Understanding the process of developing aquatic biomass energy through the domestication of algae

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Introduction to algae

It is known that of about 71% of the earth's surface is water where more than 5000 species of planktonic algae thrive (Barsanti and Gualtieri 2). The petroleum reservoirs are a product of the burial of organic carbon produced as a byproduct of algae in the shallow seas during the Jurassic period (Barsanti and Gualtieri 30).

Table 1. The classification of the ten divion of algae are presented as interpreted by Barsanti and Gualtieri

Kingdom	Division of Algae	Common Name	Class
Prokaryota eubacteria	*Cyanophyta*	blue-green algae	*Cyanophyceae*
Prokaryota eubacteria	*Prochlorophyta*	not available	*Prochlorophyceae*
Prokaryota eubacteria	*Glaucophyta*	not available	*Glaucophyceae*
Prokaryota eubacteria	*Rhodophyta*	red algae	*Bangiophyceae*
			Florideophyceae
Eukaryota	*Cryptophyta*	Cryptomonads	*Cryptophyceae*
Prokaryota eubacteria	*Heterokontophyta*	golden algae	*Chrysophyceae*
		Yellow-green algae	*Xanthophyceae*
		Diatoms	*Eustigmatophyceae*
		Brown algae	*Bacillariophyceae*
			Raphidophyceae
			Dictyochophyceae
			Phaeophyceae
Eukaryota	*Haptophyta*	Coccolithophorids	*Haptophyceae*
Eukaryota	*Dinophyta*	Dinoflagellates	*Dinophyceae*
Eukaryota	*Euglenophyta*	Euglenoids	*Euglenophyceae*
Eukaryota	*Chlorarachniophyta*	not available	*Chlorarachniophyceae*
Eukaryota	*Chlorophyta*	green algae	*Prasinophyceae*
			Chlorophyceae
			Ulvophyceae
			Cladophorophyceae
			Bryopsidophyceae
			Zygnematophyceae
			Trentepohliophyceae
			Klebsormidiophyceæ
			Charophyceae
			Dasycladophyceae

Common Name

In order to understand Algae, one must define algae. Although algae and plants have much in common, it is their dissimilarities that make them classifiable. As algae's evolutionary phylogeny is still being modified and its establishment is open to interpretation, this paper uses the classification interpreted by Barsanti and Gualtieri and is as such: prokaryotic algae are grouped into two divisions: *Cyanophyta* and *Prochlorophyta* and Eukaryotic algae are grouped into nine divisions: *Glaucophyta*, *Rhodophyta*, *Heterokontophyta*, *Haptophyta*, *Cryptophyta*, *Dinophyta*, *Euglenophyta*, *Chlorarachniophyta*, and *Chlorophyta*. This phylogeny is depicted in Table 1. (Barsanti and Gualtieri 2-10).

Scientific Name

S*ee Table 1.*

Origin and history

There are two histories of algae, one that precedes and another that proceeds the endosymbiosis event. The former consists of a prokaryotic ancestor and the latter produced the novel eukaryotic photosynthetic algae. Plastid acquisition in algae is important to distinguish the evolutionary history that can open a window on algal and plant evolution, starting from cyanobacteria. This anaerobic bacteria that evolved 2.8 billion years ago, is the first of its kind to develop a metabolic process known as photosynthesis.

Crop description and its biology

Reproduction in algae

There are various methods of reproduction that algae utilize including: vegetative division of a single algal cell, fragmentation of a colony, asexual via production of a motile spore and sexual via union of gametes. Stability of the genome and/or genotype is offered through vegetative and asexual reproduction. Both modes, most importantly are fast and energetically economical for producing a large population with little genetic variability. Genetic recombination is offered through sexual reproduction in algae that aids in genomic variation with the cost of gametes that fail to mate (Barsanti and Gualtieri 10-12).

Cell Biology

The cell wall is present in both eukaryotic and prokaryotic algae. It is rigid, homogeneous and known to be multilayered. Generally, this cell wall is composed of a microfibrillar framework inside an amorphous mucilaginous material composed of important polysaccharides, lipids, and proteins involved in various processed – where silica and calcium carbonate may be also present. The mucilaginous glycoprotein covers wholly the external surface of the cell. Underneath this layer exists the peripheral cytoplasmic layer whose structure resembles "the wired soul present in the tires" and aids in its phenomenal resistance to tearing. Next is the matrix of an arrangement of microtubules, known as the pellicles that are unorganized in places to encourage flexibility. It is important for these layers that include the cell wall, cytoplasm and algal skeleton to be denser than the medium algae is to dwell in. This is because algae are known to be motile through a flagella system that is mainly observed as biflagellate (Barsanti and Gualtieri 104).

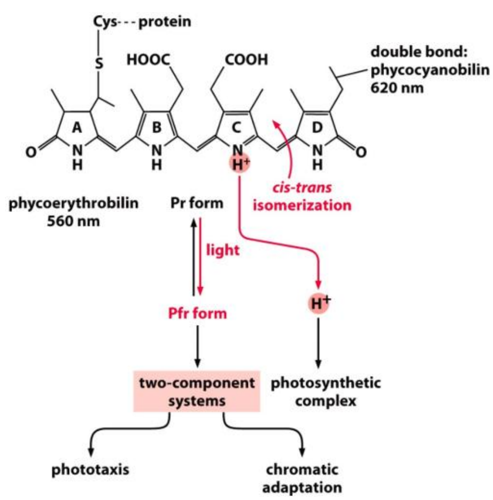

Figure 1. The data processing reaction in cyanobacteria that is drives phototaxis, and is sensitive to light conditions. (Marks et al 107).

In order to "swim" algae must stay afloat through minimum resources such as buoyancy control. The algal "eye spot" provides phototaxis abilities for algae, combined with motility allows for thriving phototrophy – where the organism can switch from a random walk to a targeted walk based on its desired stimuli's concentration (i.e. photons). The motors for detecting light (not capturing) are two types of photoreceptor proteins: rhodopsin-like proteins and flavoproteins (100).

Algal rhodopsins are used as for phototaxis or photophobic responses where a calcium ion current regulated phototatic motility of the organism (Marks et al. 107; Briggs et al. 18).

Phytochromes sense light using a bilin chromophore that undergoes photo reversible conversion between red and far red light-absorbing forms. The former is through phycoerythrobilin for short-wavelength light and the latter through phycocyanobilin for light wavelength light (Kehoe). The conversion is due to light (photon) that induces an isomerization of the pigment molecules (Figure 1) in picoseconds, the fastest biological reaction in nature (Barsanti and Gualtieri 104). This is important to understand how to successfully culture algae as these light sensitive proteins allow the organism to utilize light at wavelengths where photosynthesis is via chlorophyll is not able to use. Increasing sensitivity to photons collected on an algal photoreceptor is one way to optimize algal growth. Chloroplasts, found in all green plans are photosynthetic partitions that contain pigments for the absorption of light. Upon this, photons are channeled through a series of photochemical and enzymatic reactions that yield ATP.

Crop adaptation

The nature ecosystem/biome of algae exists successfully in aquatic and subaerial environments.

Aquatic

Aquatic algae are found almost all freshwater and saltwater reserves and therefore have a high tolerance for broad range of pH and temperature. A tolerance for variable oxygen and carbon dioxide concentration is also unique to aquatic algae. Furthermore, turbidity and osmolarity tolerance aids in algal population blooms in wasterwater and other milieus of manmade surroundings. Additional classification is such that aquatic algae can be planktonic or benthic which are defined as living in suspension or anchored, respectively. Benithic algae can be anchored to (see comment). Depth adaptability delimits many algal divisions as at lower depths red light is attenuated (due to its wavelength and water) and photosynthesis becomes more difficult. Therefore accessory pigments are necessary for viability that can absorb the available light (sometimes 5×10^{-4} % of surface light) and channel this to chlorophyll a. On the converse, marine aquatic algae is also found on the surface of water bodies and would be susceptible to photodamage if it weren't due to its accessory and protective pigments – as seen in species such as brown, golden or red algae (Table 1).

Subaerial

Subaerial algae are adapted to dry land, and exist successfully anchored to tree trunks, animal fur, hot springs, rock, soil and most notably lichens. This type of algae is known to exist in symbiosis – mainly to aid the viability of other plants in its surroundings by producing oxygen and other complex nutrients for security.
Where algae is found depends primarily on their mode of dietary intake, see Table 2.

Table 2. Different ways to classify algae. By definition obligate heterotrophic or phototrophic algae

	Primarily	Secondarily
Obligate heterotropic algae	Heterotrophy	Phototrophy
Obligate photorophic algae	Phototrophy	Phagotrophy and/or osmotrophy
Facultative mixotrophic algae	Phototropy or heterotrophy	
Obligate mixotrophic algae	Phototrophy, phagotrophy and/or osmotrophy	

Algae's role in the biosphere is such that it is a producer of oxygen (in the short run) and fossilized hydrocarbons (in the long run) that result from the decomposition of marine microalgae organic matter (Barsanti and Gualtieri 159). Algae populations are limited to growth through the following limiting factors: nitrogen, phosphorous and silicon – all of which are important for various biochemical processes and are utilized in their respectable metabolic cycles (Barsanti and Gualtieri 165). Eutrophication is also a major factor in limiting algae growth along with pollution.

Cultivation and Management

Harvesting Algae

Algae can be collected, stored and furthermore preserved through various procedures. Cultures can therefore be made to satisfy the captured organism – where the artificial conditions can can be further modified through temperature, light, pH and salinity to match a natural environment. Temperature has an intermediate value of 18 to 20^{o}C although this is mainly dependent on the specific species. Overheating can with temperatures higher than 35^{o}C confers lethality while lower temperatures can slow down growth rate. Biotechnology offers the ability to insert anti-freeze or ice nucleation genes from *Pseudomonas syringae* that would allow ice crystals to not form at a great extent inside the organism (Glick et al 614-616).

Light, as mentioned previously is the energy that drives photosynthesis in algae along with providing heat. The intensity and wavelength of light is of great importance. In batch cultures, light may be natural or produced through florescent sources that emitting in the blue or red light spectrum – as chlorophyll a is unable to use green light. Light cycling between light and dark periods may also be used as many microalgae species are not known to grow under constant illumination, possibly to phototaxis or photophobia as mentioned. The necessary pH range is important to maintain, where the optimum is 8.2-8.7 units. Salinity is important to micro algae to maintain tolerance via osmosis and turbidity. With all of these important conditions, the most important is mixing to induce proper carbon dioxide aeration of the culture and sedimentation of the culture.

Limiting any of these factors is proportional to limiting growth, as these the after effects of these conditions very much overlap that further more increases the risk of cultivating algae for biomass. (Barsanti and Gualtieri 212-214). Media must be provided with necessary nutrients and minerals as well such as those found in fresh and marine water. This is done by extracting soil, heating and filtering out the soil then adding it to the culture media where the essential macro/micro nutrients, vitamins and metal chelators (i.e. EDTA) in variable quantities can be assembled with much ease (Barsanti and Gualtieri 226-227).

Batch culturing

A closed system that is volume limited, simple to operate confers a low economic asset in the long run in producing algae. As seen in Figure 2, algal cell density increases as the cells are dependent on a growth limiting substrates. The key to a successful batch is to keep all of the culture in the exponential phase, where doing so can avoid culture crashes for many reasons that may include oxygen deficiency, nutrient depleation, temperature or pH disturbance and contamination – all which confer to lethality and loss of an financial and temporal investment. To avoid contamination overall, a proper inoculation technique must be used in the commencement of the culture (Barsanti and Gualtieri 237-239).

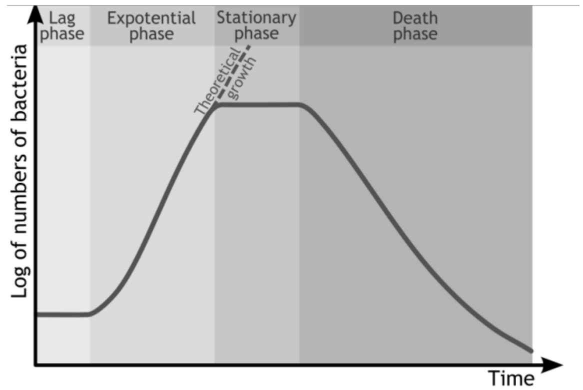

Figure 2. Cell growth pattern with time follows this routine: lag phase, acceleration phase, log (exponential phase), deceleration phase, stationary phase, and cell/colony death. Souce: en.wikipedia.org/wiki/Bacterial_growth

Continuous cultures utilize the "infinite substrate" method by cycling new nutrients in to the container, whereas semi-continuous cultures produce only an initial delivery of substrate. Outdoor ponds, with rotation arm are available commercially and allow many grains as durability of the container, experience of the company, and ability to choose a more culture specific product – all which reduce cost. It must be mentioned that although there are many species of marine algae, monospecific or polycultures can be inoculated in the culture medium. For the latter, phytoplankton boom or other fast growing species may outcompete with less dominating species. Outdoor growth also produces variable light intensities and wavelengths. Cloudy days, especially in New Jersey may dramatically reduce the number of photons per area, therefore limiting growth. Photobioreactors are completely close system batch growth chambers that do not allow exchange of gases or contaminants thereby reducing varabilities in substrate concentrations and evaporation of water (Barsanti and Gualtieri 234).

Pathology

Since algae has exists for about 3 billion years, it can be considered as relatively fit. Besides nutrient depletion, algal viruses can attack algae blooms (Science Daily). Algae are also known to be pathogenic as well toward other animals and plants. Cyanobacteria can cause blank band disease that leads to coral bleaching of coral symbionts of algae (Agrios 719). Other species can infect humans with skin infections or even weeds. Leaf spot disease by algae is common to many tropical plants. However, since there are vast types of algae that exist, the non-parasitic types can be use to outcompete parasitic varieties (Agrios 719-720).

Crop Yield and Economic Potential

Biomass Conversion Processes

Biomass is defined as any organic material that may be directly or indirectly derived from plant life and renewable in periods of less than 100 years (Probstein and Hicks 381). Unlike petroleum and coal, energy crops and agricultural waste are renewable. As shown in Figure 3, algae upon removal of water and other constituents, contains a high amount of various macromoles that can yield this organism as a good feedstock, fertilizer and also a food source (Barsanti and Gualtieri 256).

Protein	55-60% of dry matter
Carbohydrates	10-20% of dry weight
Lipid	9-14% of dry weight
Mineral fraction	6-9% of dry biomass

Figure 3. Some important dry weight containments of microalgal species *Arthrospira*

Table 3. Chemical composition of different species of algae, on a dry matter basis. (Demirbas and Demirbas 120)

Species of sample	Proteins	Carbohydrates	Lipids	Nucleic acid
Scenedesmus obliquus	50–56	10–17	12–14	3–6
Scenedesmus quadricauda	47	–	1.9	–
Scenedesmus dimorphus	8–18	21–52	16–40	–
Chlamydomonas rheinhardii	48	17	21	–
Chlorella vulgaris	51–58	12–17	14–22	4–5
Chlorella pyrenoidosa	57	26	2	–
Spirogyra sp.	6–20	33–64	11–21	–
Dunaliella bioculata	49	4	8	–
Dunaliella salina	57	32	6	–
Euglena gracilis	39–61	14–18	14–20	–
Prymnesium parvum	28–45	25–33	22–38	1–2
Tetraselmis maculata	52	15	3	–
Porphyridium cruentum	28–39	40–57	9–14	–
Spirulina platensis	46–63	8–14	4–9	2–5
Spirulina maxima	60–71	13–16	6–7	3–4.5
Synechoccus sp.	63	15	11	5
Anabaena cylindrica	43–56	25–30	4–7	–

Algae can be converted to a renewable biofuel through many processes but anaerobic digestion is the most well developed.

Anaerobic digestion

Photosynthetic algae can be used as a substrate for production of biogas or methane, where energy can thereby be produced by burning methane. There are three stages involved in this process: (1) hydrolysis to convert insoluble carbohydrates, proteins and oils to soluble substance including sugars and alcohols, (2) conversion of soluable materials to fatty acids, esters, carbon dioxide and hydrogen, (3) during methanogensis these organic acids are converted to methane. Anaerobic digestion is a batch process like growing algae and therefore follows the similar growth curve (Figure 2).

There are many things to consider when using anaerobic digestion with algae. Salinity, what makes these organisms thrive and inhibit anaerobic digestion. Methane yields can be greatly increased upon breaking of the thick and dense algal cell wall for anaerobic digestion to be at its optimum. Nitrogen also exists in these organisms quite highly and may produce high levels of ammonia that may inhibit the digestion process (Demirbas & Demirbas 119).

Table 4. **Pigment produced by each class of algae, following Table 1's order (Barsanti and Gualtieri)**

		Pigments			
Common name	**Chlorophylls**	**Phycobilins**	**Carotenoids**	**Xanthophylls**	**Storage Products**
blue-green algae	a	c-Phycoerythrin	b-Carotene	Myxoxanthin	Cyanophycin
		c-Phycocyanin		Zeaxanthin	(argine and
		Allophycocyanin			asparagine
		Phycoerythrocyanin			polymer)
					Cyanophycean
					starch
					(a-1,4-glucan)
not available	a, b	Absent	b-Carotene	Zeaxanthin	Cyanophycean
					starch (a-1,
					4-glucan)
not available	a	c-Phycocyanin	b-Carotene	Zeaxanthin	Starch
		Allophycocyanin			(a-1,4-glucan)
red algae	a	r,b-Phycoerythrin	a-and	Lutein	Floridean starch
		r-Phycocyanin	b-Carotene		(a-1,4-glucan)
		Allophycocyanin			
Cryptomonads	a, c	Phycoerythrin-545	a-, b-, and	Alloxanthin	Starch
0		r-Phycocyanin	1-Carotene		(a-1,4-glucan)
0					
golden algae	a, c	Absent	a-, b-, and	Fucoxanthin,	Chrysolaminaran
Yellow-green algae			1-Carotene	Violaxanthin	(b-1,3-glucan)
Diatoms					
Brown algae					
Coccolithophorids	a, c	Absent	a-and b-Carotene	Fucoxanthin	Chrysolaminaran
					(b-1,3-glucan)
Dinoflagellates	a, b, c	Absent	b-Carotene	Peridinin,	Starch
				Fucoxanthin,	(a-1,4-glucan)
				Diadinoxanthin	
				Dinoxanthin	
				Gyroxanthin	
Euglenoids	a, b	Absent	b-and	Diadinoxanthin	Paramylon
			g-Carotene		(b-1,3-glucan)

not available	a, b	Absent	Absent	Lutein,	Paramylon
				Neoxanthin,	(b-1,3-glucan)
				Violaxanthin	
green algae	a, b	Absent	a-, b-, and	Lutein	Starch
			g-Carotene	Prasinoxanthin	(a-1,4-glucan)

Table 5. Habitat of algal divisions, following Table 1's order (Barsanti and Gualtieri)

	Habitat			
Division of Algae	**Marine**	**Freshwater**	**Terrestrial**	**Symbiotic**
Cyanophyta	yes	yes	yes	yes
Prochlorophyta	yes	not detected	not detected	yes
Glaucophyta	not detected	yes	yes	yes
Rhodophyta	yes	yes	yes	yes
Cryptophyta	yes	yes	not detected	yes
Heterokontophyta	yes	yes	yes	yes
Haptophyta	yes	yes	yes	yes
Dinophyta	yes	yes	not detected	yes
Euglenophyta	yes	yes	yes	yes
Chlorarachniophyta	yes	not detected	not detected	yes
Chlorophyta	yes	yes	yes	yes

Conclusion

It is projected that bioenergy crops will very much influence the energy market in the future, including algae. However, the full potential of aquatic biomass energy potential is not expected to approach even one-percent of the total US energy requirements (Probstein and Hicks 390). With such discerning statistics, one is left to ask the reason behind investing in bioenergy overall. Although there are many answers that span from economical to ethical reasons the main one to consider is knowledge of new resources and endeavors. The poet Robert Burns once wrote, “the best-laid plans of mice and men often go awry, and leave us naught but grief and pain for promised joy” (23). It can be said that although many strategies for algae and other biomass sources exist, inconveniently they may pose new problems in the future.

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