Seambiotic Ltd. - Algae Pilot Plant

Ashkelon, Israel

I. Introduction

Seambiotic Ltd.'s pilot facility for the cultivation of marine microalgae was established in 2006 and is located at the Israel Electric Corporation's (IEC) Rutenberg coal-fired power station, close to the city of Ashkelon, Israel. The algae are cultivated in open ponds using flue gas from the power station, which provides intensive CO_2 enrichment. Significant experience was acquired during the design, construction, and successful operation of the facility, including experimentation with various strains of marine microalgae using the flue gas and cooling seawater condenser effluents from the operation of the power station. This experience and the technology which resulted have made it possible to begin the planning and construction of a facility on a larger scale.

Seambiotic believes that the advantages of algae cultivation using flue gas from smoke stacks are significant. In addition, many industrial companies that produce significant amounts of CO_2 are looking at microalgae cultivation technologies as a way to reduce greenhouse gas emissions.

Seambiotic is planning the construction and development of similar pilot facilities for customers around the world as well as larger scales facilities. The existing Seambiotic pilot plant has been operational for more than four years and has demonstrated the company's ability to grow marine microalgae in open ponds using flue gas and waste water directly from a coal-fired power station. Following the successful proof of concept, Seambiotic has commenced construction through a joint venture in China of a larger commercial scale facility to confirm the feasibility of scaling up the technology, while continuing its research and development of technologies to increase both the productivity of the ponds and the use of the land needed for them.

The cultivation of microalgae contributes to the mitigation of greenhouse gas emissions by enabling the direct use of concentrated CO_2 streams. Although still a relatively small industry (total production is only a few thousand tons of algal biomass per year worldwide), microalgae technologies have been the subject of extensive research over the past decade in the context of both greenhouse gas mitigation and biofuels production.

Algae can be cultivated as feedstock for valuable food additives for humans and animals, for cosmetics, and for the chemical industry and biofuels—potentially contributing to the mitigation of CO_2 by the displacement of fossil fuels with alternative products. Up to 70 tons per hectare per year of algae can be produced compared to a maximum 10 tons per hectare from terrestrial plants. In addition, using Seambiotic technology, fresh water and fertile agricultural lands are not needed.

II. The Patent

A patent application was filed in March 2008 to cover Seambiotic's method for growing photosynthetic microalgae with the flue gas from a fossil fuel power plant. Further information can be found on the U.S. Patent Office patent application website.

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(54) **METHOD FOR GROWING PHOTOSYNTHETIC ORGANISMS**

(75) Inventor: **Herman Weiss**, Rishon Lezion (IL)

Correspondence Address:
NATH & ASSOCIATES
112 South West Street
Alexandria, VA 22314 (US)

(73) Assignee: **SEAMBIOTIC LTD.**, Tel Aviv (IL)

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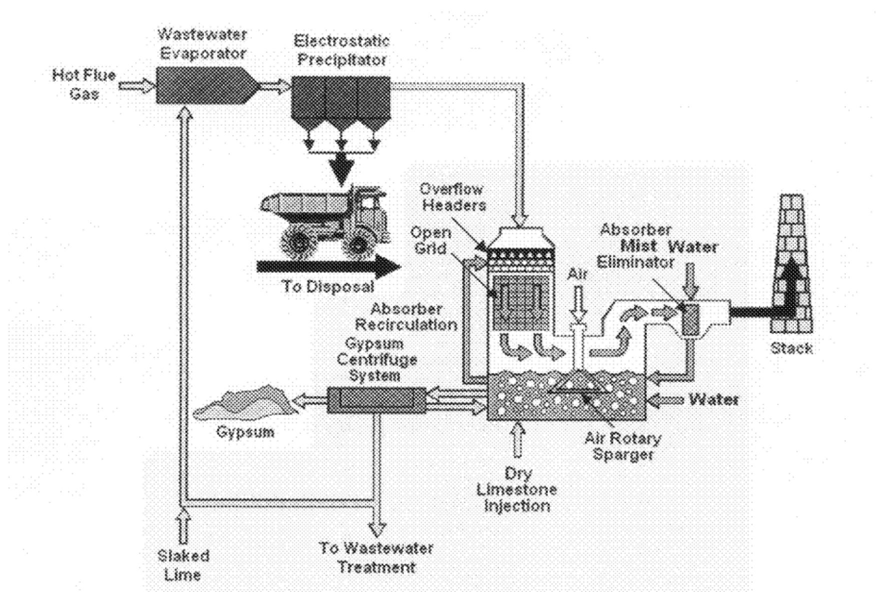
(57) **ABSTRACT**

A method of growing photosynthetic organisms comprising providing the organisms with flue gases from a fossil-fuel power plant, the gases being previously treated by desulfurization. The carbon dioxide (CO_2) concentration of the flue gases may be increased over the CO_2 concentration as released from the power plant. Also disclosed is a method for producing ω fatty acids and bio-fuels comprising growing microalgae by providing said microalgae with flue gases from a fossil-fuel power plant.

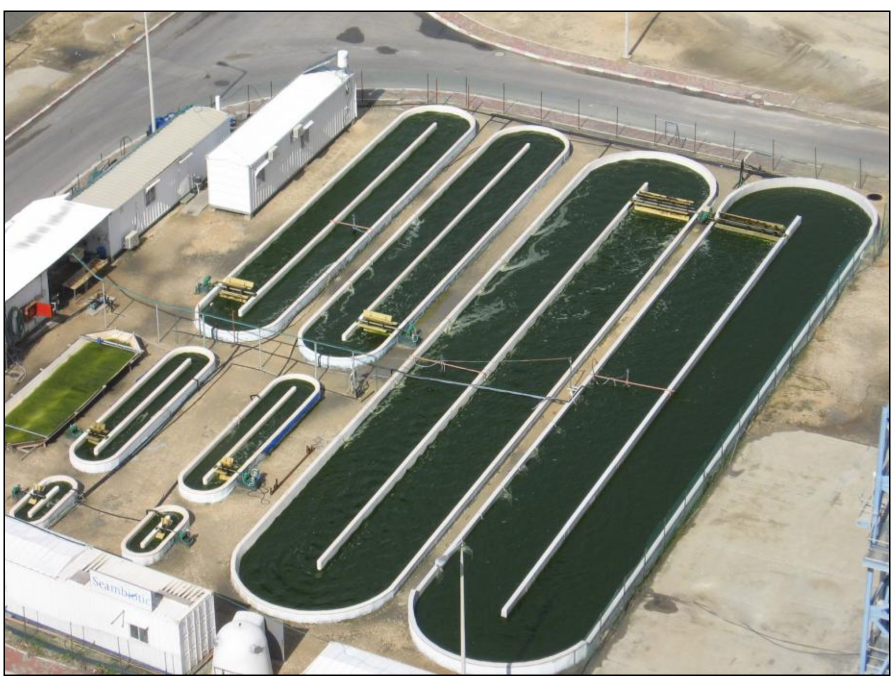


III. History of the Open Pond System

The cultivation of algae in open ponds is a well-known process that has been used throughout the world for decades. One advantage of open ponds is that they are simple, familiar, and successful. Seambiotic's system can continue for an indefinite period of time as long as the ponds are mixed and cleaned as necessary. In order to maintain the condition of the ponds in an open culture system for optimal use, and to keep algae cultures growing continuously, it is necessary to brush the pond liner to remove deposits of sand, dead algae, flocculated material, and other contaminants. A cleaning cycle of every few weeks during growth, as well as after a full harvest, is adequate to keep the ponds in continuous operation. In Seambiotic's experience, the oft-repeated statement that open ponds are easily contaminated with other microorganisms which reduce growth rate of the target microalgae, is a misunderstanding of algal population dynamics. Rather, Seambiotic has shown that healthy, high cell density algal cultures can maintain their high rate of growth for a long time in open ponds, assuming that there is sufficient scale-up supporting cultures, such as availability of a continuous feed of fresh algae into an established culture at a volumetric ratio of 1/3. Seambiotic has been cultivating algae for years, keeping the same species outdoors using the scale-up system.

IV. Seambiotic's Pilot Plant – The Process

Seambiotic's pilot plant is located within the campus of the Rutenberg power plant where land has been leased from the Israel Electric Corporation (IEC), approximately 100–150 m from the smokestack, thereby obviating issues of transport of the flue gases from the stack to the plant. The total area of the Seambiotic pilot plant is 1,600 m^2, containing open ponds with a total surface area of about 1,000 m^2.



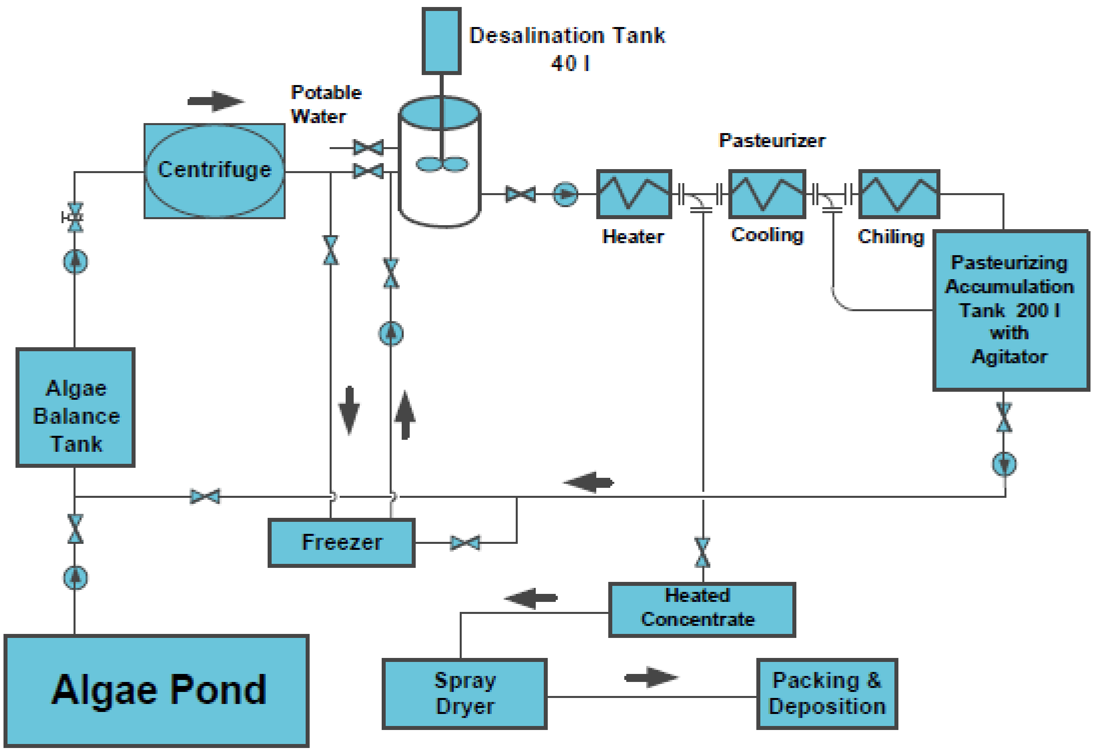
The pilot plant consists of the following main systems:

a) Algae ponds

b) Seawater supply system

c) Algae harvesting, drying and treatment system

d) Flue gases supply system



a. Water Mixing

Efficient water mixing is an important issue when cultivating microalgae. The goal is to provide each cell with the necessary conditions to absorb sufficient sunlight to optimize the photosynthetic process. Mixing is necessary, even in shallow ponds of less than 0.5 m in depth. In Seambiotic's ponds, the algae water medium is mixed by traditional paddle wheels driven by a geared electric motor. The paddle wheels are constructed using a stainless steel axis and fiberglass blades. Seambiotic is performing proprietary research and development to test alternative methods to the traditional paddle wheels that might materially increase productivity and reduce power consumption.

The paddle wheels generate unsteady water motion, including flow in the horizontal direction at 20 cm/sec and oscillations of the free surface in the vertical cross section. Therefore, the water particles have both vertical and horizontal velocities.

The available vertical velocity component is the element principally responsible for mixing the medium in the vertical plane which is crucial for raising particles from the pond floor towards the surface where they receive sufficient sunlight to participate in photosynthesis. The amount of vertical velocity depends on the paddle wheel's rotation velocity, which Seambiotic has optimized after researching and adapting to each algal species.

One main approximately 200 m long PE pipe with a diameter of 160 mm supplies the gas effluent from the blower to the algae ponds. A 160 mm manifold redistributes the gas among the ponds through 63 mm pipes to ensure even gas flow. Gas is dispersed in the pond water by underwater bubble aerators or diffusers. Large ponds are serviced by two pipes, smaller ponds by one. A compound saddle is situated on the 63mm pipe with an exit to a flexible pipe of 20 mm diameter. The diffusers are connected to the end of each 20 mm pipe. The flue gas approaching the ponds is at ambient temperature with approximately 12% CO_2 content. The amount and consistency of unabsorbed flue gas content is not checked.

b. Seawater Supply System

Seawater is supplied from the turbine condenser cooling water system of the power station's discharge channel. A submerged pump with 20 m^3/h capacity installed in the power station's discharge channel fills the ponds when necessary.

c. Algae Harvesting, Drying, and Storage

Algae are harvested from the ponds when the cultures reach a cell density of at least 100 million cells/mL, equivalent to 0.5 g/L. Algae from smaller ponds are then moved up to the larger ponds. For harvesting, Seambiotic uses a centrifuge, which increases the concentration of the algae from an initial 0.1% to approximately 15–18% solids. Although the use of a centrifuge is highly effective in separating and concentrating the harvested algae into paste form, both the capital and operating costs of a centrifuge are significant and would not be suitable for any end product other than high-grade food supplements and similar products. Successful penetration of mass markets—for example, animal feedstock or biofuels—would require the use of alternative harvesting and dewatering technologies such as wastewater harvesting by flocculation, which significantly reduces the cost of particle separation. Several other initiatives are underway, including cooperation between Seambiotic and strategic partners to study the dewatering options in order to develop an appropriate solution for the mass market.

Harvested paste is kept frozen and stored for downstream processes. Algae paste can then later be dried to form a powder using a Spray Dryer. Dried algae can be stored without cooling. Spray dryers involve a material capital and operational cost that makes this technology unattractive for mass markets such as biofuel. As with centrifuge technologies for initial dewatering, alternatives to the spray dryer are being studied.

Seambiotic's final product is dry algae powder. This product is food grade and can be used in fish, animal and human food markets. Further downstream processes can take the powder and separate the algae into its constituent parts: lipids, carbohydrates, and proteins. Each of these parts has its own mass market as long as the drying and extraction processes are economically efficient. The lipids can be used as biodiesel and, if they are further broken down, the part that contains Omega-3 poly unsaturated fatty acids or other materials, can be extracted for the food market. The carbohydrates can be turned in bioethanol, and the proteins sold into the animal feedstock market. Seambiotic is sharing the downstream processes with other partners.

d. CO_2 Uptake

The intrinsic basis of photosynthetic CO_2 uptake per unit algal biomass created is approximately 2 grams of CO_2 for each gram of algae grown. The ratio is unrelated to weather or season, which can affect the speed of growth, but not the amount of CO_2 absorbed relative to biomass created. The actual CO_2 uptake will vary according to the chemistry of the liquid growth medium and by CO_2 diffusion technology, and can be monitored. Diffusing flue gas usually dissolves CO_2 in the liquid medium to the somewhat acidic pH level of 5.2. Carbonic acid is then added to control the pH of the culture at approximately 7 while maintaining the total dissolved carbon (TDC) at 2–5 mM, thus avoiding acidity-related issues. Extreme high or low pH can increase the solubility of the TDC and accordingly change the CO_2 concentration in the water and the uptake by the algae culture.

Interestingly, the rate of algae growth using FGD gases from the IEC Rutenberg plant was found to be about 50% higher than when using pure food-grade CO_2 and fossil oil. Further analysis of the solid particles in the FGD gases showed the presence of a range of heavy metals essential for algal growth, such as vanadium, strontium, mercury, and zinc, in ppb concentrations, implying there was no further need to supply trace metals in the growth medium. it can therefore be seen that one unexpected advantage of using flue gas after FGD scrubbing as compared to pure CO_2 is that various remaining particles which might have been expected to harm or impede the growth of the algae in fact have the opposite effect of giving the algae some of the nutrients that it needs to grow, and results in a yield of almost a 50% higher rate of growth compared to pure CO_2. In addition to the nutrients in the flue gas, nitrates and phosphates are also added to the growth medium at approximately 3 mM and 0.5 mM, respectively, to assist in the growth of the algae at optimal rates.

Another major impact of the power plant configuration is the level of SO_2 resulting from the presence of the FGD system, which should be below 120 ppm. Higher concentrations of SO_2 interfere with CO_2 during photosynthesis though competitive inhibition, causing a decline in algal growth. Full growth inhibition will occur at concentrations of SO_2 above 1,000 ppm.

Seambiotic uses gas diffusers, which are placed in the liquid culture about 20 cm deep and provide the flue gas by continuous pH-controlled diffusion. No fresh water is needed. Most species of the marine unicellular algae can withstand a wide range of salinities, which allows a few growth cycles on same medium (albeit compensated for evaporation through the addition of seawater). After a few cycles of growth, the culture is harvested and restarted with fresh culture on new seawater. The typical growth cycle of the full process, from inoculation to scale-up dilution or to the harvest of the last pond, is 3 days at high season and 7 days at low season.

Many technologies can be employed for further processing and use of the biomass produced by an algae farm. As explained previously, the different approaches have their respective advantages and disadvantages, depending on the ultimate use of the end product. Centrifuges are used to separate products for human food and animal feed. In the case of high financial value food-grade materials for the food supplement and pigment product lines, a process of harvesting using a centrifuge and spray dryer is acceptable despite its relatively high capital and operational costs. Algae at the Seambiotic pilot plant are harvested through liquid-solid separation by centrifugation. The concentration of the inlet material is approximately 0.5 g/L, and that at the outlet is approximately 150 g/L, for a concentration factor of about 300. Flocculation with inorganic or organic flocculants can be used for successive biomass extraction for bioenergy, pigments, fatty acids, and so on as these products require a lower cost of production. For even lower value products (for example, biofuels), other methods such as filtration and sedimentation must be used currently in order to be economically competitive.

V. Cultivated Species

Seambiotic uses marine unicellular algae native to most oceans and seas around the globe. The selection criteria are the content of value-added products and the ease of cultivation. The primary species used, and their products, are as follows:

- *Nannochloropsis* is attractive because of its high growth rates and the fact that the lipids in the algae are relatively high in omega-3 fatty acids. It grows in seawater, at average light levels. However it requires relatively low temperatures and low pH.
- *Tetraselmis* is high in carbohydrates and can be grown in variable environments.
- *Nannochloris*, an algae strain that grows in high temperatures and is high in carbohydrates, is capable of good growth in a range of light levels and at low pH.
- *Dunaliella* is attractive because of its relatively high levels of beta-carotene for the human market at attractive prices. It can also withstand high salinity, high light, and virtually all temperatures.
- *Diatoms* are also rich in omega-3 fatty acids and can be grown in a range of salinities at medium-low temperature and low light intensity.
- *Chlorococcum*, which has interesting properties in the area of pigments, can be grown in average temperatures and high light intensity.

Seambiotic specializes in naturally sourced strains of algae and uses natural selection to further modify them. The company does not undertake research into genetically modified strains of algae species, which is an industry in its own right. Seambiotic believes that, if algae can be genetically modified to increase the preferred characteristics for a specific purpose, the company can collaborate with such research companies to pair their genetic research with Seambiotic's technology and experience in algae cultivation using power plant flue gas. In July 2010, Seambiotic has entered into a collaboration with one such company, Rosetta Green (see http://www.seambiotic.com/News/news-updates/).

All of Seambiotic's ponds contain a combination of fresh culture at first-stage growth level, as well as aged cultures at an approximate volume ratio of 1/3, respectively. The company changes species as the seasons and temperatures require in order to accommodate the best growth rate.

Bulk algal composition is manipulated by nutrition and environment. The major composition effects result from the specific nutrients, light, temperature, pH, and salinity used. Typical algal biomass is composed of 40% protein, 20-40% carbohydrate, 10-30% lipid, and 10% ash, if not deficient due to insufficient nutrition or environmental needs.

Seambiotic research suggests that, under optimal conditions and prior to additional development that may further increase productivity, the company can reach yearly average production yields averaging approximately 20 g biomass/m^2/day. The average production is kept nearly constant year round by modifying the growth salinity conditions versus temperature.

A minimum of 2 g CO_2/g algae for photosynthetic conversion of inorganic carbon to organic carbon, and a maximum of more than 5 g CO_2/g algae through the additional use of inorganic carbon in seawater, are well accepted rules of thumb for carbon requirements of algal growth. The former requirement represents only the theoretical conversion of CO_2 to organic carbon through photosynthesis. The latter requirement represents both photosynthesis as well as additional chemical conversion of inorganic carbonic acid to bicarbonate and carbonate in seawater at high pH, and then further to various salts such as calcium carbonate and magnesium carbonate. Actual ratios of CO_2 uptake to CO_2 delivered will be studied in the future. Meanwhile, attempts are being made to estimate this ratio.

Seambiotic's pilot plant is operated as a research facility rather than for optimal algae growth at all times. As a result, there are frequent changes of algae species in the ponds and time elapses between trials and projects. Despite this, the pilot project has cultivated several tons of algae per year.The plant also has the capability of producing dry powder as an end product for its harvesting process. In this respect, Seambiotic has successfully harvested several tons of dry weight for research projects and other markets for the product. Although the dry powder (from the pilot project) has not yet been sold as a specific high-value product in the market, the company expects to start selling small amounts (1–2 tons) of dry weight to a commercial purchaser in the next year.

Seambiotic does not have the equipment or capabilities to produce biodiesel on site. Therefore, the company uses subcontractors who use various methods to process the dry powder into biodiesel. Seambiotic has contracted or collaborated with third parties to produce sample—rather than commercial—amounts of biodiesel to examine the efficacy of the processes and the simplicity of the technologies involved.

Over the last 3 years Seambiotic has sold more than 3 tons of algae products, principally to third parties for their own research in the downstream process.

VI. Design of new algae farms

Seambiotic has recently signed an agreement with IEC for the lease of an additional area of 45,000 m^2 for the construction of additional ponds with a gross land surface area of 35,000 m^2. The new area will allow for the construction of larger ponds, each about 1,500 m^2 (150 x 10 m), and for testing and research of productivity and growth variables on a much larger area than available in the currently operating pilot plant. Initial planning of the site has already been completed, and the company has entered the detailed planning and permitting process. Seambiotic plans to complete construction of the new plant 2011.

In addition, Seambiotic has recently signed a License Agreement and Joint Venture Contract with companies associated with China Guodian, the fifth largest power company in China, for the establishment of algae farms in China attached to coal-fired power stations, The first farm will be situated adjacent to the Penglai power station and will consist of open algae ponds with a gross surface area of approximately 100,000 m^2. Construction is expected to be completed in the second half of 2010 (see http://www.seambiotic.com/News/news-updates/seambiotic-and-chinese-power-company-to-build-10-million-commercial-microalgae-farm-in-china).