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Commentary

Barriers to Making Algal Biofuels

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Since algae can produce many times more biomass per square foot than terrestrial plants, algal biofuels hold a great deal of promise.

Importantly, they are best suited for making biodiesel, the essential fuel. Ships, trucks, and trains are the backbone of civilization, and they depend on diesel.

We know how to grow algae, though there are no successful commercial fuel production facilities. The vast majority of commercial algal products are used for nutritional supplements, cosmetics, and other products.

The main reason fuels aren't being produced is the problem of "pond crash."

In practice, about a third of the time all of a pond's algae die within three months [1]. It doesn't take much head scratching to figure out why: The pond is wide open to invading algae predators via wind, rain, snow, insects, migratory waterfowl, and animals. Among the predators are zooplanktons. Each one can eat 200 algae a minute and crash a pond in less than 2 days [2].

They're not the only marauders. There are also killer viruses, fungi, diseases, amoebas. And open ponds are ideal breeding territory for mosquitoes, which prey not only on us, but also on algae.

Algae are Cinderella creatures. They are easily killed or grow too slowly from too much heat, cold, evaporation, pH level, saline level, UV, lack of nutrients, or too much of a nutrient [3].

Nor will just any algae do. For algal biofuels, the goal is to use obese algae with at least 60% fat to make as much biodiesel as possible for the least cost. But usually tougher, leaner, faster reproducing algae get into the pond and outcompete the plump ones.

If only a microscopic border patrol could keep them out. Why not build walls around the ponds! Oh wait, there are walls. Screens haven't worked, nor pesticides, since microscopic predators develop immunity quickly because they reproduce in just a day or two.

If algal biofuels are the future, then grains and oilseeds are the current biofuel feedstock. It's clear that terrestrial biomass doesn't scale up enough to run the world on biofuels. In Europe, it has been estimated that 2 billion metric tons of grains and oilseeds are grown a year, but that 15 billion metric tons, 7.5 times as much, would be needed to replace oil with biofuels [5]. Currently only 15,000 tons a year of algae are produced [4].

Compared to current biofuels, algae are tremendously expensive to produce, ranging from $719 to $3,000 per dry ton, versus switch grass, corn stover, and other land biomass costing $30 to $60 per dry ton [4].

Where's the land?

The ponds for growing algae have to be huge, about 1200 acres of very flat land (less than a 1% grade) containing 10-acre or more ponds for economies of scale, ideally near a city to reduce the cost of delivery. This land ideally has impermeable soil below to reduce the energy required to line and seal the ponds and prevent seepage of toxins into the groundwater.

Ponds also need to be large because they can't be deep, since sunlight doesn't penetrate algal growths for more than a couple of inches [6]. Too much sun is also harmful, since algae can suffer oxidative damage. Many species protect themselves by inhibiting photosynthesis, which constrains growth [3].

Algae feed on CO_2, which must be pumped into the ponds. A huge cost for algae farming is CO_2, up to 25% of overall costs. Yet there are very few industries emitting excess CO_2 that also have 1200 acres of very flat land nearby, nor wastewater plants to provide water for that matter [4].

The fairy-tale princess may have been overly sensitive to a pea, but algae are even more delicate. A proper berth for them would need at least 2800 hours of sunshine per year, since sunlight is the most important factor in algal growth. That much sun exists in only eight states. There'd ideally be 40 inches of rain and low evaporation rates, not likely in Arizona and the other suitable arid states. In addition, the ponds do best when the average temperature is 55 F or more, at least 200 days are above freezing, there is little wind so that predators, dust, and sand aren't swept into ponds, and heavy rain, flooding, hail, tornadoes, or hurricanes are rare.

There is competition for the use of flat lands. Algal ponds compete with agriculture and recreation, as well as solar facilities, which can produce far more energy than algae over their lifespan on considerably less land [7,8].

Where's the water?

Large scale algal biofuel production is likely to require as much water nationally as large scale agriculture [3]. Wigmosta (2011) [7] estimated that to produce 220 billion liters of algal biofuels - that would equate to 28% of U.S. transportation fuel - the evaporative loss from ponds would be 312 trillion liters per year. That is about twice the quantity of water used for irrigated agriculture in the U.S. [9].

An advantage of algae over land plants is that the water can be saline, brackish, wastewater and low-quality. The problem is that the water being evaporated is fresh, and continuing to use low-quality water to refresh the pond can introduce and concentrate killer microbes, heavy metals, chemicals and concentrates salts, toxins, and other harmful materials [3]. This would also render any co-products from algal sludge unsuitable for animal feed. If wastewater is to be used, there are not many wastewater treatment plants with thousands of acres of cheap flat land nearby to build ponds on.

Carbon dioxide problems coming and going

Unlike plants, which can make use of CO_2 in the air, commercial algae production requires concentrated CO_2 because not enough CO_2 from the air penetrates the water [3,10,11]. Coal-fired power plants would seem to be an ideal source for this CO_2. Algae, however, can only use CO_2 when the sun is shining, and not at night. Thus, in terms of the hope of using algal ponds to limit greenhouse gas emissions from coal power plants and other CO_2 emitting industries, algal ponds would not be able to offset more than 20-30% of the total power plant emissions [12].

There's another CO_2 issue with algal ponds. Ninety percent of the CO_2 pumped into an algal pond will bubble up to the surface and into the air, resulting in substantially higher net emissions from algal biofuels than petroleum, according to several studies [3,6,8]. The 2007 renewable fuel standard mandated that only biofuels which lowered greenhouse gas emissions 20% or more beyond petroleum emissions were qualified to be added to gasoline or diesel.

Microscopic algae are as voracious as food crops

The amount of nutrients required to grow enough algae to produce just 5% of transportation fuel could be as high as required by large scale agriculture [3,8]. To produce just 5% of the transportation fuels used in the United States, an algae with an oil content of 20% would need more nitrogen than the U.S. consumes today on crops, because algae can't fix nitrogen like many land crops. This same quantity of algal biofuels also would require phosphorus equivalent to up to half of what is currently consumed by U.S. agriculture [10]. There is a danger of phosphorous depletion as soon as 2080 to 2100 [13,14].

Recycling algae to get the nitrogen and phosphorous back isn't easy. It's also expensive and energy intensive to remove phosphorus and nitrogen from the dead algae after their oil has been removed to make biodiesel, so 20-40% cannot be recovered.

Where's the energy?

The main reason to make algal biodiesel is to provide a substitute for petroleum diesel. Other metrics such as CO_2 sequestration, byproducts, and GHG emissions are not as relevant. All that matters is that the EROI (Energy return on investment) is greater than 1, or perhaps as high as 10 or more to maintain our current level of civilization [15-17]. An EROI of 1 or less is not unsustainable.

An absolute showstopper is the very negative EROI of algal biofuels: far more fossil fuel energy is needed to build and grow the algae than the energy contained in the algal fuel. The energy for water management alone is seven times more than the algal biodiesel created, and water management is just a fraction of the overall energy inputs [18].

Like corn ethanol, estimates of EROI range from negative to positive [8], and again like ethanol, proponents who find positive results rely on adding the energy of the algal sludge byproduct. The NRC (2012) [8] reports that Sander (2010) [19] gave an "energy credit for using algae residuals 10 times larger than the energy content of the produced biodiesel." Yet even then the EROI was a trivial 1.77 to 3.33. Other studies found that it takes three to eight times as much fossil fuel energy inputs as the energy contained in the algal biofuel. Closed bioreactors can use up to 57 times more fossil fuel energy [8].

Sorry to let the air out of your balloon

If there are any incorrigible optimists left reading this, consider a subset of the steps and inputs needed to make algal biofuel. I've summarized the process below, and Capitalized Each Action that requires fossil fuel energy.

Algae need light to survive and grow. To get adequate light, the pond can only be a few inches deep, so ponds have to be large, which adds to construction and land costs. Water needs to be Pumped into and between ponds. The algae at the top hog most of the sunlight, so the water must be constantly Stirred, Pumped, and Circulated. On a hot day, an inch or more water evaporates, so more water must be Pumped In. After a pond crash the pond must be Thoroughly Cleaned. CO_2 must be Collected, Compressed, and Pumped into pipelines to deliver CO_2 to the facility via tubes at the bottom of ponds, which can get clogged, requiring Regular Cleaning. Agitators, Aerators, and Fountains must run constantly to distribute nutrients and CO_2 and to discourage mosquitos from breeding.

A biofuel facility is made of cement, plastic, pumps, centrifuges, chemicals, filters, pond liners, CO_2 waste treatment facilities, drying areas, fuel processing, transport, and storage infrastructure. Nitrogen, phosphorus, and other nutrients must be Produced, Transported, and Distributed in the ponds. Treating the wastewater requires Decontamination, Disinfection, and Removal of heavy metals. Water must be Heated or Cooled to maintain an optimal temperature. It also takes energy to Monitor and Keep pH levels, saline levels, nutrient, and water levels at optimal levels.

To make the algal fuel, algae are Pumped through each of these steps: Harvest, Filter, Sieved, Dry, Extract oil. Recycle nutrients, Dispose of wastewater. Getting the water out is a huge part of the energy used: algae are single cells suspended in water at concentrations below 1% solids, whereas land plants are often over 40% solids. The energy to Concentrate and Dry the algae commercially is far greater than the energy contained in the algae [3]. Extract the oil in the algae. Transform this oil into biodiesel (many steps not listed here). Finally, Store, Transport, Blend, Deliver, and Dispense algal biodiesel.

Protect algae from crashes by sheltering them in photo bioreactors

You might think algae could be protected from predators in the long glass or plastic tubes of a photo bioreactor, but microscopic creatures can also get into them and form bacterial biofilms that slow down water flow and reduce the light. However much trouble ponds may be, photo bioreactors are far more problematic and expensive, have never been scaled up to a commercial level, cost more, and use far more energy than ponds. They can't be sterilized and need to be cleaned, they need energy intensive temperature, pH, dissolved oxygen, and CO_2 controls. They are far from being commercial. Bottom line: they require far more energy than open ponds and studies have found all of them to have a negative energy return on invested [3,8].

Conclusion

Algae may be green, but they're not clean. Discharging untreated water from an algal pond can lead to eutrophication of waterways, contaminate groundwater, salinize fresh water, harm wildlife, and be a source of heavy metals, herbicides, algal toxins, and industrial effluents. Untreated water may escape in a flood, earthquake, tornado, high rainfall, and when the pond leaks or breaks. If a foreign or bio-engineered algal species escapes, it could threaten local and regional ecosystems by displacing native species and causing dense algal blooms that block sunlight.

Algae also compete with agriculture for very flat land.

There are simply too many showstoppers. Algae are greedy little bastards, needing more water, nitrogen, and phosphorous than corn or soybeans, placing unsustainable demands on energy, water, and nutrients [8].

Clearly algal fuels are far from being commercial, unless you can get the military to pay for it that is. In 2009, the Pentagon spent $424 a gallon on algae oil [20].

Scientists, entrepreneurs, and the U.S. government have been trying to make algal biofuels for over 45 years, ever since the 1970 oil shocks, and have studied over 3,000 kinds of algae for their biofuel potential. But after decades of research, the Department of Energy gave up and stopped funding in 1995 [21].

And don't be fooled by the recent research, it's focused on cleaning up CO_2 from power plants to lower greenhouse emissions [4], not to provide biofuels to keep trucks running [22], which are absolutely essential for our fossil-fueled civilization.

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