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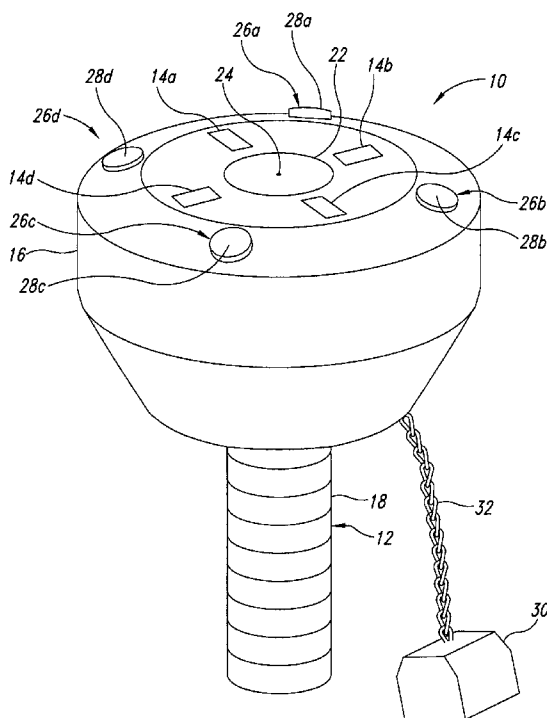


FIG. 1

(57) Abstract: An apparatus selectively fertilize sea water with iron and/or other micronutrients to foster phytoplankton blooms which sink carbon dioxide. An electrical potential is applied to a sacrificial electrode structure, and in some embodiments may be applied in succession from a distal to a proximate portion. The apparatus may generate power from renewable sources such as solar or wind, and may store electrical power. The apparatus may include local control which may be based on sensed information. The apparatus may communicate with remote facilities, allowing monitoring and remote control.

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APPARATUS, SYSTEM AND METHOD OF SEA WATER FERTILIZATION

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application Serial No. 60/902,452, filed February 20, 5 2007.

BACKGROUND

Technical Field

This disclosure relates to the fertilization of sea water with iron and optionally other micronutrients to promote the growth of carbon dioxide 10 fixating phytoplankton.

Description of the Related Art

The role of iron in promoting phytoplankton growth is well documented. See, for example, Martin, et al., 1991-1995. By increasing trace amounts of dissolved iron in otherwise iron-free areas of ocean surfaces, 15 phytoplankton growth can be stimulated three to thirty-fold above the background levels. Other micronutrients such as manganese and phosphorous may also be beneficial.

Phytoplankton fixes carbon dioxide from the atmosphere in the photosynthesis cycle, and upon death of the microorganism, a portion of the 20 fixed carbon dioxide is deposited on the sea floor. This is part of the oceanic carbon cycle, and is a well-documented natural phenomenon. Using iron fertilization, others have estimated that a 300,000:1 leverage of carbon dioxide fixation per unit of iron is possible, by encouraging phytoplankton blooms. Experiments have been conducted by dumping iron in solution from ships, and 25 theoretical results verified to varying degrees. (e.g., Iron ExI, Iron ExII.)

However, dumping iron in solution from ships presents a number of problems. Dumping iron in solution presents solubility problems. There is

also a point of iron saturation, whereby additional iron provides diminishing returns. This point of diminishing returns has not been well quantified by iron fertilization experimentation to date, and cannot, in the opinion of this inventor, be precisely done using ship-based fertilization techniques.

5 The use of lumbering ships operating as "crop dusters" leads to impreciseness in distribution of the iron. The use of ships also has high attendant costs, including the costs of fuel, cost of labor, as well as the production of carbon dioxide.

BRIEF SUMMARY

10 At least one embodiment may be summarized as an apparatus operable to fertilize sea water with iron including at least one sacrificial anode structure; at least one source of electrical power to provide an electrical potential to the at least one sacrificial anode structure to cause a reduction reaction between the sacrificial anode structure and the sea water; and at least
15 one buoyant member physically coupled to the sacrificial anode structure, at least one buoyant member provide sufficient buoyancy such that the apparatus floats in the sea water. The use of a sacrificial electrode may allow precise control over the distribution of iron and may advantageously release atomic sized iron. The sacrificial anode structure may be made of at least one of cast-
20 iron or steel. The buoyant member may be a ring buoy. The sacrificial anode structure may be a pipe. The pipe may include at least three distinct sections, and the apparatus may further include at least a first circuit to selectively electrically couple electrical power to a first one of the sections, at least a second circuit to selectively electrically couple electrical power to a second one
25 of the sections and at least a third circuit to selectively electrically couple electrical power to a third one of the sections.

 The apparatus may further include a controller configured to selectively couple electrical power sequentially to the sections from a most distal one of the sections first to a most proximate one of the sections last, as
30 respective ones of the sections are depleted. Each section may form a

respective water-tight compartment. Each of the water-tight compartments may hold at least one of nitrogen or air.

The at least one source electrical power may include at least two independent sources of renewable electrical power. The at least one source
5 electrical power may include at least one photovoltaic array. The at least one source electrical power may include at least one blade mounted for rotation and at least one turbine physically coupled to be driven by rotation of the blade. The apparatus may further include at least two ports, the two ports each having a respective opening, the openings facing different directions from one another,
10 the at least two ports providing fluid communication with the at least one blade. The apparatus may further include at least one rechargeable power storage device electrically coupled to sink excess power from the at least one source of electrical power and to source power to the sacrificial anode structure when power produced by the at least one source of electrical power is below a
15 threshold level.

The apparatus may further include at least one cathode structure electrically coupled to receive an electrical potential from the at least one source of electrical power.

The apparatus may further include at least one wireless
20 communications device; and at least one control system communicatively coupled to the wireless communications device and configured to control the supply of the electrical potential to the at least one sacrificial electrode. The apparatus may further include at least one wireless location determination device to determine a location of the apparatus. The apparatus may further
25 include at least one navigational transponder configured to transmit a signal indicative of at least a presence of the apparatus.

The apparatus may further include an anchor physically coupled to the at least one buoyant member.

At least one embodiment may be summarized as a method of
30 operating buoyant apparatus to fertilize sea water with iron including receiving a wireless control signal at a buoyant apparatus; and selectively supplying an

electrical potential to a sacrificial electrode of the buoyant apparatus from at least one source of electrical power to control an amount of iron released into a sea water by a reduction of the sacrificial electrode based at least in part on the wireless control signal. Selectively supplying an electrical potential to a sacrificial electrode may include selectively applying respective electrical potentials to each of a plurality of portions of the sacrificial electrode, initially a distal most portion and finally a proximate most portion.

The method may further include determining an amount of reduction of at least one of the portions of the sacrificial electrodes; and determining at least one of when to supply the electrical potentials or which of the portions of the sacrificial electrodes to supply the electrical potentials to based on the determined amount of reduction.

Receiving a wireless control signal may include receiving the wireless signal at the buoyant apparatus via a satellite from a central control system remotely located with respect to the buoyant apparatus. The method may further include transmitting a wireless signal from the buoyant apparatus indicative of an amount of reduction of the sacrificial electrode.

The method may further include transforming light into electrical power to supply the electrical potential. The method may further include transforming wind into electrical power to supply the electrical potential. The method may further include producing electrical power from a renewable power source; storing the electrical power; and releasing the stored electrical power to supply the electrical potential.

The method may further include transmitting a signal from the buoyant apparatus indicative of at least a presence of the buoyant apparatus. The method may further include determining a location of the buoyant apparatus; and transmitting a signal from the buoyant apparatus indicative of the determined location.

At least one embodiment may be summarized as a system to fertilize sea water with nutrients including an iron fertilization subsystem including a plurality of buoyant apparatus, each of the buoyant apparatus

operable to fertilize sea water with iron; a sensor subsystem operable to detect at least one characteristic indicative of a phytoplankton bloom; and at least one control system configured to control operation of the plurality of buoyant apparatus based at least in part on the at least one characteristic indicative of a phytoplankton bloom detected by the sensor subsystem. Each of the buoyant apparatus may include a respective renewable power subsystem that produces electrical power from a renewable source of power and a sacrificial electrode electrically coupled to receive an electrical potential from the produced electrical power. Each of the buoyant apparatus may include a respective controller to control an electrical potential applied to the sacrificial electrode based at least one part on information received from the control system. The control subsystem may be communicatively coupled to receive information from the buoyant apparatus indicative of an operational characteristic of the buoyant apparatus. The control subsystem may be configured to control the buoyant apparatus based at least in part of the received information. The received information may be indicative of a remaining operational life of the sacrificial electrode. The at least one control system may be remotely located with respect to the plurality of buoyant apparatus. Each of at least some of the buoyant apparatus may include a respective controller, at least one sensor communicatively coupled to the controller and at least one sacrificial electrode that releases iron into the sea water as part of an electrolytic reaction in response to the application of an electrical potential to the at least one sacrificial electrode, the controller configured to control the application of the electrical potential to the sacrificial electrode based at least in part on the sensor. The controller may be further configured to control the application of the electrical potential to the sacrificial electrode based at least in part on a signal received from the control system that is remotely located with respect to the buoyant apparatus.

At least one embodiment may be summarized as a sacrificial anode structure to fertilize sea water including an elongated pipe member of a material containing iron that is released in to sea water as part of a reduction

reaction in response to an application of an electrical potential to at least part of the elongated pipe member. The elongated pipe member may include at least three distinct sections. Each of the sections may be a sealed section having a respective interior. The interior of each of the sections may be filled with one of
5 nitrogen or air.

The sacrificial anode structure may further include at least a first electrically conductive path to selectively provide a first electrical potential to a first one of the sections; at least a second electrically conductive path to selectively provide a second electrical potential to second of the sections; and
10 at least a third electrically conductive path to selectively provide a third electrical potential to third one of the sections.

At least one embodiment may be summarized as a sacrificial anode structure to fertilize sea water including a hollow elongated member that releases iron and at least one of manganese or phosphorus into sea water as
15 part of a reduction reaction in response to an application of an electrical potential to the elongated member. The elongated member may include at least three distinct sections. Each of the sections may be a sealed section. Each of the sealed sections may have a respective interior filled with at least one of nitrogen or air. The elongated member may include at least one of an
20 alloy of cast iron or an alloy of steel.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various
25 elements and angles are not drawn to scale, and some of these elements are arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn, are not intended to convey any information regarding the actual shape of the particular elements, and have been solely selected for ease of recognition in the drawings.

Figure 1 is an isometric view of an apparatus operable to fertilize sea water with iron, including a buoyant member, a sacrificial anode structure at least one source of electrical power to provide an electrical potential to the at least one sacrificial anode structure and an optional anchor, according to one
5 illustrated embodiment.

Figure 2 is a side elevational view of the apparatus of Figure 1.

Figure 3 is a top plan view of the apparatus of Figure 1.

Figure 4A is a schematic view showing a system including various electrical and electronic components to provide power and communications for
10 the apparatus, according to one illustrated embodiment.

Figure 4B is a schematic view of a system including three groups of apparatus, at least one control facility, at least one satellite that provides communications between the control facility and the apparatus, and a ship that receives navigational warnings and/or other information from the apparatus, ,
15 according to one illustrated embodiment.

Figure 5 is a flow diagram showing a method of operating an apparatus to selectively release iron into sea water, according to one illustrated embodiment/

Figure 6 shows a method of providing communications with the
20 apparatus, according to one illustrated embodiment.

Figure 7 is a flow diagram illustrating a method of producing, storing and supplying power for the apparatus, according to one illustrated embodiment.

Figure 8 is a flow diagram showing a method of producing power
25 from solar insolation, according to one illustrated embodiment.

Figure 9 a flow diagram showing a method of producing power from fluid flow, according to another illustrated embodiment.

Figure 10 is a flow diagram showing a method of monitoring an operating parameter of the apparatus, in particular an amount of reduction of a
30 sacrificial electrode, according to one illustrated embodiment.

Figure 11 is a flow diagram showing a method of selectively applying electrical potentials to portions of the sacrificial anode structure based on an amount of reduction of those portions.

Figure 12 is a flow diagram showing a method of providing
5 navigational warning signals from the apparatus, according to one illustrated embodiment.

Figure 13 is a flow diagram showing a method of tracking a location of the apparatus, according to one illustrated embodiment.

DETAILED DESCRIPTION

10 In the following description, certain specific details are set forth in order to provide a thorough understanding of various disclosed embodiments. However, one skilled in the relevant art will recognize that embodiments may be practiced without one or more of these specific details, or with other methods, components, materials, etc. In other instances, well-known structures
15 associated with wireless communications, position determination, power production including rectification, conversion and/or conditioning, have not been shown or described in detail to avoid unnecessarily obscuring descriptions of the embodiments.

Unless the context requires otherwise, throughout the
20 specification and claims which follow, the word "comprise" and variations thereof, such as, "comprises" and "comprising" are to be construed in an open, inclusive sense, that is as "including, but not limited to."

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic
25 described in connection with the embodiment is included in at least one embodiment. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Further more, the particular features, structures, or characteristics may be combined in any suitable manner
30 in one or more embodiments.

As used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the content clearly dictates otherwise. It should also be noted that the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates
5 otherwise.

The headings and Abstract of the Disclosure provided herein are for convenience only and do not interpret the scope or meaning of the embodiments.

Figure 1 shows an apparatus 10 operable to fertilize sea water with iron and/or other nutrients, according to one illustrated embodiment. The apparatus includes at least one sacrificial anode structure 12, at least one source of electrical power, for instance photovoltaic (PV) arrays 14a-14d and at least one buoyant member that provides sufficient buoyancy such that the apparatus 10 floats above, at or below the surface in sea water.
10

The sacrificial anode structure 12 may be formed of a variety of materials that contain iron which is released into sea water as part of a reduction reaction in response to an application of an electrical potential to at least part of the sacrificial anode structure 12. The sacrificial anode structure 12 may also optionally release other micronutrients into sea water as part of the reduction reaction, for example at least one of manganese or phosphorous.
15 The sacrificial anode structure 12 may, for example, be formed of cast iron or an alloy of steel. The sacrificial anode structure 12, may for example, take the form of a 36 inch diameter pipe that extends downward approximately ten feet from a center of the buoyant member 16. The sacrificial anode structure 12 may be removable from the buoyant member 16, and may include a center lifting lug to allow easy removal from and replacement in buoyant member 16 using a crane on a ship.
20 25

The sacrificial anode structure 12 may be engineered to maximize a rate at which constituents are dissolve in sea water per unit of current applied. For example, the sacrificial anode structure 12 may have a variety of shapes and/or configurations. For example, the sacrificial anode structure 12 may take
30

the form of a pipe, having an outer wall 18 forming an interior passage 20 (best illustrated in Figure 3). In some embodiments, the outer wall may be cylindrical. Employing a cylindrical hollow pipe configuration maximizes the surface area of the sacrificial anode structure 12 for a given amount of material. Such
5 increases the efficiency of the sacrificial anode structure 12 for a given amount of material.

The sacrificial anode structure 12 may be engineered to dissolve in a predetermined fashion from a free or distal end to a fixed or proximate end. For example, the sacrificial anode structure 12 may comprise a plurality of
10 sections 12a-12j. Each section may include a bulkhead or other structure to form a water-tight compartment. Each water-tight compartment may hold air or nitrogen. As described in more detail below, electrical potentials may be selectively applied to the various sections 12a-12j to achieve beneficial results. The section 12a closest to the buoyant member 16 is referred to as the most
15 proximate section while the section 12j located farthest from the buoyant member is referred to as the most distal section.

The buoyant member 16 should provide sufficient buoyancy that the apparatus floats above, at or slightly below the surface of the sea. Initial estimates suggest that the displacement of the buoyant member 16 should be
20 approximately triple the mass of the sacrificial anode structure 12. Buoyancy should be sufficiently large to optimize a balance between serviceable stability and the economic costs construction. The weight of a 36 inch steel pipe with a wall thickness of 1-3/16 inch is approximately 441 pounds per foot, which coincidentally is approximately the weight of the approximately 7 cubic feet of
25 water displaced by the pipe per linear foot. Thus, the sacrificial anode structure 12 may be made initially near-neutrally buoyant.

The buoyant member 16 may take a variety of forms. For example, the buoyant member 16 may be a ring buoy, shaped for serviceability. The buoyant member 16 may include one or more sealed compartments
30 containing air. The buoyant member 16 may include one or more access ports 22 which are accessible via one or more water-tight hatches 24. The access

port 22 may provide access to mechanical, electrical and electronic components that may be housed in a hull of the buoyant member 16, for servicing, repair or replacement. In some embodiments, some or all of the mechanical, electrical and electronic components that may be housed in a
5 super-structure that resides a top the buoyant member 16.

The buoyant member 16 may further include one or more ports 26a-26d which may be surrounded by a wind scoop 28a-28d. Such may capture wind for use in generating electrical power. The ports 26 and wind scoops 28 may be distributed about the buoyant member 16, facing in different
10 directions (e.g., offset by 90 degrees relative to one another) to increase the likelihood that wind will be captured.

In some embodiments, the apparatus 10 may include an anchor 30 and cable or chain 32 to secure the apparatus to the sea bed. Such may advantageously limit the potential for the apparatus 10 to become a
15 navigational hazard. The cable or chain 32 should be secured to the buoyant member 16 rather than the sacrificial anode structure 12, since the sacrificial anode structure 12 will be destroyed in use. The anchor 30 may, for example, take the form of a sea anchor or the like. Some embodiments may employ a propulsion system, for example, an electrical motor that drives a shaft and a
20 propeller or screw. In some embodiments, the apparatus 10 may advantageously exclude any propulsion system, since such adds unnecessary cost, weight and maintenance issues, and disadvantageously would drain power that could otherwise be used for the reduction reaction.

Figure 4A shows a system 400 operable to provide power, control
25 and communications for an apparatus to fertilize sea water with iron, for example, the apparatus 10 of Figures 1-3.

The system 400 includes a power subsystem 402 that includes one or more sources of electrical power. The sources of electrical power preferably include sources of renewable electrical power. For example, the
30 power subsystem 402 may include one or more PV arrays 404a-404d configured to produce direct current when illuminated, for example, by solar

insolation. The inclusion of two or more PV arrays 404a-404d may provide redundancy. Additionally, or alternatively, the sources of electrical power may include one or more turbines 406a-406d coupled to one or more propellers or blades 408a-408d such that the propellers or blades 408a-408d drive a shaft of the turbines 406a-406d in response to a fluid flow over the propellers or blades 408a-408d. The inclusion of two or more wind turbines may provide redundancy. The turbines 406a-406d and/or propellers or blades 408a-408d may be located in a hull of the buoyant member 16. In at least one embodiment, the propellers or blades 408a-408d are driven by a flow of wind which may be captured and routed to the propellers or blades 408a-408d via one or more ports and/or scoops, for example, ports 26a-26d and/or scoops 18a-28d (Figures 1-3). The power subsystem 402 may also include one or more energy storage devices 410 configured to selectively store and release electrical power. The energy storage device 410 may take a variety of forms, for example, one or more rechargeable batteries and/or one or more rechargeable super- or ultra-capacitors. The power subsystem may for example have an capacity of approximately 500 W or 1000 amp-hours.

The power subsystem 402 may include a power supply subsystem 412. The power supply subsystem may include one or more power buses 414 (e.g., 12V, 24V, 48V) and one or more rectifiers, alternators, converters or other power conditioning subsystems. For example, the turbines 406a-406d may be coupled to one or more rectifiers 416a-416d to rectify an alternating current (AC) produced by the turbines 406a-406d to a direct current (DC). The rectifiers 416a-416d may take a variety of forms, for example a passive diode bridge or an active rectifier including one or more power transistors (e.g., FET or IGBT). One or more power converters 418 may convert the direct current from the rectifiers 416a-416d, for example, by stepping up or stepping down a voltage to a voltage suitable for the power bus 414. The power converter 418 may take a variety of forms, for example, a passive transformer or an active switch mode converter which includes one or more bridges formed from power transistors. The power converter 418 may, for

example, be controlled via gate drive signals (arrow 421) from one or more gate drives 420 to selectively operate the power converter 418 to achieve a desired conversion. In some embodiments, the power converter 418 may also perform rectification in addition to stepping up or stepping down a voltage and/or other
5 power conditioning, eliminating the need for separate rectifiers 416a-416d.

A power converter 422 may convert a direct current produced by the PV arrays 404a-404d to a form suitable for the power bus 414. The power converter 422 may, for example, take the form of passive device (e.g., transformer) or an active device such as a switch mode power converter
10 operable to step up or step down a voltage of the direct current and/or perform other power conditioning. Where active, the power converter 422 may be controlled via gate drive signals (arrow 423) from a gate drive 424.

A power converter 426 couple direct current between the power bus 414 and the energy storage device 410. The power converter 426 may, for example, step up or step down a voltage of direct current. The power converter 426 may, for example, take the form of a passive device (e.g., transformer) or an active device such as a switch mode power converter. Where active, the power converter 426 may be controlled via gate drive signals (arrow 427) from a gate drive 428.
15

The power supply system 412 may also include a control system power converter 430 for supplying power at an appropriate voltage to a control system 432. The control system power converter 430 may take the form of a passive device or an active device.
20

The control system 432 may include one or more processors 434, read only memory (ROM) 436 and/or random access memory (RAM) 438 all coupled by one or more buses, for example, power buses, data buses and/or instruction buses. The memories 436, 438 may store instructions executable by the processor 434 to control operation of the system 400. The processor 434 may take a variety of forms including one or more microprocessors, digital
25 signal processors (DSP), application specific integrated circuits (ASIC) and/or
30

one or more field programmable gate arrays (FPGA). Instructions stored in the memories 436, 438 may be updatable.

The processor 434 may be configured to control operation of the gate drives 420, 424, 428 via one or more control signals represented by
5 arrows 435.

The processor 434 may be configured to control an application of an electrical potential or current to the sacrificial anode structure 440. Varying the electrical potential or current applied to the sacrificial electrode structure 440 may drive iron and other elemental micronutrients alloyed with the iron
10 such as manganese and/or phosphorus into the sea water in the vicinity of the apparatus at a precise and controllable rate. The iron and other element micronutrient particles introduced into the sea water are on the order of atomic scale, addressing the solubility issues endemic to other iron fertilization techniques. A nominal 10 foot length of 36 inch steel pipe weights
15 approximately 4400 pounds. If half of the iron in the pipe may be induced into solution through the application of the DC electrical potential or current, then approximately 1000kg or 2200 pounds of iron may be released into the sea water in the immediate vicinity of the apparatus. The ionic iron and other trace micronutrients may be disbursed by natural diffusion and currents into an
20 expected effect area, the extent of which could be determined based on engineering studies and by direct or indirect detection or measurement. The ionic iron and trace micronutrients may combine with other free radicals in sea water, which may form iron oxide and/or other molecules which may be useful for phytoplankton metabolism. While subject to change, an apparatus could
25 theoretically fix 300,000 metric tons of carbon dioxide from the atmosphere. Thus, about 3333 apparatus of the size described herein may theoretically fix 1 billion metric tons of carbon dioxide annually, as described in the Branson prize. However, to promote phytoplankton blooms for a target area in a matter of days or weeks, and given a physical limit of dissolution rate per unit of electrical
30 potential or current applied, more apparatus may be necessary than the bare minimum cited above.

Sea water is notoriously corrosive to iron. Applicant has not quantified the rate at which iron can be driven into sea water by application of DC electrical potentials or currents. One estimate cited by others () is approximately 1 gram per amp-hour, which is the equivalent of approximately 1 kg of iron dissolved with the application of 10 A over 100 hours. The use of a sacrificial electrode structure with a relatively large surface area (e.g., pipe) may increase this rate, although such has not been ascertained. The usefulness of ionic iron and other elemental micronutrients to phytoplankton is also under continuing investigation.

In some embodiments, processor 434 may be configured to control an application of an electrical potential or current to selected portions 440a-440n of the one or more portions of a sacrificial anode structure 440. Additionally or alternatively, the processor 434 may control when and/or to which portion of the sacrificial anode structure 440 an electrical potential or current is applied. In particular, the processor 434 can provide one or more control signals 437 to a switching device such as a multiplexer 442 to selectively apply an electrical potential or current from the power bus 414 to selected ones of the portions 440a-440n of the sacrificial anode structure 440. The multiplexer 442 may apply the electrical potential via one or more wiring harnesses 444. To promote the "burning" of the anode electrical structure 440 from a distal end to a proximate end, the sacrificial anode structure 440 may be partitioned into portions using bulkheads (e.g., one inch thick steel plates welded to the wall of the sacrificial anode structure 440. Each of the portions may form a water tight compartment, that, as previously noted, may be filled with air or nitrogen. Energizing electrodes of the wiring harness may be applied, optimally, at a center of each bulkhead. As each water tight compartment fails in process, the processor detects such as energize the next set of electrodes, successively closer to the buoyant member. Alternatively, multiple sets of electrodes may be energized in parallel to maximize a rate of iron dissolution.

In some embodiments, the system 400 may include a cathode structure 446 electrically coupled to receive an electrical potential or current via the power bus 414. The cathode structure 446 may, in some embodiments, be required to induce sufficient current flow. The cathode structure 446 has an
5 opposite electrical polarity from the sacrificial anode structure 440. The cathode structure 446 may, for example, be a part of or all of the hull of the buoyant member (e.g., buoyant member 16 of Figures 1-3) or the chain or cable 32 (Figure 1) for the anchor 30. In such embodiments, the hull of the buoyant member 16 or chain or cable 32 may be formed from a material lower
10 in the galvanic series than the material that forms the sacrificial anode structure 12 such that in passive mode (*i.e.*, when no current is applied), the cable 32 or hull of the buoyant member 16 is cathodically protected from corrosion.

The system 400 may include a communication subsystem 448. The communication subsystem 448 may include one or components operable
15 to provide communications from, to or between the apparatus 10 (Figures 1-3) and a remotely located device. For example, the communication subsystem 448 may include one or more satellite transceivers 450 and one or more associated antennas 452 operable to provide communications with a remote site or facility via one or more satellites.

20 The communications may include transmitting data collected at the apparatus that may be indicative of one or more operational characteristics of the system 400 and/or physical characteristics of the sea water. For example, the data may be indicative of an operational characteristic of the sacrificial anode structure 440. For instance, the data may be indicative of an
25 amount of reduction of one or more portions 440a-440n of the sacrificial anode structure 440. Such data may be useful in predicting a useful life of the sacrificial anode structure 440 and/or the need for replacement of such sacrificial anode structure 440. For example, failing water tight compartments or portions may serve as an indication of a useful remaining service life of the
30 sacrificial anode structure 440. A weight of iron remaining in the sacrificial anode structure 440 may be determined based on the number of water tight

compartments that have failed as determined by the processor, empirically estimating the quantity of iron oxide formed on the anode surface and precipitated, summing the total amp-hours supplied to the sacrificial anode structure 440, and measuring the current displacement of the buoyant structure
5 as determined by conventional onboard displacement instrumentation.

The data may be indicative of power production and/or condition of the power storage device or other operational aspect of the system or various subsystems. The data may additionally or alternatively be indicative of an amount of phytoplankton in the ambient sea water environment and/or an
10 amount of iron. Such may be used to control an amount or level of electrical potential or current applied to the sacrificial anode structure 440. While discussed above in terms of the satellite transceiver 450, such data may alternatively or additionally be used by the processor 434 for locally controlling the level of applied electrical potential. In some embodiments, the processor
15 434 performs local control based on a first level of feedback while a remote facility performs remote control based on a second level of feedback.

The communication system 448 may also include a global positioning system (GPS) receiver 456 and associated antenna 458. Such may be used to determine a precise global location of the apparatus 10. Such may
20 be useful where the apparatus 10 is free floating. Such may also be useful where the apparatus 10 is anchored, since the precise position of the apparatus 10 will vary significantly even when anchored. For example, the length of the chain or cable 32 (Figure 1) may be very long in many applications, allowing significant drift of the apparatus 10 based on tides, waves and/or wind.
25 Location information derived via the GPS receiver 456 may be used by the processor 434 and/or may be relayed to remote sites or to passing ships.

The communications system 448 may further include one or more navigational transponders 460 and associated antennas 462. The navigational transponders 460 and antenna 462 may provide a wireless signal within a
30 relatively limited range of the apparatus 10 to notify shipping of the presence of the apparatus 10 which may otherwise be considered a navigational hazard.

While illustrated as being coupled to the processor 434, the navigation transponder 460 may be independent of the processor 434, simply deriving power from the power system 412, but otherwise uncontrolled by the processor 434. Additionally, or alternatively, the communication subsystem 448 may
5 include one or more light sources 464 and/or speakers 466 to provide a localized warning of the presence of the apparatus 10 to shipping.

The system 400 may include one or more sensors 454 operable or configured to detect one or more operational aspects of the apparatus, the system, various subsystems and/or the ambient environment. For example,
10 one or more sensors may detect or measure an operational characteristic of the sacrificial anode structure 440, for instance an amount of reduction of one or more portions 440a-440n of the sacrificial anode structure 440. One or more sensors 454 may detect or measure an amount of power production and/or a condition of the power storage device. Such may determine an amount of
15 electrical potential that may be applied to the sacrificial anode structure or provide an indication that servicing is required to repair or replace a failed or failing component. One or more sensors 454 may detect or measure other operational aspects of the system or various subsystems, for example communications. One or more sensors 454 may detect or measure an integrity
20 of the buoyant structure. One or more sensors 454 may detect or measure an amount of phytoplankton (e.g., opacity, conductivity, etc.) in the ambient sea water environment and/or an amount of iron. One or more sensors 454 may detect or measure temperature of the ambient environment, for example the sea water and/or air.

25 Figure 4B shows a system 468 including a number of groups or sets of apparatus 470a-470c geographically distributed about an ocean, a remotely located facility 472 to monitor and control operation of the apparatus. a satellite 474 to provide communications between the apparatus and the control facility 472, and also shows a ship 476, according to one illustrated
30 embodiment.

The apparatus may be geographically located in groups or sets 470a-470c of two or more apparatus, geographically distributed about the ocean(s) or seas, for example worldwide. The inclusion of extra apparatus in a group or set 470a-470c may provide redundancy in case one or more of the
5 apparatus in the group or set 470a-470c fail prematurely. Such may allow sufficient time to repair the failed apparatus without significantly effecting the ability of the group or set of apparatus 470a-470c to supply iron to the sea water in some geographic area. Groups or sets 470a-470c may be precisely scaled to maximize phytoplankton potential at any given location. The groups
10 or sets 470a-470c may be located in deep water, away from shipping lanes. The apparatus in each group or set 470a-470c may be serviced yearly, primarily to maintain the electrical and communications systems, and secondarily for replacement of the sacrificial electrode structure which may last several years.

15 Each apparatus may be autonomously or semi- autonomously controlled, for example based on programmed instructions executed by the respective processor and/or based on a first level of feedback in response to the data produced by the one or more sensors.

The satellite 474 provides communications 478 between the
20 apparatus and one or more remotely located facility 472. The facility 472 may simply receive the communications, allowing monitoring of the operation of the various apparatus and/or resultant phytoplankton blooms. Such may allow computers and/or personnel to assess the operation and/or determine whether maintenance is required. In some embodiments, the facility 472 may provide a
25 remote control of the apparatus, for example based on a second level of feedback based on the data by one or more sensors. Such may include data produced by sensors that are part of the apparatus, and/or other sensors for example sensors carried by aircraft, ships and/or satellites. For example, visual and infrared sensing via satellites or aircraft, as well as measurements from
30 sensors carried by some or all of the apparatus and/or ships, may produce such

data. Such may allow precise closed loop control between the rate of iron fertilization and the phytoplankton blooms.

The facility 472 may operate the groups or sets of apparatus 470a-470c based on a larger scale than would otherwise be possible under the autonomous control, accounting for all or many of the deployed apparatus.

One embodiment may employ a purse seine or other retention device to corral a multiple apparatus 10. The purse seine or other retention device may, for example, release the apparatus once a bloom has successfully been produced.

Figure 5 is a flow diagram showing a method 500 of operating an apparatus to fertilize sea water with iron, according to one illustrated embodiment.

At 502, the apparatus receives a wireless control signal. At 504, the system of the apparatus selectively supplies an electrical potential to a sacrificial anode from at least one source of electrical power to control an amount of iron released into sea water by a reduction of the sacrificial anode based at least in part on the received wireless control signal. For example, a processor may selectively apply signals to a multiplexer to supply an electrical potential to the sacrificial anode structure via a power bus from one or more power sources and/or power storage devices.

Figure 6 shows a method 600 of providing communications with the apparatus, according to one illustrated embodiment.

At 602, the system receives the wireless signal via a satellite from a control system remotely located with respect to the apparatus. Satellite communications may be two-way communications. The remotely located control system may be a remotely located facility and/or may include communications from other groups or sets of apparatus. Communications other than satellite communications may be employed, for example low frequency radio communications.

Figure 7 is a flow diagram illustrating a method 700 of producing, storing and supplying power for the apparatus, according to one illustrated embodiment.

At 702, electrical power is produced from a renewable power
5 source. The renewable power source may take a variety of forms including forms that convert solar, wind, wave or currents to useful power, for example electrical power. The renewable power source may, for example, produce alternating current or direct current.

At 704, the produced electrical power is temporarily stored in a
10 power storage device. In some embodiments, the produced power may first be rectified, stepped up or stepped down, or otherwise converted or conditioned.

At 706, the stored electrical power is released from the electrical power storage device to supply an electrical potential to a sacrificial anode structure. Such may allow operation of the apparatus even when there is no or
15 little solar insolation and/or no or little wind. In some embodiments, the supplied power may first be stepped up or stepped down, or otherwise converted or conditioned.

Figure 8 is a flow diagram showing a method 800 of producing power according to one illustrated embodiment.

At 802, light is transformed into electrical power to supply the
20 electrical potential. The apparatus may employ one or more PV arrays to transform solar insolation into DC electrical power. One or more converters may be employed to step up or step down a voltage of the DC electrical power.

Figure 9 a flow diagram showing a method 900 of producing
25 power, according to another illustrated embodiment.

At 902, wind is turned into electrical power to supply the electrical potential. The apparatus may employ one or more turbines to generate AC electrical power from wind and/or from ocean currents. One or more rectifiers may be employed to rectify the AC electrical power to produce DC electrical
30 power. One or more converters may be employed to step up or step down a voltage of the DC electrical power.

Figure 10 is a flow diagram showing a method 1000 of monitoring an operating parameter of the apparatus, in particular an amount of reduction of a sacrificial electrode, according to one illustrated embodiment.

At 1002, an amount of reduction of at least one of the portions of
5 the sacrificial electrode is determined. Such may take a variety of forms including determining a thickness and/or length or other dimension of the portion of the electrode, monitoring a level and amount of time that an electrical potential has been applied to the respective portion. Such may include optically detecting changes in dimension, electrically, capacitively or inductively
10 detecting a change in dimension or an absolute dimension, or may employ other forms of sensors.

At 1004, a wireless signal is transmitted from the apparatus indicative of an amount of reduction of the sacrificial anode. Such may allow one or more central controllers to monitor groups of apparatus and to control
15 individual apparatus in those groups accordingly. In some embodiments, the amount of reduction may be employed by a processor of the apparatus itself to perform local control.

Figure 11 is a flow diagram showing a method 1100 of selectively applying electrical potentials to portions of the sacrificial anode structure based
20 on an amount of reduction of those portions.

At 1102, an amount of reduction of at least one of the portions of the sacrificial anode is determined. At 1104, it is determined at least when to supply the electrical potentials or which of the portions of sacrificial anode to supply the electrical potential to based on the determined amount of reduction.
25 At 1106, respective electrical potentials are selectively applied to each of a number of the portions of sacrificial anode. For example, electrical potentials may initially be applied to a distal most portion and finally applied to a proximate most portion. Such will allow the sacrificial anode structure to be reduced successively from the distal most end to the proximate most end. Such
30 ensures the structural integrity of the anode structure through its useful life.

Figure 12 is a flow diagram showing a method 1200 of providing navigational warning signals from the apparatus, according to one illustrated embodiment.

At 1202, a signal is transmitted from the apparatus indicative of at least a presence of the apparatus. The signal may, for example, be a radio or microwave signal, or other wireless signal. Such may provide notification to shipping allowing avoidance of the apparatus or allowing the apparatus to be located for servicing.

Figure 13 is a flow diagram showing a method 1300 of tracking a location of the apparatus, according to one illustrated embodiment.

At 1302, a global location of the apparatus is determined. For example, the apparatus may rely on one or more GPS receivers to determine a global location.

At 1304, a signal is transmitted from the apparatus indicative of the determined location. The signal may be transmitted locally, thereby providing shipping with notification of the precise position of the apparatus. Such may allow shipping to avoid the apparatus which would otherwise be considered a navigational hazard. Such may also be employed to locate the apparatus for servicing. Additionally or alternatively, the signal may be transmitted to a more remote location, for example, via one or more satellite transceivers. Such may be used to track and control groups or sets of the apparatus.

In some embodiments the apparatus 10 may be completely biodegradable. For example, the buoyant member may be formed of wood which supports a set of photo-voltaic arrays formed of silicon, while anode degrades due to the reduction reaction. Such advantageously ensures that the apparatus does not pose a navigation hazard or an eye sore after the useful life of the apparatus is exhausted.

Some embodiments may employ the communications systems to allow tracking, for example real time tracking, of the performance of the apparatus. Such may advantageously allow a market to be formed to pay for or

subsidize the manufacture and distribution of the apparatus. For example, individuals or business entities may pay to offset their carbon dioxide production. Such may associate an individual or entity with a respective one or more of the apparatus. The individual, entity or others may be able to track the amount of offset using a computer or other communications device based on feedback provided by the particular apparatus. Such may be conveniently displayed as number, a graph or with icons. Such can be displayed as an absolute amount of carbon dioxide sequestered or as an amount offset from an identified amount produced. Thus, for example, an airline traveler may be presented with an opportunity to offset some or all of the carbon dioxide that will be produced by the trip by purchasing or leasing one or more of the apparatus. The airline traveler may view the performance of the particular apparatus or group of apparatus to ensure that an adequate amount of carbon dioxide was offset. The carbon dioxide footprints of other people, business or groups can be offset in a similar manner.

The above description of illustrated embodiments, including what is described in the Abstract, is not intended to be exhaustive or to limit the embodiments to the precise forms disclosed. Although specific embodiments of and examples are described herein for illustrative purposes, various equivalent modifications can be made without departing from the spirit and scope of the disclosure, as will be recognized by those skilled in the relevant art. The teachings provided herein of the various embodiments can be applied to other fertilization systems, not necessarily the exemplary iron fertilization systems generally described above.

For instance, the foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, schematics, and examples. Insofar as such block diagrams, schematics, and examples contain one or more functions and/or operations, it will be understood by those skilled in the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware,

or virtually any combination thereof. In one embodiment, the present subject matter may be implemented via Application Specific Integrated Circuits (ASICs). However, those skilled in the art will recognize that the embodiments disclosed herein, in whole or in part, can be equivalently implemented in
5 standard integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more controllers (e.g., microcontrollers) as one or more programs running on one or more processors (e.g., microprocessors), as firmware, or as virtually any
10 combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of ordinary skill in the art in light of this disclosure.

In addition, those skilled in the art will appreciate that the mechanisms of taught herein are capable of being distributed as a program
15 product in a variety of forms, and that an illustrative embodiment applies equally regardless of the particular type of signal bearing media used to actually carry out the distribution. Examples of signal bearing media include, but are not limited to, the following: recordable type media such as floppy disks, hard disk drives, CD ROMs, digital tape, and computer memory; and transmission type
20 media such as digital and analog communication links using TDM or IP based communication links (e.g., packet links).

The various embodiments described above can be combined to provide further embodiments. To the extent that they are not inconsistent with the specific teachings and definitions herein, all of the U.S. patents, U.S. patent
25 application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification and/or listed in the Application Data Sheet, including but not limited to U.S. provisional patent application Serial No. 60/902,452, filed February 20, 1997 are incorporated herein by reference, in their entirety. Aspects of the embodiments
30 can be modified, if necessary, to employ systems, circuits and concepts of the

various patents, applications and publications to provide yet further embodiments.

These and other changes can be made to the embodiments in light of the above-detailed description. In general, in the following claims, the
5 terms used should not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

CLAIMS

1. An apparatus operable to fertilize sea water with iron, the apparatus comprising:

at least one sacrificial anode structure;

at least one source of electrical power to provide an electrical potential to the at least one sacrificial anode structure to cause a reduction reaction between the sacrificial anode structure and the sea water; and

at least one buoyant member physically coupled to the sacrificial anode structure, at least one buoyant member provide sufficient buoyancy such that the apparatus floats in the sea water.

2. The apparatus of claim 1 wherein the sacrificial anode structure is made of at least one of cast-iron or steel.

3. The apparatus of claim 1 wherein the buoyant member is a ring buoy.

4. The apparatus of claim 1 wherein the sacrificial anode structure is a pipe.

5. The apparatus of claim 1 wherein the pipe includes at least three distinct sections, the apparatus further comprising:

at least a first circuit to selectively electrically couple electrical power to a first one of the sections, at least a second circuit to selectively electrically couple electrical power to a second one of the sections and at least a third circuit to selectively electrically couple electrical power to a third one of the sections.

6. The apparatus of claim 5, further comprising:
a controller configured to selectively couple electrical power to sequentially to the sections from a most distal one of the sections first to a most proximate one of the sections last, as respective ones of the sections are depleted.
7. The apparatus of claim 5 wherein each section forms a respective water-tight compartment.
8. The apparatus of claim 7 wherein each of the water-tight compartments holds at least one of nitrogen or air.
9. The apparatus of claim 1 wherein the at least one source electrical power includes at least two independent sources of renewable electrical power.
10. The apparatus of claim 1 wherein the at least one source electrical power includes at least one photovoltaic array.
11. The apparatus of claim 1 wherein the at least one source electrical power includes at least one blade mounted for rotation and at least one turbine physically coupled to be driven by rotation of the blade.
12. The apparatus of claim 11, further comprising:
at least two ports, the two ports each having a respective opening, the openings facing different directions from one another, the at least two ports providing fluid communication with the at least one blade.
13. The apparatus of claim 1, further comprising:
at least one rechargeable power storage device electrically coupled to sink excess power from the at least one source of electrical power

and to source power to the sacrificial anode structure when power produced by the at least one source of electrical power is below a threshold level.

14. The apparatus of claim 1, further comprising:
at least one cathode structure electrically coupled to receive an electrical potential from the at least one source of electrical power.

15. The apparatus of claim 1, further comprising:
at least one wireless communications device; and
at least one control system communicatively coupled to the wireless communications device and configured to control the supply of the electrical potential to the at least one sacrificial electrode.

16. The apparatus of claim 15, further comprising:
at least one wireless location determination device to determine a location of the apparatus.

17. The apparatus of claim 1, further comprising:
at least one navigational transponder configured to transmit a signal indicative of at least a presence of the apparatus.

18. The apparatus of claim 1, further comprising:
an anchor physically coupled to the at least one buoyant member.

19. A method of operating buoyant apparatus to fertilize sea water with iron, the method comprising:

receiving a wireless control signal at a buoyant apparatus; and
selectively supplying an electrical potential to a sacrificial electrode of the buoyant apparatus from at least one source of electrical power to control an amount of iron released into a sea water by a reduction of the sacrificial electrode based at least in part on the wireless control signal.

20. The method of claim 19 wherein selectively supplying an electrical potential to a sacrificial electrode includes selectively applying respective electrical potentials to each of a plurality of portions of the sacrificial electrode, initially a distal most portion and finally a proximate most portion.

21. The method of claim 20, further comprising:
determining an amount of reduction of at least one of the portions of the sacrificial electrodes; and
determining at least one of when to supply the electrical potentials or which of the portions of the sacrificial electrodes to supply the electrical potentials to based on the determined amount of reduction.

22. The method of claim 19 wherein receiving a wireless control signal includes receiving the wireless signal at the buoyant apparatus via a satellite from a central control system remotely located with respect to the buoyant apparatus.

23. The method of claim 19, further comprising:
transmitting a wireless signal from the buoyant apparatus indicative of an amount of reduction of the sacrificial electrode.

24. The method of claim 19, further comprising:
transforming light into electrical power to supply the electrical potential.

25. The method of claim 19, further comprising:
transforming wind into electrical power to supply the electrical potential.

26. The method of claim 19, further comprising:
producing electrical power from a renewable power source;

storing the electrical power; and
releasing the stored electrical power to supply the electrical potential.

27. The method of claim 19, further comprising:
transmitting a signal from the buoyant apparatus indicative of at least a presence of the buoyant apparatus.

28. The method of claim 19, further comprising:
determining a location of the buoyant apparatus; and
transmitting a signal from the buoyant apparatus indicative of the determined location.

29. A system to fertilize sea water with nutrients, the system comprising:

an iron fertilization subsystem including a plurality of buoyant apparatus, each of the buoyant apparatus operable to fertilize sea water with iron;

a sensor subsystem operable to detect at least one characteristic indicative of a phytoplankton bloom; and

at least one control system configured to control operation of the plurality of buoyant apparatus based at least in part on the at least one characteristic indicative of a phytoplankton bloom detected by the sensor subsystem.

30. The system of claim 29 wherein each of the buoyant apparatus includes a respective renewable power subsystem that produces electrical power from a renewable source of power and a sacrificial electrode electrically coupled to receive an electrical potential from the produced electrical power.

31. The system of claim 30 wherein each of the buoyant apparatus includes a respective controller to control an electrical potential applied to the sacrificial electrode based at least in part on information received from the control system.

32. The system of claim 31 wherein the control subsystem is communicatively coupled to receive information from the buoyant apparatus indicative of an operational characteristic of the buoyant apparatus.

33. The system of claim 31 wherein the control subsystem is configured to control the buoyant apparatus based at least in part of the received information.

34. The system of claim 33 wherein the received information is indicative of a remaining operational life of the sacrificial electrode.

35. The system of claim 29 wherein the at least one control system is remotely located with respect to the plurality of buoyant apparatus.

36. The system of claim 31 wherein each of at least some of the buoyant apparatus includes a respective controller, at least one sensor communicatively coupled to the controller and at least one sacrificial electrode that releases iron into the sea water as part of an electrolytic reaction in response to the application of an electrical potential to the at least one sacrificial electrode, the controller configured to control the application of the electrical potential to the sacrificial electrode based at least in part on the sensor.

37. The system of claim 36 wherein the controller is further configured to control the application of the electrical potential to the sacrificial

electrode based at least in part on a signal received from the control system that is remotely located with respect to the buoyant apparatus.

38. A sacrificial anode structure to fertilize sea water, comprising:

an elongated pipe member of a material containing iron that is released in to sea water as part of a reduction reaction in response to an application of an electrical potential to at least part of the elongated pipe member.

39. The sacrificial anode structure of claim 38 wherein the elongated pipe member includes at least three distinct sections.

40. The sacrificial anode structure of claim 39 wherein each of the sections is a sealed section having a respective interior.

41. The sacrificial anode structure of claim 40 wherein the interior of each of the sections is filled with one of nitrogen or air.

42. The sacrificial anode structure of claim 40, further comprising:

at least a first electrically conductive path to selectively provide a first electrical potential to a first one of the sections;

at least a second electrically conductive path to selectively provide a second electrical potential to second of the sections; and

at least a third electrically conductive path to selectively provide a third electrical potential to third one of the sections.

43. A sacrificial anode structure to fertilize sea water, comprising:

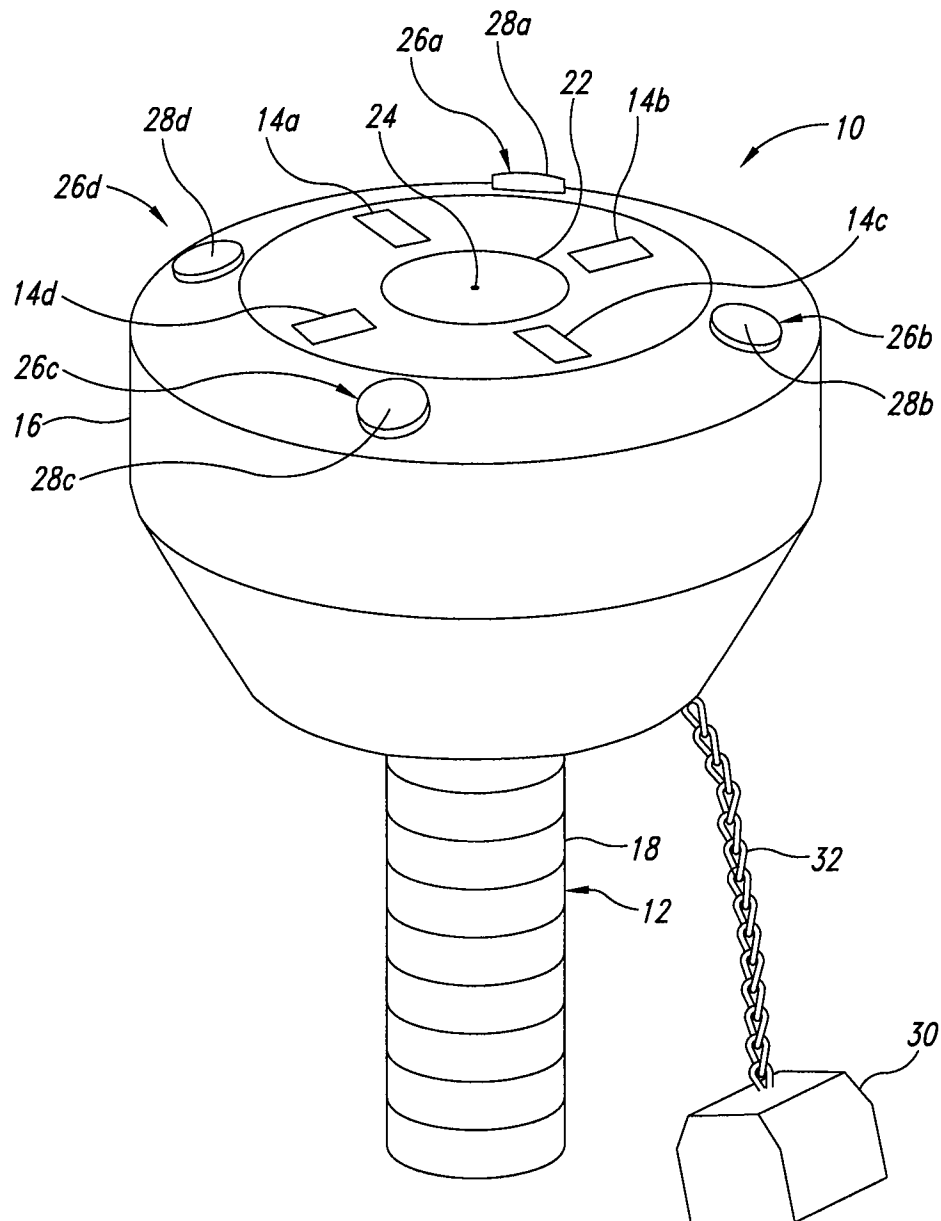
a hollow elongated member that releases iron and at least one of manganese or phosphorus into sea water as part of a reduction reaction in response to an application of an electrical potential to the elongated member.

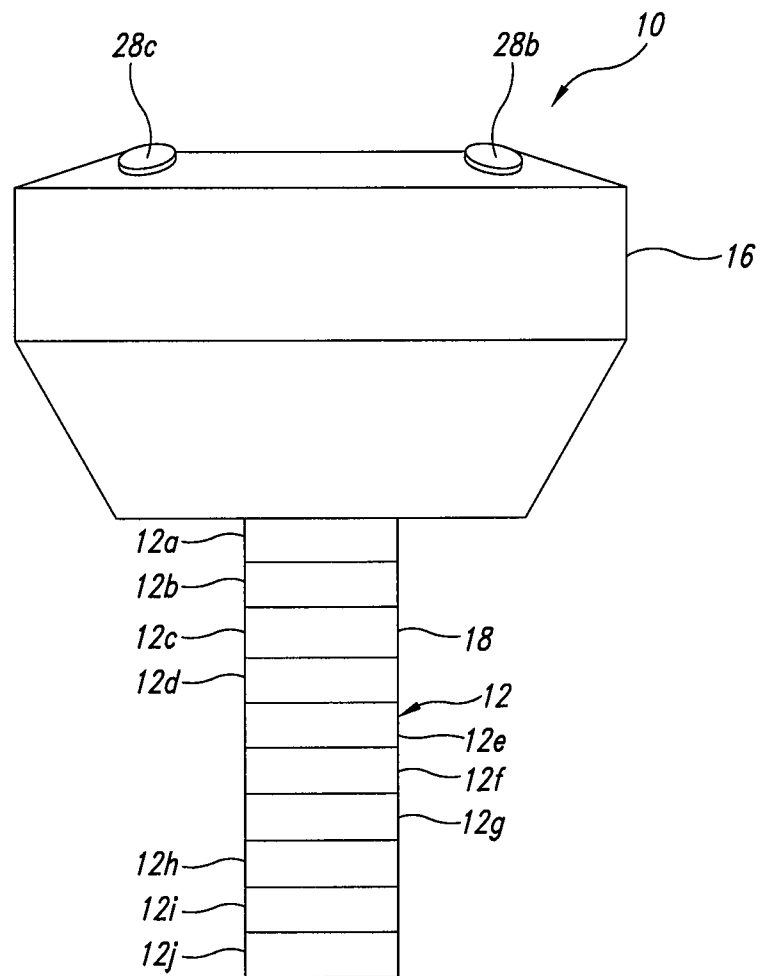
44. The sacrificial anode structure of claim 43 wherein the elongated member includes at least three distinct sections.

45. The sacrificial anode structure of claim 44 wherein each of the sections is a sealed section.

46. The sacrificial anode structure of claim 45 wherein each of the sealed sections has a respective interior filled with at least one of nitrogen or air.

47. The sacrificial anode structure of claim 43 wherein the elongated member comprises at least one of an alloy of cast iron or an alloy of steel.

*FIG. 1*

*FIG. 2*

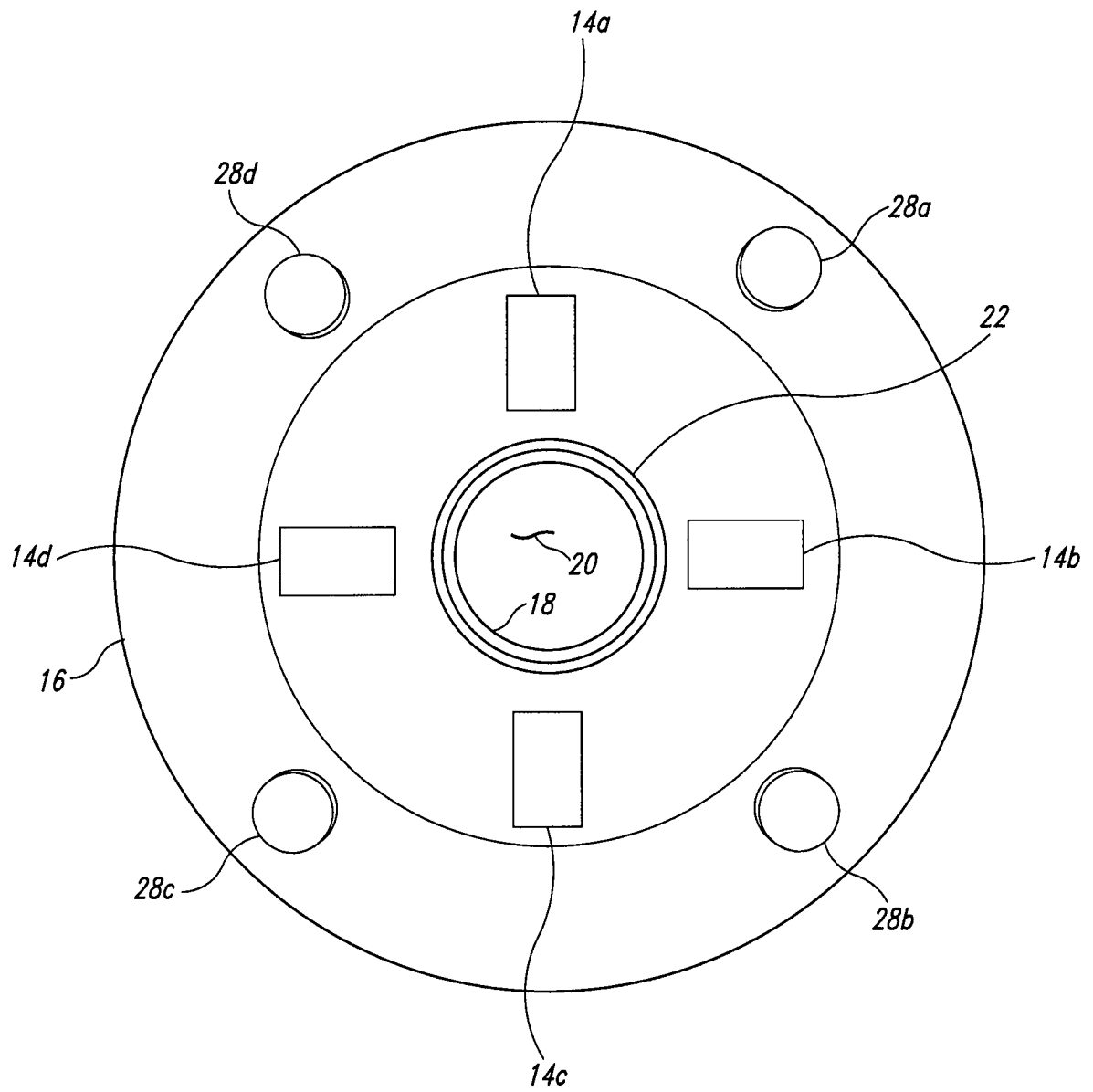


FIG. 3

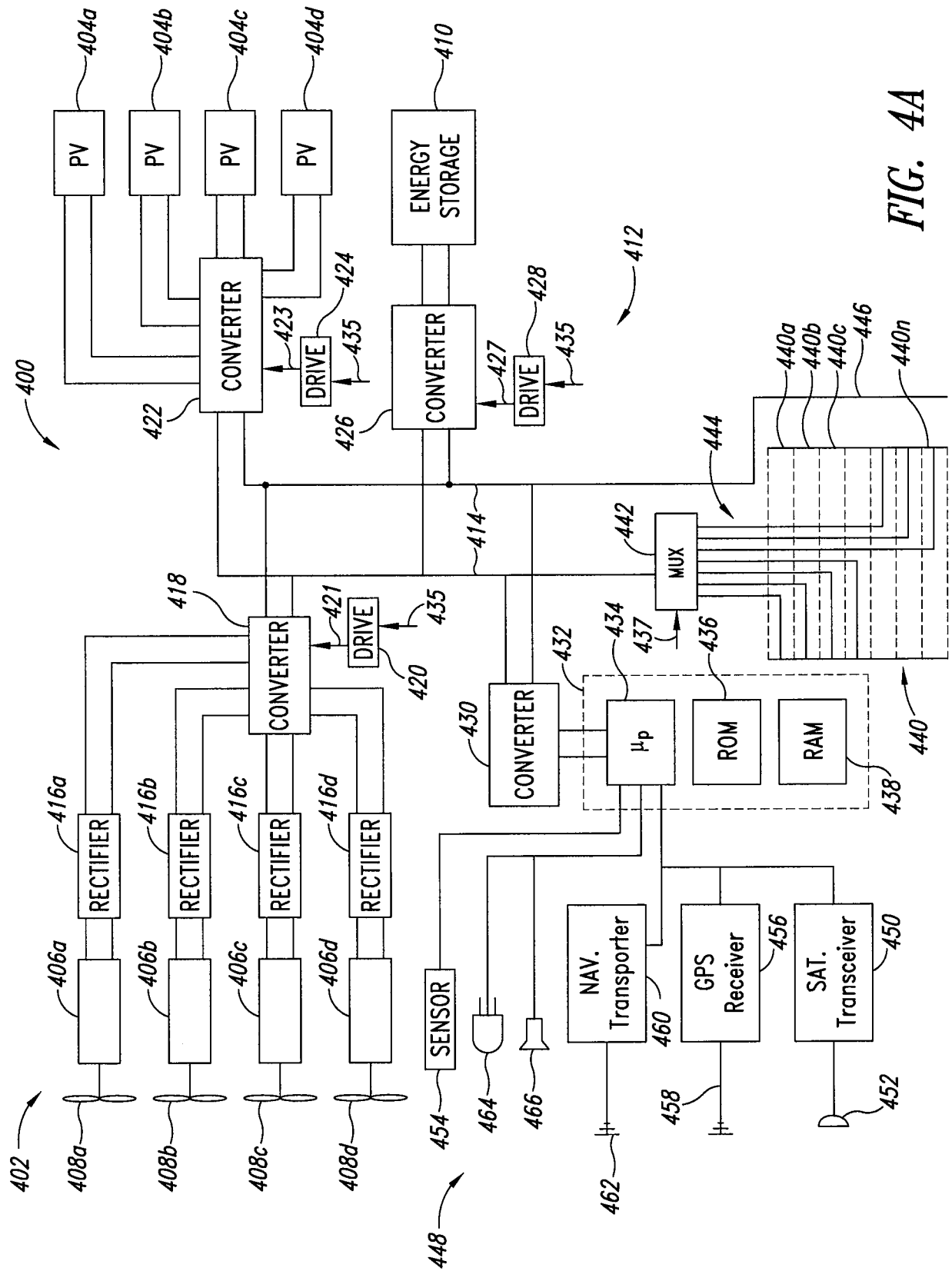


FIG. 4A

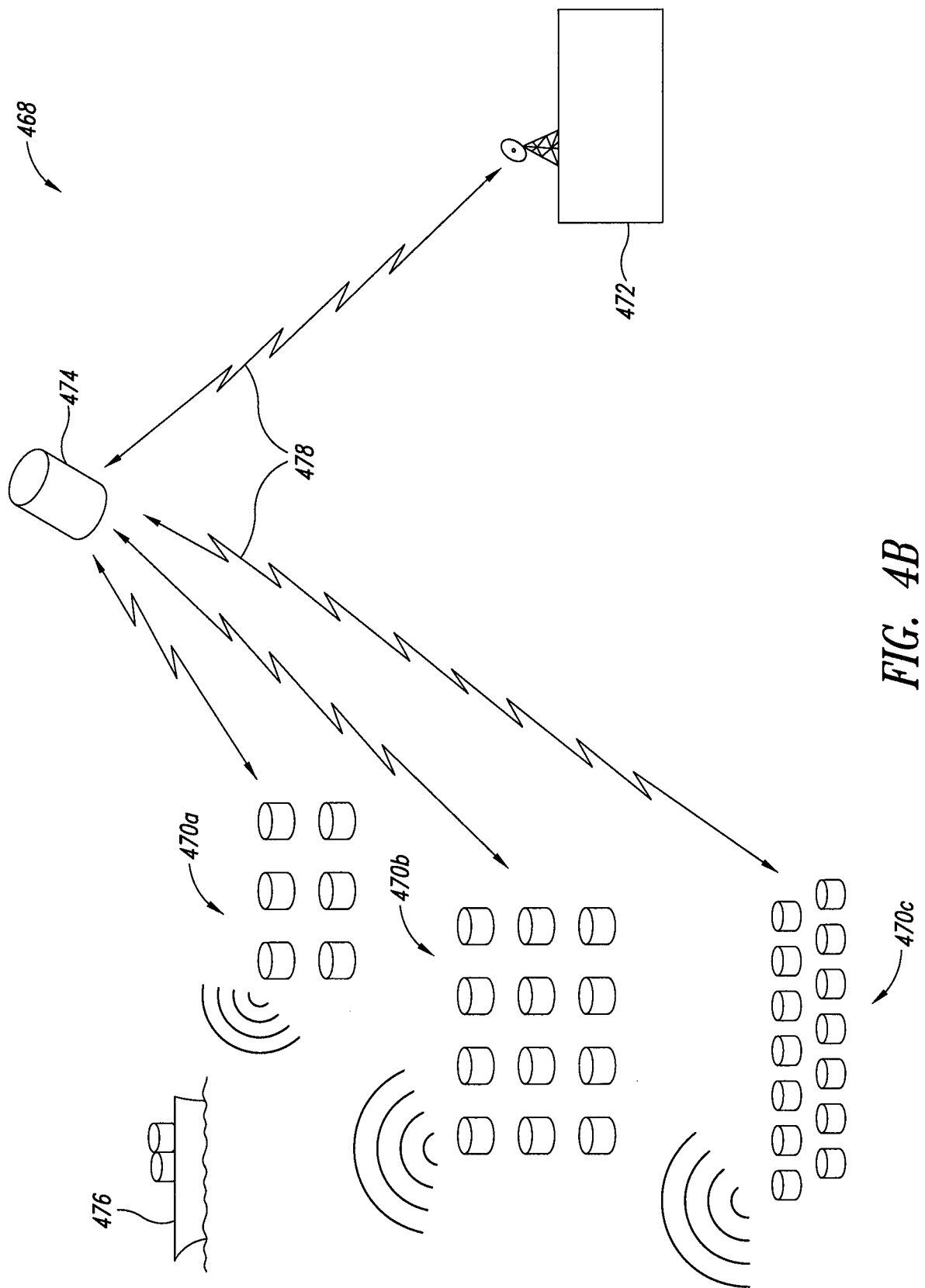
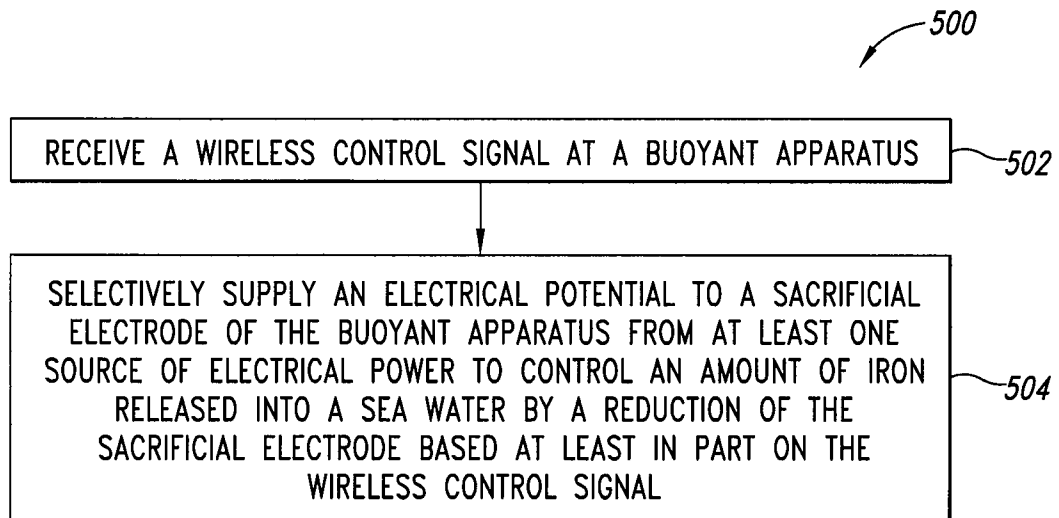
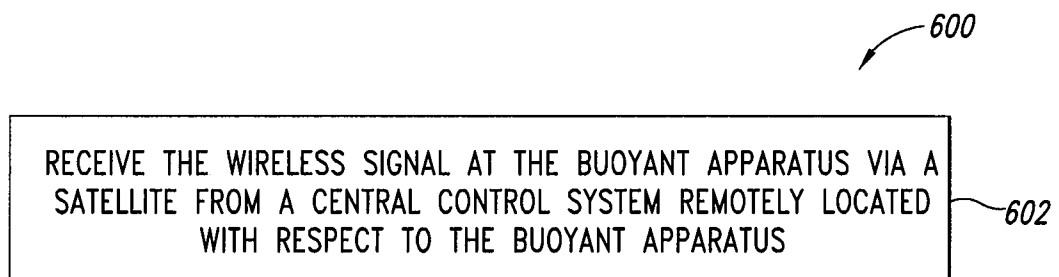
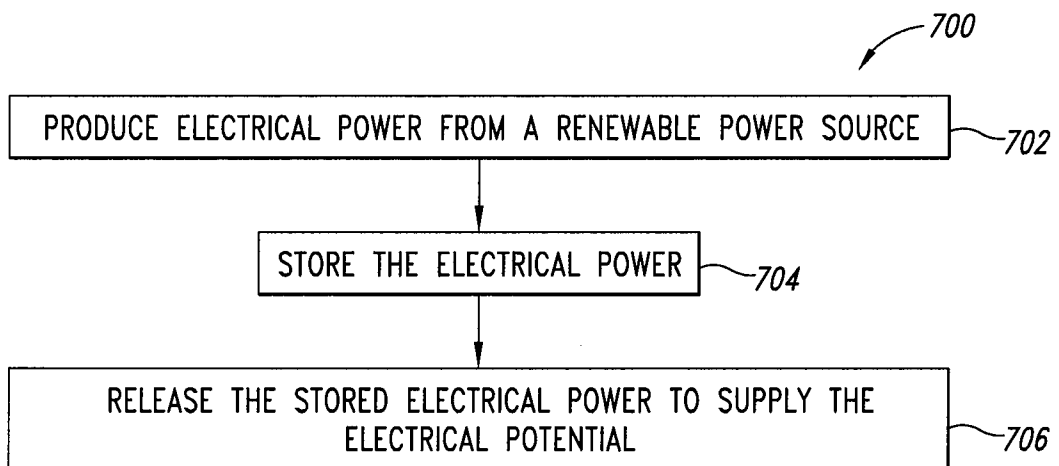
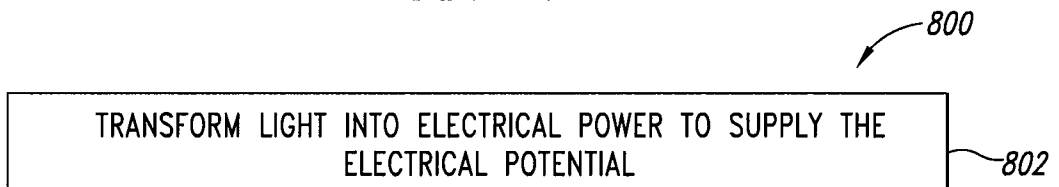
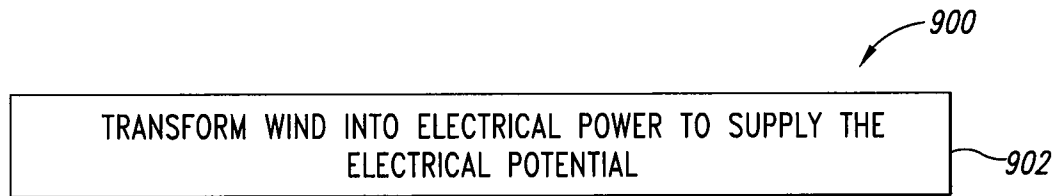
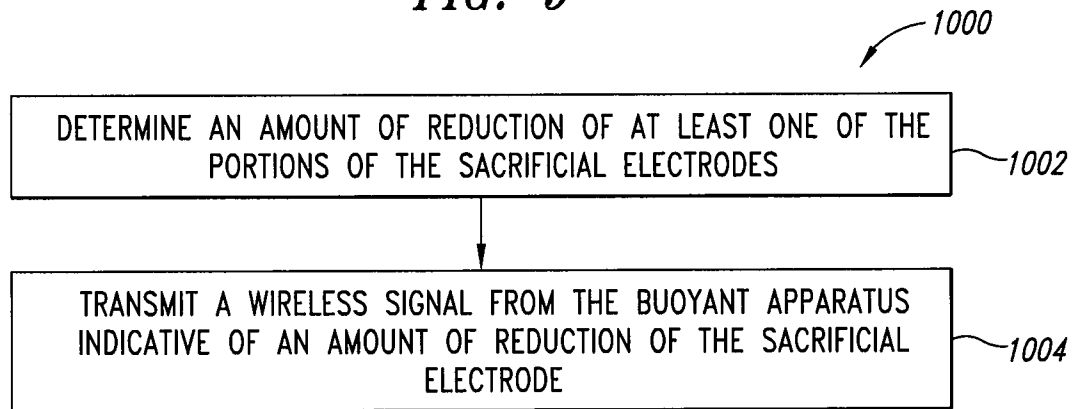
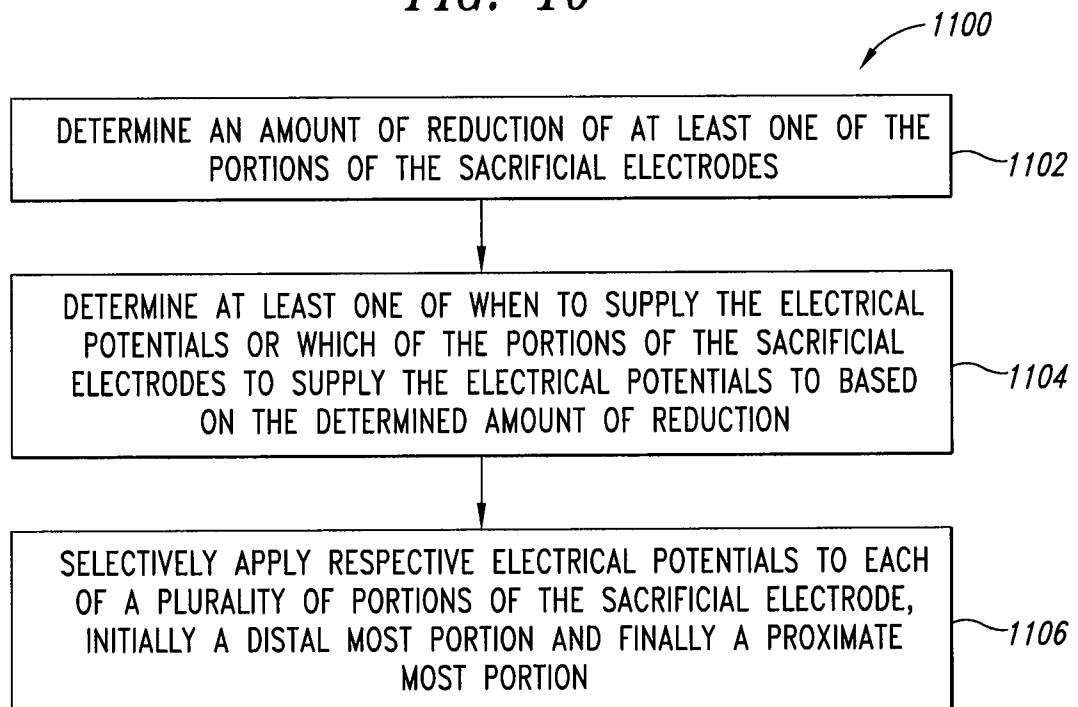
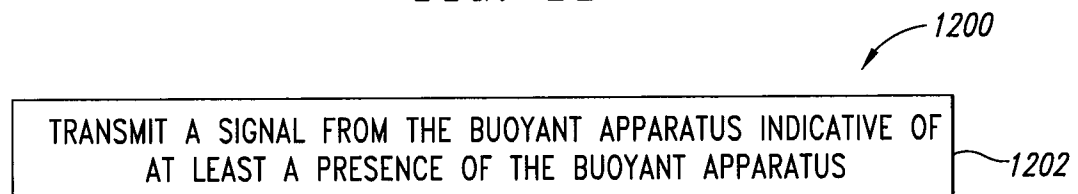
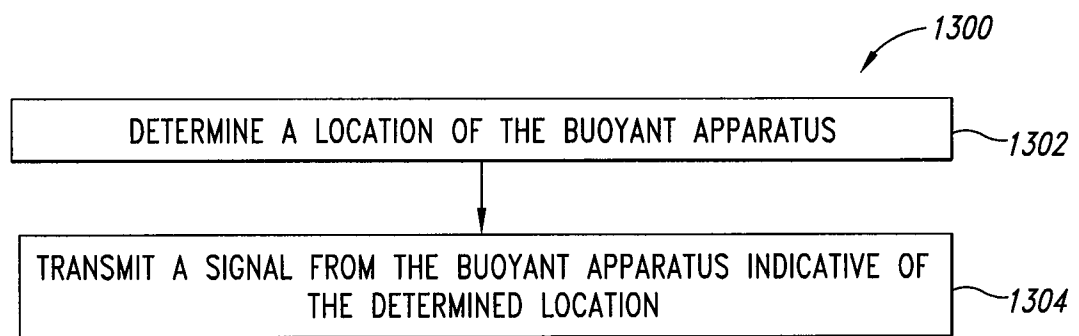


FIG. 4B

*FIG. 5**FIG. 6**FIG. 7**FIG. 8*

*FIG. 9**FIG. 10**FIG. 11**FIG. 12*

*FIG. 13*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/054311**A. CLASSIFICATION OF SUBJECT MATTER*****A01K 61/00(2006.01)i, B01D 53/84(2006.01)i***

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 8 A01K 61/00, A01G 7/00, C23F 13/00, C25B 1/00, F03D 9/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility models since 1975

Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS, USPTO, JPO, Delphion

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6100600 (Tassilo Pflanz) 08 August 2000 See abstract; figures 1-5; columns 1,4-9; and claims 1-42	1 - 47
A	US 5807023 (Leo M. Krenzler) 15 September 1998 See abstract; figures 1-13; columns 1-8; and claims 1-24	1 - 47
A	US 6199317 (Masamichi Saiki et al.) 13 March 2001 See abstract; columns 3,5-10; and claims 1-4	1 - 47
A	US 4623433 (Antonius O. Streichenberger) 18 November 1986 See abstract; columns 1-4; and claims 1-11	1 - 47
A	JP 55-69270 A (Sumitomo Metal Ind. Ltd.) 24 May 1980 See claim 1; and pages 1-3	1 - 47

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

30 JUNE 2008 (30.06.2008)

Date of mailing of the international search report

30 JUNE 2008 (30.06.2008)

Name and mailing address of the ISA/KR

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Facsimile No. 82-42-472-7140

Authorized officer

JUNG, Jin Wook

Telephone No. 82-42-481-8167



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2008/054311

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

- I. Claims 1-28 directed to an apparatus operable to fertilize sea water comprising at least one sacrificial anode structure, at least one source of electrical power and at least one buoyant member and a method thereof.
- II. Claims 29-37 directed to a system to fertilize sea water with nutrients comprising an iron fertilization subsystem, a sensor subsystem and at least one control system.
- III. Claims 38-42 directed to a sacrificial anode structure comprising an elongated pipe member of a material.
- IV. Claims 43-47 directed to a sacrificial anode structure comprising a hollow elongated member.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2008/054311

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