BTI

Algae to Energy Systems Lab - Student Background

Think about how you get to school, the store, the movie theatre, and your friend's house. Do you take a car, ride the bus, bike, or walk? We often find ourselves driving from place-to-place because it's easy and fast. But with a nation of drivers, these miles add up. Currently, the US transportation sector contributes 28% of our greenhouse gas emissions and 95.4% of US transportation is fueled by non-renewable energy sources. But what would happen if we could develop a more **sustainable** solution to our energy needs? We are now turning to biofuels and other renewable energy sources to provide such sustainable alternatives that reduce our dependence on fossil fuels (e.g., petroleum and oil). Believe it or not, microalgae may hold the potential to reduce our nation's consumption of fossil fuel resources, and greenhouse gas emissions.

Algae grow in the ocean, lakes, ponds, water fountains, birdbaths, fish tanks, and even puddles. Although algae are **protists**, they share a distant **common ancestor** (Figure 1), with and are similar to plants, as they both utilize **photosynthesis** to convert carbon dioxide into sugars using water and energy from the sun. There are more that 14,000 known species of green algae with great genetic variation within and among species. This variation is key to the development of algal-based renewable energy.

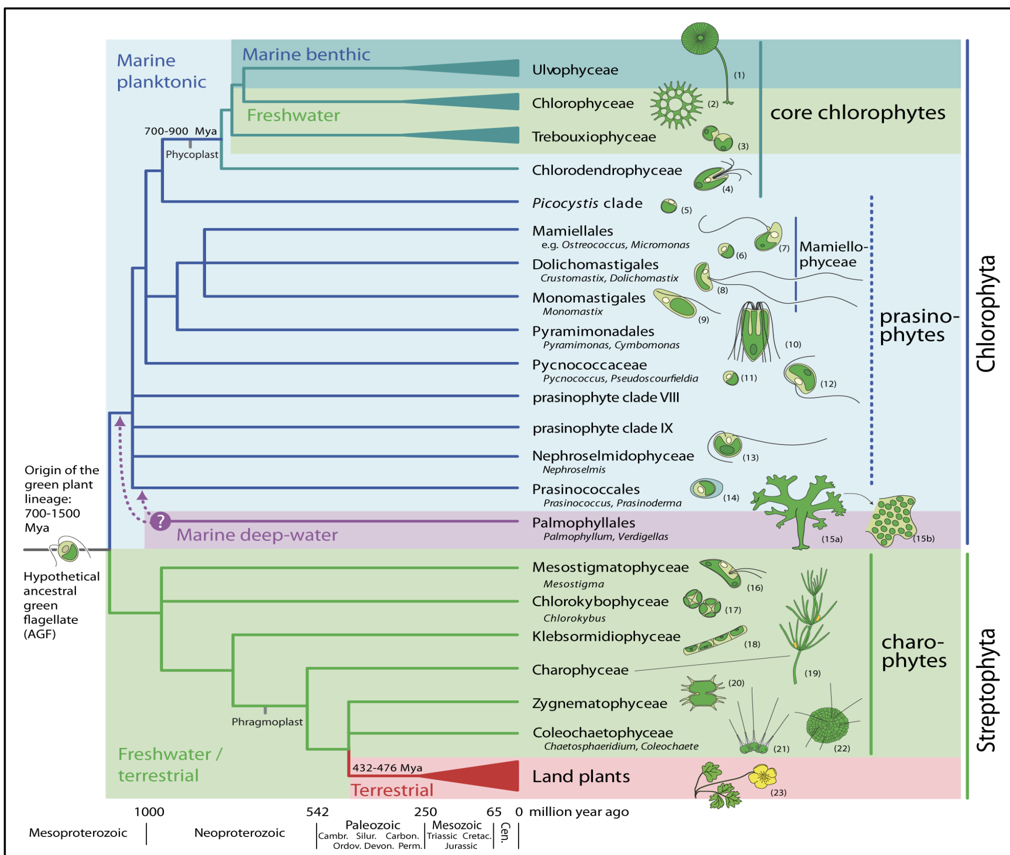

Figure 1. Deep phylogeny of freshwater and marine, green algae. (Figure 1 *in* Leliaert et al [2011], BioEssays 33: 683-692).

Algae store some of the sugar produced in photosynthesis as lipids. These lipids can then be removed from the cell and converted to **biodiesel** through a process known as **transesterfication** (Figure 2). Biodiesel has many of the same qualities of petroleum-based diesel and can be used in existing diesel engines with few modifications.

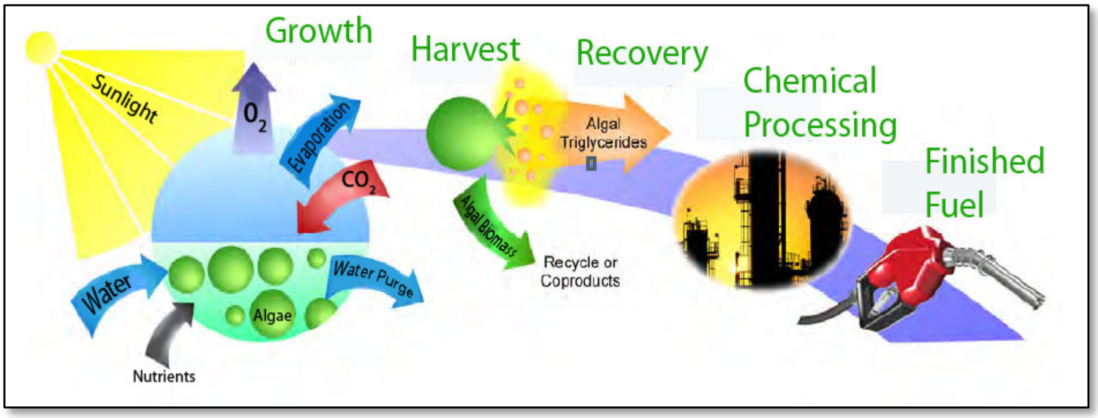

Figure 2. The process of converting algae to biofuel (National Academy of Science [2012]. Sustainable development of Algal Biofuels in the United States, National Academic Press, Washington, D.C.).

Microalgae require sunlight, carbon dioxide (CO_2), nitrogen, phosphorus, and a significant amount of water to grow. However, they do not require agricultural land space to grow, meaning they can be grown on land that is marginal and/or unsuitable for conventional agriculture. Algal production systems, such as **raceway ponds** and **photobioreactors**, can be constructed in deserts to obtain lots of sunlight, along coastlines to be near water sources, and/or next to factories or coal-fired power plants to harvest and incorporate waste CO_2 – a greenhouse gas – into the "algal pipeline" that would otherwise be released into the atmosphere (Figure 3).

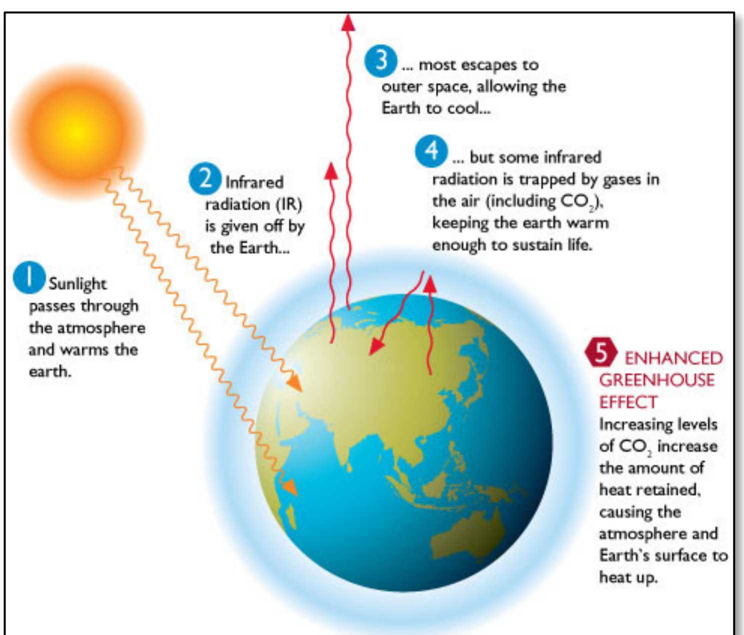

Figure 3. The greenhouse effect: the role of carbon dioxide (CO_2) and other greenhouse gases (Courtesy of CO_2 Cooperative Research Centre; Barton, Australia)

Unlike corn, soybeans, and cane sugar, algae production does not require food crop production. Moreover, regarding their culture and production, they have several advantages over competing, biofuel crops (Table 1).

Characteristic	Advantages
Rapid growth rate	Outgrow competing species; reduced culture area
High Oil content	Value of biomass increases with increasing oil content.
Growth in extreme environment	Reduced risk to contaminating bacteria or competing algae
Large cell size, colonial or filamentous morphology	Easy harvest and process
Wide tolerance of environmental conditions	Can readily control culture conditions
CO_2 tolerance and uptake	CO_2 sequestration and use of waste CO_2
Tolerance of shear force	Cheaper pumping and mixing methods
Tolerance of contaminants	Potential growth in polluted water
No excretion of autoinhibitors	No growth inhibition at high densities (exponential growth dependent upon culture conditions and time).

Table 1. Characteristics and associated advantages of microalgae grown for biofuel (Griffiths and Harrison [2009], Journal of Applied Phycology 21:493-507)

Scientists, chemists, and engineers are currently working on ways to optimize algae growth to make algae production more sustainable – see Figure 4, below, for a brief stroll along a proposed "algae-to-biofuel pipeline." For example, algae are now being grown in saltwater and wastewater and the nutrients are being recycled. Even with these improvements, a gallon of algal biodiesel is still very expensive. To lower the cost of production, the byproducts are being sold to make protein-rich animal feed, fertilizer, and biogas that can then be used to produce a source of energy.

Although these benefits are enticing, there are still many hurdles for scientists and engineers to overcome before algal biofuel can compete on the market with petroleum-based fuel. The **energy return on investment** must increase, meaning the amount of energy we gain from algae production must be higher than the amount of energy needed to produce the algae, or the system will not be profitable or environmentally sound. Scientists are currently working toward the sustainable production of algal biodiesel by researching many algal species and varieties within species known as **strains**, and their optimal growing conditions. They are working to improve algal strains so they will produce more oil and require lower levels of nutrients. BTI scientists are currently using **biotechnology** to develop algae that grows rapidly and produces more oils in less time. There is no perfect solution to our energy needs, but with some improvements, algal biofuel may be one important piece of the puzzle.

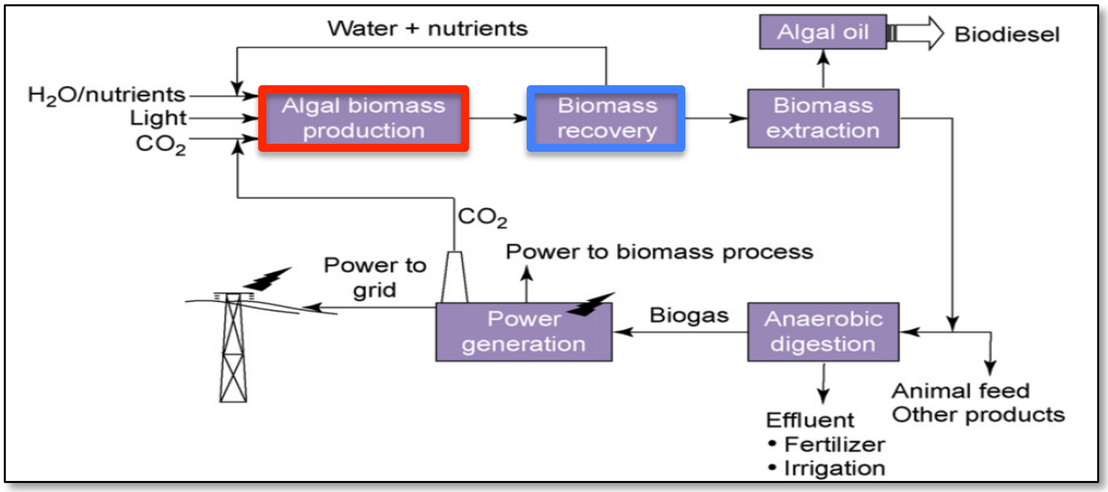

Figure 4. Schematic representation of the conceptual "algae to biodiesel pipeline" (Figure 1 in Chisti [2007], Trends in Biotechnology 26:126-131). The focus of your photobioreactor laboratory – highlighted in RED – is to optimize alga growth, and hence, overall biomass recovery (BLUE). Water, inorganic nutrients, carbon dioxide (CO_2), and light are provided to algal cultures, and cells within the liquid media are separated from the water and nutrient in the biomass recovery phase. The latter nutrients and water are then captured and returned (recycled) for use in the growth of subsequent generations of algae. From recovered algal biomass, TAGs (oils) are extracted and separated for conversion to biodiesel and other bioproducts.

Key Scientific Vocabulary

Algae
Photosynthetic plant-like organisms known as protists. They contain chlorophyll, are fast growing, and can live in fresh, salt, and waste water. Some types of algae, like Chlorella, are unicellular and microscopic, while others, like seaweed, are multicellular and macroscopic.

Biotechnology
Manipulation and development of biological organisms, their processes, systems and components to make useful products, and/or understand basic biological processes, often by means of genetic engineering.

Biodiesel
A biodegradable transportation fuel that can be used in diesel engines. Biodiesel, a fatty acid methyl ester, is produced through transesterfication of oils or fats from plants or animals.

Energy Return on Investment
Ratio of the amount of energy gained from a system to the amount of energy put into the production. An energy return on investment of less than one (when energy out is divided by energy in) the system would be considered not sustainable

Photobioreactor
An enclosed vessel used to grow algae where sunlight, water, carbon dioxide and nutrients are regulated. This system promotes the growth of high concentrations of algae and high oil yields that can then be converted into biodiesel and other products.

Photosynthesis
The chemical process by which organisms convert carbon dioxide into sugars, using the energy from sunlight.

Protists
Eukaryotic organisms, often unicellular and microscopic, sharing certain characteristics with animals, plants and/or fungi.

Raceway Pond
An open system where algae is grown in large ponds outside that are mixed. Algae concentrations in these systems are typically not as high as in photobioreactors, but the energy required to maintain the system is typically lower than the energy required to maintain photobioreactors.

Strain
A variety of species that is relatively uniform genetically because of continued inbreeding and artificial selection. Certain characters appear in successive generations as a result of inbreeding or self-fertilization, creating varieties within a single species that share similar, but unique genetic backgrounds.

Sustainability
The economic, environmental, and social stability of a practice, when considering meeting the needs of present and future generations. This is sometimes evaluated in a cradle to grave analysis.

Transesterification
The main reaction for converting oil to biodiesel, a chemical process by which lipid molecules are broken and rearranged using catalysis.

Yield
The amount of ending material derived during a process.