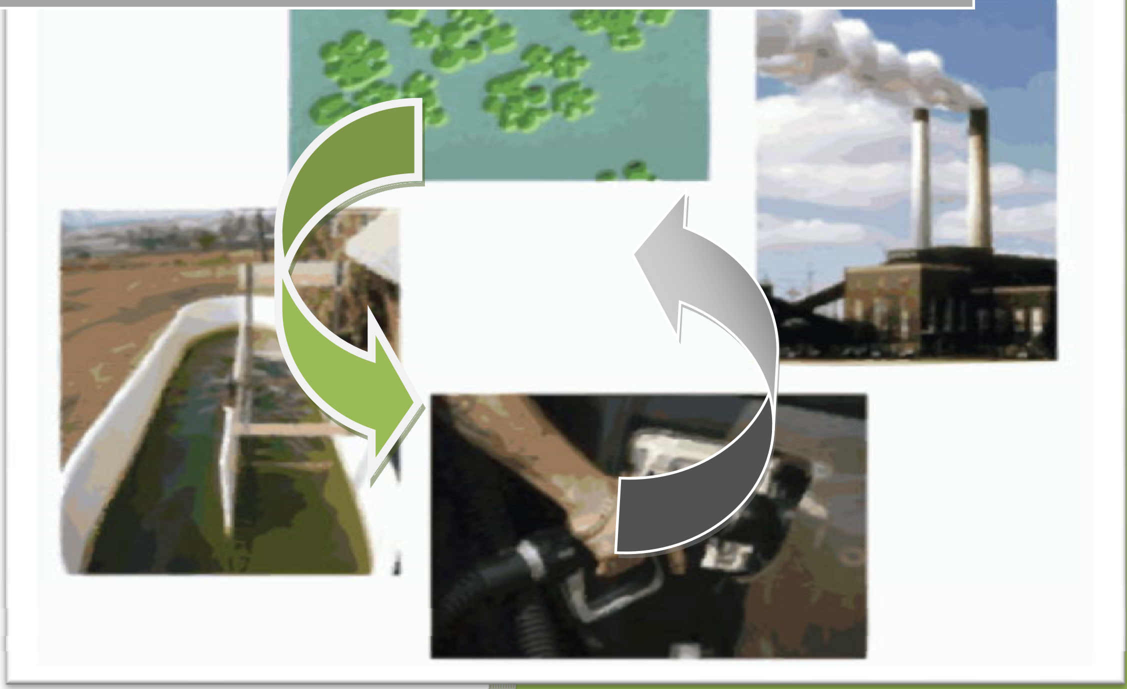
Fall 2010

Illini Algae Project Final Report



Derek R. Vardon & Prof. Lance Schideman

University of Illinois at Urbana-Champaign

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1. Project Summary

The Illini Algae Project was commissioned in the spring of 2008 to demonstrate algae bioenergy production and pollution mitigation technology and to promote educational outreach and public engagement in sustainable energy practices. These goals have been accomplished through efforts by students and faculty at the University of Illinois, members of the *Water Environment Federation* and *Engineers Without Borders* student organizations, technicians at Abbott Power Plant, and staff at the Illinois Sustainable Technology. In pursuit of these goals the following objectives have been accomplished:

1.1 Algae cultivation and biofuel production has been achieved through the use of a modular algal growth and harvesting system that supplies biomass for biofuel conversion. The growth system has been designed for year-round operation at Abbott power plant and the university greenhouse facilities. At Abbott power plant, the reactors utilize a coal-boiler flue gas delivery system recently installed by plant technicians. Algal biomass produced on site is then processed at the Illinois Sustainable Technology Center to extract oil used for conversion into biodiesel by the *Engineers Without Borders* student organization or delivered to researchers in the Department of Agricultural and Biological Engineering for direct conversion under hydrothermal conditions into biocrude oil.

1.2 Research involvement and technological advancement has been achieved through student-led independent study projects and collaboration with the Illinois Sustainable Technology Center. Independent study projects were conducted by Derek Vardon, Anna Oldani, Oliver Hui, Alex Valvasorri, and Ben Kuo from the departments of Civil and Environmental Engineering, Agricultural and Biological Engineering, Chemistry and the Illinois Math and Science Academy. Their experiences were showcased at the university's *Undergraduate Research Symposium* and *WaterCAMPWS* summer REU program. The project has also served as a springboard for auxiliary research projects. A $15,000 contribution was provided by BioAlternative, a local biodiesel company, for research into algal lipid extraction technologies and $35,000 was recently contributed by a private donor to determine the feasibility of algae for residential black-water remediation and bioenergy production. The project's student lead, Derek Vardon, has also received fellowship support for five years by the National Science Foundation and Environmental Protection Agency to continue algae biofuel and pollution remediation research.

1.3 Educational outreach and public engagement has been provided through the construction of an educational website, *Algae.Illinois.edu*, and public demonstration exhibits. The website has been operational since the summer of 2009 and incorporates interactive material that highlights the potential of algae for biofuel production and pollution mitigation. The site hosts informative webcasts that cover topics ranging from basic algae biology to recorded seminars on the latest algae bioenergy research at the University of Illinois. In 2010 alone, the site has already received over 1,583 visits, 4,884 page views, with an average time on site of 3 minutes and 10 seconds from over 55 countries (usage data tracked by Google Analytics). Demonstration tours on algae biofuel production have also been provided to Chicago-land high school students from the *World Youth Science & Engineering* (WYSE) and *Researchers and Pioneers* (RAP) program and graduate students from the university's *Center for Advanced Bioenergy Research* (CABER) program.

2. Algal Cultivation

The core mission of the Algae Biofuel Facility is to demonstrate the latest technology and research for cultivating algae for bioenergy production and pollution remediation. This task is accomplished by dividing efforts into four primary areas including 1) algae cultivation and growth monitoring 2) biomass harvesting and dewatering 3) biofuel conversion 4) and educational outreach and public engagement. The latest efforts in these areas are summarized below:

2.1 Inoculation & Growth Monitoring

Algae cultivation serves as the starting point for biofuel production and pollution remediation. Strains of algae are selected based on their growth rate, lipid content, and ability to sequester carbon dioxide and wastewater nutrients. Species selected for the project include *Chlorella vulgaris, Nannochloropsis,* and *Scenedesmus Dimorphis* that were obtained from commercial and academic phytoculture facilities. Culture discs embedded with cells are inoculated into 2-L laboratory vials and subsequently scaled to 20-L containers after a 10-day growth period (Figure 1).

Figure1. Algal strains are received on culture discs and scaled over a 10-day growth period into 2-L and 20-L laboratory flasks.

Algal cell growth is tracked using a variety of methods depending on the degree of accuracy required. Growth monitoring methods include cell counts with visible microscopy, chlorophyll density with a multi-plate fluorometer, and optical density using a spectrophotometer. Cultures are also monitored for the presence of invasive species to ensure optimum health. Additional parameters pertinent to biofuel production and pollution remediation are tracked including dry weight, ash content, neutral lipid accumulation, carbon dioxide concentration, and dissolved nutrient levels (Figure 2).

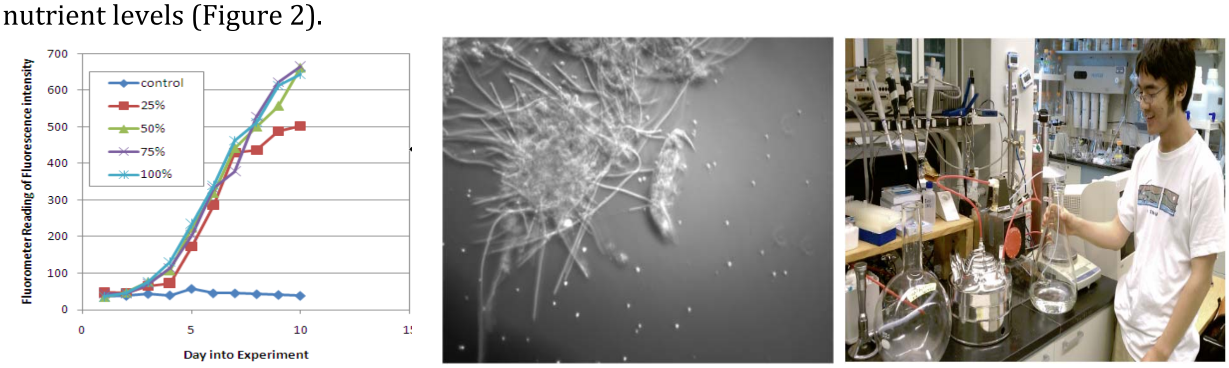

Figure 2. Growth parameters are tracked to determine cell concentrations (left), the presence of invasive species (middle) and dissolved nutrient levels (right).

2.2 Modular Algal Bioreactor Design

Algae cultures maintained in the lab are scaled-up for biofuel conversion using a series of modular bioreactors designed for project site mobility and expandable capacity. The reactors were purchased from Aquatic Ecosystems located in Tampa, FL and are constructed out of semi-transparent fiber glass for maximum light penetration and durability. Each reactor holds 200-L and is capable of producing between 100-1000 grams of algae per day (based on a density of 1-10 g/l and a daily harvest rate of 1/2 the reactor volume) as shown in Figure 3. For indoor applications, bottled carbon dioxide is blended with atmospheric air using a rotary-vane air pump with equivalent suction and discharge pressure. At Abbott power plant, the incoming gas line can be switched from bottled CO_2 to waste flue gas depending on the coal-fired boiler's operational status. The gas is then diverted using a throttling manifold and individually metered to each tank using adjustable flow meters. The tank pH is monitored and controlled using a digital pH meter coupled to a solenoid valve. As elevated dissolved CO_2 levels increase and cause the pH level to drop, the solenoid valve shuts to bypass CO_2 through a bleed-off line. During their growth, algae consume the dissolved CO_2 causing the pH level to increase, reopening the solenoid valve and resuming gas delivery.

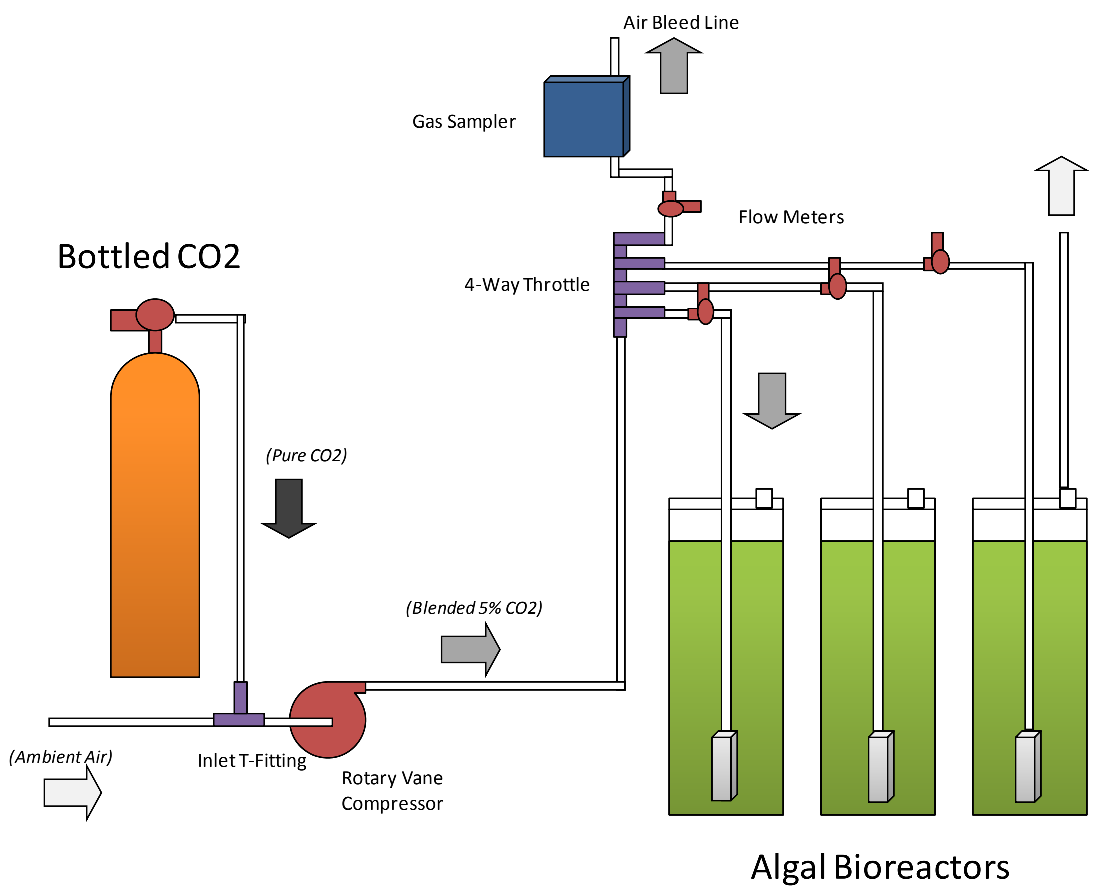

Figure 3. Schematic for modular algae bioreactor and gas delivery system that is designed for expandable capacity and enhance site mobility.

The modular design of the algae bioreactor system allows for year-round operation since the tanks can easily be relocated from Abbott Power Plant to the university greenhouse on Goodwin Ave during fall and winter months (Figure 4). The mobility also facilitates ongoing research and improves public access and visibility throughout the year.

Figure 4. Additional site locations for the modular algal bioreactors include the Agricultural and Biological Engineering courtyard (left) and university greenhouse facilities (middle and right).

3. Biomass Harvesting

Algae grown in the modular bioreactor system are then harvested and dewatered prior to lipid extraction for biodiesel conversion. Cells are harvested using techniques applied in wastewater treatment and include the addition of chemical flocculating agents and use of a membrane filtration system. Methods are selected based on the downstream biomass processing conditions.

3.1 Flocculation & Membrane Filtration

Chemical flocculation and membrane filtration are two prevalent methods used in the wastewater industry for separating biomass solids from incoming water streams. During flocculation, chemicals added to the suspension form charged ions that cause algal cells to clump together and coagulate (Figure 5). The large cellular conglomerates can then settle out of solution and be collected using large pore filtration assemblies. While flocculation is an effective method, the chemicals are adsorbed to the biomass, limiting downstream applications for animal feed and fertilizer.

Figure 5. Algal cells can be harvested from the modular bioreactor system (left) using chemical flocculating agents that cause the cells to aggregate (middle) and settle rapidly out of solution (right).

Algal cells can also be harvested from the bioreactor system using membrane filtration systems which alleviate the need to add additional chemicals. The membrane filtration modules are constructed out of micro-porous tubes that allow water to pass through the material while retaining suspended cells (Figure 6). The tube surface is continuously sparged with air to prevent cells from adhering to the membrane and blocking pore channels. The culture water can also be recycled back to the bioreactor system to utilize nutrients for future growth cycles and minimize water consumption.

Figure 6. The membrane harvest unit (left) consists of a series of micro-porous tubes bound together (middle) that allow water to pass through while retaining the algal cells. The water can then be recycled for future growth cycles (right).

3.2 Biomass Dewatering

Once the algal cells have been harvested, the resulting concentrated slurry still contains greater than 90% moisture and must be further concentrated and dewatered prior to lipid extraction for biodiesel production. Excessive moisture limits the extraction solvent's ability to permeate through the cell walls and solubilize lipids during extraction. Therefore, the harvested cells are further concentrated using a batch centrifugation process to produce cell pellets. The pellets are spread thin and dried in a convection oven to less than 5% moisture (Figure 7).

Figure 7. The harvested algal slurry (left) is further concentrated using batch centrifugation to produce cell pellets (middle). The pellets are then spread thin and oven-dried to <5% moisture prior to lipid extraction (right).

4. Algal Biofuel Production

Algae can be converted into biofuel through two processing routes 1) the moist biomass can be dewatered and the lipids extracted for biodiesel conversion 2) the moist biomass can be converted whole into bio-crude oil through a hydrothermal conversion process. A summary of each method is provided below:

4.1 Lipid Extraction and Analysis

Lipids are extracted and analyzed from dewatered algae at the Illinois Sustainable Technology Center prior to biodiesel conversion. The dried algae cake is ground into a fine flake using a batch grinder to maximize the surface area during the extraction process. The ground algae flake is then loaded into a Soxhlet extractor which re-circulates the extraction solvent to minimize solvent consumption and maximize lipid recovery (Figure 8). The solvent is then recovered from the lipid extract using a turbo-evaporator and recycled for future use.

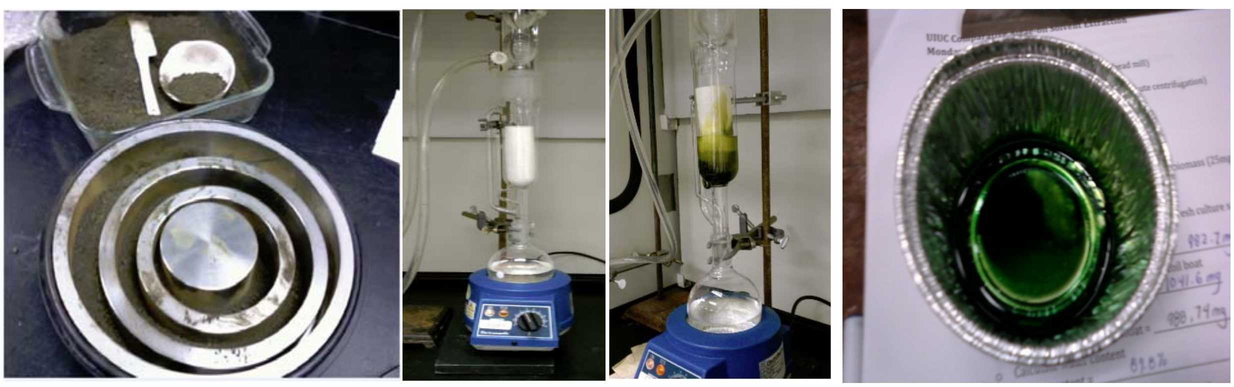

Figure 8. The dried algae cake is ground into a fine powder (left) to maximize the surface area and extracted using a Soxhlet solvent extractor (middle). The solvent is recovered for future use and leaving behind the extracted lipids (right).

Lipids extracted from the algae flake are then analyzed to determine their chemical composition and quality for biodiesel conversion. Depending on the strain selection and environmental growth conditions, algae can be produce a wide range of lipid compounds well-suited for biofuel, nutraceutical, or food processing applications. Data are collected to provide feedback for the cultivation process and to determine the effect of environmental variables on downstream processing applications. The composite lipid extract is separated into neutral, glyco-, and phospho-lipid fractions using solid phase silica extraction cartridges. The compounds present in the various fractions are further classified using high performance lipid chromatography as shown in Figure 9. After analysis, extracted lipids are then delivered to the *Engineers Without Borders* student organization for conversion into biodiesel.

Figure 9. The composite lipid extract is separated into neutral, glyco-, and phospho-lipid fractions using solid phase extraction cartridges (left). The chemical compounds in each fraction are further identified using high performance liquid chromatography (middle and right).

4.2 Hydrothermal Conversion

Project members are also collaborating with researchers from the Department of Agricultural and Biological Engineering to convert high-moisture algal biomass directly into biocrude oil using a hydrothermal liquefaction process. Hydrothermal liquefaction is a promising route for biofuel production since the entire biomass is broken down into biocrude oil under high pressure and temperature with water as the reaction solvent (Figure 10). Since the conversion takes place under aqueous conditions, it bypasses the need to dewater the algal biomass and further reduces energy and water consumption. While this process is still under development, the Illini Algae Project has provided a platform to highlight and demonstrate this promising technology.

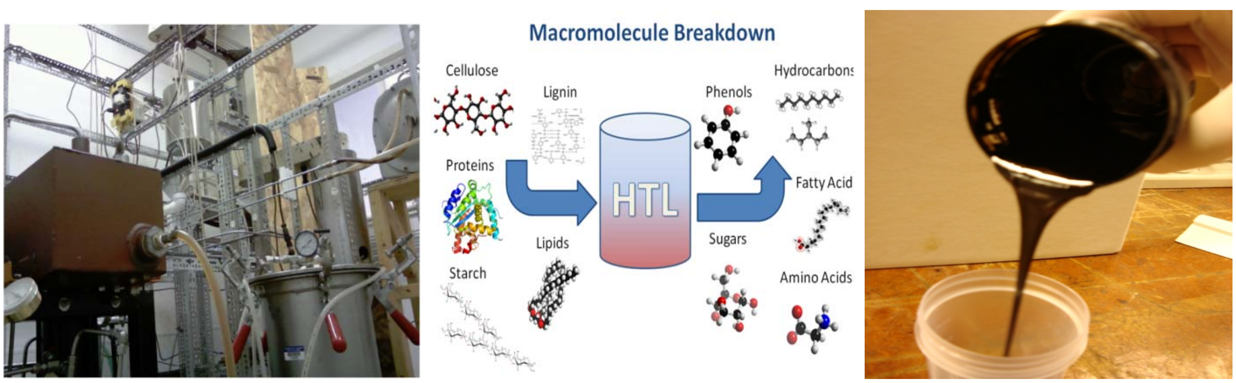

Figure 10. High temperatures and pressures are maintained during hydrothermal liquefaction (HTL) to breakdown biomass macromolecules into bio-crude oil using water as a reaction medium.

5. Implementation at Abbott Power Plant

Our project highlights the ability to grow algae using waste flue gas from coal combustion at a demonstration site located on the south-side of Abbott Power Plant. The sites hosts modular bioreactor units during summer months and carbon dioxide is supplied by sampling the flue gas exhaust from the coal-fired boilers. The system setup is described below.

5.1 Flue Gas Delivery System

Flue gas is sampled from the coal-fired boilers using a rotary vane air pump, cooled to ambient temperature by circulating the gas through a water-cooling barrel, and delivered to the algal bioreactors (Figure 11 & 12). The flue gas sample line was installed during the spring of 2010 and the necessary electrical connections and weather-proof enclosure were finalized during the summer of 2010 (Figure 13). Due to the intermittent operation of the coal flue stack, bottled CO2 cylinders are currently being installed to allow for continuous operation. Plans are also underway to tap into the natural-gas flue stack to allow for uninterrupted operation on waste flue gas.

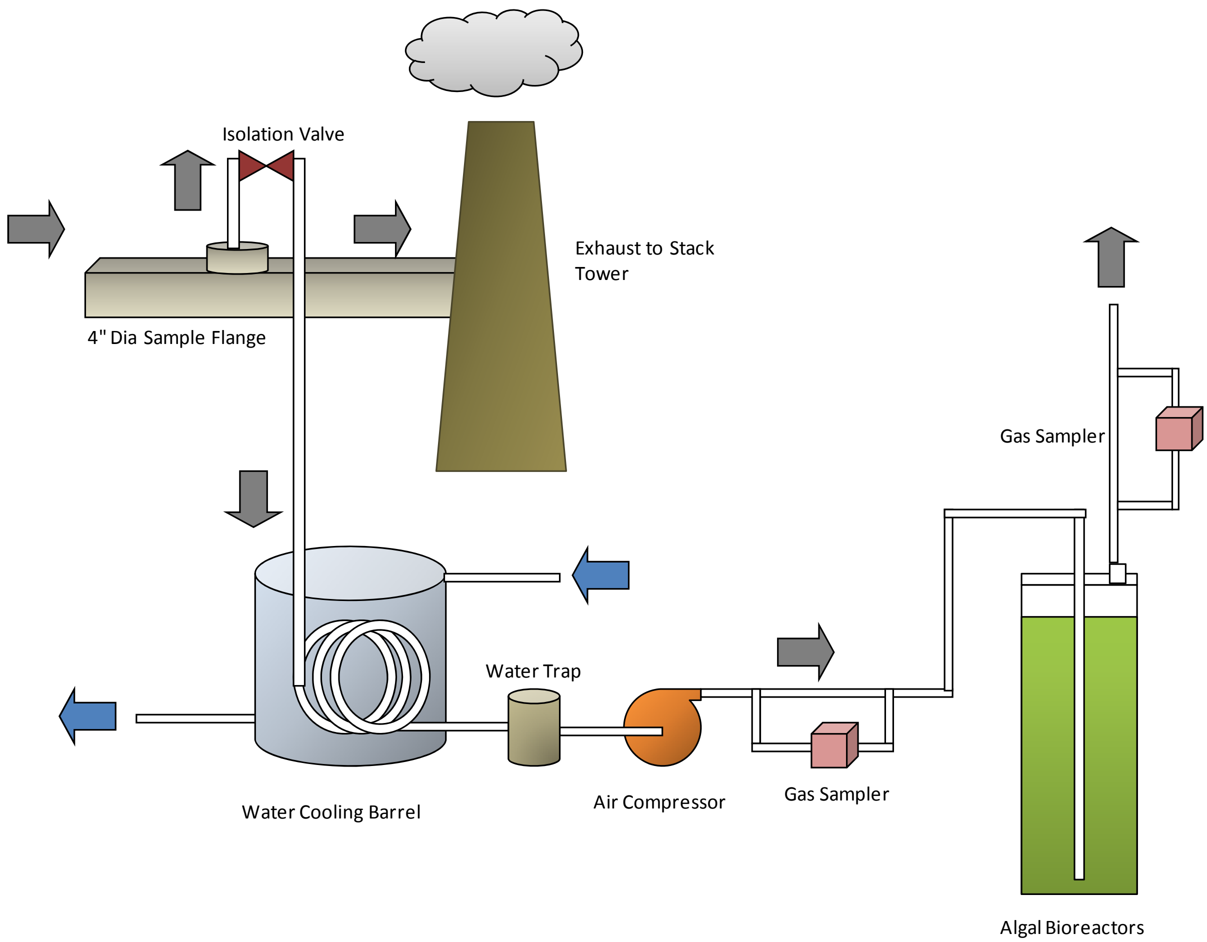

Figure 11. Schematic of Abbott Power Plant flue gas sample and delivery line for algal cultivation. Flue gas is sampled from the coal-fired boilers, cooled down to ambient temperature, and pumped to the modular reactor system.

Figure 12. The gas sample line taps into the coal-boiler exhaust stack (left) and is cooled to ambient temperature (middle) before being delivered to the modular bioreactors (right).

5.2 Algal Biomass and Culture Water Testing

This summer, a preliminary trial run was conducted to determine the composition of the algal biomass and culture water aerated with coal-boiler flue gas to certify it's safety for disposal. The bioreactors were located above a containment basin to capture any culture water inadvertently released during operation. Flue gas was delivered to both a control and spiked bioreactor to determine trace metal concentrations, nutrient levels, and biochemical oxygen demand after a 14-day growth period. Both the control and spiked reactors contained negligible quantities of metals and were certified safe for disposal.

Figure 13. The installation of the weatherized electrical and gas control system was finalized over the summer of 2010 (left & center). The bioreactors were operated over a preliminary trial run (right) to certify its safety for disposal.

6. EDUCATIONAL OUTREACH & PUBLIC ENGAGEMENT

The Illini Algae Project has strived to raise awareness of renewable energy and pollution mitigation technologies and encourage student involvement in research and engineering. This has been accomplished through student-led independent study projects, the construction of an interactive educational website, and involvement in educational outreach activities described below.

6.1 Independent Study Projects

Through independent study projects, students involved with the Illini Algae Project have been able to explore in-depth areas related to renewable energy and pollution mitigation. Topics have ranged from designing a modular algal bioreactor cultivation system, exploring novel lipid extraction and dewatering technologies, developing chemical characterization techniques for profiling algal lipids, and implementing a digital carbon dioxide monitoring and data collection system. These projects were conducted by Derek Vardon, Anna Oldani, Oliver Hui, Alex Valvasorri, from the departments of Civil and Environmental Engineering, Agricultural and Biological Engineering, and Chemistry.
Even at the high school level, the project has supported student involvement through the *Water CAMPWS* summer research program. Ben Kuo, a high school student from the Illinois Math and Science Academy, conducted an 8-week research experience testing the feasibility of wastewater for supporting algal growth and assisting with the Abbott power plant demonstration site. Findings from their experiences have been showcased at the university's *Undergraduate Research Symposium* in the spring of 2010 and *WaterCAMPWS REU* program in the summer of 2010.

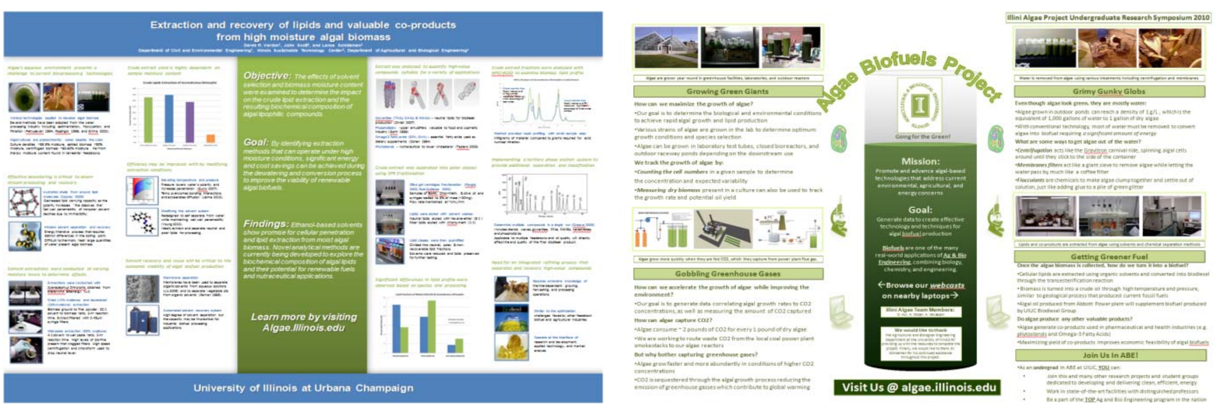

Figure 14. Student independent projects were showcased at poster presentations during the *Undergraduate Research Symposium* in the spring of 2010.

The project has also served as a springboard for auxiliary research projects. A $15,000 contribution was provided by BioAlternative, a local biodiesel company, for preliminary research into novel algal lipid extraction technologies and $35,000 was recently contributed by a private donor to determine the feasibility of algae for residential black-water remediation and bioenergy production. The project's student lead, Derek Vardon, has also received fellowship support for five years by the National Science Foundation and Environmental Protection Agency to continue algae biofuel and pollution remediation research at the University of Illinois.

6.2 Educational Website - *Algae.Illinois.edu*

The project has strived to reach a global audience through the educational website, *Algae.Illinos.edu,* which was launched in the summer of 2009*.* The site hosts informative information on algae cultivation, biomass harvesting, biofuel conversion, and carbon sequestration (Figure 15). Additionally, webcast videos are posted that cover topics ranging from the basics of algal biology to recorded seminars on the latest algae bioenergy research at the University of Illinois.

Figure 15. The project hosts an education website, *Algae.Illinois.edu,* that highlights the potential of algae for bioenergy production and pollution remediation.

The site also serves as a coordination hub for the Illini Algae student organization and hosts the group's photos, blog and event calendar. In 2010 alone, the site has already received over 1,583 visits, 4,884 page views, with an average time on site of 3 minutes and 10 seconds from 55 countries (usage data tracked by Google Analytics as shown in Figure 16).

Figure 16. Usage data for the website is tracked using Google Analytics to obtain information on the number of visitors, page views, popular content and country of origin.

6.3 Public Engagement

The project has also engaged the public in renewable energy production and pollution remediation practices through demonstration exhibits and local press releases. During the spring of 2010, members coordinated with graduate students from the university's *Center for Advanced BioEnergy Research* (CABER) program to construct an integrated food digester, methane generator, and algae carbon capture-bioenergy exhibit for Engineering Open House. Renewable energy tours that highlight the potential of algae are also provided annually to high school students from the Chicago-land area *World Youth Science & Engineering* (WYSE) and *Researchers and Pioneers* (RAP) program through the Department of Agricultural and Biological Engineering. Project efforts were also highlighted this year in news articles by the Daily Illini and Mother Nature Work.

Algae could be used as gas alternative in next 10 years

BY BRYNN TWAIT
STAFF WRITER

In the near future, people could be filling up their cars with biofuels made from algae.

Lance Schideman, assistant professor of agricultural and biological engineering, said certain kinds of the seaweed can be turned into biodiesel, which has some advantages over corn-based ethanol. Schideman will give a lecture on the topic Monday at 4 p.m. in the ACES library.

"The basic idea with algae is that some algae have a high lipid (fat) count, which can be turned into biodiesel," Schideman said. "One area where we've made some progress is making algae into a biocrude product via hydrothermal process (pressure-cooking), when we can convert the non-oils into oils," Schideman said.

He added that biodiesel does not require changes to a vehicle's engine, like ethanol does. It is also more energy-dense, containing an estimated 20 percent more energy, he said.

"Algae can grow very fast, so the productivity is faster than corn or other possibilities to biofuels," Schideman said. "(It) can be grown on water bodies, so it doesn't compete for prime agriculture land."

He added that it can grow in both fresh and salt water, even if the water is polluted.

However, there are some limitations to using algae as a fuel.

"One is that you must have high-oil algae (to convert to fuel)," Schideman said.

Another problem is that there are two general categories: algae closely related to plants and bacterial algae, said Manfredo Seufferheld, assistant professor of crop sciences who studies the plant's biology. Bacterial algae is easier to cultivate, he added. Some plant-like algae have a tendency to have more oils than bacterial algae, and some of the fastest-growing algae are not high in oil, Schideman said.

Getting rid of the water that the algae grows in is also a problem, but pressure-cooking is a good way to get around this. Pressure-cooking the algae produces self-separating oil, meaning it can be easily separated from the water Schideman said.

"For water removal, we looked at using flocculation, a chemical process that causes algae to flock together." said Derek Vardon, a senior in Engineering who researches the viability of algae as an energy source at the Abbott Power Plant.

"The other aspect of (limitations) is the biology of algae, because we are going to grow them in contaminated waters. Depending on the species, we need to know the requirements," Seufferheld said.

Seufferheld said he is trying to understand how the photosynthesis process for algae works and improve how the algae grow.

Yan Zhou, graduate student in agricultural and biological engineering, said she focuses on fast-growing algae and using waste water to grow it. As the algae is growing, it cleans the water and the air.

"We are enhancing the environment, while producing energy," Zhou said.

One advantage is that water used to grow fast-growing algae contains high nutrients, so nutrients can be recycled and money and water can be saved, Zhou said.

While there are some limitations, however, commercial use of an algae-produced biofuel might not be that far off.

"We could have some algae fuels in the next ten years," Schideman said.

"We are enhancing the environment, while producing energy."
YAN ZHOU, graduate student

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MNN.COM › STATE REPORTS › ILLINOIS › EM-J STAPLES'S BLOG

Algae blooms in research labs

Students and faculty involved in environmental engineering use green source for biofuel.

By Em-j Staples, Local Correspondent | Thu, May 20 2010 at 9:11 PM EST | Comments

SUBLIME SLIME: Students at the University of Illinois are transforming algae in biofuel. (Photo: Yhan Zou)

Figure 17. Project efforts were highlighted this year in articles by the Daily Illini and Mother Nature Network.

7. Conclusion

The Illini Algae Project has strived to positively impact the university's student body and surrounding community by demonstrating the potential of algae for bioenergy production and pollution mitigation, supporting student research involvement and technological advancement, and pursuing educational outreach and public engagement in renewable energy practices. These goals have been accomplished thanks to involvement from students and faculty at the University of Illinois, members of the *Water Environment Federation* and *Engineers Without Borders* student organizations, technicians at Abbott power plant, and staff at the Illinois Sustainable Technology Center. Support from the *Student Sustainability Committee* has made this possible and has promoted a better, cleaner, safer, lasting sustainable environment for the University of Illinois.

9. APPENDIX

9.1 History Timeline

9.2 Budget & Expenditures