.

Currently, only macro-algae (seaweeds) are cultivated at sea, for which very simple mechanisms are used (mainly tying them to anchored floating lines). Intensive and CO2-enriched micro-algae culture for energy in saltwater tanks on land is a very different and specialized niche. Seaweeds resemble higher plants in many ways, including appearance and size, while not in others since they do not require soil (nor its cultivation), and are already provided with all the water they need (in itself a major advantage since water is the most limiting factor for the expansion and, faced with climate change, even the survival of agriculture, a view upheld by the CGIAR to the point of saying “mitigation is about gases, adaptation is about water”(7)—which is also the reason why I turned to the sea years ago).

Seaweeds are classified into three broad groups based on pigmentation and other characteristics: brown (Phaeophyceae), red (Rhodophyceae), and green (Chlorophyceae). Many species are known evidencing a vast potential, though only a few are currently cultivated or harvested to any extent(9,10). Historically, seaweeds have been valued around the world for a variety of uses, mainly for food, but also for fertilizer, feed, and a growing phycocolloid industry currently valued at billions of US$. Though harvesting from the wild is significant and hard to quantify, the FAO estimates that a large percentage of world production is from cultivation(10). This is important since harvesting massive amounts of naturally occurring seaweed populations (e.g., the Sargasso Sea) could be equivalent to large scale deforestation in terms of atmospheric CO2 addition and habitat loss and fragmentation.

Early attempts to cultivate seaweeds for biofuels date back to the 1970s, particularly in the USA through what came to be known as the Giant Kelp Project, with apparently a counterpart in Japan(11), and sought to produce methane from biomass. Such efforts faced several seaweed and energy production problems and were filed as unfeasible. Given that seaweed cultivation and biofuel production techniques have greatly advanced in recent years, and for the many reasons already presented, it is obvious that not only feasibility but most likely the need is now at hand. At least us in Costa Rica and others in Japan(11) are restarting the production of seaweeds for energy.

Energy applications from seaweed biomass are similar to those from land vegetation. The simplest option is direct burning for electricity and heat generation, such as it is currently done with bagasse from sugarcane and not unlike coal-fired power plants in principle—in fact, biomass co-firing together with coal is already implemented, partly to reduce net CO2 emissions in the electrical power sector. Next is the production of biofuels like ethanol, biodiesel and methane. Current biofuel production technologies may suffice for some cases, while next generation technologies will come to improve biofuel yields.

However, even if only for burning to generate electricity, seaweed cultivation can quickly begin yielding large amounts of net carbon-neutral biomass which could be burnt directly or after extracting compounds of high market value (including some for biofuels), a process that should include cold pressing its liquids out, perhaps plus some drying taking advantage of high insolation where available. A speculative quantification based on direct seaweed biomass burning follows.

Taking a modest production of combustible solids (dry matter minus ash) of 30 t/ha/yr, and assuming a specific energy density of 15 MJ/kg for dry seaweed biomass (common for whole plant biomass), a gross energy yield of 450 GJ/ha/yr could be obtained. This is approximately 10 tonnes of oil equivalent (toe) in terms of energy or more than 70 barrels of oil/ha/yr. At $100 per barrel of oil, the gross profit would be over $7000/ha/yr—if that energy could be used as cost-efficiently as oil. For 10 Gtoe of world annual fossil fuel consumption and 10 toe/ha/yr from seaweed biomass, a Gha or 10[7] km[2] of sea area would be needed to grow seaweeds. This an area similar to a large country, less than 3% of the world's oceans, and about 20% of the land area currently in agriculture (70% of which is in pastures). Considering the rather modest biomass and biofuel goals set for the coming years in the USA and the EU, a small fraction of that sea area would be needed to fully substitute for biofuel production in land.

Such estimated energy yields from seaweed biomass could be greatly increased when placed in the proper hands (e.g., the kind that achieved a five-fold increase in corn yields in the USA during the past century, and the kind that currently farm extensive land areas around the world), advancing biomass and biofuel productivity, partly through the selection and development of seaweed varieties with desired traits.

Moreover, 30 Gt of biomass production from 1 Gha of seaweed farms weigh on CO2 balance. Assuming a standing—rather, floating—biomass of 10 Gt between harvests, that by itself represents several Gt of atmospheric CO2 permanently sequestered. However, the largest contribution to CO2 reduction comes from cutting net CO2 additions from equivalent decreases in fossil fuel combustion, at the mentioned upper goal of 10 Gtoe per year. With a carbon market currently paying 30 US$ per tonne of CO2 equivalent, there is an astronomic amount of money just in selling carbon sequestration through seaweed cultivation and the use of biomass for energy. Some of that money could surely be used as start-up funds for experimental seaweed farming at the proper scale.

Once adequate areas for each ocean region are identified, the main external input to implementing large scale seaweed farming for energy will be the addition of nutrients—as evidenced by so many ocean iron fertilization efforts to promote micro-algal growth. However, agriculture-like production requires large quantities of all the plant nutrients because large quantities are removed at harvest. Common agricultural fertilization, besides being costly and energy consuming, would add large amounts of nutrients to the oceans with unknown results. There is, nonetheless, a great and grossly misused nutritional resource: domestic wastewaters. Their application on large seaweed fields grown for energy—an already explored option(12)—could find economically-sound use for the millions of tonnes of untreated wastewaters dumped daily into the sea through direct outfalls or submarine "emissaries" everywhere in the world. The service fee to be charged for properly disposing of wastewaters would come to lower nutrient handling costs.

Besides bioenergy, and considering growing climate-change limitations to agriculture, seaweed use as food should be established as a world priority. China is already leading the way consuming 5 billion tonnes per year, taking advantage of excellent seaweed nutritional composition, which is naturally high in protein9. Moreover, to better suit preferences, many organoleptic and other characteristics could be altered through genetic manipulation and food science technologies—nothing new to agricultural scientists.

Thus, seaweed cultivation for energy, food and other uses can bring about large and ecologically friendly planetary improvements, extending our lease on Earth on the hope that we will eventually mature as a species and a society. For this, and given the fact that sea waters, particularly those within exclusive economic zones of each country, are still in the hands of governments, this new set of activities may as well constitute the basis for generating a more equitably distributed new wealth.

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