PLYLIGHT

SCIENCE & LIGHT

AQUAMERSION™ OVERVIEW DOCUMENT

A NEW TECHNOLOGY to *IMPROVE THE ECONOMICS*

and *ENABLE THE SCALING UP* of ALGAE PHOTO BIOREACTORS

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AQUAMERSION™

ESSENCE OF PBR DESIGNS COMPARED

- Traditional **PHOTO BIOREACTORS (PBRs)** are containers, most likely made of glass or plastic tubes, or poly bags. Algae culture and CO^2 are pumped into these containers. Pumping in the very long tubes continues all the way to harvest. By design the light for algae photosynthesis comes from *outside* these tube or bag containers and some is absorbed as it passes *through* their walls. As the algae grows its increasing density blocks additional light which limits the design depth/diameter of these containers to a few inches. The irony is that the very act of algae growth is a limiting factor in these PBR designs.
- Many of these traditional PBR systems are built outside to take advantage of natural sunlight – good if you have it. But if the light comes from an artificial source much of that light will *miss* its intended target - the container of algae. The cost of these containers along with the additional cost of wasted energy could render such systems uneconomical and *limit* their practicality when it comes to selecting a commercial PBR system.
- On the other hand, the beauty of **AQUAMERSION™** is that the light necessary for photosynthesis is located *within* the algae culture - *within* the container. All that light, whether it be artificial or natural, is used - no wasted light or money. In addition these containers need *not* be limited in size or shape based on light penetration as per traditional PBRs that employ thousands of poly bags or hundreds of meters of tubes.
- An **AQUAMERSION™ PBR** is simply a large diameter, *internally* illuminated, tank into which algae culture and CO^2 are pumped. As the algae grows it naturally floats to the surface for harvesting. The simplicity of operation and potential for scalability should make AQUAMERSION™ the natural choice for a commercial scale PBR system.

INTRODUCTION: PROBLEMS AND PROMISES

THE PROBLEM IS SCALABILITY – THE SOLUTION IS *INTERNAL* ILLUMINATION

THE ALGAE POTENTIAL:

The demand for algae is surging as researchers discover new applications for it across the food, pharmaceutical, nutraceutical, cosmetic and biofuel industries. Algae can be used as a nutritional supplement to add vitamins or healthy fats to food; as a producer of biologic and all natural drugs; as an antioxidant in food supplements or rich oils in cosmetics and as the basis for clean fuels such as biodiesel. It's no surprise why algae is attracting so much attention. Algae cultivation doesn't compete with agricultural land or production, and remains independent of raw material imports. It draws on sunlight as a main energy source and converts carbon dioxide into biomass and oxygen while it produces high concentrations of proteins, lipids, pigments and acids, and can be grown in salt water, freshwater or wastewater.

Algae is a versatile organism, and as a result, the industrial algae market has hit $1 billion and continues to grow. But despite algae's potential, producing cost-effective yields for the many applications remains a problem. Few standards exist for industrial algae growth, and the calls for higher algae yields, greater efficiency and lower costs are resounding, especially in the biofuel industry. Will the patented ***AQUAMERSION™*** *light distribution tube* by Plylight be the solution?

THE PROBLEM:

The growth of algae is receiving a significant amount of attention due to its perceived uses as a source of combustible fuel, a source of nourishment, a raw material for biodegradable plastics, and a consumer of carbon dioxide which is widely viewed as a threat to the environment. Most forms of algae require light to thrive. *In anticipation of a large demand for algae, it would be preferable to grow algae in very large tanks.* If such tanks are intended to grow algae on a continuous basis, there is a need to supply light throughout the interior of these tanks. Light simply directed from the ***exterior*** onto the top or outside surfaces of large tanks, even if these tanks were formed of a transparent material, would be inadequate since the algae close to the surface and sidewalls of these tanks would block infiltration of light into the interior***. Light is wasted***.

THE SOLUTION:

AQUAMERSION™ is a light distribution systems for photo bioreactors. These tubes would be liquid filled, with a liquid such as water or other suitable clear liquid, providing an illumination system having a weight and internal pressure similar to the pressure of the intended submerged environment thereby minimizing or eliminating the pressure difference between the exterior (submerged environment) and the tube interior. These tubes would be located on the ***interior*** of the tanks allowing for easy distribution of light and unlimited scalability. ***Light is not wasted.***

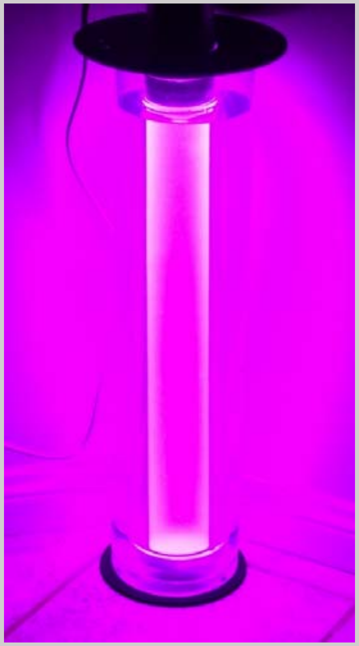
SUMMARY

WHY YOU SHOULD USE AQUAMERSION™

BENEFITS OF AN AQUAMERSION™ PHOTO BIO REACTOR

- **INCREASE ALGAE PRODUCTION WITH FULL DEPTH AND BREADTH LIGHTING**
- **THE LIGHT SOURCE IS LOCATED *WITHIN* THE ALGAE CULTURE NOT *OUTSIDE* IT – THE MOST EFFICIENT WAY TO ILLUMINATE**
- **LIGHT SOURCE OPTIONS TO INCLUDE LEDs AND *SUNLIGHT***
- **SIMPLE CONTROL OF LIGHT INTENSITY AND COLOR**
- **CAN PULSE THE LIGHT TO STIMULATE PHOTOSYNTHESIS**
- **MAXIMUM CONTROL OF TOTAL GROWING ENVIRONMENT**
- **DESIGNED FOR CONTINUOUS OPERATION AND HARVESTING**
- **CONSUMES CO_2 - SAVES THE ENVIRONMENT**
- **ENABLES SIMPLE SCALING OF A REACTOR BECAUSE THE LIGHT SOURCE IS *WITHIN* THE BIOREACTOR AND NOT *EXTERNAL* TO IT**

AQUAMERSION™ LDT IN TANK OF WATER



THE NEXT STEP FOR AQUAMERSION™

TO FIND A PARTNER TO PROTOTYPE

A COMMERCIAL SCALE SYSTEM

- **THE TECHNOLOGY IS PATENT PROTECTED: US PATENT 8,998,472 B2 WAS ISSUED TO WALTER A. JOHANSON ON APRIL 7, 2015**
- **THE TECHNOLOGY IS FULLY DEVELOPED**
- **A PROOF OF CONCEPT MODEL WORKS IN A LAB SETTING**
- **WITH HELP WE ARE READY TO “BUILD OUT” TO THE NEXT FULL PHASE**
- **AN OPPORTUNITY EXISTS TO BE ON THE CUTTING EDGE OF A SCALABLE PHOTO BIOREACTOR SYSTEM WITH AQUAMERSION™**

THE ALGAE MARKET

IT *IS* A BIG DEAL

- **Algae-Based Biofuels Represent a Trillion Dollar Potential Market Opportunity, but Cost is an Obstacle to Commercialization, Says Pike Research**
- According to a recent report from Pike Research, the scale-up potential of algae is substantial compared to other non-food based feedstocks. …the cleantech market intelligence firm projects that the value of renewable fuels derived from algae will reach $1.3 billion by 2020.
- "Scale-up of algae-based biofuels will depend on the realization of value in non-fuel end-markets. As key capital and operating cost hurdles are overcome, algae-based biofuel production should expand rapidly."
- The use of algae to produce crude oil for renewable fuel production can deliver a number of environmental benefits compared to other advanced biofuel feedstocks. Algae can be grown on non-arable land, co-located with stationary CO2 emissions sources, and utilize a wide variety of water resources including wastewater and seawater.
- **Algae can double its volume overnight.** Up to 50 percent of an alga's body weight is comprised of oil, whereas oil-palm trees - currently the largest producer of oil to make biofuels - yield just about 20 percent of their weight in oil. Algae are the fastest-growing plants in the world. But if it were easy to extract the fuel, most of the world's biodiesel would already be made from microalgae grown on nonagricultural land, close to coal-fired power plants. It's critical to understand how to select the right algae species, create an optimal photobiological formula for each species, and build a cost-effective photobioreactor that can precisely deliver the formula to each individual algae cell, no matter the size of the facility, or its geographical location.
- **Soy produces some 50 gallons of oil per acre per year; canola, 150 gallons; and palm, 650 gallons. But algae are expected to produce 10,000 gallons per acre per year, and eventually even more. Algae oil production is 75% - 250% greater than Soy Beans, Camelina, Rape Seed, Jetropha, or Palm oils for the same lot of land.**

TWO GOALS TO IMPROVE ALGAE PRODUCTION

•DISTRIBUTE LIGHT UNIFORMLY *WITHIN* A PHOTO BIOREACTOR

•MAKE IT *SCALABLE*

WHAT HAS BEEN TRIED:

- **LED LIGHT STRIPS WITHIN TUBES INSTALLED INSIDE BIOREACTORS, BUT:**
  - **ELECTRICITY MAY ENTER WATER IF A TUBE FAILS**
  - **AN AIR FILLED TUBE WILL FLOAT**
  - **HYDROSTATIC PRESSURE MAY DAMAGE TUBE**
- **REMOTE SOURCE LIGHTING IS NOT AN OPTION**
- **EXTERNAL LIGHTING OF A PBR IS WASTEFUL AND THEREFORE COSTLY**

WHAT NEEDS TO BE TRIED:

- **WATER FILLED LIGHT TUBES INSTALLED *WITHIN* BIOREACTORS**
- **REMOTE SOURCE LIGHTING TO KEEP ELECTRICAL SOURCE OUT OF TANKS AND PROVIDE A SOLAR SOLUTION**
- **PERMANENT INSTALLATION OF TUBES OUT OF THE HARVEST ZONE**
- **USING AS MANY TUBES AS NEEDED IN AS LARGE A TANK AS NEEDED WILL ENABLE *UNLIMITED SCALABILITY***
- **INTERNAL LIGHTING OF A PBR IS *VERY* EFFICIENT**
- **AQUAMERSION™ IS THE SOLUTION**

TYPICAL POND BIOREACTOR

(LIKE A FARM)

In a typical algae-cultivation system, such as an open pond, light only penetrates the top 3 to 4 inches (76–102 mm) of the water, though this depends on the algae density. As the algae grow and multiply, the culture becomes so dense that it blocks light from reaching deeper into the water. Direct sunlight is too strong for most algae, which can use only about $^1⁄_{10}$ the amount of light they receive from direct sunlight; however, exposing an algae culture to direct sunlight (rather than shading it) is often the best course for strong growth, as the algae underneath the surface get more light.

To use deeper ponds (or closed systems in tanks), growers agitate the water, circulating the algae so that it does not remain on the surface. Agitation lifts algae from the lower regions. Agitation also helps prevent over-exposure to the sun.

From Wikipedia.

TYPICAL PHOTO BIOREACTOR

(LIKE A GREENHOUSE)

Cultivation of algae is in a controlled environment, hence there is a *potential* for much higher productivity.

- **Large surface-to-volume ratio. PBRs offer maximum efficiency in using light and therefore greatly improve productivity. Typically the culture density of algae produced is 10 to 20 times greater - and can be even greater than pond grown algae.**
- **Better control of gas transfer.**
- **More uniform temperature.**
- **Better protection from outside contamination.**
- **Space saving - Can be mounted vertically, horizontally or at an angle, indoors or outdoors.**

An enclosed PBR design will enhance commercial algal biomass production by keeping algae genetics pure and reducing the possibility of parasite infestation.

CHALLENGES FOR *TRADITIONAL* BIOREACTORS:

THE MAIN PROBLEM IS THAT THEY ARE *EXTERNALLY* ILLUMINATED

FOR A POND BIOREACTOR

- ***EXTERNAL*** **LIGHTING FROM THE SUN ABOVE LIMITS ALGAE GROWTH TO A 3”- 6” DEPTH**
- **TO IMPROVE THE YIELD THE ALGAE CULTURE MUST BE CIRCULATED**
- **TO *SCALE UP* MORE LAND IS REQUIRED**
- **CONTAMINATION OF ALGAE CULTURE IS A POTENTIAL PROBLEM IN AN OPEN POND**
- **THE LIMITED CONTROL OF TEMPERATURE AND LIGHT MAY COMPROMISE THE ALGAE CULTURE GROWING ENVIRONMENT**

FOR A PHOTO BIOREACTOR (PBR)

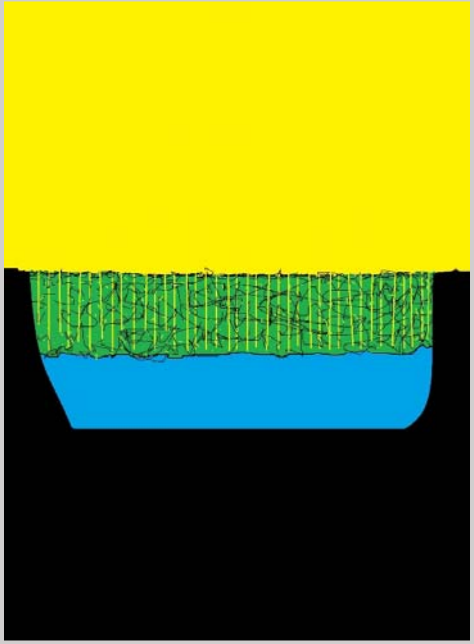
- **LIGHT FROM THE SUN OR AN ARTIFICIAL SOURCE IS *EXTERNAL* TO THE PBR TUBES**
- **PENETRATION OF LIGHT INTO THE ALGAE CULTURE THROUGH THE PBR TUBE LIMITS THE TUBE DIAMETER TO 6”- 8” EVEN WITH CONSTANT FLOW**
- **REQUIRES VERY LONG LENGTHS OF TUBES AND CONTINUOUS PUMPING OF THE ALGAE CULTURE**
- **ANY STOPPAGE IS A CATASTROPHE**
- **SCALING UP IS COSTLY BUT DOABLE**

TRADITIONAL BIOREACTOR DIAGRAMS

EXTERNAL ILLUMINATION LIMITS GROWTH AND SCALING

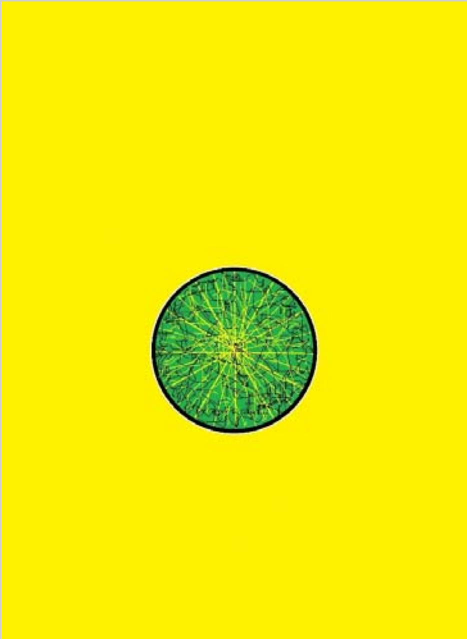
POND BIOREACTOR SECTION

AS ALGAE GROWS IT BLOCKS THE SUNLIGHT WHICH *LIMITS* GROWTH TO THE TOP FEW INCHES OF THE POND



TYPICAL PHOTO BIOREACTOR SECTION

LIGHT FROM THE *OUTSIDE* CAN PENETRATE ONLY A FEW INCHES INTO ALGAE *LIMITING* THE DIAMETER OF THE PBR TUBE



BENEFITS OF AN AQUAMERSION™ SYSTEM

INTERNAL ILLUMINATION – NO LIMIT TO GROWTH OR SCALING

SINGLE TUBE PER TANK

- **A SINGLE TANK WILL HAVE A DIAMETER OF 16”-18” WITH A 6” DIAMETER AQUAMERSION™ LDT CENTERED *WITHIN* THE TANK**
- **HEIGHT OF TANK IS DETERMINED BY THE RATE OF ALGAE GROWTH**
- **ALGAE GROWS AND FLOATS UPWARD ALONG THE FULL LENGTH AND DEPTH OF THE TANK FOR HARVESTING**
- **AQUAMERSION™ LDTs CAN BE REMOTELY ILLUMINATED WITH ARTIFICIAL SOURCES OR FIBER FED SUNLIGHT**

MULTIPLE TUBES PER TANK

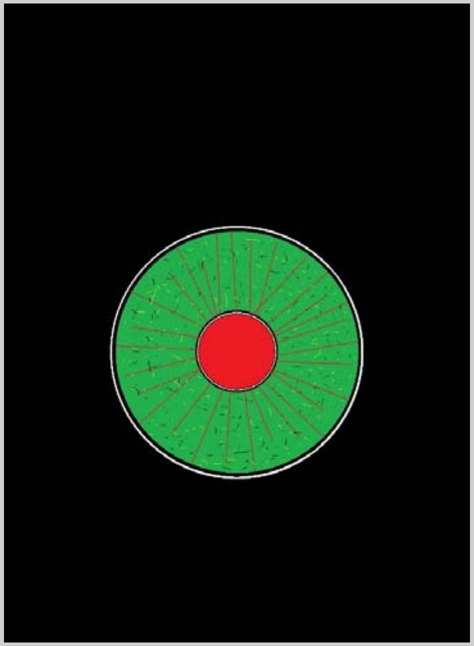
- **NO MINIMUM TANK BREADTH**
- **NO MINIMUM TANK HEIGHT**
- **DIMENSION LIMITS ARE DETERMINED BY THE GROWTH RATE OF ALGAE AND YOUR NEEDS**
- **ALGAE CAN GROW IN THE FULL DEPTH OF THE TANK AND WILL FLOAT TO THE TOP WHERE IT IS HARVESTED**
- ***NO SCALE LIMITS***

AQUAMERSION™ BIOREACTOR DIAGRAMS

MAXIMUM LIGHT SATURATION EQUALS MAXIMUM GROWTH WITHOUT LIMITS

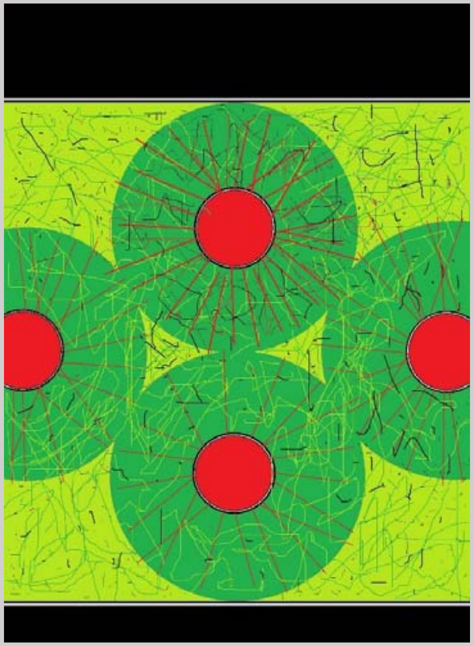
SINGLE TUBE SINGLE TANK

TANK AND TUBE ARE SIZED TO MAXIMIZE LIGHT SATURATION FOR ALGAE GROWTH FROM AN *INTERNAL* LDT



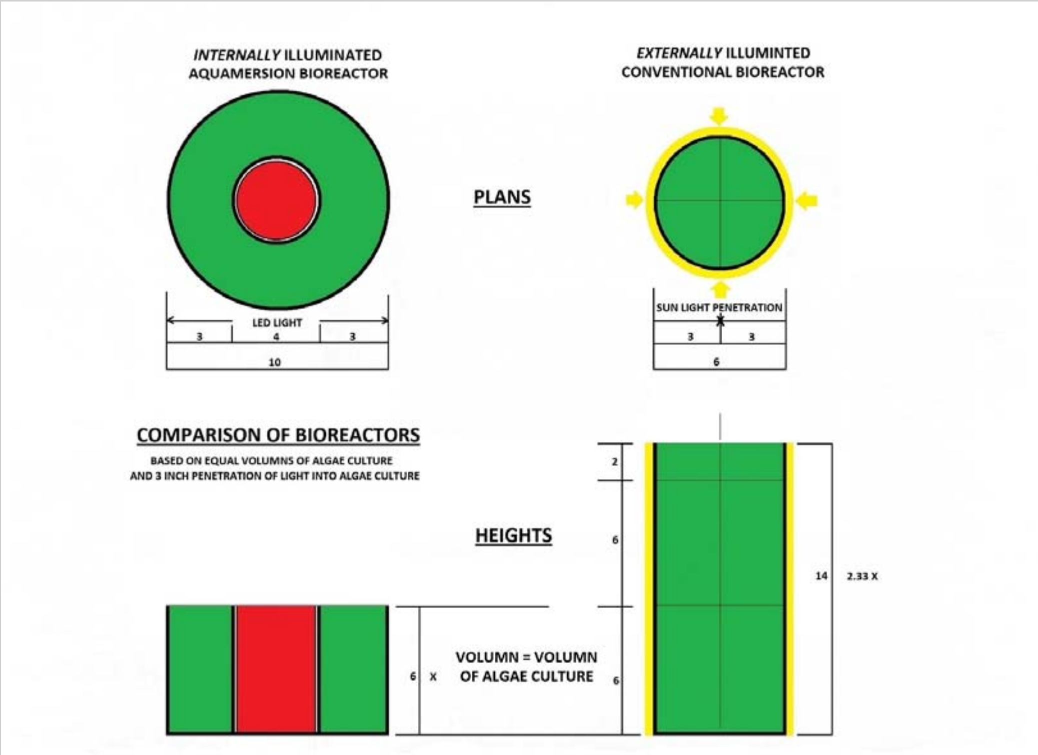
MULTIPLE TUBES SINGLE TANK

TUBE SPACING IN *SINGLE LARGE* TANK TO MAXIMIZE LIGHT SATURATION FOR ALGAE GROWTH – NO LIMITS TO SCALING



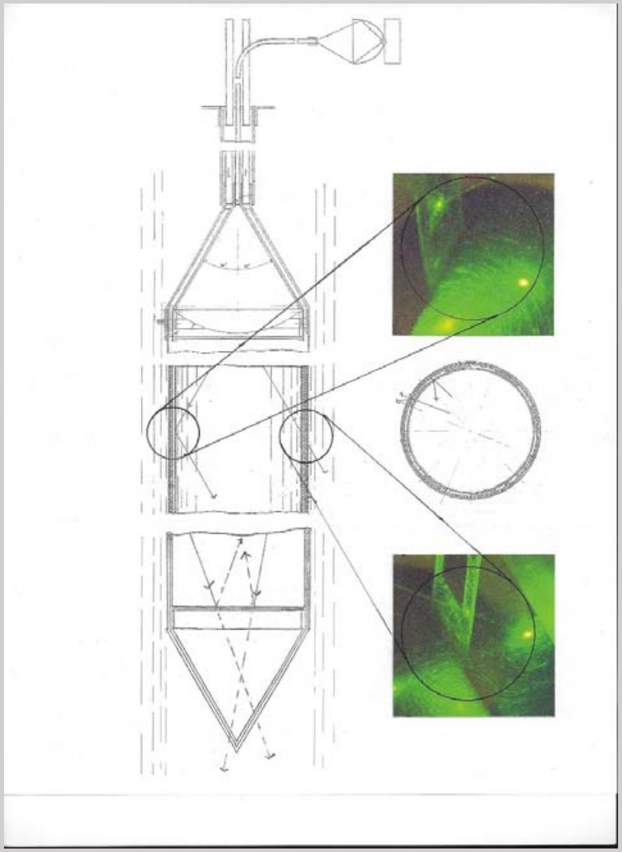
SIZE COMPARISON OF TYPICAL PBR AND AQUAMERSION™

WITH 3 INCH LIGHT PENETRATION AND EQUAL VOLUMNS OF ALGAE CULTURE



AQUAMERSION™ PATENT:
LIQUID FILLED LDTs

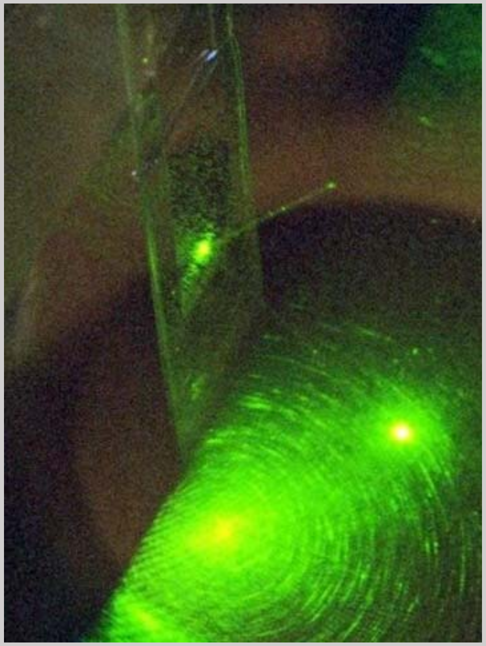
US Patent 8,998,472 B2 is for illumination devices and illumination systems for use in photo bioreactors that utilize light distribution tubes (LDTs) which are substantially filled with water or other suitable liquid. These we call **AQUAMERSION™ LDTs.** Illuminators for these tubes may be positioned outside of the water and are connected directly or via light carrying connectors such as fiber; or these illuminators may be positioned inside the water environment in sealed housings integrally connected to the LDTs. Light is injected at a critical angle of incidence and the patented structure of the tube wall either allows the light to pass through or to be reflected and held within the tube. The light extraction means may extend substantially the full longitudinal length and cause the LDTs to emit light evenly over their entire submerged lengths.



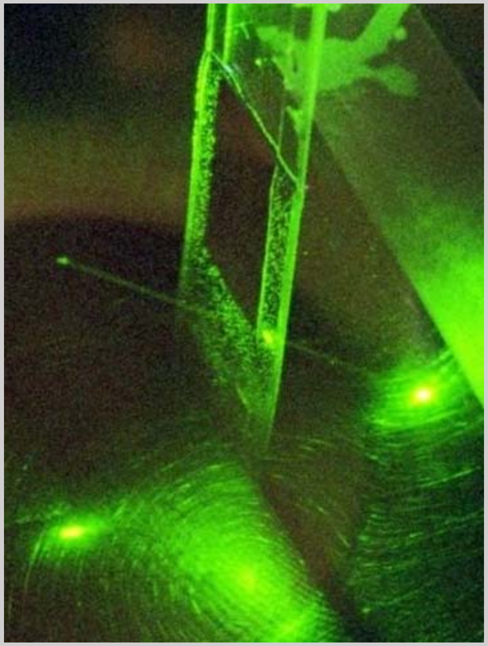
PROOF OF CONCEPT

LIGHT PATHS

LIGHT STRIKING A *VOID (AIR POCKET)* WITHIN A WALL WILL BE TOTALLY REFLECTED BACK INTO THE TUBE



LIGHT STRIKING A *VOID-LESS (SOLID)* AREA WITHIN A WALL WILL PASS THROUGH INTO ALGAE TANK



PROOF OF OPERATION:

WATER FILLED LDT ILLUMINATING A WATER FILLED TANK

THE BULB:

15 WATT PAR20 LED GROW SPOT LIGHT 450 LUMENS

THE AQUAMERSION™ LDT

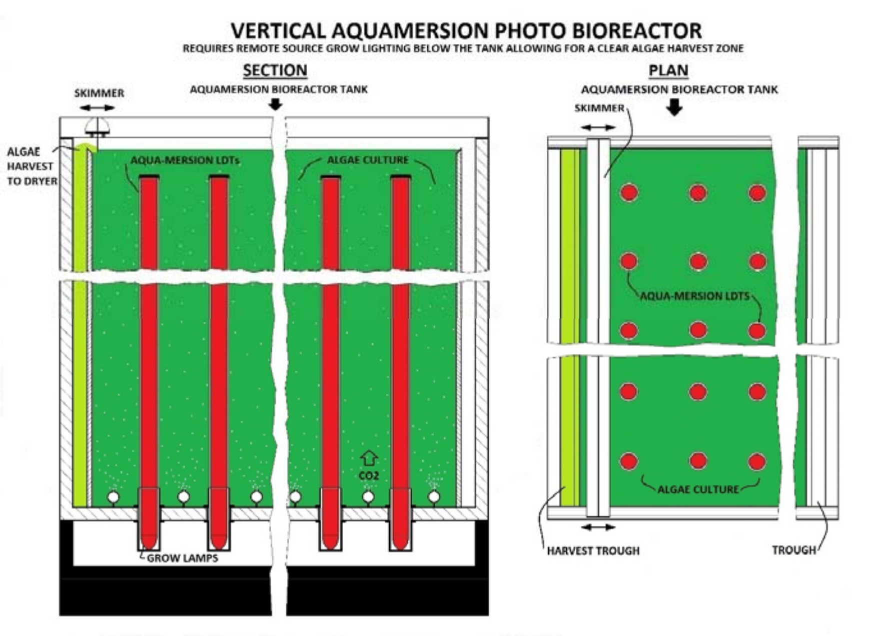
3” DIAMETER X 24” LONG LDT IN A TANK OF WATER

PLYLIGHT PHOTO-BIOREACTOR - PBR

CONFIGURATIONS WITH AQUAMERSION™ LDTs

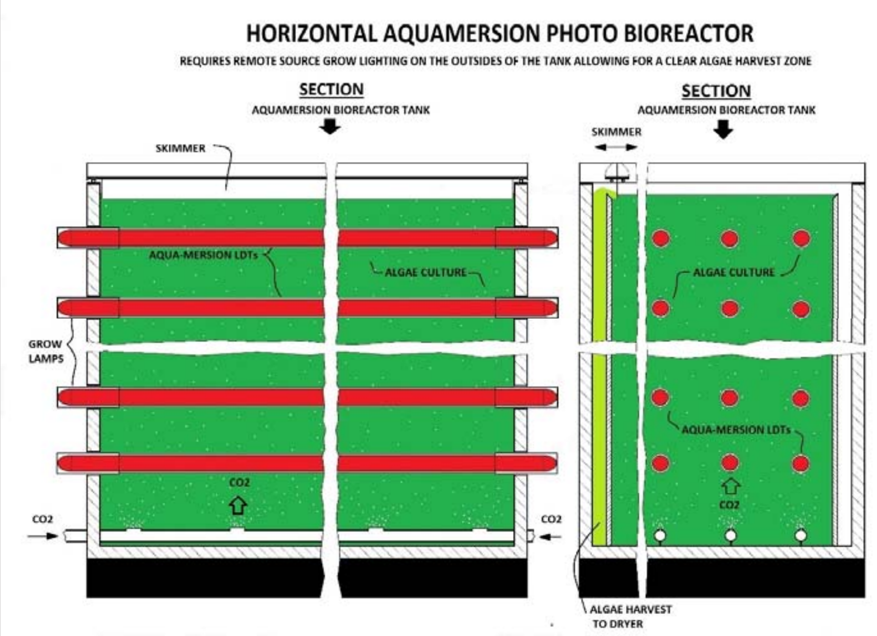
VERTICAL AQUAMERSION™ LDTs

REMOTE SOURCE GROW LAMPS AT BOTTOM



HORIZONTAL AQUAMERSION™ LDTS

REMOTE SOURCE GROW LAMPS AT SIDES

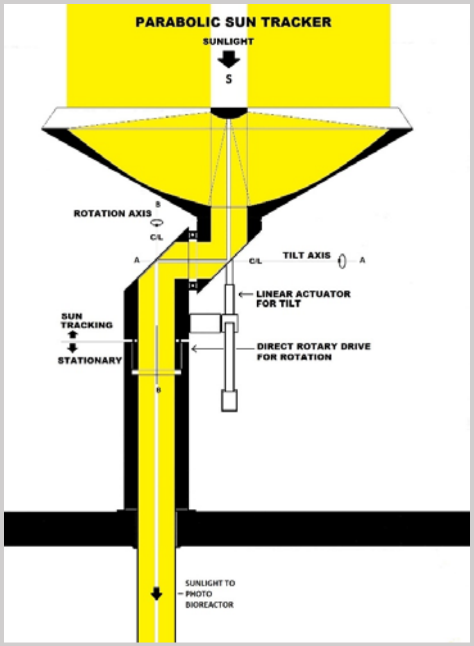


PLYLIGHT PHOTO-BIOREACTOR - PBR

OPTIONAL CONFIGURATION WITH SOLARMERSION™ ILLUMINATION

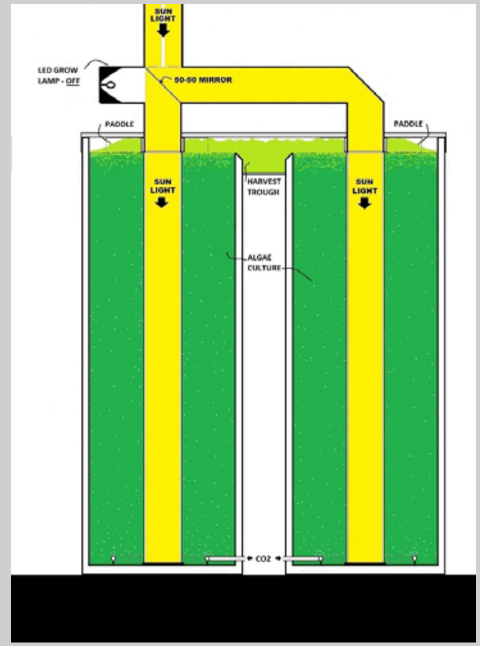
THE SOLARMERSION™ SUN TRACKER

SEE WWW.SOLARMERSION.COM



AQUAMERSION™ WITH SUNLIGHT

SEE WWW.AQUAMERSION.COM



PLYLIGHT

SCIENCE & LIGHT

PARTIAL BACKGROUND:

In 1989 Walter A. Johanson founded a company that has evolved into **PLY**LIGHT. He is the sole owner, and is focused on the design and manufacture of light distribution systems (LDTs). His LDTs are formed from multiple polycarbonate films allowing the tubes to be assembled in the flat, shipped flat, and then rolled into fully functional light distribution tubes at or near their ultimate destination. To this day he continues to explore concepts, design systems, and invent components to achieve his goal of blending ***science and light.***

In addition, Walter holds numerous patents on tubular and solid structures for the controlled diffusion and distribution of light. His patent on a *solar hybrid lighting system* describes a system that can collect, concentrate, and recollimate sunlight, and then distribute that sunlight, with or without artificial light, in the same light distribution system (LDT). This system he calls **SOLARMERSION™**. Most recently, he received a patent on a tubular structure for the *distribution of light in a liquid environment* to aid in the cultivation of algae. This tubular system he calls **AQUAMERSION™**.

Walter has a Master of Architecture degree from the University of Pennsylvania and a Bachelor of Arts degree in Physical Science from Colgate University.