Executive Summary

Simgae™ Algal Biomass Production System

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Introduction

Diversified Energy Corporation (www.diversified-energy.com), a privately-held alternative and renewable energy company, is developing and commercializing an innovative algal biomass production system. Aimed at addressing the shortage and rising prices of oil and carbohydrates for biofuels production, food versus fuel crop challenges, the growing lack of antioxidants in diets, all coupled with accelerating environmental concerns from fossil fuel emissions, Simgae™ (for simple algae) offers a *low cost* and *simple* approach to growing algae at large scale. The focus on cost and simplicity addresses the major reason algae production has yet to materialize in any meaningful volumes. Diversified Energy® (DEC) has filed for intellectual property protection as both inventors and co-inventors of the technology.

Simgae™ Overview

Algae has received substantial attention as a high-promise source of biofuel oil to alleviate the supply shortages and high prices of traditional feedstock sources like soybean, palm, canola, animal fats, waste greases, etc. Since the feedstock can contribute roughly 80% to the cost of biofuels production, keeping the feedstock affordable and readily available is paramount for continued growth of the biofuels industry. Algae has been shown to produce 25 – 100X more oil and require substantially less water to grow per surface area compared to other biofuels crops like soybeans. In addition, the non-oil components (i.e., carbohydrates and proteins) left over after oil extraction can be used for a multitude of purposes – as inputs into animal feed, fish feed, fertilizers, dyes, etc. or used to produce fuels/energy through fermentation, gasification or anaerobic digestion. Certain algae strains also produce polyunsaturated fatty acids (omega-3's) similar to nutritionally beneficial antioxidants found in fish oils. These additional products can substantially enhance the overall marketability and economics of producing algae. Algae

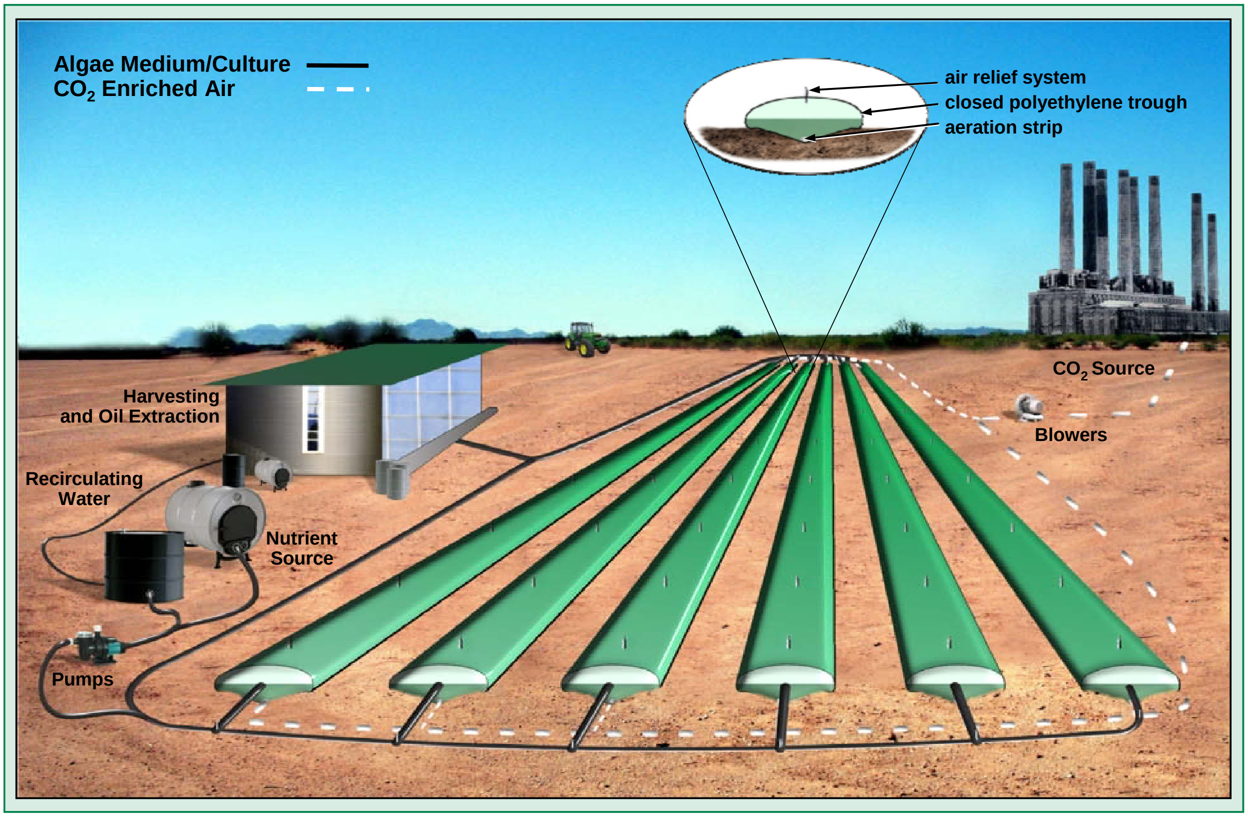

Figure 1: Simgae™ System Conceptual Layout

consume inputs like sunlight, water, CO_2 and nutrients, and can generally be cultivated on land not suitable for other purposes. The ability to ingest CO_2 and produce oxygen through photosynthesis is particularly attractive as a means to curtail carbon emissions.

Given all these benefits, algae production has yet to materialize in any meaningful volume. The reason for the lack of market adoption is centered upon the significant capital and operations and maintenance (O&M) costs to build and maintain the systems. Algae, being biological organisms, are easy to grow in small volumes (i.e., laboratory systems), but not easily extrapolated into large-scale architectures producing consistent algae yields over long periods of time. The resulting production costs have been the Achilles' heel for investors and developers. Open architecture approaches (e.g., ponds or traditional raceways), while possibly the cheapest of all current techniques, suffer challenges with contamination, evaporation, temperature control, CO_2 utilization, and maintainability. The preferred alternatives are closed approaches, generally known as "photobioreactors," where the algae fluid remains in a closed environment to enable accelerated growth and better control over environmental conditions. These glass or plastic enclosures, often operated under modest pressure, can be mounted in a variety of horizontal or vertical configurations and can take many different shapes and sizes. Rigid frameworks or structures are typically used to support the photobioreactor enclosures. As a consequence, the myriad customized photobioreactor components result in high installation, capital, and O&M costs for large-volume applications (i.e., 1000+ acres). The industry response to this challenge has been to add further "bells and whistles" to the photobioreactors and to search for optimal algae strains. Performance has been increased as a result, but at the expense of additional cost and complexity.

The DEC Simgae™ system is an agriculture-based solution to large-scale algal biomass production that has the benefits of both open and closed systems. Instead of creating elaborate and complex architectures designed to push yield to its maximum, the proposed system makes *cost* and *simplicity* the driving variables. The approach can basically be thought of as the "farmer's solution" to algae production. **Figure 1** depicts a notional small-scale Simgae™ implementation. The system utilizes a series of clear, thin-walled polyethylene tubing material. This tubing is analogous to conventional drip irrigation tubes, but can be optimized with the addition of certain UV inhibitors, color schemes, and reflectivity. The current design for the tubing is based on trough shapes (tubes that are v-shaped on the bottom) that may or may not be

Figure 2: Traditional Equipment and Practices Used for System Architecture Fabrication and Installation

closed on the top. These tubes are laid horizontally across a field in troughs created by traditional farming equipment. The land not only acts as the supporting structure for the system, but can also provide some thermal management control. Under slight pressure, an initial culture containing water, the necessary nutrients (e.g. nitrogen, phosphorous, potassium and micronutrients) and a small concentration of algae are slowly pumped into the biotape. As the flow moves along the trough tubes, CO_2 enriched air is injected and oxygen is relieved through a proprietary aeration and air relief system. The sources for CO_2 could include power plants, ethanol facilities, breweries, food processing centers, and landfills, among many others. After a period of time, the flow leaves the tubes with a markedly greater concentration of algae than was started. Scale-up is enabled by simply laying more fields of tubing.

The system provides a continuous flow of concentrated algal biomass for harvesting (algae removal and dewatering) and oil separation. DEC is evaluating a number of candidate approaches to harvesting and oil separation being developed by other companies and will leverage those advances into the Simgae™ architecture. Most of the water is reused in the process. Plastic mulch, common in the agriculture industry, can be laid below and on top (for the open trough tubes, in order to provide a closed effect) of the tubes for temperature, moisture, light exposure, and weed control. Standard tractors and equipment are used to prepare the fields and install the system. **Figure 2** depicts common polyethylene extrusion machinery and agriculture hardware/techniques that would be utilized in the Simgae™ approach.

Key Benefits

DEC has reinvented the status quo photobioreactor system by leveraging technologies and processes standard to the agriculture industry. The trough-based tubing material leverages commercial technologies and manufacturing techniques. The CO_2 injection and O_2 relief system are based on extensions of commercial products and advances in polyethylene extrusion. The remaining pieces (e.g., pumps, mulch, piping, etc.) are all derived from traditional agriculture products. By avoiding complex architectures with lots of custom designed components and rigid structures, Simgae™ can be installed and operated for substantially less cost than competing systems. The simplicity of the architecture also allows for widespread adoption. It is not dependent upon any one source of CO_2 or nutrients, and should provide the flexibility to adapt to a range of sunlight and temperature conditions. The ability of the system to handle saline water is also possible, opening up the potential to utilize a wider variety of algae strains.

Preliminary estimates are that Simgae™ capital costs (including installation and a rough estimate for harvesting and oil extraction, but not covering the costs of land) will be less than $20k per gross acre. Competing systems have publicly claimed ranges anywhere from $100k – $1M per acre. Simgae™ is therefore expected to deliver a roughly 5X – 50X reduction in capital costs. Simgae™ annual yield is expected to be on the order of 22 tons of dry algal biomass per gross acre (equating to a reactor surface area productivity of 23 g/m^2-day), with oil content anywhere from 20 – 30%. This yield and oil content range is dependent upon a number of conditions, including sunlight and temperature, sources of CO_2 and nutrients, algae strain used, and emphasis on oil versus carbohydrate/protein production. These yields and costs correlate to "Generation 1" physical test results conducted by DEC in both indoor and outdoor systems. The yields are also consistent with academic and industry experience in growing algae in open and closed architectures. With advanced growth techniques and stimulants, it is DEC's goal to increase yields to greater than 40 tons/acre. DEC is also focused on utilizing algae strains with applications for the nutraceutical markets.

The substantially lower Simgae™ capital costs, coupled with its competitive yields, ultimately translate into attractive project economics. Based on a discounted cash flow, net present value analyses, DEC believes algal oil for biofuels could be produced much cheaper than current market prices of renewable oil from sources like soybeans. In addition, algal biomass systems like Simgae™ offer a clear path to a stable, domestic, secure, and non-food based source of renewable feedstock. A summary of the key Simgae™ benefits include:

1) Simple, low risk architecture based on common agriculture components and processes
2) Easy installation and operations and maintenance
3) Substantial capital cost reductions, coupled with competitive yield expectations
4) Widespread geographic potential
5) Nutraceutical benefits through the production of antioxidants

Path Forward

DEC has completed preliminary engineering and modeling of a commercial-scale Simgae™ architecture, to include performance and economic projections. DEC has built and tested various tubular designs and implementation approaches at an indoor facility in Gilbert, Arizona. DEC has also worked with others to test design concepts at an outdoor facility in Casa Grande, Arizona that experimented with tubes of various shapes and dimensions, multiple aeration and air relief approaches, and several sources of nutrients and CO_2. These 2007 – 2008 activities collectively represent the "Generation 1" development work completed to date.

DEC has now defined a follow-on development and optimization plan for a "Pre-commercial Demonstration." It will build upon the results generated to date and includes a multi-acre fully integrated system serving to finalize design aspects, operating parameters, 3rd-party harvesting and oil extraction approaches, algae strain selection, among other parameters. It will focus on eliminating key risks in the areas of a) aeration, b) air relief, c) thermal control, d) biofouling, and e) system monitoring and control. This approximately two-year activity will be used as the precursor to larger-scale commercial systems. DEC is now in the process of engaging various investment and technical partners to begin the Pre-commercial Demonstration. Oak Ridge National Laboratory (ORNL), a U.S. Department of Energy national laboratory, is anticipated to be one such partner in this endeavor. In parallel, DEC is exploring approaches to combine its Centia™ technology (a technology to make petroleum-like biofuels from any renewable oil) with Simgae™, thereby demonstrating an end-to-end algae to biofuel system.