

Patent Application of Eli M. Rabani for:

TITLE: Efficient Biomass Cultivation Featuring Light- and Thermal-
Management, Processing of Biomass to Useful Materials & Manufactured
Articles, Nutrient Recycling and Cellular Agriculture, by Near-Closure Self-
5 Replicating Systems.

RELATED APPLICATIONS:

This application further develops and applies material disclosed in provisional
Application No. 61/188726, filed 2008 Aug 11 by the present inventor, U.S.
10 Provisional Application Ser. No. 61/852,324 by the present inventor, filed 2013
Mar 15, Application No. 14/217473 transmitted 2014 Mar 17 (2014 Mar 18
acknowledged), Application No. 12/807,708 by the present inventor, which
claims the benefit of provisional Application No. 61/276220, filed 2009 Sep 9
by the present inventor, Application No. 12/462950, mailed 2009 Aug 11,
15 Provisional Application No. 62/728,953 filed 2018 Sep 10 by the present
inventor, and Provisional Application No. 62/728,968 filed 2018 Sep 10, U.S.
National Phase Application No. 17/287,987 filed 2021 Apr 22, which claims
benefit of PCT/US19/057505, now WO/2020/08632, which claimed benefit of
Provisional Application No. 62/749,117, filed 2019 Oct 22, all by the present
20 inventor, further adding new material. The foregoing are all incorporated
herein by reference.

FIELD OF THE INVENTION:

This invention relates to the fields of nanotechnology, self-replicating
25 systems, chemistry, biochemistry, medical devices, information processing
and electronics, electromechanical devices, solar energy, wind energy,
materials processing, fabrication, micro- and nano-fluidics, assembly and
robotics, and cultivates biomass to effect ambient carbon dioxide removal
from the ocean, reverse ocean acidification, and transform captured carbon
30 to useful materials such as materials for construction and infrastructure.

DETAILED DESCRIPTION OF THE INVENTION:

The present invention provides enhanced systems for the efficient cultivation of photosynthetic organisms, methods and means for processing the biomass thereof to useful materials, and fabricating desired articles from said useful materials, including subsystems of the present invention.

5

Most simply, light such as solar illumination may enter a photobioreactor via a transparent surface or window. More preferably, light management subsystems may comprise a heliostat or solar-tracking means, and means for separating ranges of wavelengths or bands of light frequencies into at least two or more preferably three or more bands, (frequency bands include

10

infrared radiation [which may be further subdivided into near-IR and IR], photosynthetically active radiation [PAR, which may be further subdivided according to specific chlorophylls, pigments or light-harvesting antennae they excite], and ultraviolet [UV] radiation).

15

Light management preferably includes means for spatially concentrating incoming photon fluxes, such as convex lenses, superlenses or Fresnel lenses, any of which may be cylindrical or uniaxial lenses where desired. Alternatively, concave mirrors (e.g. parabolic mirrors) or wedge-optics exploiting total-internal-reflection may be used to concentrate incoming light. Light concentration means permit light to be processed or channeled through an optical gallery to direct light derived from different portions of incoming light along distinct light-paths to different destinations. Light separation means may comprise prisms or their Fresnel equivalents,

20

gratings (e.g. blazed gratings produced by replicated optics methods, or wire gratings produced by situating tensioned wires or fibers in a frame with appropriate spacings), superprisms (e.g. metamaterials or photonic crystals), or nanocomposite films (e.g. multilayer thin film optics). Similarly or alternatively, reflective films or partially reflective films may be used to redirect and or modify illumination; multilayer dielectric films (e.g. [DruT08]) can be designed to act as hot-mirrors or cold-mirrors, i.e. preferentially reflect infrared or visible light while transmitting other light.

25

30

So for example, film transparent to visible light modified to reflect infrared radiation may redirect infrared radiation to the receiver of a heat engine or a heat reservoir, while transmitting photosynthetically active radiation to a photobioreactor or the light input aperture thereof, or light receiving means
5 therefor.

Light is directed along lightpaths or waveguides such as fiber optics or slab optics to desired destinations. Infrared radiation may be directed to thermal processing subsystems (e.g. pyrolysis, distillation, hydrothermal
10 degradation, wet pyrolysis, torrefaction, dry pyrolysis, dry distillation, pyrolytic processing, sintering, eutectic fusion, etc.) and/or a heat engine for providing mechanical energy or driving an electrical generator; IR may also or alternatively be directed to radiant cooling means for re-emission through radiant cooling means, preferably directing heat to be re-emitted to
15 space. PAR may be delivered to photobioreactors, greenhouses or cultivation areas. UV may be delivered to fabrication systems for use as actinic radiation (e.g. to activate photoinitiators or to cross-link materials to surfaces or activate surfaces or activate photochemical reactions, such as polymer grafting, materials bonding, photoisomerizations, or
20 photopolymerization.

Sintering is used to produce articles and structures for use as means for some high-temperature processing operations. Magnesium oxide,
25 strontium oxide, aluminum oxide, silicon carbide and silicon nitride are preferred materials, and these may be produced as nanoparticles by subsystems of the present invention from inputs derived from seawater, sediment or biomass.

30 Photonic crystals, metamaterials, superprisms, and superlenses may be formed by stacking and bonding films comprising relief structures embossed into or molded into films (e.g. fabricated by roll-to-roll processing

means, or film casting onto a master roll or master belt comprising a complementary relief to that desired) with thin regions preferably thinner than 0.5 wavelengths and more preferably thinner than 0.25 wavelengths.

5

Biomass may be processed in a variety of ways. Most preferably, if it is initially obtained as a suspension, seaweed/kelp tissue, or filtrate, it is first dewatered (e.g. by distillation or vacuum distillation of water), followed by lysis using detergent and hydrolytic enzymes (lysozyme, cellulase and/or
10 chitinase, unless respective substrates are desired as polymers), or by lysis due to infection by lytic virus or bactiophages or phagemids expressing lytic enzymes, and/or using ultrasound (via MEMS capacitor mechanical oscillators driven at ultrasound frequencies (for which they are designed to be resonant) to liberate biomass components.

15

Biomass may be dewatered and subjected to torrefaction or gasification yielding biochar. Preferably, this is conducted at or includes a high-temperature step at greater than 700°C or more preferably above 800°C to avoid/decompose polyaromatic hydrocarbons and halocarbons (e.g.
20 dioxins). [Tomc20]

Alternatively, biomass may be processed by anaerobic digestion to obtain methane and residues from which nutrients may be recycled. Methane so obtained may be used as a feedstock, including for pyrolysis, preferably at
25 temperatures above 1250 K to yield H₂ and solid carbon; pyrolysis to carbon may be conducted at higher temperatures without catalysts with deposition onto carbon catalysts. Suitable carbon catalysts include biochar, carbon black, glassy carbon, carbon nanotubes, and graphite-like carbon. [Mar21] Herein, this pyrolysis is preferably conducted in vessels composed
30 of sintered silicon-carbide or silicon-nitride, which is more preferably reinforced with carbon nanofibers.

Among compounds recoverable from distillates derived from biomass pyrolysis are phenols including resorcinol. These may be reacted with formaldehyde to form phenol-formaldehyde resin oligomers such as
5 novolacs. These may be molded in elastomeric relief molds, crosslinked and then pyrolyzed to glassy carbon, as taught in [Sch97], and are useful both as electrodes and strong high-temperature materials, as well as relief structures for embossing other materials. On pyrolysis from phenol-formaldehyde resin, structure shrink isometrically, so that smaller spatial
10 features or resolutions are achieved. Glassy carbon relief structures may be used in the present invention for embossing polymer films or casting of complementary reliefs from molten polymers or liquid polymer precursors, especially elastomeric materials, most especially for microfluidic or nanofluidic devices, and for replicated optics, photonic crystals and
15 metamaterials. Most preferably, glassy carbon relief secondary masters are pyrolyzed while slightly curved by being deposited on a roller surface, such that the glassy carbon product is curved to match a roller surface (multiple such articles tiled on a roller surface, then transferred and affixed at higher density to a production roller in a tiled configuration), whereby it is suitable
20 for use in roll-to-roll manufacturing.

Hollow fiber and membranes from roll-to-roll fabricated spinnerettes, and application of hollow fiber membranes to cellular agriculture:

25

Among useful micro- or nanofluidic devices are nozzles for electrospinning or wet-spinning of fibers, especially composite nozzles for wet spinning of hollow fibers, especially porous hollow fibers. These nozzles are favorably composed of glassy carbon, and constructed by facing juxtaposition of
30 compound reliefs, as shown in Fig. 1. Useful materials for hollow porous fibers include cellulose, hemicellulose, chitin, chitosan, and alginate. Spinnerettes may be fabricated by molding resins such as phenol-

formaldehyde resins using elastomeric molds, preferably by roll-to-roll manufacturing methods, and then pyrolyzing the molded polymer to form glassy carbon with the desired structures. FIG 1A-E shows component structures for spinnerettes. FIG. 1A shows a half-tube with wings featuring

5 wide grooves for accomodating the wings of the smaller half-tube in FIG. 1B; FIG. 1B shows a smaller half-tube with wings; FIG.1C shows a partial plan view of the underside of the half-tube in FIG. 1B; FIG. 1D shows a half-spinnerette comprising the assembly of the half-tube in FIG 1A assembled onto the half-tube in FIG 1B, with both assembled into the the end of a

10 recessed half-tube in an outer-block. The assembly in FIG. 1D is facingly juxtaposed with a similar assembly to form a spinnerette for wet-spinning hollow fibers. FIG. 1E shows the end view of the concentric orifices through which hollow wet-spun fibers exit the spinnerette; the micro/nanocapillary or tube orifice for the inner nonsolvent is denoted by 110, the

15 micro/nanocapillary or tube orifice for the polymer solutions is denoted by 120, and 130 denotes the micro/nanocapillary or tube orifice for the outer non-solvent sheath is denoted by 130. FIG. 1F depicts plates with orifices located to match the locations of orifices of the spinnerettes; a pair of such plates stacked together both aligned to spinnerette orifices before fiber

20 spinning may be drawn away after fiber spinning has commenced, such that fibers are threaded through plate orifices and spinnerettes; one of the pair of plates is slidingly translated to reduce the net opening size and clamp fibers securely between plate orifice borders, as shown by the overlap of solid and dotted lines in FIG. 1F; the resulting assembly features an

25 organized array of fibers which may be tensioned between said spinnerettes and said plates. A similar method and arrangement may be applied to the fabrication of arrays of non-hollow fibers or clad fibers (e.g. the same or a different polymer solution or a sol (e.g. for forming a silicate gel or metal-oxide gel) flowed through central rather orifice 110). Fiber arrays may be

30 produced with a pitch suitable for use as optical (wire-like) diffraction gratings.

Hollow fibers, especially porous hollow fibers, may be spun and formed into membranes, with ends retained in the spinnerette (which is part of an array of spinnerettes), and fibers are preferably oriented e.g. by combing, such that open ends are at a border distal from spinnerettes, or more preferably
5 as arrays as described above. After hollow fibers are spun, the inner tubule feeds fluid into hollow tubules. Membranes thus constructed may be used as substrates for the cultivation of cells for cell culture, especially for cellular agriculture. Cells thus cultivated may be animal cells (especially myocytes) to produce meat, fungal cells or plant cells, preferably from
10 organisms familiar to agriculture (or stem-cells or protoplasts or spores derived therefrom). Hollow fibers may deliver growth factors or hormones, nutrients and/or gases and transport wastes including gases away; controlled delivery of growth factors facilitates avoidance of residual excess growth factors or hormones in grown tissues, which may be undesirable.
15 Similarly, for plant thin cell layers, plant hormones may be provided early during growth but withdrawn later. Preferably, a chemically defined growth medium substantially free of materials harvested from animals are used, either or both surrounding cultured cells and/or as medium for circulation through hollow-fibers. Nutrients for cellular agriculture of these
20 embodiments of the present invention may be obtained from biomass cultivated in the bioreactors of the present invention and separated by fractionation thereof or recovered during nutrient recycling. Alternatively, cells may be cultivated on a substrate of a non-hollow fiber membrane (which may have cellular adhesion molecules and spreading molecules
25 grafted or bound thereto, with cells thereupon being overlaid with the foregoing hollow-fiber membrane, optionally including material or including spacers to prevent cellular adhesion to hollow fibers, which may thereby be reused rather than becoming bound to produced tissue. As cells typically grow faster as monolayers, cultivating cells for tissue culture as monolayers
30 on membranes that either will later degrade or do not interfere with desired product properties, and then stacking or rolling these layers to achieve thicker tissue structures, especially with addition of adhesion molecules

(e.g. laminin for animal cells) to media before stacking or rolling; cells that grow well as multilayers (e.g. fungi or thin layer plant cell cultures) may similarly be stacked into thicker structures.

5

Albedo and prevention or mitigation of sea-surface temperature elevation due to thermalization of light energy during photosynthesis:

Photosynthetic organisms at high concentrations can increase ocean
10 albedo, which is superficially a desirable effect mitigating climate-change driven sea-surface warming. However, photosynthesis is accompanied by thermalization in the photic layer (instead of transmission to deeper ocean strata), increasing sea surface temperature. [Kah93]

15 For our present purposes, we can mitigate this effect through heat re-radiation (radiative cooling, especially using composite films, e.g. [YiZ21] or metamaterial-based antennae) or both mitigate and exploit this for energy production using ocean thermal energy conversion (OTEC), especially concurrent with nutrient upwelling, as shown in FIG. 3. More preferably,
20 nutrients from upwelled waters are bound by ion exchange resins, polymers bearing chelating groups, or, for phosphate, by precipitation with elevated concentrations of calcium.

OTEC systems as taught in US Patents Nos. 4,474,142, 4,311,012 and/or
25 3,312,054 may be utilized but are more preferably constructed from materials produced according to the present invention or taught in U.S. National Phase Application No. 17/287,987 filed 2021 Apr 22 by the present inventor (incorporated herein by reference), and fabricated and assembled as taught therein or herein. For use with the present invention, before heat
30 transfer, drawn-up cold water is flowed through an insulated temporary vessel or channel where nutrients therein are adsorbed to a binding matrix or precipitated (e.g. precipitation of phosphate by increased calcium

concentrations, capture of iron by polymers or fibers derivatized with iron-chelating ligands such as tiron or siderophores.

FIG. 2 shows the structure of a molecule suitable for reversibly binding

5 bicarbonate as a pendant group bound to a polymer backbone or a fiber or to a polymer matrix for use as a selective ion exchange resin.

Deprotonation of the protonated benzylic nitrogen shown greatly reduced the binding enthalpy for bicarbonate anions. Polymers or fibers bearing this moiety may be exposed to seawater to bind bicarbonate, moved to a

10 growth medium which has been alkalized due to reversal of the carbon dioxide hydration reaction during photosynthesis, whereby a proton is consumed and the binding equilibrium shifts towards release of the bound bicarbonate. The net result is to selectively transport bicarbonate and a proton from external seawater into a closed photobioreactor.

15

FIG. 3 shows a block diagram of a system for cultivation of photosynthetic microorganisms featuring light management and thermal management including OTEC with concurrent nutrient upwelling, processing of resulting biomass, and nutrient recovery/recycling.

20

FIG. 4 shows a cross section, perpendicular to the roller axis, of a scroll in roll-to-scroll fabrication. A first film 410 is rolled atop and together with a second film 420 onto a roller 400, to which the ends of both films are optionally clamped by pressure clamp 430. In this configuration, the entire

25 areas of facing films 410 and 420 may be in intimate contact for extended periods, while fabrication or processing or modifications of those films may take place, compared to only for limited times and limited areas of contacts between rollers or other components of conventional roll-to-roll fabrication lines. Films input to the scroll may each be simple unilayer films, composite

30 films, or either of these situated on a backing film. Backing films may limit which sides of films are contacted or modified. Alternatively, one backing film may comprise relief structures to modify the film situated on a second

backing film, and this second backing film may optionally additionally similarly comprise relief structures to modify the surface structure of said first film, or said second backing may comprise active device elements such as ultraviolet light-emitting diodes or electroluminescent devices for causing the illumination with actinic radiation of said first film, e.g. for causing polymerization or crosslinking of chemical or polymer compounds therein. In a yet further alternative, one or more backing films may form a waveguide for actinic radiation illuminated for total internal reflection, wherein the film it is contacted with is modified via near-field transmission of actinic radiation only within approximately less than one wavelength from the surface of said backing film waveguide.

Depth Cycling of macroalgae to Enhance Nutrient Availability for Macroalgae & Increase Growth Rates:

Recently, Navarete et al. [Nav21] have shown that depth cycling enables macroalgae to grow faster by reducing nutrient limitation, and found four-fold increase in bioproductivity rates. Macroalgae are grown on ropes or frames, and these are lowered at night to depths where nutrients are more abundant to effectively enhance bioproductivity rates. If this effect scales, this brings a macroalgae (the giant kelp *Macrocystis pyrifera*) well within the range of bioproductivities useful for present purposes, to an estimated 0.069 kg/d.m^2 based on other estimates of the growth rate of this organism during fall and winter (when grazing does not significantly limit bioproductivity. Depth-cycled ropes and frames can also descend to avoid weather hazards.

Facilitated upwelling or nutrient capture from deeper waters (e.g. via wave energy driven pumping or concurrent to OTEC) can likewise reduce nutrient limitation.

Open cultivation of macroalgae, including but not limited to kelp and sargassum can be conducted in areas subject to eutrophication due to elevated nutrients (e.g. due to run off) for local mitigation, and nutrients recovered from the resulting biomass and transported to cultivation systems situated in the open ocean, or be processed as amendments to fertilizers.

Note that these same organisms may be cultivated in closed systems where nutrient levels may be adjusted freely, but here, carbonate or CO₂ levels may also be increased (as in greenhouses for terrestrial plants) to further increase growth rates. In that case, since grazing is eliminated, cultivation may occur for longer than two seasons.

Preparation of silicon-carbide or silicon-nitride nanoparticles and articles therefrom:

Diatoms (e.g. *Thalassiosira pseudonana*) are grown in closed photobioreactors, harvested and dewatered. Carbon black (preferably from pyrolysis of microalgae such as spirulina or photosynthetic picoplankton, also grown in closed photobioreactors) are combined in an effective ratio for carbothermal reduction of the quantity of silica produced by said diatoms (simple experimentation may optimize this ratio). For production of silicon nitride, urea or ammonia may be added stoichiometrically. Teachings of methods applied to diatomaceous earth rather than diatoms may similarly be applied. Particles are then cast as taught in [Gan16], and sintered to produce smooth, heat and oxidation resistant ceramic articles. Casting may be done by plastic molds including 3-D printed molds.

Roll-to-roll and roll-to-scroll manufacturing of films, optical materials:

A master (e.g. glassy carbon) of a ruled grating of lines, preferably of

square or rectangular profile is used to cast a film or emboss a film of an optically transparent material, e.g. polystyrene or cyclic olefin copolymer, e.g. casting from a polymer melt onto a master situated on a roll of a roll-to-roll apparatus, or a melt is slot-extruded onto said master and embossed thereon before completely hardening, cooled and stacked with a similarly and concurrently produced grating film, where at least one of the contacted surfaces is first exposed to vapor of a solvent for said polymer, such that the two films are scrolled together. The scroll is then subjected to elevated gas pressure (as is done for hot isotactic pressing), such that the fusion operation described in [Kel16] for cyclic olefin copolymer using hexane to fuse layers into microfluidic devices is accomplished, but for a full roll of films to be bonded together at once, rather than slowly and serially in a press of limited dimension. Photonic crystals useful as superprisms useful for light management for the present invention may be fabricated by repetitions of this process to create crystals of, e.g. 16 or more layers, which may still be only a few microns thick. Operations involving elevated pressure are conducted in vessels composed of materials reinforced with carbon nanofibers, e.g. as produced in PCT/US2019/057,505 by the present inventor, incorporated herein by reference.

20

EXAMPLES:

In the following examples,

Example I: Open cultivation of macroalgae with nutrient enhancement,
5 processing of resulting biomass to materials for construction of closed
photobioreactors for cultivation of microalgae, phytoplankton, nanoplankton
or cyanobacteria.

Example II: A heliostat tracking the sun aims an optical assembly
10 comprising a first polymer nanocomposite film for reflecting ultraviolet
radiation to an ultraviolet receiver (for guiding said ultraviolet radiation to a
nanofabrication subsystem utilizing actinic ultraviolet radiation) and
transmitting visible and infrared radiation, which pass to a second polymer
nanocomposite film for reflecting infrared radiation to a receiver of a heat
15 engine composed of heat-resistant material such as silicon-carbide and for
transmitting visible radiation to a cultivation area or to a photobioreactor or
to light collection means for distributing light in a cultivation volume.

Example III: A heliostat and optical assembly of Example II illuminating
20 an attached photobioreactor wherein cyanobacteria, purple photosynthetic
bacteria, microalgae, and or phytoplankton are cultivated as films on
supports such as filters, membranes or support sheets.

Example IV: A heliostat and optical assembly of Example III wherein at
25 least a first organism selected from the group consisting of cyanobacteria,
purple photosynthetic bacteria, microalgae, and or phytoplankton, and a
second organism are cultivated as films on different supports or in discrete
areas on a support such as said first organism and said second organism do
not come in contact.

30

Example V: A heliostat and optical assembly and attached
photobioreactor of Examples II, III or IV, wherein at least one autotrophic

organism is cocultivated with a third organism growing heterotrophically or mixotrophically, said second organisms optionally being a nitrogen fixing bacterium or an organism which synthesizes vitamin B₁₂ or another nutrient.

5 Example VI: A system comprising a a cultivation volume for cultivating photosynthetic organisms or a photobioreactor and means for radiative cooling of the cultivation volume or said photobioreactor.

10 Example VII: A system comprising a a cultivation volume for cultivating photosynthetic organisms or a photobioreactor and means for cooling of the cultivation volume or said photobioreactor comprising utilizing low-grade heat in an OTEC subsystem, said system utilizing energy produced in said OTEC subsystem.

15

* * *

20

REFERENCES:

25 [Ari03] Arik, H. (2003). Synthesis of Si₃N₄ by the carbo-thermal reduction and nitridation of diatomite. *Journal of the European Ceramic Society*, 23(12), 2005-2014.

30 [BaoH17] Bao, H., Yan, C., Wang, B., Fang, X., Zhao, C. Y., & Ruan, X. (2017). Double-layer nanoparticle-based coatings for efficient terrestrial radiative cooling. *Solar Energy Materials and Solar Cells*, 168, 78-84.

[DruT08] Druffel, T., Mandzy, N., Sunkara, M., & Grulke, E. (2008). Polymer

nanocomposite thin film mirror for the infrared region. *small*, 4(4), 459-461.

- [Gan16] Gan, K., Xu, J., Zhang, X., Huo, W., Yang, M., Qu, Y., & Yang, J. (2016). Direct coagulation casting of silicon nitride suspension via a dispersant reaction method. *Ceramics International*, 42(3), 4347-4353.
- [Kah93] Kahru, M., Leppanen, J. M., & Rud, O. (1993). Cyanobacterial blooms cause heating of the sea surface. *Marine Ecology Progress Series*, 1-7.
- [Kel16] Keller, N., Nargang, T. M., Runck, M., Kotz, F., Striegel, A., Sachsenheimer, K., ... & Helmer, D. (2016). Tacky cyclic olefin copolymer: a biocompatible bonding technique for the fabrication of microfluidic channels in COC. *Lab on a Chip*, 16(9), 1561-1564.
- [Kel97] Kelley, S. S., Wang, X. M., Myers, M. D., Johnson, D. K., & Scahill, J. W. (1997). Use of biomass pyrolysis oils for preparation of modified phenol formaldehyde resins. In *Developments in thermochemical biomass conversion* (pp. 557-572). Springer, Dordrecht.
- [Mar21] Marquardt, T., Wendt, S., & Kabelac, S. (2021). Impact of Carbon Dioxide on the Non-Catalytic Thermal Decomposition of Methane. *ChemEngineering*, 5(1), 12.
- [Mat07] Matovic, B., Saponjic, A., Devecerski, A., & Miljkovic, M. (2007). Fabrication of SiC by carbothermal-reduction reactions of diatomaceous earth. *Journal of materials science*, 42(14), 5448-5451.
- [MusJ21] Mustafa, J., Mohammad, A. F., Mourad, A. A. I., Al-Marzouqi, A. H., & El-Naas, M. H. (2021, February). Treatment of saline wastewater and carbon dioxide capture using electrodialysis. In *2021 6th International Conference on Renewable Energy: Generation and Applications (ICREGA)*

(pp. 158-162). IEEE.

[Nav21] Navarrete, I. A., Kim, D. Y., Wilcox, C., Reed, D. C., Ginsburg, D. W., Dutton, J. M., ... & Wilcox, B. H. (2021). Effects of depth-cycling on nutrient
5 uptake and biomass production in the giant kelp *Macrocystis pyrifera*.
Renewable and Sustainable Energy Reviews, 141, 110747.

[Sch97] Schueller, O. J., Brittain, S. T., Marzolin, C., & Whitesides, G. M.
10 (1997). Fabrication and characterization of glassy carbon MEMS. Chemistry
of Materials, 9(6), 1399-1406.

[Tomc20] Tomczyk, A., Sokołowska, Z., & Boguta, P. (2020). Biochar
physicochemical properties: pyrolysis temperature and feedstock kind
15 effects. Reviews in Environmental Science and Bio/Technology, 19(1), 191-
215.

[YiZ21] Yi, Z., Xu, D., Xu, J., Qian, H., Zhao, D., & Yang, R. (2021). Energy
saving analysis of a transparent radiative cooling film for buildings with roof
20 glazing. Energy and Built Environment, 2(2), 214-222.

5

* * *

10

15

20

All citations, and teachings therein, are incorporated herein by reference. Specific embodiments and examples detailed are described for illustration
25 rather than limitation. The appended claims will be understood to
comprehend any equivalents, including those not presently known in the
relevant arts where these may be operatively substituted. The present
invention is limited only by the breadth of the appended claims.

30

Whereforth, I claim:

Claims:

1. A system for the open cultivation of macroalgae with nutrient enhancement, processing of resulting biomass to materials for construction of closed photobioreactors for cultivation of microalgae, phytoplankton, nanoplankton or cyanobacteria, comprising a subsystem for the cultivation of heterotrophic cells or heterotrophic organisms.
2. A system comprising a heliostat tracking the sun which aims an optical assembly comprising a first polymer nanocomposite film for reflecting ultraviolet radiation to an ultraviolet receiver (for guiding said ultraviolet radiation to a nanofabrication subsystem utilizing actinic ultraviolet radiation) and transmitting visible and infrared radiation, which pass to a second polymer nanocomposite film for reflecting infrared radiation to a receiver of a heat engine composed of heat-resistant material such as silicon-carbide and for transmitting visible radiation to a cultivation area or to a photobioreactor or to light collection means for distributing light in a cultivation volume.
3. A heliostat and optical assembly of claim 2 illuminating an attached photobioreactor wherein cyanobacteria, purple photosynthetic bacteria, microalgae, and or phytoplankton are cultivated as films on supports such as filters, membranes or support sheets.
4. A heliostat and optical assembly of claim 3 wherein at least a first organism selected from the group consisting of cyanobacteria, purple photosynthetic bacteria, microalgae, and or phytoplankton, and a second organism are cultivated as films on different supports or in discrete areas on a support such as said first organism and said second organism do not comingle.
5. A heliostat and optical assembly and attached photobioreactor of any of claims 2, 3 or 4 wherein at least one autotrophic organism is cocultivated with a third organism growing heterotrophically or mixotrophically, said

second organisms optionally being a nitrogen fixing bacterium or an organism which synthesizes vitamin B₁₂ or another nutrient.

6. A system comprising a cultivation volume for cultivating photosynthetic organisms or a photobioreactor and means for radiative cooling of the cultivation volume or said photobioreactor.

7. A system comprising a a cultivation volume for cultivating photosynthetic organisms or a photobioreactor and means for cooling of the cultivation volume or said photobioreactor comprising utilizing low-grade heat in an OTEC subsystem, said system utilizing energy produced in said OTEC subsystem.

8. A process for cultivating organisms comprising growing said organisms in a cultivation volume for cultivating photosynthetic organisms or a photobioreactor and means for radiative cooling of the cultivation volume or said photobioreactor.

9. A process for cultivating organisms comprising growing a first set of organisms in a cultivation volume for cultivating photosynthetic organisms or a photobioreactor and cultivating at least second organism on the biomass or material derived from the biomass from said first set of organisms, comprising separating incoming light into at least two energetic bands.