Hawaii Renewable Energy Development Venture
Technology Assessment
Algae Oil Production & Extraction

1. Overview

Many existing processes are built upon assumptions that are not well supported or, in some cases, incorrect. Also, most appear to still require far more engineering development in terms of process integration and plant installation and operation than most companies are prepared for (i.e., biofuel from micro-algae is actually a chemical plant built onto the back-end of an intensive agricultural process and most small venture capital companies are ill prepared to deal with the entire process). More specifically, bio-oil from micro-algae requires a culture production in open ponds which includes a significant inoculation stage, a primary harvest and 1st stage dewatering step, a 2nd stage dewatering step, an extensive extraction process that may include the use of a volatile solvent, and production of a large biomass end-product that must disposed of either through digestion (e.g., anaerobic digestion or enzymatic hydrolysis), composting, combustion, or consumption as animal feeds. Consequently, most players in this industry are not proposing micro-algal pond cultivation coupled to simple harvest and biomass drying platforms, but rather more extensive “chemical engineering” like unit operations built onto the back-end of what is already a significant micro-algal production pond process. More often than not these efforts will require capital-intensive unit operations as well as installation requirements in terms of safety and code requirements that may be far beyond their available investment capital resources. Also, the labor force to run this process safely will be extensive and expensive (requiring process engineers, plant managers, and scientifically trained personnel). In summary, bio-oil from microalgae is a process that is a challenging and unique mix of agricultural farming and chemical engineering plant operations.

2. Status of Commercial Readiness

Basic growth and harvesting in open pond systems coupled to simple dewatering and drying schemes are commercially viable. An example would be a system in which a polymer flocculent is first added to a harvested culture. The solution is then passed through an expansion valve (to promote flocculation of the cells into a cottage-cheese like substance) that in turn passes the mixture into a concrete bed possessing a micro-porous bed that supports overnight vacuum filtration. In the morning the solids residue can be withdrawn with a front loading tractor and carried to another concrete or asphalt surface where it can be piled in rows that are constantly turned until dry. The dried biomass could then be combusted for energy recovery. This general process is already employed to create bio-solids from anaerobic treatment plant solids. While cheap from an energy perspective, it remains relatively unattractive because it is low tech and requires large land use. The capital cost of the vacuum beds is also significant but likely competitive with large-scale membrane units or centrifuges. An added plus is the ability to recycle the water pumped from the vacuum beds, either back to the micro-algae ponds, to sewage treatment, or for agriculture use.

What remain problematic are many of the more elaborate processes that are currently proposed for the production of bio-oils. Most of these are designed to increase biomass productivity (i.e., closed bioreactors for high density culture, hanging bag reactors, open pond systems coupled with mechanisms for cell recycle or heavy inoculation, night time additional of sugars) and offer preferred dewatering and extraction routes that lead to bio-oil. Nearly none of these, however, have been trialed or tested at pilot scale, let alone commercial scale.

One of the biggest issues in bringing the process to market/deployment is the fact that even under the best of circumstances, the energy efficiency (i.e. ratio of energy gained in fuel versus energy used to produce it) is already marginal. Simply put, sunlight limitation is severe and microalgae cannot be grown to particularly high densities or productivities above 60 gdw m^{-2} day^{-1}.[1] The water load is massive and impresses a particular stress on downstream processing. Another significant issue is the requirement of carbon dioxide for higher density cultivation as well as the availability of large tracks of flat land and abundant sunlight. In order to make biofuels from microalgae commercially successful, not only do the processing issues mentioned above need to be solved, but also a supply of CO_2, water, land, and sunlight must be available. Although abstract, another issue is the heavy focus on using microalgal cultivation to meet current biodiesel demands. In many respects, expectations are too high.

There are a few researchers (including some in HNEI) that are focused on the development of novel solvent based technologies that work in the presence of water and with minimal energy use. It can be argued that the key “game changer” technologies will lie in dewatering and extraction. With respect to the latter, it can be argued that the best approach is liquid phase extraction that works in the presence of water and in such a way that permits that water to be recycled. There are also some potentially unique approaches such as the application of sonication (high frequency, high power sound) in the presence of liquid phase extraction. These techniques promise to extract lipids without killing the cells which promises improved recycling of water and biomass. Although an interesting concept, its scale-up remains an issue and would require greater thought into the engineering of larger systems that conserve energy.

3. Appropriateness to Hawaii

It can be argued that the biggest hurdle facing application in Hawaii is water use. Unless water recycling plays a dominant role, all the way through the extraction step, water use can become extraordinarily expensive. Even with full water recycling, the loss of water due to evaporation remains a significant expense.

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[1] grams dry weight per square meter per day

The use of microalgae will be of particular importance in Hawaii where there are a number of potential projects utilizing systems that take advantage of local resources. These projects also recognize the lack of landmass available for larger traditional bio-energy farming activities.

The production of heavy carbon biofuels such as those made from bio-oils is of increasing importance to Hawaii for the displacement of imported petroleum fuels. These liquid phase fuels of high carbon number (that is, heavy oils) are of particular importance to the local shipping and trucking industry.

Is this a technology that is a key to success in other areas (cross cutting)?
Microalgal cultivation in open ponds can be used to further treat wastewater from anaerobic digestion. Recently, the EPA has proposed multi-million dollar fines for the City & County of Honolulu for discharging waste from primary treatment facilities. The mayor has argued that the cost of installing secondary treatment facilities to further clean the water is too expensive. Without question microalgal cultivation could play a role in wastewater treatment, often providing a cheap alternative to second stage purification – assuming land is available. If one imagines a process in which primary treated discharge from waste treatment facilities is further clarified using microalgal ponds, from which some energy is recovered in the form of dried biomass, that could be considered cross cutting.

4. Considerations

Microalgae must be cultivated from the following resources: sunlight, carbon dioxide, water, and added nutrients such as nitrate and phosphate. Sunlight is abundant. The abundance of water is debatable. Carbon dioxide is available from power plant emissions or gas emissions from the fermentation of ethanol. Nitrogen and phosphate could be available from sewage waste streams or other agricultural wastes.

5. Contacts

National labs: NREL (Al Darzins) and Sandia (Ron Pate, Grant Heffelfinger).

Consultants: John Benneman

Key technology providers: Phycal, Valcent,

Regulators;

Public policy makers:

Utility leaders; and,

Commercial and residential end-use constituencies.