VERMONT BIOENERGY INITIATIVE

A program of the Vermont Sustainable Jobs Fund

ALGAE

U.S. DOE Award #DE-FG36-08GO88182

ABOUT THE VERMONT BIOENERGY INITIATIVE

The purpose of the **Vermont Bioenergy Initiative** (VBI) was to foster the development of sustainable, distributed, small-scale biodiesel from oilseeds and algae and grass/mixed fiber industries in Vermont that would enable the production and use of bioenergy for local transportation, agricultural, and thermal applications. Our investments in feasibility analyses, research and development, and demonstration projects for various bioenergy feedstocks were intended to lead to their commercialization over 7 year time horizon. This initiative was a statewide market building approach to sustainable development that may be replicated in other rural states around the country.

As a grant-making entity, project manager, and technical assistance provider, the Vermont Sustainable Jobs Fund (VSJF) solicited and selected the best sub-recipient proposals for bioenergy related projects through a competitive Request for Proposal process and conducted a number of staff directed investigations, all designed to support the four key priorities of the U.S. Department of Energy's EERE Strategic Plan:

1.) Dramatically reduce dependence on foreign oil;
2.) Promote the use of diverse, domestic and sustainable energy resources;
3.) Reduce carbon emissions from energy production and consumption;
4.) Establish a domestic bio-industry.

Thank you to the office of U.S. Senator Patrick Leahy for securing three U.S. Department of Energy congressionally directed awards (FY08, FY09, FY10) to financially support the Vermont Bioenergy Initiative.

Learn more at

VERMONT BIOENERGY INITIATIVE

http://vermontbioenergy.com

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ALGAE SUMMARY

As described in the National Algal Biofuels Technology Roadmap, algal biofuel production is attractive due to the possibility of 1) high per-acre productivity, 2) non-food based feedstock resources, 3) use of otherwise non-productive, non-arable land, 4) utilization of a wide variety of water sources (fresh, brackish, saline, marine, produced, and wastewater), 5) production of both biofuels and valuable co-products, and 6) potential recycling of CO_2 and other nutrient waste streams.

As a small, rural, northern climate state with significant per-capita fossil fuel use, Vermont was interested in opportunities for displacement of large volumes of liquid fuels such as diesel and heating oil. The development of algal bioenergy feedstocks was pursued with VBI funding due to the potentially high area-specific yields of this approach and the possible nutrient and carbon conversion opportunities present when co-located with anaerobic digesters or landfills. The funding was focused on the development of locally possible solutions in close partnership with university and food system stakeholders.

The specific work completed through sub-recipient projects and VBI staff-directed initiatives focused on the following areas:

1) Feedstock Development
2) Production Systems
3) Harvest and Conversion Technology
4) Education and Outreach

The early stage results of this body of work include:

Feedstock Development

- A curated collection of one hundred (100) oil-rich native Vermont algal strains for commercial oil production and nutrient recovery were isolated and are being maintained in a purpose-built facility with ten (10) of these strains being classified as best performers.
- Several Vermont strains that were isolated were transferred to pilot research demonstrations at a closed landfill and at a dairy farm with an anaerobic digester.

Production Systems

- The integration of a pilot-scale algal biomass production system with an anaerobic digester demonstrated the use of waste CO_2 and nutrient (N and P) rich digester effluent.
- The integration of a pilot-scale algal biomass production system with a landfill power plant demonstrated the use of waste CO_2 sources and tolerance of algal production potential exhaust contamination (i.e., flue gas).
- An experimental platform was established to study the fluid dynamics of mixing and flow related to optimal algal biomass production systems at the University of Vermont School of Engineering.

Harvest and Conversion Technology

- A bench-scale photochemical algal fuel processing system was developed that is capable of producing biofuel more cost effectively and with less energy investment compared to standard oil extraction and transesterification.
- A bench-scale photochemical algal fuel processing system was developed that demonstrated production of a fuel with superior cloud point, pour point, cold filter plugging point, and heat of combustion when compared to fuel produced using transesterification.

Educational and Outreach Programming

- Educational materials related to algal bioenergy production specific to Vermont have been developed and published.
- A conference focused on algal bioenergy production in the Northeast was held to share research findings and strengthen the research network.
- A Vermont network of relevant stakeholders with interest in algal bioenergy has been established.

THE OPPORTUNITY

Algae as a bioenergy feedstock provides an attractive alternative to other biomass oil sources due to its differentiation as a non-food production system with high potential yields per acre and the ability to integrate with other agricultural and food system enterprises as a nutrient sink. Previous work has shown that integration of algal biomass production with waste treatment could be a cost-effective approach. Projected yield estimates approach 3,500 gallons of oil per acre in sunny, subtropical regions (National Research Council, 2012) compared to 70-100 gallons per acre from oilseed crop feedstocks. However, algae oil production at commercial scale is not yet a reality due to the challenges in cost-effective algal biomass production, harvest and separation (Ferrell et al., 2010).

Feedstock development via strain isolation was necessary in Vermont to select those strains with local vigor that are effective oil producers. The availability of robust oleaginous (i.e., oil producing) algae strains specifically relevant to algal bioenergy production was a key challenge noted at the start of the VBI. In the National Algal Biofuels Technology Roadmap, the U.S. Department of Energy (DOE) prioritized the isolation of new, native strains directly from unique environments (Ferrell et al., 2010). **Limited work had been done in the Northeast region on strain isolation and no work had been done in this area specifically in Vermont.** Importantly, no cost-effective and robust algal bioenergy production system integrated with nutrient rich waste streams has been developed for algal biofuel production with a positive energy return on investment. Most of the research done in algal production systems has generally explored open, surface water systems in warm climates that are distinctly different from potential production systems in Vermont.

Tightening state and federal water quality guidelines support the development of effluent capture and treatment systems such as anaerobic digesters. In 2012, Vermont enacted Act 148 as the *universal recycling* law for solid waste, which may lead to an increase in the number of anaerobic digesters in the coming years in order to take advantage of an additional load of nutrients to manage on top of existing dairy manure nutrients. In 2015, Vermont enacted Act 64, the most comprehensive water quality legislation in Vermont's history, creating new regulations and devoting more resources to reduce pollution from farms, The potential synergy of algal bioenergy production with wastewater treatment is therefore of particular interest given the prioritization of needed improvements in water quality and significant reductions in excessive nutrient loading of waterways. Another opportunity involves the integration of algal bioenergy production with CO_2 sources such as landfill gas fueled power plants. Additionally, the diversion of organics from landfills to digesters would add to the digester nutrient load as described in the Biogas Opportunities Roadmap (USDA, USEPA, USDOE, 2014).

An overarching challenge to algal bioenergy development is cost effective and energy efficient production methods and mechanisms. For example, ensuring optimal mixing and exposure to light are critical for algal biomass production and these both require careful design and attention to energy use.

Harvesting algae and oil separation in order to prepare the feedstock for conversion to biodiesel fuel remains a challenge for commercialization of algae systems. While some in-situ conversion methods have been explored in the literature they remain mainly undeveloped and are seen as a potential game-changer in this area.

Based on the limited level of algal research in Vermont and other northern climates, the VBI prioritized research efforts focused on the unique challenges of these areas. In addition to specific strain isolation, the intention of our sub-recipient projects was to explore new processes and patentable approaches that could advance algae bioenergy in Vermont and in other parts of the country at a scale not possible locally.

STATEMENT OF PROJECT OBJECTIVES

The Vermont Sustainable Jobs Fund, through its Vermont Bioenergy Initiative, made a series of grants to sub-recipients in the area of algal bioenergy focused on research and development, production systems, and education and outreach (Task D).

To address the question of algal bioenergy as a viable option for Vermont, this project pursued four objectives:

1) **Feedstock Development:** To curate collections of local algal strains with commercially desirable traits.

2) **Production Systems:** To explore integration of algal production systems with existing agricultural infrastructure (e.g. anaerobic digesters on dairy farms) and landfills. In addition, researchers explored fluid dynamics related to algae production.

3) **Harvest and Conversion Technology:** To explore novel approaches to producing drop-in fuel replacements from algal feedstocks.

4) **Education and Outreach:** To integrate algae research into conferences, field day, and undergraduate educational platforms..

Task D: Algae Feedstock Analysis and Production Techniques

SUB-TASK D.1: RESEARCH

The objective of this task was to provide sub-recipient award funding to researchers, entrepreneurs, and others to experiment with the development of algae feedstocks that are adaptable to nutrient-rich waste streams and suitable for Vermont's colder climate. Research included how algae could interface with other Vermont-scale agricultural activities (e.g., anaerobic digesters and landfills).

- **Algepower:** The objective of the Algepower, a start-up business, was to quantitatively estimate increase in lipid production by the freshwater microalgae Chlorella vulgaris grown in a specially designed Algeponics™ system, and correlate with the nutrient recovery data.

- **GSR Solutions:** GSR Solutions, a research laboratory run by Dr. Anju Dahiya Krivov, investigated the use of robust high-lipid producing algae strains that could be grown in non-sterile environments (e.g., farm or industrial wastewaters) capable of capturing nitrogen and phosphorus from diverse waste streams.

- **Carbon Harvest (CHE):** The objective of Carbon Harvest, a start-up business, was to research the suitability of landfill gas combustion products as a supply of CO_2-rich flue gas for commercial algae cultivation.

- **University of Vermont, School of Engineering:** The objective of this project was to develop a testing facility that could be used by students and faculty in the School of Engineering at the University of Vermont to study novel methods for algae growth rate enhancement using different types of fluid mixing.

SUB-TASK D.2: LOGISTICS / PRODUCTION

The objective of this task was to provide sub-recipient award funding for algae feedstock logistics and new methods for optimizing production processes that fit the scale of Vermont farms and communities. Funding supported lipid optimization, harvest, dewatering, oil extraction, and refined oil and algal biomass research.

- **Green Mountain Spark:** The objective of Green Mountain Spark, a start-up business, was to investigate the feasibility of using photochemistry to create a single system for oil extraction from micro-algae and biofuel production from the separated oil.

SUB-TASK D.3: PROCESSING / DEMONSTRATION

The objective of this task was to provide sub-recipient award funding for demonstration projects (e.g., analysis of prototype for algal biodiesel production facility.)

- **No sub-recipients for this sub-task**

TABLE 1: VBI ALGAE BIOENERGY SUB-RECIPIENTS

Fiscal Year(s)	Sub-Recipient	DOE Funds	Total Cost Share	Total Project Cost
FY08	**Algepower:** Production Systems	$20,000	$5,606	$25,606
FY08-FY10	**Carbon Harvest Energy:** Production Systems	$233,349	$66,225	$299,574
FY08-FY10	**GSR Solutions:** Feedstock Development	$133,833	$106,244	$240,077
FY09	**Green Mountain Spark:** Conversion Technologies	$65,000	$33,651	$98,651
FY09	**University of Vermont School of Engineering:** Production Systems	$44,828	$24,673	$69,501
	TASK SUBTOTAL	**$497,010**	**$236,399**	**$733,409**

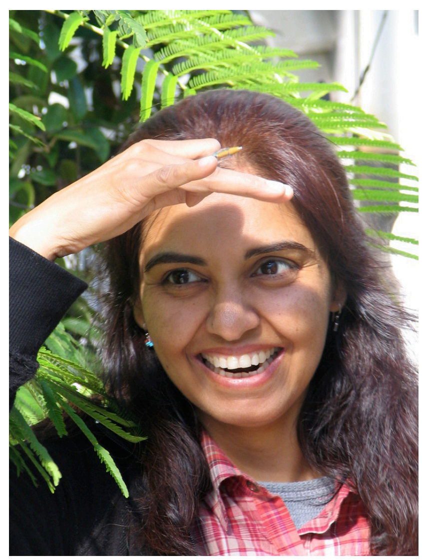
Feedstock Development

The VBI supported GSR Solutions in the isolation of oil feedstock producing regional strains. GSR Solutions investigated the use of robust high-lipid producing algae strains that could be grown in non-sterile environments (e.g., farm or industrial wastewaters) capable of capturing nitrogen and phosphorus from diverse waste streams. Cutting edge methods were used to isolate native strains and an algae culture collection facility was established. The best performing algal strains were scaled up for higher volume production in a greenhouse setting to represent the operational environment of a real world scenario such as a dairy farm or an industrial application such as a brewery.

With USDA Rural Development funding, a farm-scale pilot system was subsequently developed at Nordic Farms in Charlotte and the first large scale implementation is anticipated at the proposed Green Mountain Power community digester project in St. Albans. These projects, sited at dairy farms, could enable the demonstration and deployment of algal technologies in order to manage excess nutrients.

"The DOE support through the VBI helped GSR Solutions build cutting edge waste to energy technology utilizing the fastest growing plants on the planet, microalgae, to capture waste nutrients. By increasing our technology readiness level with supply chain and strategic partners we are gearing up to bring our technology to market for production of a range of innovative products from biofuels to fertilizer to animal feed."

—Anju Dahiya Krivov, President, GSR Solutions LLC



Dr. Anju Dahiya Krivov is a professor at the University of Vermont and principal of GSR Solutions.

Establishment of a Strain Collection Using Rapid High-Throughput Methodologies

GSR Solutions tested algal strain potential for lipid accumulation, nutrient recovery from wastewaters (nitrogen and phosphorus), carbon intake, and potential for byproducts including fertilizer manufacture. As part of this project, GSR Solutions isolated over 4,000 algal cells from different Vermont environments—ranging from farms, compost facilities, lakes, and rivers—and successfully collected over 300 strains found to have potential for lipid production. Out of these 300 strains, the 100 best performing strains were selected and are currently maintained in GSR Solutions' collection. All are capable of growing in different modes (i.e., photoautotrophic, mixotrophic, and heterotrophic).

Screenshots of the software infrastructure for algal biofuel project. Credit: GSR Solutions LLC.

GSR Solutions then screened the ten (10) best performing strains from this collection based on:

1) high growth,
2) high oil content,
3) uptake of nitrogen and phosphorus,
4) uptake of carbon, and
5) resistance to contaminants in the wastewater environment.

A statistical model of algal growth, including software infrastructure, was developed to support experimental design, data collection, and analysis. A rapid screening lipid quantification method was tested for lipids and nutrients analysis in order to obtain correlations between lipids contents and nutrients. Lipophilic dyes-based rapid screening methods using fluorescent lipophilic dye (e.g., Bodipy) were successfully implemented. This project also enabled GSR

Solutions to establish an algal culture collection facility in a laboratory setting where the isolated strains are being maintained. **One overall outcome of this activity is that a curated collection of one hundred (100) oil-rich native strains for commercial oil production and nutrient recovery were isolated and are being maintained in a purpose-built facility, with ten (10) of these being classified as highest performers.**

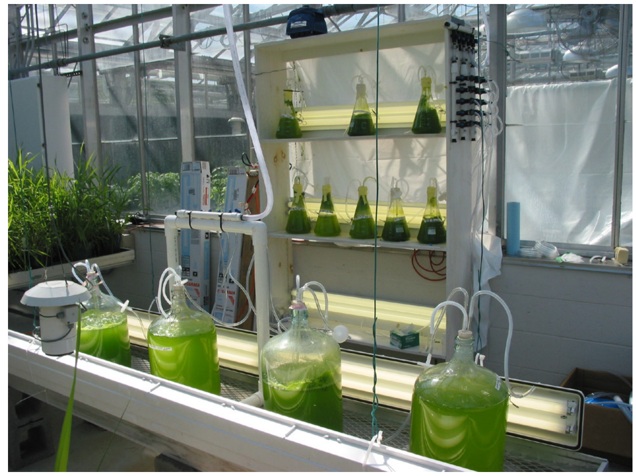
Development of High-performance Oleaginous Algal Growth in Vermont / Northeast

GSR Solutions undertook several algal biomass up-scaling experiments that used batch bioreactors of varying capacities (e.g., 2L to 80L), utilizing the algal strains isolated in the software noted above. The algal growth in the reactors was monitored and the biomass harvested was analyzed for lipid and nutrients (i.e., nitrogen and phosphorus) analyses. The best performing algal strains were successfully up-scaled utilizing waste nutrients.

These algal strains were cultivated for production of oil. The biomass was harvested and oil was extracted. The oil was analyzed for Fatty Acid Methyl Esters (FAME) in the form of

Native algae samples, University of Vermont, 2012. Photo credit: GSR Solutions LLC.

triacyl glycerols (TAG). Under controlled environmental conditions, the oil content ranged from 15% to 55% by dry weight with the most abundant fatty acids found to be C16:0 to C20:3. Algal biomass exceeded the benchmark production of 25 grams per square meter per day. On an acreage basis, GSR Solutions's selected proprietary strains under photoautotrophic (light-driven photosynthetic) conditions are predicted to produce over 3,800 gallons per acre per year of bio-crude (biofuel intermediate).



Algae inoculation lab, University of Vermont, 2012. Photo credit: GSR Solutions LLC.

Development of a Algal Biofuel Network

Over the project period, GSR Solutions has engaged in in-state networking efforts and brought together suppliers, processors, and potential end users of algal biofuel technology, including: Vermont Farm Bureau, National Biodiesel Board, Vermont Fuel Dealers Association, and Commercial Aviation Alternative Fuels Initiative. Nordic Farm (Charlotte, Vermont) has been engaged as host to the project.

Production Systems

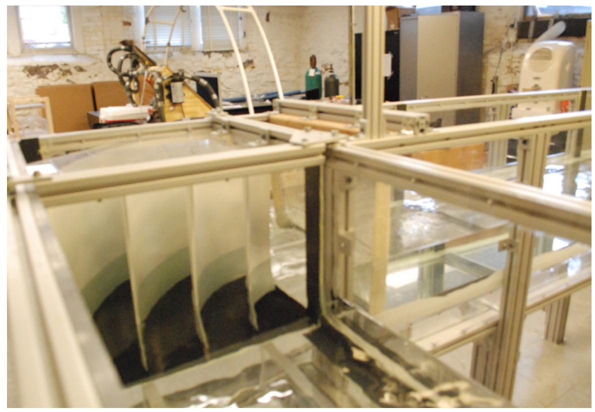
To address the need for understanding and improving production systems, several projects were funded by the VBI. The VBI supported the research and development of a flume system at University of Vermont School of Engineering, and funding was also provided for research into commercially oriented production processes by Carbon Harvest Energy and Algepower.

UVM College of Engineering and Math Sciences – School of Engineering

The objective of this VBI-funded project was to develop a testing facility that can be used by students and faculty in the School of Engineering at the University of Vermont to study novel methods for algae growth rate enhancement using different types of fluid mixing. Mixing is an important aspect of algae production systems because it enables maximum utilization of incident light throughout the production system.

The facility developed with this funding, referred to as the "algae mixing test facility" or AMTF, will enable detailed examination of different fluid mixing approaches using state-of-the-art fluid flow instrumentation. It will also allow examination of the effect of fluid mixing on the growth rate of microalgae suspended in the fluid stream.

Overview of the flume filled with water. The lighting system suspended above the flume is not shown in this photo.

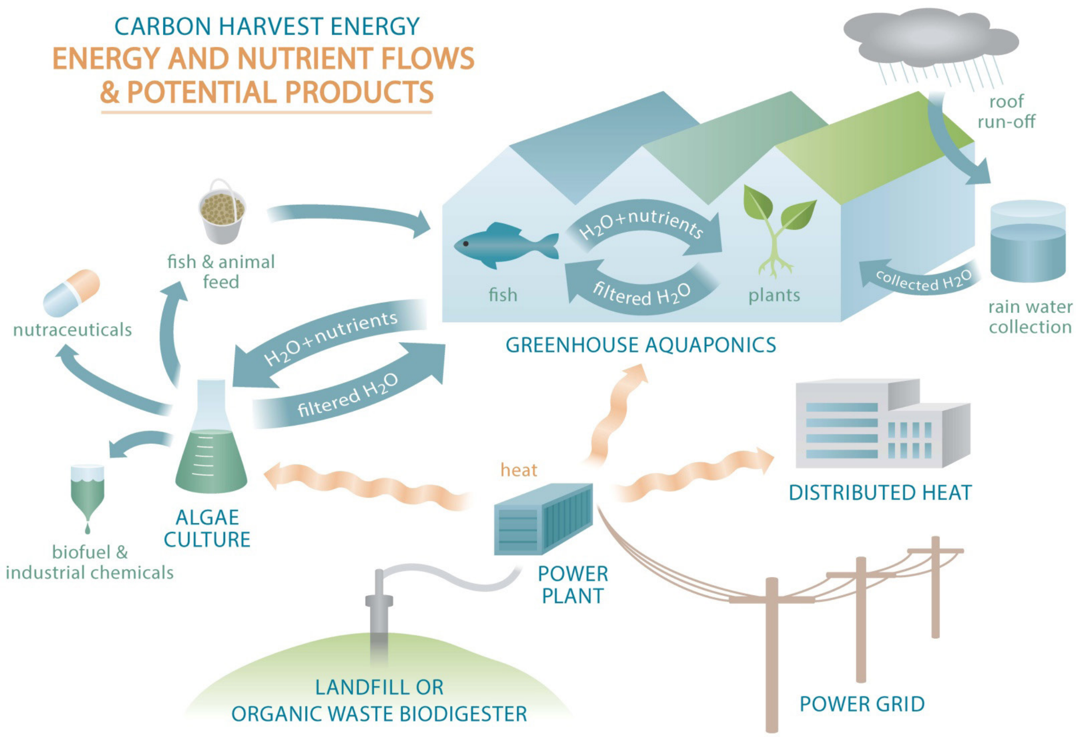


View of the flume showing guide vanes placed at the corner to minimize boundary layer separation.

Carbon Harvest Energy

In 2009, Carbon Harvest Energy (CHE) initiated a project to construct and operate a highly integrated sustainable food production facility. Using established technologies from aquaculture and hydroponics, CHE incorporated an underutilized source of energy and heat in the form of landfill gas (LFG) from the retired site of the Windham Solid Waste Disposal District, located in Brattleboro, Vermont.

CHE's plan was to develop a model/prototype, beginning with the use of a highly potent greenhouse gas (GHG)—methane—as fuel for a combined heat and power (CHP) generator.



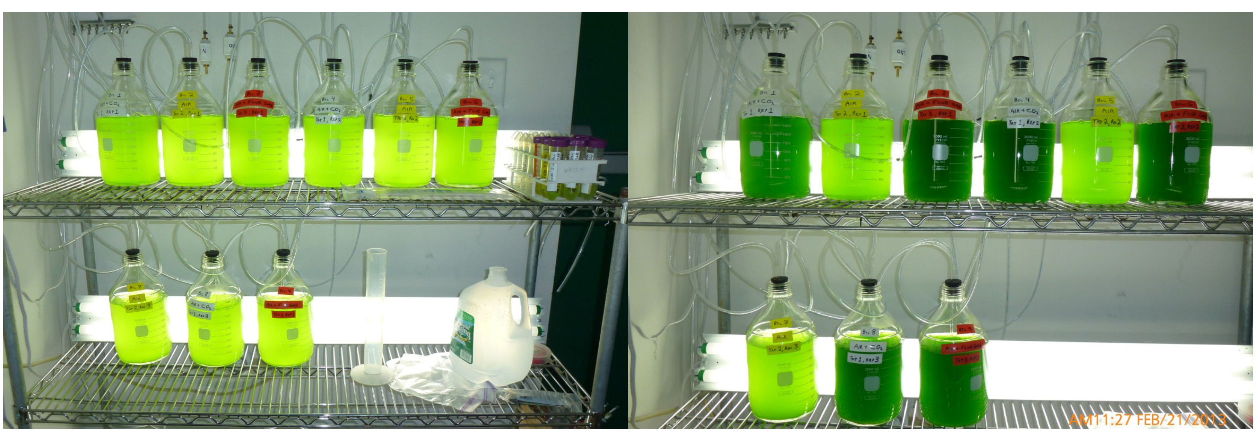
The Carbon Harvest closed loop concept.

Electricity produced by the generator would be sold to the grid, and heat from the generator would allow for the operation of an aquaponics greenhouse on a year round basis at a reduced cost.

The objective of the VBI-funded CHE project was to research the suitability of landfill gas combustion products as a supply of CO_2-rich flue gas for commercial algae cultivation. With VBI funding, CHE worked jointly with researchers at the UVM Rubenstein School Ecosystem Science Lab to explore the response of local algae strains to flue gas condensate from a landfill gas system. This project focused on three strains known to exist locally in Lake Champlain and also with potentially strong oil production characteristics. The strains were shown to tolerate a 1% concentration of flue gas condensate without significant impact to growth and production.

These preliminary benchtop results were leveraged to develop pilot trials in larger scale 2 ft x 4 ft "flat-bag" photobioreactors in order to measure the growth rates of two cultures in parallel and to explore lower cost nutrient mixes. In this second phase of work, tests were successfully conducted that introduced CO_2 rich flue gas to growth vessels with marked improvement in

Landfill gas take-off plumbing is shown in the foreground with the CHE greenhouses in the background.



Flue gas experiment shows the visual impact of differences in cell density between air plus CO_2 (white labels), air only (yellow labels), and air plus flue gas (red labels) at time of stocking (left) and 48 hours later (right).

Inoculating the CHE raceway.

growth rates and dry matter production. Importantly, these tests demonstrated that regardless of CO_2 source (flue gas or pure bottled gas) the growth rate impact was equivalent. Researchers were also able to measure reasonable fatty acid methyl ester production in the algae over time. This is a measure of the oil production in the algae. Additional work was done to quantify the heavy metal content of flue gas and the impact of it on algal biomass.

In the third and final phase of VBI-funded work, CHE produced a 9 foot x 38 foot algae raceway to demonstrate earlier work at a larger scale. The chief challenges noted in this phase had to do with structural design of the raceway, temperature control and light limitations. Biomass harvest was not conducted in this final phase due to production mass limitations.

The results of the flue gas experiments demonstrate that flue gas from combustion of LFG is quite suitable for use as a source of CO_2 for algae biomass production. The researchers concluded, however, that even in consideration of all the potential physical systems needed to maintain good environmental conditions for algae culture, and the theoretical economic value

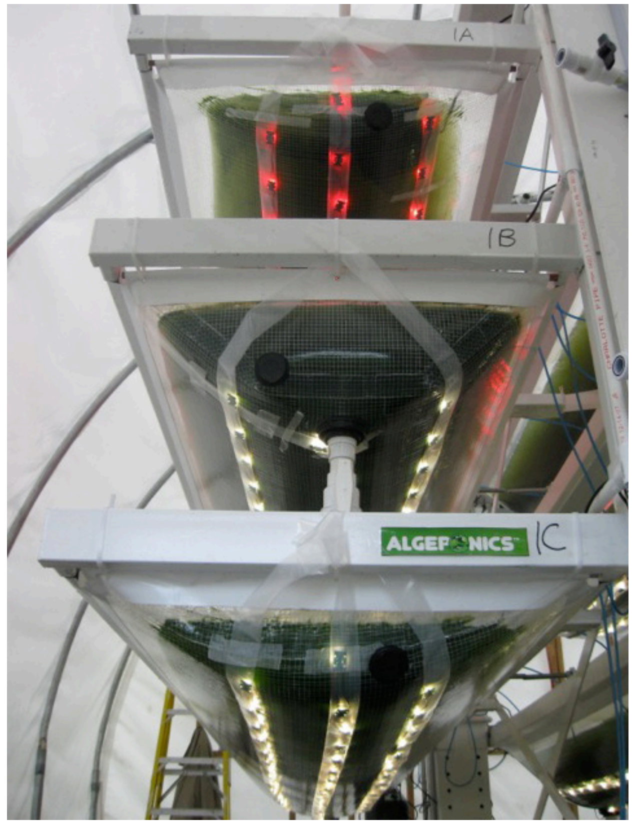
A view of the CHE prototype algae raceway and key components.

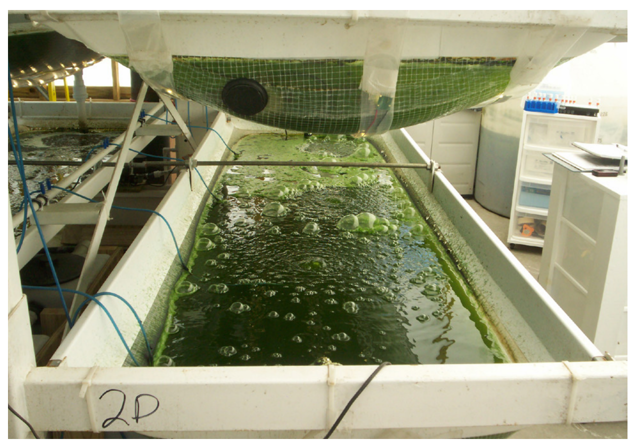
of reduced costs for power and CO_2 through use of LFG and flue gas, under current economic conditions, it is not feasible to grow algae in Vermont on a year-round basis for production of biofuel. However, given all of the specific conditions that need to be corrected, and assuming that it will eventually be possible to reasonably control problems with contamination, it could be possible to profitably produce algae biomass in Vermont for high-value bio-products such as astaxanthin, EPA, DHA, and various industrial chemicals. What will be necessary is to demonstrate that algae biomass produced for such purposes has a higher value on a $\$/ft^2/yr$ basis than competing vegetables which could be grown in the same greenhouse space.

Unfortunately, Carbon Harvest entered into Chapter 11 bankruptcy in April 2013 and the algae research they started was never completed.

Algepower

The objective of the Algepower project was to quantitatively estimate an increase in lipid production by the freshwater microalgae Chlorella vulgaris grown in especially designed Algeponics™ system, and correlate this with the nutrient recovery data. This project leveraged algal strain isolation work by GSR Solutions who provided the starting culture. The Algeponics™ system was developed to accelerate the onsite cultivation of algae in a pilot scale design, linked to an on-farm anaerobic digester at Blue Spruce Farm in Bridport, Vermont. This system was a photobioreactor designed to convert the main by-products of anaerobic digesters, CO_2, N, and P—into algal biomass and water—through photosynthesis and other biological processes. This project was not completed due to several technical challenges including difficulty with inoculation and initial growth and temperature control of the system, as well as insufficient funding to maintain the company's research and develoment.





Algepower prototype racks at Blue Spruce Farm in Bridport, Vermont.

Harvest & Conversion Technologies

The VBI funded a research project by Green Mountain Spark focused on a novel conversion process that avoids biomass separation, chemical inputs, and the time required when using traditional methods.

Green Mountain Spark

The objective of the Green Mountain Spark project was to investigate the feasibility of using photochemistry to create a single system for oil extraction from micro-algae and biofuel production from the separated oil. **The outcome of this research was an algae fuel processing system capable of producing biofuel more cost effectively and with less energy investment compared to standard oil extraction and transesterification.** The system also demonstrated production of a fuel with superior cloud point, pour point, cold filter plugging point, and heat of combustion.

Green Mountain Spark, LLC makes green diesel in Burlington, Vermont, 2012.

Green Mountain Spark, LLC holding a sample of green diesel produced by their prototype reactor.

A photochemical reactor was built to support the conversion algae feedstock and associated oil to diesel fuel, termed "green diesel." After reaction of the feedstock in the photochemical reactor, green diesel samples were collected until enough sample was available for a suite of biofuel property tests. These tests included cloud point, pour point, cold filter plug point, and heat of combustion (ASTM methods D445, D2500, D97, D6371, and D240, respectively). The results are shown in Table 2 below.

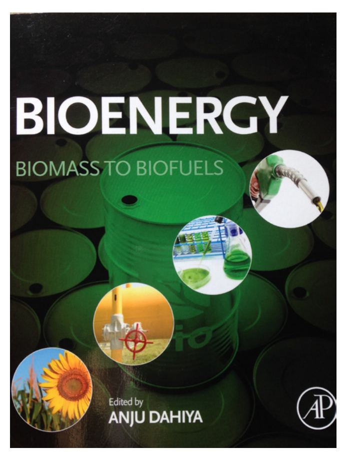
TABLE 2: COMPARISON OF GMS-1 FUEL PROPERTIES

Biofuel Type	Cloud Point (C / F)	Pour Point (C / F)	Cold Filter Plugging Point (C / F)	Heat of Combustion (BTU/lb)
GMS-1 Green Diesel	-27 / -16.6	-37 / -34.6	-22 / -7.6	18,344
Canola Biodiesel (Methyl Esters)	-4 / 24.8	-10.8 / 12.5	3.6 / 38.5	15,500
Canola Oil	0 / 32	-9 / 15.8	18 / 64.4	17,100
Diesel #2	-15 to -25 / 5 to -13	5 to -25 / 41 to -13	-6 to -12 / 21 to 10.4	19,300

The results from the GMS-1 green diesel biofuel clearly show a strong advantage in its cold flow properties compared to canola biodiesel (methyl ester), canola oil, and diesel #2. Specific highlights are the remarkable improvement in cold-weather fuel properties (i.e., lower cloud point, lower pour point, and lower cold filter plugging point), an important aspect of fuel use in the Northeast. Successful development of this technology will give microalgae oil biofuel producers a more efficient oil extraction and biofuel conversion process and lead to superior fuel properties. The work of this project resulted in a patent covering the process (Holmes & Wurthmann, 2016).

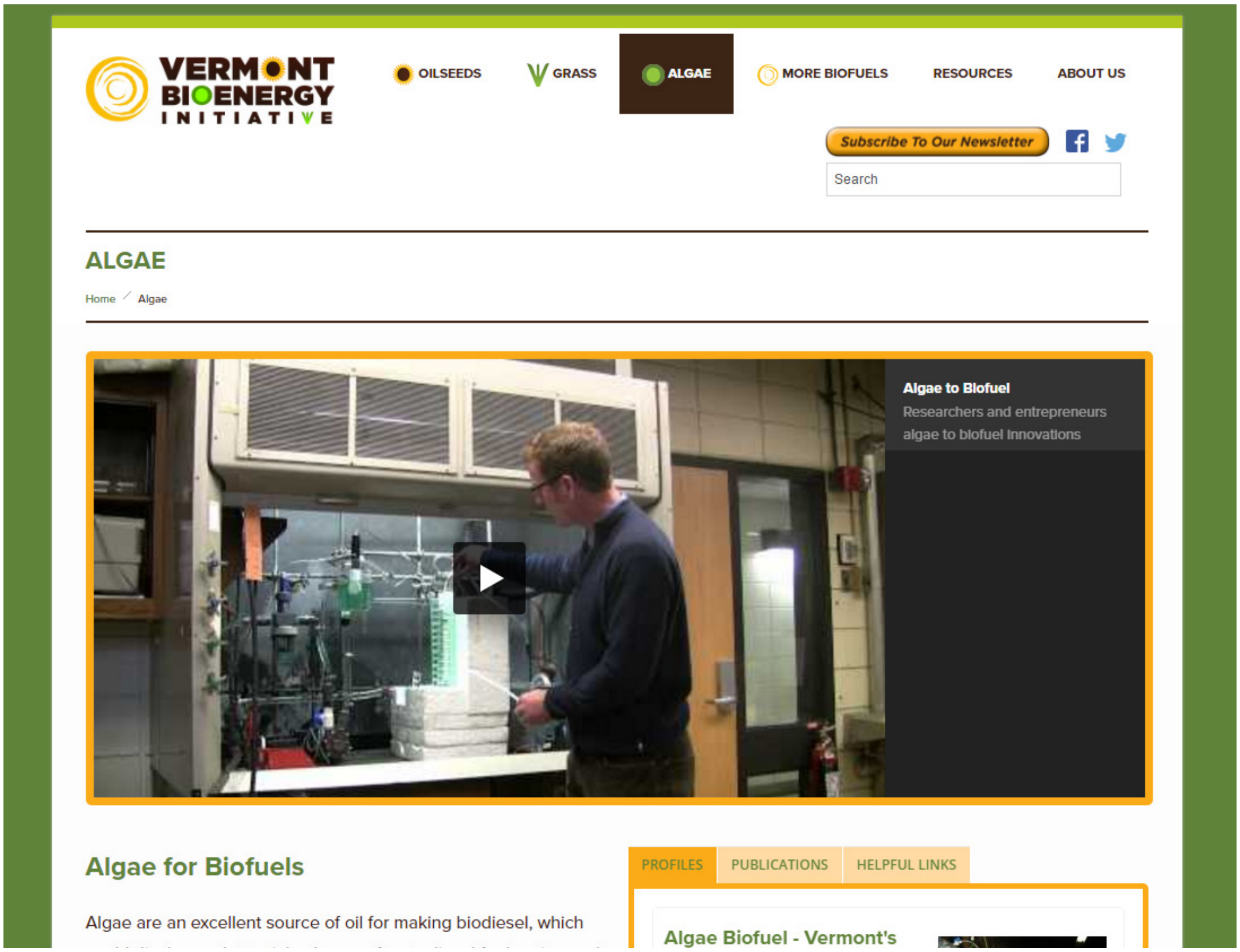
Educational and Outreach

A variety of algae bioenergy resources—including reports, videos, links, and photographs—were compiled on the Vermont Bioenergy Initiative website, including a Bioenergy Now! video—Algae to Biofuel—that continues to receive wide viewership (uploaded in 2013 with more than 27,000 views as of July 2016).



Dr. Krivov edited a Bioenergy textbook.

Several VBI-supported researchers and educators contributed to the development of a bioenergy textbook edited by Dr. Anju Dahiya Krivov, *Bioenergy: Biomass to Biofuels* (Krivov, 2014). The textbook examines current and emerging feedstocks and advanced processes and technologies enabling the development of all possible



The Vermont Bioenergy Initiative website is a repository of all materials and resources developed by VSJF and subrecipients, including a video on algae and bioenergy that has been viewed more than 27,000 times.

alternative energy sources: solid (wood energy, grass energy, and other biomass), liquid (biodiesel, algae biofuel, ethanol), and gaseous/electric (biogas, syngas, bioelectricity). Divided into seven parts, Bioenergy gives thorough consideration to topics such as feedstocks, biomass production and utilization, life cycle analysis, energy return on energy invested, integrated sustainability assessments, conversion technologies, biofuel economics and policy. In addition, contributions from leading industry professionals and academics, augmented by related service-learning case studies and quizzes, provide readers with a comprehensive resource that connect theory to real-world implementation.

The work of the algae projects was highlighted at a VBI-sponsored conference, **Algae and Energy in the Northeast**, held in August 2010 in Burlington. This event drew 123 attendees from around the region for a day focused on sharing research findings, demonstration project progress, and lesson learned from research to-date. Response to the event was very strong with evaluations highlighting interest in the area and acknowledging the work supported by the VBI.

Presentations and abstracts from the conference are available here: www.uvm.edu/~epscor/index.php?Page=events/2010_algae_for_energy_conference.php.

- **Development of Microalgal Biofuels: A National Laboratory Perspective**
  Dr. Al Darzins, Principal Group Manager, NREL
- **Pumping Algae! An Alternative Energy Future**
  Donald Redalje, University of Southern Mississippi Department of Marine Science and Cofounder of HR BioPetroleum Inc.
- **Algae Grown on Agricultural Wastewater: Algal Production, Composition and Utilization**
  Dr. Walter Mulbury, Environmental Management and Byproducts Lab, USDA Beltsville, Maryland
- **Algae Farming for Biofuel Feedstocks**
  Dr. Ron Putt, Chemical Engineering Department, Auburn University
- **Algae to Biofuel: Opportunities and Challenges**
  Vikram M Pattarkine, PhD - CEO, PEACE USA and formerly CTO/Chief Scientist, OriginOil
- **Algae for Biofeeds and Biofuels**
  Dr. Ira Levine, University of Southern Maine
- **Reflections of a Life Time of Working with Algae Towards Useful Ends**
  Dr. John Todd, University of Vermont
- **Algae Culture and Biofuels Development in Integrated Systems**
  Dr. Mary Watzin, University of Vermont
- **Microalgae Production of Biodiesel**
  Dr. Ihab H. Farag, University of New Hampshire

NEXT STEPS

VBI efforts related to algal biofuels have led to regionally relevant strain isolation with strong promise for future oil production in cold climates. The work has also explored the synergies of algal biofuel production in conjunction with waste streams high in nutrients and CO_2. Lastly, a novel photoreactor system has been developed that dramatically improves direct production of biodiesel from algal systems. The combination of these outputs points to novel, regionally appropriate technologies that have the potential to make algae a future fuel scenario for Vermont and the Northeast.

- Isolated, regional algae strains will be leveraged in projects aimed to scale up production through integration with waste streams such as new community biodigesters.
- With the granting of a U.S. Patent for their system, Green Mountain Spark intends to pursue commercialization and scaling activities to further develop their photoreactor.

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