Teacher Background Information
"Making Fuel from Algae" Lesson Plan

1. **Fossil Fuels**

- Fossil fuels are a finite resource including coal, oil, and natural gas. These were produced from materials such as algae and woody biomass that were continuously buried millions of years ago by newer layers of sediments. The materials were not exposed to oxygen and were warmed by intense heat from the Earth's core and pressure from sediment layers above.
- Coal is recovered by mining, oil is recovered by drilling, and natural gas is recovered by hydraulic fracturing (fracking). These processes affect the ecosystems both near and potentially far from where the mining and drilling activities occur.
- Fossil fuels release greenhouse gases when burned, which increases the total atmospheric concentration of greenhouse gases because these gases are being produced at a much faster rate than they are being cycled back underground again.
- Fossil fuel reserves (fuels currently available) will likely last another 100 years at the current rate of use. Fossil fuel resources (which can become available will further technological advances) are enough to last hundreds of years.
- Fossil fuel use contributes to climate change [rising temperatures, changes in local climate (wetter/drier seasons, harsher storms), sea level rise, ocean acidification]
- About ~80% of world energy consumption is from fossil fuels

2. **Renewable Energy**

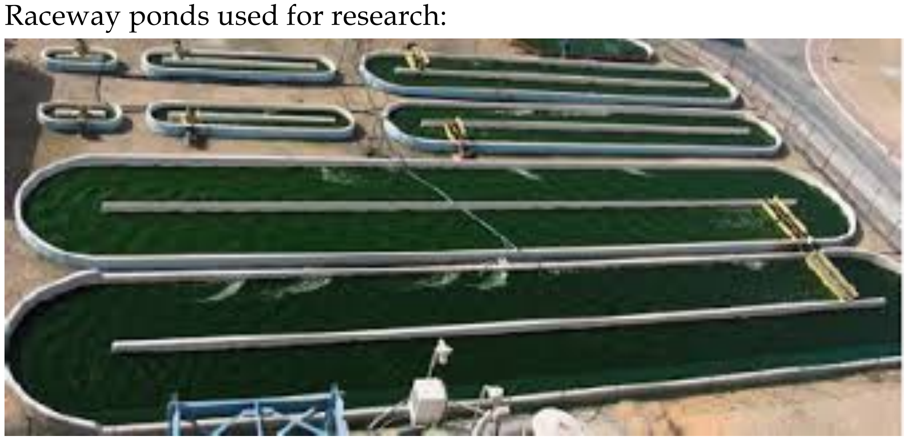
- Renewable energy sources include wind, solar, geothermal, hydroelectric, nuclear, and bioenergy.
- Bioenergy = energy produced from living things
- Examples of bioenergy sources: crops such as corn and sugar cane whose sugars are used to make ethanol; crop wastes whose cellulose is used to make ethanol; soy beans and other crops whose oil is used to make biodiesel; organic wastes which are digested anaerobically to make biogas (methane source).
    - Bioenergy is regarded as carbon "neutral" because the organisms (or organic wastes) took in carbon dioxide by photosynthesizing during their lifetime. The carbon dioxide that is emitted when bioenergy is burned is theoretically the carbon dioxide that was taken in during the plant's lifetime. However, carbon dioxide emission can occur during the processing stages that create the bioenergy fuel, so the entire process is not actually carbon-neutral.

3. **Algae Biofuel Advantages**

- Algal biofuels are a type of renewable bioenergy because they are made from living organisms that can be grown over and over again. The most common biofuel made from algae is biodiesel, which is made from the lipids in algae, but other parts of the algae can be used to make other fuels, such as ethanol from carbohydrates/sugars.
- Compared to other crops that are grown for biofuels, algae biofuels have several advantages:
    - They do not require arable land (land that can be used for agricultural crops), so do not compete with or reduce the supply of food crops
    - They can be grown year-round (in warm, sunny climates)
    - Algae have a higher oil yield (gallons per acre per year) than other oil crops (for example, soy beans)
    - Algae do not require freshwater (can be grown in sea water and wastewater) so do not put a burden on freshwater supplies, which are becoming more scarce in southwestern U.S. states
    - Algae can divert carbon dioxide emissions from power plants to use for growth
    - In addition to oils, algae can be used to make numerous co-products including animal feed, fish feed, food dyes, and nutrient supplements

4. **What are algae and how are algae grown to make biofuels?**

- Algae are photosynthetic eukaryotes that are classified as microalgae (single-cell, microscopic algae) and macroalgae (seaweeds). The term "algae" is an umbrella term describing many diverse organisms with different taxonomic classifications. Algae biofuels can be made from both micro- and macroalgae, but most of the time we refer to algal biofuels made from microalgae.
- Algae need light, carbon dioxide, water, and nutrients (including nitrogen, phosphorus, vitamins, and minerals) to grow
- Algae are cultivated to two alternative systems, termed "reactors"
    - Open pond reactors, such as raceway ponds, are shallow outdoor systems that are open to the environment.
        - Raceway ponds used for research:



- Photobioreactors are systems that are entirely closed around the algae culture so that nothing can get inside. For example, these can include flat panels, clear tubing, and hanging plastic bags.
  - Example of plastic bag photobioreactors:

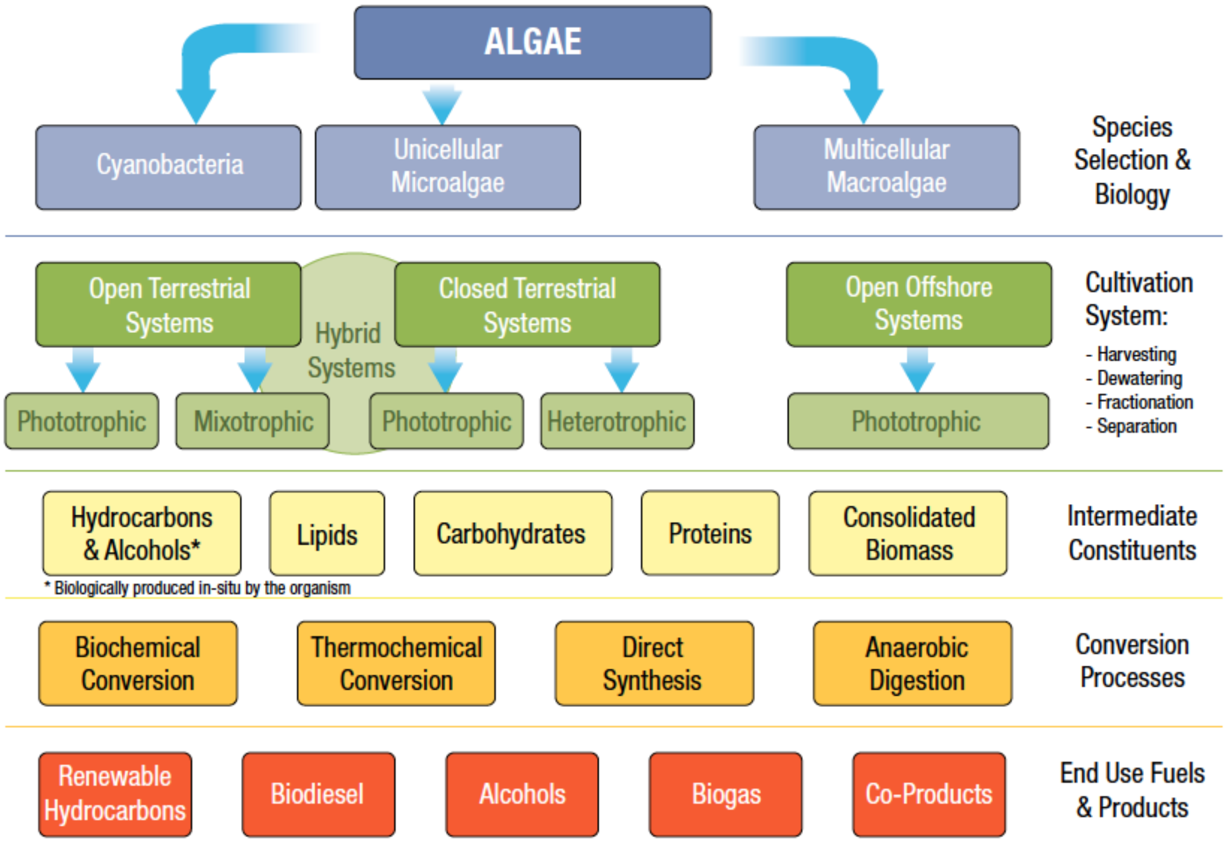
- There are benefits and drawbacks to both growth systems, but open ponds are generally regarded as cheaper and therefore more feasible for large-scale cultivation. Below is a table comparing open and closed reactors for growing algae[1]:

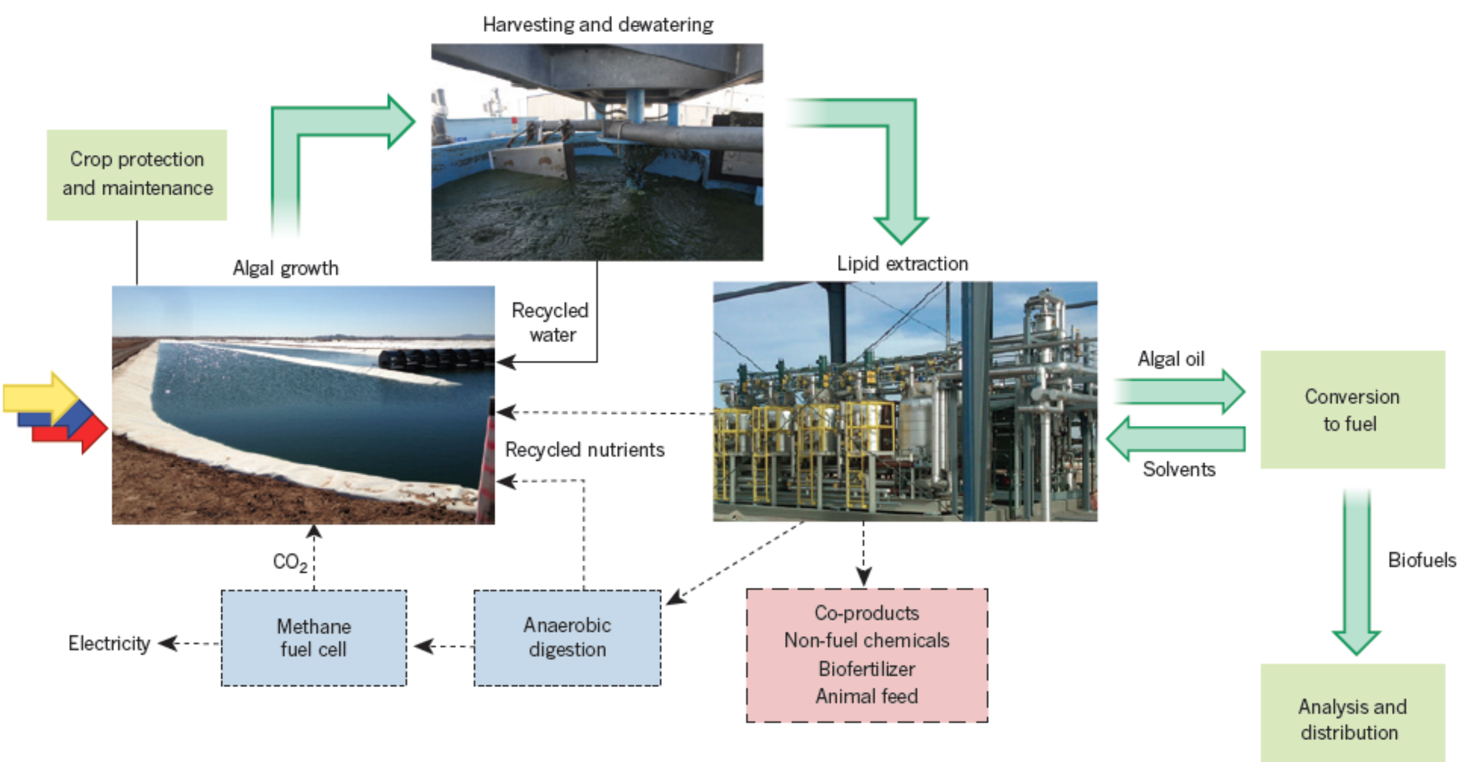
Exhibit 3.1 *Comparative features of microalgal cultivation approaches*

		ADVANTAGES	CHALLENGES
Photoautotrophic Cultivation	Closed Photobioreactors	• Less loss of water than open ponds • Superior long-term culture maintenance • Higher surface to volume ratio can support higher volumetric cell densities	• Scalability problems • Require temperature maintenance as they do not have evaporative cooling • May require periodic cleaning due to biofilm formation • Need maximum light exposure
	Open Ponds	• Evaporative cooling maintains temperature • Lower capital costs	• Subject to daily and seasonal changes in temperature and humidity • Inherently difficult to maintain monocultures • Need maximum light exposure

- Algae must be grown in areas with year-round temperatures and light intensities that can support fast algae growth. Facilities must also be near sources of seawater or wastewater, and a source of carbon dioxide emissions.
- The cell components of algae that are used to make fuels include lipids and carbohydrates. These are carbon storage compounds, and algae store carbon in these compounds when they are "stressed" due to lack of nutrients. Therefore, algae are nutrient-starved before they are harvested so that they will accumulate these carbon storage compounds.
- After cultivation, algae are harvested from the reactors by various methods that are currently being researched and optimized. These can range from simple settling to the bottom of the reactor, filtration, centrifugation, and more.

- Algae are then processed which includes removing excess water, extracting cell components of interest, and then converting these cell components into fuels and other co-products by various means as depicted in the flow diagrams[1,3] below:





5. **Algal Biofuels: Research Needs**

- Algal biofuels are not commercially viable yet because in most cases the costs are greater than the revenue, and the fossil fuel energy used to produce algal biofuels is greater than the energy in the algal biofuels produced (return on investment is less than 1 for both money and energy)
- Some of the major research developments needed to improve the feasibility of algal biofuels:
    - Identify undiscovered algae strains with promising features for biofuel production: high fat/oil accumulation, ability to handle fluctuating environmental conditions, easily harvested by simple and low-cost methods, fast growth rate, efficiency of nutrient use, not easily susceptible to viruses and predators
    - Genetically engineer algae so that they acquire the traits listed above
    - Optimize physical processes for algae growth, such as light penetration in ponds or photobioreactors where algae are grown, and mixing the algae
    - Reuse the water and nutrients from growth medium after the algae are harvested to grow a new batch of algae that will achieve equal productivity as the original batch
    - Use wastewater and carbon dioxide emissions to grow algae without the algae accumulating potentially harmful substances
    - Choose and optimize algae harvesting process (e.g., settling, filtration, centrifugation)
    - Assess how algae biomass and fuels will perform under different transport and storage conditions
    - Determine optimal locations for algae biofuel facilities by considering temperatures, light intensity, rainfall, proximity to sources of seawater/wastewater and carbon dioxide emissions, and non-arable land where algae growth reactors can be built

7. **Who is researching and developing algal biofuels?**

- Academic institutions all around the world, with many types of researchers including biologists, economists, computer scientists, chemists, biochemists, environmental engineers, chemical engineers, biological engineers, civil engineers, physicists, and more
- In the U.S., national government laboratories such as the National Renewable Energy Laboratory and Sandia National Laboratories
- Start-up companies such as Cellana, Solazyme, Algenol, and Sapphire Energy

Sources and additional resources:

1. Algal Biofuels Roadmap, U.S. Department of Energy, 2010. Available at: http://www1.eere.energy.gov/bioenergy/pdfs/algal_biofuels_roadmap.pdf

2. Algal Biofuels Fact Sheet, U.S. Department of Energy. Available at: http://www1.eere.energy.gov/bioenergy/pdfs/algalbiofuels.pdf

3. Exploiting diversity and synthetic biology for the production of algal biofuels. *Nature* 488, 2012. Link: http://www.nature.com/nature/journal/v488/n7411/full/nature11479.html

4. Making Biofuel from Microalgae. American Scientist. 2011. http://www.americanscientist.org/issues/feature/2011/6/making-biofuel-from-microalgae

5. Biofuels - Basic Information. US EPA. 2013. http://www.epa.gov/ncea/biofuels/basicinfo.htm

6. Algae: The Scum Solution. Neil Savage. Nature Outlook. 2011. Article included in student HW reading packet.

7. Personal blog posts in Duke University blog “Fuel for Thought” with additional resource links in posts

Using wastes for algae growth
http://blogs.nicholas.duke.edu/fuelforthought/one-mans-trash-is-another-mans-algae-food/

Applying agricultural principles to algae growth
http://blogs.nicholas.duke.edu/fuelforthought/algae-farming/

The risks and rewards of genetically modifying algae for biofuel production
http://blogs.nicholas.duke.edu/fuelforthought/green-foreigners/

The obstacles of predators getting into outdoor algae cultures
http://blogs.nicholas.duke.edu/fuelforthought/dealing-with-microscopic-cows/

Does algae diversity help algae biofuel production?
http://blogs.nicholas.duke.edu/fuelforthought/does-algae-diversity-help-algae-biofuel-production/

More questions?
Feel free to contact me at sarah.loftus@duke.edu for questions, comments, and additional sources.

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