Discover a better way to grow.

PUREALGAEGROWTHSYSTEMS.COM
Microalgae have existed for millions of years and have been used by our ancestors as a food supplement for both man and domestic animals. Recently they have been the focus of many firms as potential sources of transportation fuel and various other niche applications. Microalgae help address the world’s need for increased food production, better health, improved energy security, reduced wastewater pollution and lower greenhouse gas emissions. However, the reliable commercial growing of specific Microalgae species affords many technical and operational problems. These problems manifest themselves during required scale-up operations, invasion by predators or simple competition from feral native species.

**THIS REPORT OFFERS INSIGHT AND OPERATIONAL DATA FOR A NOVEL AND RELIABLE GROWING SYSTEM.** This system uses components and procedures developed for the microelectronics and pharmaceutical industry that ensures both high growth rates, predictable growth cycles and almost total immunity from outside contamination. The system was designed and installed on a demonstration level in the state of Hawaii. This application required the growth of a specific algae species and the ability to introduce it to a waste water treatment system in a controlled and concentrated manner. The objective was to assimilate the nutrients of phosphorus and nitrogen into the algae biomass where it could be removed and later converted to various scaleable products.

The base system has been improved and is patent pending. The system is capable of producing specific Microalgae species in almost any geographical environment. It can use waste carbon dioxide from industrial operations and is capable of almost total recycle of both feedstock and nutrients.

**PURE ALGAE GROWTH SYSTEMS HAS DEVELOPED AND TESTED A BETTER WAY TO GROW MICROALGAE.** Our system includes a unique closed-loop photo-bioreactor and innovative cross-flow filtration process. The photo-bioreactor utilizes proprietary seamless clear tubing for maximum algae growth. Combined with a scaled up version of a pharmaceutical standard filtration system, the resulting algae biomass is concentrated while maintaining its overall health. The Microalgae may be used for a variety of beneficial purposes.

**LEAD ENGINEER**

Martin Johnson
PE / MLJ PROCESS ENGINEERING / B.S. CHEMICAL ENGINEERING / M.S. CHEMICAL ENGINEERING / M.S. MECHANICAL ENGINEERING

Martin is responsible for developing the system. He brings more than 30 years’ experience in the design, construction and operation of industrial facilities for Fortune 500 type firms. Experience includes process and manufacturing system design, contract development, negotiation and project management.

**SIFTEX EQUIPMENT COMPANY INC.**

Steven Weil
PRESIDENT
B.S. AGRICULTURAL ECONOMICS

Manufacturer of proprietary polyurethane tubing products used by the global powder and bulk solids processing industry. Siftex has over 30 years’ experience supplying parts to food, pharmaceutical and chemical processing facilities.

**NON-PROVISIONAL UTILITY PATENT APPLICATION PENDING**

PATENT FILED JUNE 16, 2016 | SERIAL NUMBER 15/184,994
Pure Algae Growth Systems is an apparatus designed for the purpose of growing selective monoculture algae in a safe, convenient and economical manner. The system is a closed environment where outside influences are virtually nonexistent. Materials such as nutrients, diluents, and carrier media are carefully screened and cleaned to an almost totally sterile condition. Factors such as nutrient concentration, temperature and chemical levels are all optimized for the intended growth of a specific species. The result is algae nirvana growing conditions designed for clean production of algal biomass.

The system allows contained and controlled growth under conditions where regulatory approval is possible and safety can be assured.

One of the modes of operations could be to produce a single algae that is not a rapid grower but produces a useful bio-product. The unique design of Pure Algae Growth Systems provides better culture conditions than existing photo-bioreactors. Due to the tightly controlled design, the system is well-suited to the large scale growth of single algae for high value applications and food grade material. Another potential use is for scaled up growth of genetically manipulated microalgae. Transgenic techniques have the capacity to greatly enhance the productivity of photosynthesis in microalgae.

The fear that unintended release of these organisms could endanger the environment hinders their use in most algal production systems. Pure Algae Growth Systems allows contained and controlled growth under conditions where regulatory approval is possible and safety can be assured.

FROM A BROAD PERSPECTIVE, PURE ALGAE GROWTH SYSTEMS ESSENTIALLY COMPRISSES A TANK FOR RECEIVING, MIXING, AND DISPENSING INPUT MATERIALS. The input materials include algae feedstock, a micro-nutrients supply, a cleaning solution, a sterile gas, a heating/cooling fluid, a carbon dioxide supply and a raw water supply with a water treatment system. A plurality of output stations include a vent to atmosphere stations, a heating/cooling media return station, a cleaning disposal station, and an algae concentration/product station. The vent to the atmosphere station is coupled to the tank. The heating/cooling media return station is coupled to the heating/cooling media supply through the tank. The cleaning solution disposal station is coupled to the tank with a pump followed by a nano-bubbler and an algae growing system. An algae concentrate/product station is coupled to the tank. An algae dewatering system is intermediate the tank and the algae concentrate/product station. A water return line couples the algae dewatering system and the water treatment system. Pure Algae Growth Systems is capable of other embodiments and of being utilized in various ways.
Pure Algae Growth Systems utilizes proven industrial unit operations that guarantee an environment that offers control of the species of microalgae being grown. It eliminates contamination by competitors and predator species. And, it optimizes the environment for algal cultivations. Unlike most current microalgae growing systems which operate in batch mode and require significant time for startup, cleaning, etc, Pure Algae Growth Systems offers several novel features which minimize these penalties. These include simplified scale up within an enclosed loop, pressurized reactors, continuous operation and in-situ cleaning whenever required.

The system comprises a pressurized mixing and recycling chamber, pressurized modular transparent light reactors of a 100mm diameter by 100 meter length, and a liquid pumping system capable of circulating the algal culture in turbulent flow greater than a Reynolds number of 10,000. The pressurized mixing chamber is used to assure that introduced inputs (e.g., macro- and micronutrients, fresh medium, and makeup water) are efficiently and homogeneously distributed throughout the entire system. Additionally, the mixing and recycling chamber allows efficient introduction of carbon dioxide (CO2) and removal of excess oxygen (O2). The pressurized mixing and recycling tank provides pressure needed to drive the algal culture into the modular light reactors and through the entire loop for return to the mixing tank. The applied pressure expands the modular light reactors and ensures that any transfer of materials or gases is out of the culture system, thereby reducing the chance for contamination.

Pure Algae Growth Systems is applicable to many varied end uses. Modifications of the system can be made as needed to ensure that the end use of the microalgae is taken into account, and requirements of the cultured species are met including specific growing conditions such as nutrients and light. Other modifications involving the type of dewatering required, uses of non-potable water, waste waters, addition of fixed carbon substrates or use of industrial carbon dioxide emissions can be added to the system with no or minimal operational risk. The process equipment required for system modifications is well-known and used in other processes.

The system can be modified with no or minimal operational risk to ensure that the end use of the microalgae is taken into account.
THE LIGHT REACTORS USED IN THE PURE ALGAE GROWTH SYSTEM ARE DESIGNED TO BE BROUGHT INTO THE PRODUCTION CYCLE SEQUENTIALLY WHEN THE CULTURE DENSITY HAS REACHED AN OPTIMAL LEVEL. This sequential introduction of additional light reactor modules or “runs” is facilitated automatically through the mixing and recycling chamber (essentially a manifold). This removes the need for serial transfers to larger and larger culture volumes as currently practiced in open raceways and enclosed photo-bioreactors.

PURE ALGAE GROWTH SYSTEMS DELIVERS TURBULENT FLOW IN THE MODULAR LIGHT REACTORS THAT PROVIDES SIGNIFICANT ADVANTAGES TO THE ALGAE PRODUCTION PROCESS. The turbulent flow minimizes the amount of time the algae spend in the interior of the culture where light levels are limiting. It maximizes the mixing of gas bubbles containing CO2 to keep the gas and algal cells in better contact thereby increasing the available CO2 for cellular growth. Turbulent flow also provides a scouring effect on the interior walls of the modular light reactor tubes to minimize accumulation of biofilms.

ANOTHER BENEFIT OF THE TURBULENT FLOW FEATURE IS IT ALLOWS THE USE OF SIMPLE SUGARS TO ACT AS FOOD WHEN SUNLIGHT IS NOT AVAILABLE. The quick response of Pure Algae Growth Systems’ process will allow residual CO2 to be stripped from the medium in approximately four minutes. Simple sugar is then introduced as replacement food. This unique feature permits operation in a true mixotrophic mode. Typically, the use of a fixed carbon growth process (heterotrophic growth) is much faster than the phototropic process. Heterotrophic growth rates allow more than doubling of the biomass yield on a daily basis.

CURRENT MICROALGAE SYSTEMS ARE LARGELY GROWN OUTSIDE AND ARE EXPOSED TO NATURAL CONTAMINATION FROM WIND OR OTHER SURFACE BORNE SOURCES. Pure Algae Growth Systems provides a controlled environment located outdoors or indoors that is free of contamination sources by design. This factor in conjunction with the proven initial feedstock guarantees a healthy culture which can multiply at an accelerated rate. This system allows food and nutrients to be introduced at a predictable rate which ensures optimum growth.
Pure Algae Growth Systems uses pressurized CO2 in a contained space. This results in as much as a twenty-fold improvement in carbon dioxide utilization versus existing commercial systems.

The technique was first used in a first-generation design at a commercial installation in Hawaii in 2011 and the installation received an EPA Environmental Award. For this project, the carbon dioxide was a waste stream from an industrial process (naphtha reformer). This project led to improvements by locating superior materials of construction for the actual microalgae growing volumes. This capability affords a much broader choice of waste gases for the algae food. Volume or mole percentages as low as 25% CO2 will provide adequate food stock with minimal degradation in carbon dioxide utilization.

"Their system pipes carbon dioxide and wastewater from an oil refinery into tanks that accelerate algae growth, and demonstrate emission reductions. In November, 2011 their project, constructed at Chevron’s Hawaii oil refinery, successfully achieved the nation’s first connection of industrial CO2 from an oil refinery with a working algae production site."

STATEMENT FROM EPA ENVIRONMENTAL AWARD

The CO2 could be naturally occurring or introduced as a mixture of gases. The higher partial pressure of the carbon dioxide is used to enhance the dissolving process. The result is high food utilization and its attendant reduced component cost. The projected utilization of CO2 is estimated to be twenty times better than existing systems. The actual growth rate of biomass will also be significantly better than current systems.

**An innovative gas introduction and retention system maintains carbon dioxide levels over the entire length of each modular light reactor.**
Pure Algae Growth Systems’ process is designed as a robust, industrial facility. There is considerable tolerance in the feedstocks that can be introduced and converted to algae biomass.

The system could be used to scrub undesirable pollutants from aqueous waste streams or vapor emissions. Many industrial processes produce wastewater that are high in materials useful for algal growth (nitrogen compounds, phosphates, other micronutrients). Pure Algae Growth Systems can be utilized to effectively scrub these nutrients and produce cleaner water. A recent experience at Chevron’s Hawaii refinery in 2013 demonstrates the effectiveness of the system.

While the use of industrial waste mostly precludes the use of the biomass for food and feed applications, purified bio-products can be made for renewable chemical production. Alternatively this biomass can be used as a bio-fertilizer for fields or as a feedstock for biofuel production.

**TECHNOLOGY READINESS LEVEL ASSESSMENT FOR PURE ALGAE GROWTH SYSTEMS UNIT OPERATIONS**

<table>
<thead>
<tr>
<th>UNIT</th>
<th>OPERATION</th>
<th>TRL NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GROWING MICROALGAE IN LIGHT REACTORS*</td>
<td>6 – 7^A</td>
</tr>
<tr>
<td>2</td>
<td>USE OF INDUSTRIAL WASTE CO2 AS NUTRIENT SOURCE</td>
<td>7 – 8^A</td>
</tr>
<tr>
<td>3</td>
<td>CROSSFLOW FILTRATION DEWATERING</td>
<td>5 – 6^A</td>
</tr>
<tr>
<td>4</td>
<td>NANO-BUBBLER</td>
<td>8 – 9^A</td>
</tr>
<tr>
<td>5</td>
<td>IN-SITU SCALE-UP OF PROCESS</td>
<td>6 – 7^C</td>
</tr>
<tr>
<td>6</td>
<td>IN-SITU COOLING OF MEDIA</td>
<td>4^D</td>
</tr>
<tr>
<td>7</td>
<td>USE OF SIMPLE SUGAR AS ALGAE FEED</td>
<td>8 – 9^E</td>
</tr>
<tr>
<td>8</td>
<td>WATER PURIFICATION FOR REUSE</td>
<td>8 – 9^F</td>
</tr>
<tr>
<td>9</td>
<td>AIR PURIFICATION / STERILIZATION</td>
<td>9^G</td>
</tr>
<tr>
<td>10</td>
<td>PROCESS CONTROL VARIABLE SENSITIVITY</td>
<td>6 – 7^H</td>
</tr>
</tbody>
</table>

* 100MM DIAMETER POLYURETHANE SEAMLESS FLEXIBLE TUBE

**NOTE:** The results are detailed in *Algae-Mediated Valorization of Industrial Waste Streams*, August 2015 edition of *Industrial Biotechnology*.
One central utility plant provides climate control and nutrients to the algae growing light reactors. Central process utilities manage the activities of 1 to 10 SGM (standard growing module) production.

There are 10 light reactors per one standard growing module (1 SGM). Each light reactor is constructed of 100 mm diameter ultra UV-resistant, clear, seamless tubing. Flexible light reactors can be extruded in 100 meter seamless lengths. Sanitary Tri-Clover connections allow for increases to maximum length of 500 meters per light reactor. The rolls of tubing are compact and easily shipped to be installed on-site with a minimum of labor.

**Benefits of the Pure Algae Growth System Design**

- **SCALABILITY**
- **VERY LOW WATER USE**
- **LESS LAND AREA**
- **LESS SITE DEVELOPMENT**
- **SUSTAINABILITY**
- **HIGHER BIOMASS YIELD**
- **LOWER COST LIGHT REACTORS**
- **HIGH VALUE MONO-ALGAE**
- **DAY/NIGHT GROWING**
- **INDOOR/OUTDOOR GROWING**

Pure Algae Growth Systems design scales from 1,000 meters to 10,000 meters of algae growing light reactors without expanding central utilities.

1 SGM* = 1,000 meters = 7,850 L

**YIELD IS UP TO 4 TONS OF PURE ALGAE BIOMASS PRODUCTION ANNUALLY**

10 SGMs = 10,000 meters = 78,500 L

**YIELD IS UP TO 40 TONS OF PURE ALGAE BIOMASS PRODUCTION ANNUALLY**

---

* A MINIMUM OF 21 RACEWAY PONDS IS REQUIRED TO MATCH PURE ALGAE GROWTH SYSTEMS’ 1SGM GENERATING ONLY 1 METRIC TON PER YEAR OF BIOMASS.

A RACEWAY POND IS 10 METERS LONG X 3 METERS WIDE WITH SINGLE PADDLEWHEEL SELECTED AS OPTIMUM FOR BIOMASS YIELD.

PURE ALGAE GROWTH SYSTEMS 1SGM REQUIRES 3 ACRES OF LAND VERSUS THE RACEWAY REQUIREMENT OF 7 ACRES. WHEN SCALED TO 10SGM, THE LAND REQUIREMENT FOR PURE ALGAE GROWTH SYSTEMS’ CENTRAL UTILITIES AND LIGHT REACTORS IS 8 ACRES.

The raceway ponds would need at least 23 acres to generate the same biomass yield. The reduced land use benefit of Pure Algae Growth Systems is augmented by less stringent site and grading requirements. The robust, flexible light reactor tubes can be installed resting upon lightweight tarps or roughly graded dirt.

There are many candidate applications where the winters are extreme and microalgae cannot be grown outside during that season. Such opportunities could be abundant raw material availability or physical needs where an algae product should be grown in cold regions. Pure Algae Growth Systems can be easily constructed indoors using synthetic and/or selected wavelength light sources. Current light emitting diode (LED) technology allows a specific wavelength of light to be generated via a very efficient energy conversion process. Commercial sources of the LED devices are readily available. Another opportunity is to operate the system using simple sugar in continuous “night-time” mode. Pure Algae Growth Systems is designed for modification to allow indoor growth and temperature regulation such that virtually no location is off-limits.
Pure Algae Growth Systems is a closed system from start to finish. All raw materials, inputs and growing conditions are prepared and managed by the central utilities.

Water is treated via filtration and UV sterilization before being exposed to the process. The water temperature is controlled via a cooling capability built into the surge tank. High circulation rates allow temperature control to within +/- 2 degrees C of the optimum algae growing temperature. Sterile air and feed gases are prepared via pharmaceutical industry standard practices to eliminate gases contaminated with unwanted substances. Oxygen generated by photosynthesis will be removed from the water by stripping with gaseous nitrogen in the surge tank. Micro and macro nutrients not consumed during algae growth will be carried along with the water during the dewatering step and recycled.

There are critical differences in the process used by Pure Algae Growth Systems and an open raceway pond farm. At the same levels of biomass output, differences are seen in the types of inputs and output streams as well as the magnitude of those streams. Pure Algae Growth Systems is more efficient in incorporation of the added CO2. It uses <5% of the carbon dioxide to produce the same biomass quantities. This is due to its closed design and recycle/reuse set-up of the mixing and recycling chamber as well as the pressurized system and delivery of the carbon dioxide with the nano-bubbler. Water is more efficiently used by Pure Algae Growth Systems. The 10SGM installation would “spend” 350 kg per day compared to the greater than 8,000 kg per day of water lost in the raceway system. The raceway loses water mainly due to evaporation and dewatering a lower density algae culture.

**In incorporation of the added CO2, the system uses <5% of the carbon dioxide to produce the same biomass quantities.**

<table>
<thead>
<tr>
<th>INPUT STREAM</th>
<th>PURE ALGAE KG/DAY</th>
<th>RACEWAY KG/DAY</th>
<th>STREAM TYPE</th>
<th>AUG TEMP °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROCESS WATER</td>
<td>350</td>
<td>8,916</td>
<td>LIQUID</td>
<td>25</td>
</tr>
<tr>
<td>CARBON DIOXIDE</td>
<td>15</td>
<td>300</td>
<td>GAS</td>
<td>25</td>
</tr>
<tr>
<td>MICRO-NUTRIENTS</td>
<td>5</td>
<td>120</td>
<td>LIQUID</td>
<td>25</td>
</tr>
<tr>
<td>ALGAE SEED STOCK</td>
<td>0</td>
<td>160</td>
<td>LIQUID</td>
<td>25</td>
</tr>
</tbody>
</table>

**1SGM VS 21 OPEN RACEWAYS / COMPARISON OF MAJOR INPUT STREAM USE FOR PRODUCTION OF 4 KG OF DRY ALGAE BIOMASS PER DAY**

Pure Algae Growth Systems introduces algae seed stock via a metering pump into the surge tank. The initial volume in the tank is kept low to minimize the risk of over-dilution. Initial inoculation volumes are relatively small and the system evolution is controlled by valves which cause additional growing volumes to become active. The growing operation is designed for a very quick response time. The turbulent flow maintains consistent and uniform algae concentrations to optimize growth rates. Pure Algae Growth Systems offers major improvements in performance compared to the lack of agitation and low sunlight penetration inherent in raceway ponds. In addition, whereas open raceways are capable of growth only during daylight hours, Pure Algae Growth Systems is built to switch to simple sugar to accelerate growth at night.

**AS A “CLOSED” OPERATION, PURE ALGAE GROWTH SYSTEMS IS NOT AT THE SAME LEVEL OF RISK FOR ALGAE DIE-OFF AND SYSTEM “CRASHES”.** Open raceways are very susceptible to contamination. Cleaning, sterilizing and refilling is typically a daily occurrence which requires expensive inputs, labor and wasted time. In contrast, should Pure Algae Growth Systems require cleaning, it is designed to use common industrial CIP techniques which save time and money.
Pure Algae Growth Systems design allows for harvesting on a continuous basis when the system is operated at 24/7/365 using sunlight/CO2 (daytime) and sugar (night-time) as the food source.

Continuous harvest improves process productivity and reduces unit labor cost. The system is designed so harvesting does not affect maintaining the optimum algae concentration throughout the system.

**Another innovative component of Pure Algae Growth Systems is cross flow filtration used for dewatering.**

Our process generates a toothpaste consistency material of about 10 grams per liter algae. This represents a 20x concentration of the algae biomass starting with 0.5 grams per liter media. This concentration is our base line product and essentially removes 95% of the water for recycle. Further concentration is possible via additional process equipment which would be application specific.

**Appendix / comments pertaining to TRL assessment of unit operations**

- This algae was used as seed stock for a system simulating a portion of the existing plant’s waste water treatment system. The high algae concentration was introduced to scavenge both nitrogen and phosphorus down to nearly non-detectable levels. The simulated system was 100,000+ liters in volume.

- Many industrial facilities discharge waste CO2. Most refineries need hydrogen which is produced on site; typically by reforming some hydrocarbon feedstock. In this case naphtha was used and the carbon dioxide was nearly pure but was saturated with water. The water created corrosion problems in processing equipment which had to be solved before ultimate process success.

- This technology is used in the pharmaceutical industry to purify vaccines and other parenteral products. These stringent unit operations are much harder to execute than the concentration (dewatering) of algae which are much larger than their parenteral counterparts.

- Gas introduced as small bubbles in a liquid cause the surface area to volume ratio to become quite large. This enhances the mass transfer which must occur before the algae can assimilate the carbon dioxide as food.

- Most commercial algae growing systems must relocate to larger volumes during their growth cycle if they are commercially viable. The PAGS process has built in scale-up features which affords larger volumes by simply opening a valve.

- Algae growing media sometimes becomes too hot for efficient growth. The PAGS process uses dry gas (either nitrogen or air) as a protective blanket. Gas can be introduced as fine bubbles below the media liquid surface. This gas has two beneficial effects:
  - It evaporates some media water thereby cooling similar to a direct contact cooling tower.
  - It strips product oxygen from the media thereby promoting the desired algae growth photosynthesis.

- Many industrial firms use simple sugars to grow specific strains of algae. Normally, the growth rates are higher than the photosynthesis process and many algae strains actually prefer sugars as food material.

- The microelectronics industry has the highest water purity criteria. “Pure” water is a poor conductor and actually has a resistance of 18 meg-ohms per centimeter. This standard has required development of water purification technology. The processes and equipment used in Pure Algae Growth Systems simply borrows this technology.

- The pharmaceutical and microelectronics industry must maintain almost absolute cleanliness. Most foreign bodies are carried via the air. This requirement has spawned development of filters and supporting equipment to protect both product and personnel. Pure Algae Growth Systems process uses this technology with little modification.

- Most functioning industrial chemical processes work best when significant inertia is in play. This brings robustness and normally translates to high mass flows allowing stability and gradual change. Pure Algae Growth Systems process is built around these tenets.

Discover a better way to grow.

PUREALGAEGROWTHSYSTEMS.COM