Institute of Design
ILLINOIS INSTITUTE OF TECHNOLOGY

# Project Phoenix
# Macro-Design Proposals for Confronting Global Warming
# *Fire Reversed*

Charles L. Owen



**Reissued: July, 2004**

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***Methodology of Project Phoenix. Structured Planning*** (in Japanese, translated by Akira Harada). **Industrial Design** [Japan], Special Feature 3: Research Papers, No. 155 (October 1991): 38-46.

Owen, Charles and Howard Kavinsky. ***Project Phoenix, Fire Replaced: Solar Power and Global Warming.*** In **SPS 91, Power from Space. 2nd International Symposium,** Proceedings, Section C1.11, 596-603. Paris, France: Société des Ingénieurs et Scientifique de France, 1991.

***Project Phoenix: Options for a World Growing Warmer*** (in Japanese and English). **Design Scene** [Japan] No. 27 (December 1992): 23-26, 38-42.

Detailed information on the Structured Planning process used for this project can be found in papers by Prof. Charles Owen on the Institute of Design web site: www.id.iit.edu

An additional **Phoenix** project report is available under the title:
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## Preface

The report on Project Phoenix was first published in 1990. In this reissuing, it has been edited slightly to reflect the time that has passed and advances in communication technology. This entailed some tense changes, some extensions of figure captions for electronic publishing purposes, and the separation of the full report into two, more compact reports. The appendix on Structured Planning was also removed. Articles describing Structured Planning can now be seen on the Institute of Design web site: ***www.id.iit.edu***. Those interested should look for research papers by Charles Owen.

Several events of interest have taken place since the project was completed. All of us concerned with the project in 1989 had grown to believe that the global warming problem was real and that a strictly scientific approach—that is, to understand the problem and stop doing what was causing it—was not enough. A design approach—to ***do*** something that would both reduce carbon dioxide concentrations ***and*** have economic and societal benefits—needed serious consideration. The project, as a demonstration of this, was thought to be important enough to be passed to government officials who might be able to take advantage of its approach and ideas. It was sent in 1991 to Senator Al Gore, an advocate for environmental responsibility, and President George H. W. Bush—along with the governmental leaders of the UK, Germany, Russia, France and Japan. Responses were received from the UK and Germany. Both governments sent the project to their science ministries for evaluation, received positive responses, and requested permission to pass it on to relevant organizations in their countries.

A number of articles in the press and radio/television shows carried the message over the next several years. Through 1997, the Institute of Design was aware of 33 articles and five radio and TV reports. Twenty-five live presentations were made by Charles Owen or members of the team. Among the more visible communications were a cover story for the Chicago Tribune Sunday Magazine (October 29,1989), a segment of the CNN-TV Future Watch program (1990), a paper given in Paris for the 2nd International Symposium on Power from Space (1991). and an article, "Reversing the Greenhouse", in the August 1991 issue of Popular Science.

In the fall of 1991, the editors of Popular Science magazine honored the project at their ceremony in New York for the "Fourth Annual Best of What's New – The Year's 100 Greatest Achievements in Science and Technology". The project not only was recognized among the 100, it received a Grand Award (one of ten given) in the Environmental Technology category.

Over the years since the project, the urgency of confronting global warming has increased. Additional evidence confirming the problem continues to be uncovered, and its cumulative persuasive weight cannot continue to be ignored. The kinds of projects suggested by Project Phoenix are multiply beneficial with economic and societal as well as environmental payoffs. We need governmental leadership with the vision to see how projects undertaken from a systems design point of view can be good business as well as good government. The public works needed will be massive—but they need not be economy-breaking, single-goal expenditures; ***they don't have to just stop something***. They can contribute to building economies and societies—***and stop*** the worst ravages of global warming.

Charles L. Owen July, 2004



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## Original Preface, 1990

Mounting evidence suggests that the works of man are finally influencing the climate of the Earth. Wishful thinking will no longer suffice. The ***Greenhouse Effect*** appears to be beginning to take control of the Earth' s temperature regulating systems. Evidence of global warming shows an increase in temperature worldwide since 1860, with the greatest increase taking place in the 1980' s. Surface sensors record the six warmest years as 1988, 1987, 1983, 1981, 1989 and 1980. Although the increase has not been uniform in distribution or rate, it has resulted in a rapid rise of about one-half degree Celsius since the beginning of the century.

Despite this, and other convincing evidence, the debate on global warming continues. Although the discussion is now out of the laboratories, the cost of real action is so enormous that politicians are paralyzed. Complete confirmation, which may take another ten years, may be required to authorize action. Ironically, timeliness could be essential to avoid cataclysmic damage.

Balanced against the costs of drastic climate change, anything we could do would be cost-effective. Ocean levels may increase as much as a meter in ;the next 50 – 100 years. If the West Antarctic Ice Sheet melts, the prediction increases to four to five meters. Coastal cities will be inundated or storm threatened, including large areas of the eastern and southern U.S. seaboard, parts of northern and eastern South America, northeastern Europe along the North and Baltic seas, the delta lands of Bangladesh and Egypt, and much of Japan' s Kanto plain.

Although it is still highly uncertain, the rate of mean global temperature rise could increase to as much as 1 degree Celsius per decade, with warming at higher latitudes at least twice the global average. In the higher latitudes, this would mean a climate shift of 100 to 150 kilometers per decade. The effect would be to move the temperate zones toward the poles faster than ecosystems can follow. Widespread destruction of ecosystems would result. Tundras would deteriorate; forests, prairies and savannas would succumb.

Human society would find it difficult to cope with such changes. The situation would not stabilize, but would worsen on a grand scale as the mean temperature rises. At any but the best of projections, the prospect is bleak, with great cost to mankind and the Earth. If the worst fears of the scientists are right, ***heroic actions may already be called for***. In any case, we cannot afford to wait and see.

## Introduction

### The Problem

While a number of sources contribute to the so-called "greenhouse" gases causing global warm-up, the unbalancing source has been created by man. Two gases, carbon dioxide and methane, are the primary culprits. Both are produced as byproducts of many of the industrial, commercial and even individual activities of human society.

The ***Greenhouse Effect*** is caused by the absorptive characteristics of the greenhouse gases as they react to radiant energy. While they are transparent to radiant energy in the visible spectrum (and, therefore, pass sunlight through to the Earth), they absorb radiant energy in the infrared range of the spectrum. Heat generated on Earth that would otherwise radiate away to outer space is trapped and re-radiated back to Earth by the greenhouse gases. In normal proportions, there is a balance among the gases of the Earth' s atmosphere that maintains

temperatures and climate in the familiar life-supporting patterns we know. Although they compose less than 1 per cent of the Earth' s atmosphere by volume, the greenhouse gases are a vital factor in this life support system.

Of the greenhouse gases, carbon dioxide is the gas of most concern. While methane is 20 times more effective than carbon dioxide in trapping heat, its concentration in the atmosphere is less than one one-hundredth that of carbon dioxide. Other greenhouse gases, nitrous oxide and—particularly—the chlorofluorocarbons (Freon is a commercial example) are very potent, but less influential because of their lower concentrations in the atmosphere. Their increasing presence is worrisome also for other reasons—acid rain and the destruction of the ozone layer.

In a normal year, many billions of metric tons of carbon are removed from the atmosphere by the natural processes of photosynthesis and the physico-chemical diffusion of carbon dioxide into the seas. The Earth, in turn, returns back to the atmosphere approximately the same number of billions of metric tons of carbon in the form of carbon dioxide through processes of soil and plant respiration and physico-chemical diffusion from the seas. Over the last two centuries, man has upset the balance. Scientific estimates now place the number of metric tons of carbon removed from the atmosphere annually by natural processes at approximately 204 billion. Added to the atmosphere are approximately 207 billion metric tons of carbon, of which 5 billion tons are produced by burning fossil fuels and 2 billion tons are released by deforestation. The ***net gain*** of ***3 billion metric tons of carbon per year*** is the primary cause of global warming.

**The Project**

The Greenhouse Effect, was the topic for investigation by teams of fourth year and graduate students in the Institute of Design' s***Systems and Systematic Design*** class in the fall of 1988. Work began in 1988, continued independently into 1989, and beyond in the development of a computer-produced presentation of some of the concepts. Using a computer-supported design process called Structured Planning to gather and organize information from a large number of sources, the teams devised two proposals to confront the global warming problem.

Both proposals grow out of reflection upon a basic greenhouse equation: carbon plus oxygen produces carbon dioxide—the chemical representation of the common phenomenon of fire. The first approach takes the equation as is and asks what can be done to contain its effect. In this approach, the effort is toward reducing the amount of $CO_2$ in the air by reducing the amount of carbon burned—in essence, replacing fossil fuels as a source of energy. The second approach, the subject of this report, reverses the equation and asks what can be done to remove existing $CO_2$ from the air. This approach leads to means for augmenting photosynthetic processes.

Conducted on a massive scale (the only scale that can significantly deflect the ravages of a full Greenhouse Effect), either project could have major beneficial impact. Together, they provide hedges against unforeseen problems—and a welcome multiplicity of tactics. The clinching argument for their consideration is that they have commercial and societal benefits well beyond their intended global warming objectives. Solar Power Satellites were conceived from the beginning as profitable enterprises and are timely projects, in any case, as our resources of fossil fuels decline. The reclamation of desertified areas benefits not only the world, but the countries in which the deserts exist—which gain a renewed environment and even, perhaps, a more favorable climate. The growing need for agricultural products should also provide enhanced financial opportunities for

these areas. Floating wetlands not only offer extended green environments for photosynthesis, they provide new breeding grounds for many of the marine species of fishes and invertebrates whose coastal nurseries are fast disappearing (coastal wetlands are rapidly being overrun as a result of the encroachment of human settlements). Floating wetlands also have great potential as locations for the mariculture of shellfish, algae and other marketable products of the ocean. Over the course of the year' s work the ***Project Phoenix*** design teams developed the proposals introduced above from a number of concepts created to blend the best ideas discovered in the process of information gathering with new ideas invented to fulfill un-met needs. The results, outlined in this report, should be treated as ***conceptual plans***—really ***problem statements*** for projects to be carried on at a more detailed level. The ***Systems and Systematic Design*** class is charged with teaching the Structured Planning process for converting data to information to concepts. Projects conducted in the class characteristically produce ideas that exhibit complex interactions and mutual goal-supporting behavior. The objective is to deal with information-intensive problems at a high enough conceptual level that solutions can be postulated and tested against a wide range of contextual information before detailed solutions are attempted. In this case, final concepts were visualized with drawings and models, and (for the first time) computer-generated renderings produced under Howard Kavinsky' s direction by a project subteam consisting of Howard, Peter Beltemacchi, Kenneth Greenlee and Mahmoud Nagib. The 27 computer renderings are included as figures in this report and ***Fire Replaced.***

One of the things that a university can and should do is involve itself in projects that have social value. Although these (desirably) could have commercial value, they may be too risky or of too uncertain value for industry to undertake. ***Project Phoenix*** is such a project. Like many previous projects undertaken at the Institute of Design, it confronts important problems not yet being addressed by others. For ***Project Phoenix,*** the design teams volunteered nearly 10,000 man-hours of time, only a small part of it required for the purposes of the class. We hope that the results of their work will motivate others also to timely efforts on the global warming problem—before it is too late.

***Design/Planning Team***
***Peter Beltemacchi, Jr.***
Team Leader
***Jonathan Durston***
***Kenneth H. Greenlee***
***Gregory :Mostovoy***
***Andre Charles Smith***
***Masayasu Yamamoto***

## Project Phoenix: *Fire Reversed*

***Granted reform of the industrial system, replenishment and reinforcement of Earth's photosynthesizing process could alone stabilize the situation—in essence, reversing the oxidation process of fire, reducing carbon dioxide to its constituent elements, and recombining carbon into solid compounds.***

### The Recovery of the Ecosystem

Deforestation has played a significant role in upsetting the balance. World deforestation has reached a pace of approximately 120,000 square kilometers of forest cleared annually. It continues unabated, causing an introduction of now more than 2 billion metric tons of carbon per year as carbon dioxide. Reduction of wholesale deforestation practices could make a significant contribution to the restoration of photosynthetic balance. On the active side, the reintroduction of plant ecosystems where they no longer exist, or the introduction of plant systems where they have been unsuccessful previously, could have an even more substantial impact on the situation.

Recovery of barren spaces is a viable option. Depending on its composition, a forest of 1 to 2 million square kilometers (about the size of Mongolia, Libya, or a combination of Texas, New Mexico, Arizona and Utah) can store annually 1 billion metric tons of carbon. Although such large contiguous areas are unlikely to be wholly available for reforestation, it is reported that as much as 15 per cent of the Earth' s land mass, 8.5 million square kilometers of once forested land, is now barren. Of this, nearly 5 million square kilometers are currently unused and could, in principle, be reforested immediately.

Most of these areas are no longer livable or economically valuable. They include land destroyed by poor agricultural practices, logged out forests that have lost top soil through erosion, formerly wooded areas denuded of their trees by generations of impoverished local firewood seekers, areas bordering deserts that are enlarging their boundaries, and areas that once were viable, but have endured climatic change. Classic cases are well known. The cedar forests of Lebanon once provided materials for shipping and construction throughout the Middle East. On the island of Hispaniola, Haiti stands nearly barren beside its healthy neighbor, the Dominican Republic. Countries in Northeast Africa watch grazing and planting lands vanish before advancing deserts. Because they have lost value, these areas are ideal for large scale revitalization. Rather than battle national and local governments over controversial deforestation in politically charged environments, ***Project Phoenix*** would work cooperatively with governments anxious to recover land no longer of value.

An even greater arena for action is the world' s oceans. As well as a vast soup of atmospheric gases (including greenhouse gases) dissolved in salt water, the oceans are the vital force of life for the littoral zones surrounding the continents. Along ocean shores, salt marshes and mangrove swamps cradle and protect the young of untold numbers of species of sea animals. At the same

time, they form a major link in the chain of photosynthetic ecosystems. And with them, growing from holdfasts in shallow waters and floating in deeper, calm waters are the algae systems, another link. Both of these plant systems with their associated animals—most particularly the mollusks—are potentially recruitable for extended service in the reduction of carbon dioxide.

Away from the shores, where waters are deep, there are vast stretches of ocean that are out of the way, untraveled and only marginally supportive of sea life. These areas are suitable for macro-designed, floating ecosystems large enough to contribute substantially to reducing carbon dioxide and, at the same time, able to provide new habitats for the sea life being dispossessed of their shore nurseries everywhere by encroaching civilization.

**Desert Regreening**

The first of the macro-designed systems envisioned by ***Project Phoenix*** deals with "regreening" the deserts and barren lands. Macro-scale is necessary for these operations because climatic conditions are hostile. Conducted on a very large scale, the regreening process will not only be easier to implement, it will induce local climate modifications of its own making that will help to maintain the environmental changes.

The removal of vegetation in dry regions causes rainfall to diminish because the amount of sunlight reflected back as heat from the Earth to the lower atmosphere increases. As the air is warmed, and maintained at a high temperature, it becomes too warm for water vapor to reach the dew point—which is what allows the formation of clouds and rain. Conversely, as vegetation increases in density, reflected heat is diminished, plant respiration adds moisture to the air, and conditions improve for cloud and rainfall generation. Geological formations complicate the problem because they affect wind patterns and block cloud movements. Relatively infertile lands leeward of forested areas, and unblocked by geological features, frequently avoid desertification because they receive rainfall generated by the forests to windward.

***Project Phoenix's*** strategy is to introduce, beginning at the windward side of a desert fringe, dome-like covering structures under which a carefully selected plant ecosystem can thrive. A wall of these domes is then extended toward the harsher center of the desert. As the leading edge of the covered environment penetrates the desert, it leaves behind it an enlarging area of covered ground under which new generations of plants are growing. When the planted environment under a system of domes has reached sufficient maturity to chance survival without shelter, the coverings are removed and taken to the leading edge of the advancing system to re-enter the cycle. The effect seen from high above in time lapse photography would be a thin line of dome clusters growing along the windward fringe of a desert area and then expanding in breadth into an amoeba-like sheet that advances across the desert, ingesting barren land before it and uncovering behind it a functioning ecosystem of trees and plants.

The choices of trees, shrubs and other plants to be used depend on the locale. Several factors are involved. Surrounding ecosystems will be influenced by any new species introduced, so choices must respect local species that have demonstrated success in similar environments. For Australia, this might mean using varieties of eucalyptus for large and small trees; for the United States, desert ironwood and mesquite might be used along with varieties of oak and maple. Soil conditions will also affect choice. Alkalinity, acidity, salinity, drainage, soil constituents, and the presence or absence of nutrients are variables that must be considered. The availability of water sources for temporary irrigation is another factor, as is the range of temperature that will exist at the beginning and end of a regreening operation.

This last factor is related to one of the most important concerns: the survivability of an ecosystem when it is no longer protected. This involves questions of how rapidly the local climate will change over once the new ecosystem is exposed. If the climate changes slowly, plants will have to withstand conditions not greatly different from those originally encountered. Prairie and forest vegetation will do poorly; desert vegetation will do well. As the climate changes to a wetter, milder condition, desert vegetation very likely will be over-watered and will rot; prairie and forest vegetation will thrive.

Because it is difficult to control or predict these conditions, the best strategy is a mixed strategy. Plant groups are alternated in the dome clusters. Clusters to be removed early are seeded more frequently with dry climate plants; domes scheduled for later uncovering receive plant mixes more appropriate to wetter conditions. Vegetation not well enough suited to the conditions it finds will die off to provide nourishment for vegetation better acclimated. A careful coordination of uncovering schedule and plant type mixing by location allows successful plants to reseed adjacent areas, replacing plants lost to climate stress. The more rapidly the climate can be changed, however, the more effective will be the contribution of the renewed environment to the task of removing carbon dioxide. Grassland and forest plants have more stomata, the openings through which plants respire, and thus can absorb carbon dioxide in greater quantities and grow faster.

**The Dome System**

Domes for the regreening process are made of strong, lightweight, plastic fabric impermeable to water and reflective to heat, but transparent to the visible and ultraviolet spectra of sunlight. Tent-like in many respects, they are hexagonal in shape, 250 meters on a side. Each covers .1624 square kilometers; 19 together (including the space of one used for electromechanical support functions) cover 3.1 square kilometers and make up a self-sufficient "Dome Cluster". 33 clusters cover slightly more than 100 square kilometers.

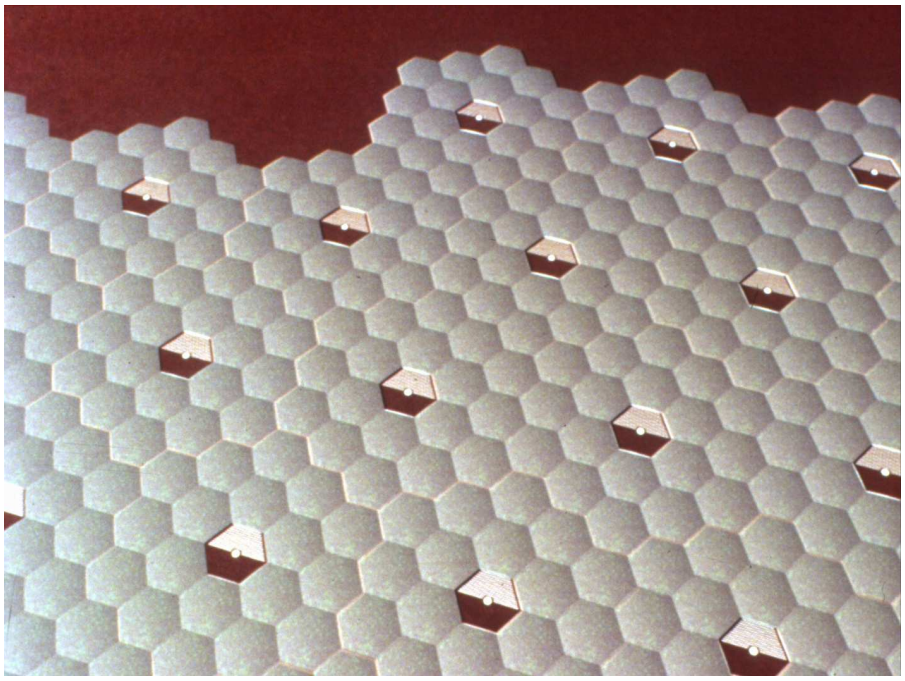

Figure 1 **Desert Regreening**

Barren areas, formerly green, are regreened progressively by sheltering vast areas with a system of tent-like, air-supported Domes. Modular clusters of 18 domes surround mechanical cores. Thirty-three clusters cover 100 square kilometers.

The height of a dome can be extended. As the plants within it grow, it is raised from an initial height of 5 meters at the corners to a maximum height of 15 meters. At the center, a dome is approximately 32 meters high initially, rising to a maximum height of 42 meters.

Air-operated, six-section, telescoping poles are the primary elements of the rigid support system for the domes. Rising 23 meters above the dome corners, they anchor the domes and provide connection points for suspension cables strung between poles and over the edge junctions between domes. Hanging between the poles in catenary curves, the suspension cables, by means of a series of vertical drop cables, hold the seams of adjoining dome edges in the proper reversed catenary curve of their geometric intersection. Alternating vertical cables (at 4 meter intervals) continue to the ground and are attached to ground anchors. Posts around the perimeter of a cluster are guyed with additional cables to ground anchors outside the cluster.

Vertical walls around the perimeter of a Dome Cluster must also extend as the domes are raised, in order to maintain atmospheric security. Made of the same plastic material as the dome, they are connected securely at the top to the dome edges. At the bottom, they are rolled to remove slack and anchored to the ground.

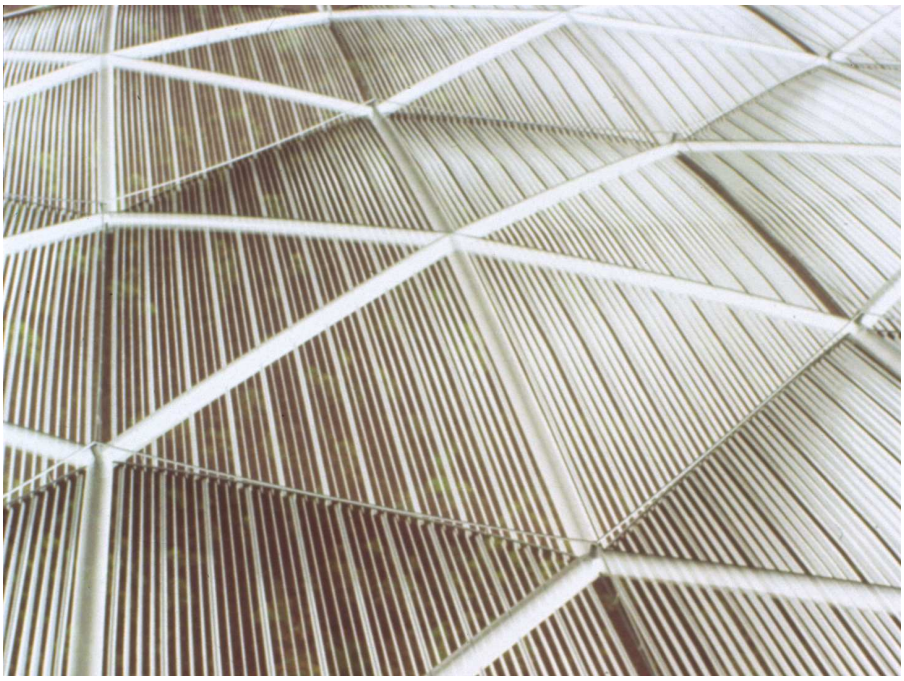

Figure 2 **Dome Modules**
Sheltering Domes are hexagonal, 250 meters on a side. A slight positive air pressure inside maintains general structural integrity. Large, ten meter diameter tubes both stiffen the structure against storms and channel air to the periphery of a cluster. Returning air cools the environment and supplies fresh $CO_2$.

The primary means of support for the Dome Cluster system is air pressure. Air pressure in the domes is maintained at a level slightly above that of the surrounding air. This not only provides pneumatic air support, it enables ***Project Phoenix*** regreening process managers to control air temperature and freshness, ensuring that there is no oxygen buildup or carbon dioxide depletion. To transport air within a Dome Cluster, six fabric "air tubes", ten meters in diameter, are incorporated into each dome surface, running from the corners to the center. These contribute additional rigidity to the dome surface and provide the

distribution channels for incoming air. At each corner intersection between domes, where the air tubes of three domes come together, a "doughnut" shaped air plenum surrounding the pole support connects the tubes into a continuous air channel serving the entire Dome Cluster.

**Mechanical Core**

The Mechanical Core is the operation center for a Dome Cluster. Air and water distribution are handled from here, and all electromechanical functions are controlled from this space. The Core contains solar power generation arrays; a helipad; two holding pond reservoirs for the runoff from excessive rainfall; pumping equipment; fans; electrical generation, storage and distribution equipment; and a minimal administrative support facility.

Power generated at a Mechanical Core is used primarily for moving air and pumping water; incidental uses include a minimal lighting system, communications support, and battery recharging for electric vehicles. Power for operations is derived from sunlight. Approximately one half of the 162,400 square meters available in the hexagonal space is devoted to solar power generation. A parabolic trough collector system provides about 7 megawatts (MW); excess power is diverted to the electrolysis of water into hydrogen and oxygen. Energy stored as hydrogen is used to power generators at night and when weather conditions prevent adequate power generation by solar means. For very large regreening operations, where it is economically advantageous, an SMES (Superconducting Magnetic Energy Storage) may be shared by all clusters.

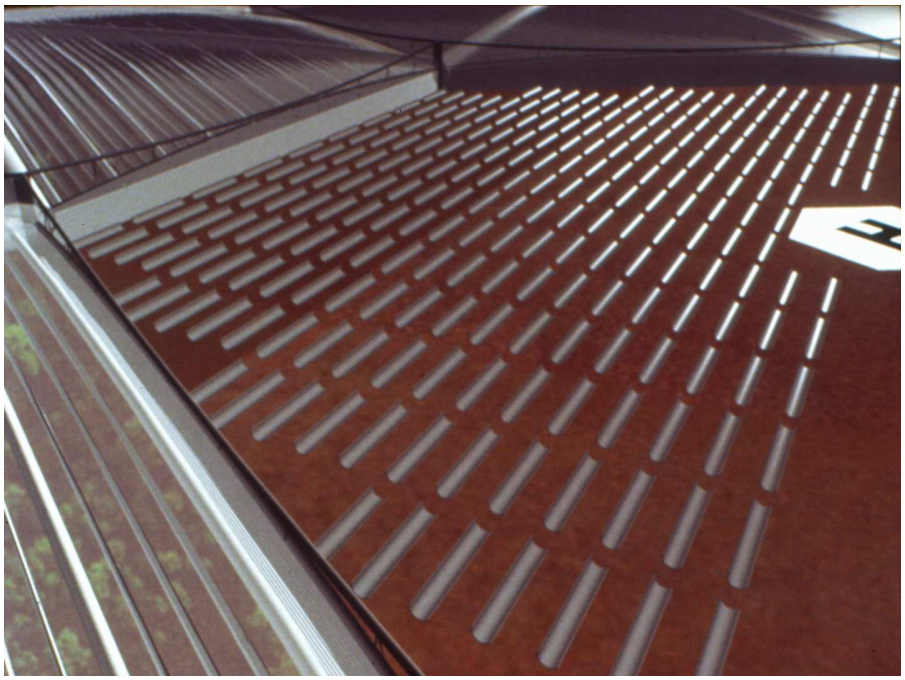

Figure 3 **Mechanical Core**
Distribution of water and pressurized air for each cluster of Domes is regulated from a mechanical core powered by solar collectors.

Air is circulated throughout a cluster by the main fans located in the Mechanical Core. These are 1.5 megawatt (MW) units, with 3 meter impellers capable of blowing 14,160 cubic meters of air per minute. Positioned at the six corners of the hexagonal Core, the fans are used in opposite pairs, two at a time, to blow fresh air through the cluster during the day. Fresh air enters the Dome Cluster

through the ten meter radial tubes in the domes adjoining the Mechanical core and spreads out through the tubes of connected domes until it reaches the periphery of the cluster. In the peripheral domes, the air is vented to the interior space of the cluster, from there flowing centrally back over the vegetation to the Mechanical Core at the cluster center, where it is released through pressure vents to the atmosphere. Ventilating the cluster during the day cools the covered environment and replenishes the carbon dioxide when it is most needed—during the daily growing cycle.

Also during the day, a second set of smaller fans in the Mechanical Core (2 at a time of 6 available) blows through a manifold to selectively expand a special set of 2 meter "shading tubes". These are held by collars under the dome surfaces in straight lines 2 meters apart running from Core to cluster periphery in an orientation parallel to the path of the sun. Depending on the age of the plants and the heat of the day, the shading tubes can be set in patterns of alternating inflation and deflation to partially shade plants under them.

At night, much cooler temperatures condense the moisture on the domes' inner surfaces. Moisture collects at low points, particularly on the evenly-spaced collar mounts for the shade tubes. These are designed to participate in this way as drip points, distributing condensation water evenly in the environment.

Water for the clusters is drawn from wells dug to aquifers (water is often available underground in desert areas). If water is unobtainable from aquifers or other nearby sources, it may be brought in from more remote river or lake sources, or from desalination plants on the sea coast. In all cases, water demands will not be excessive because the dome system conserves its water through evaporation management.

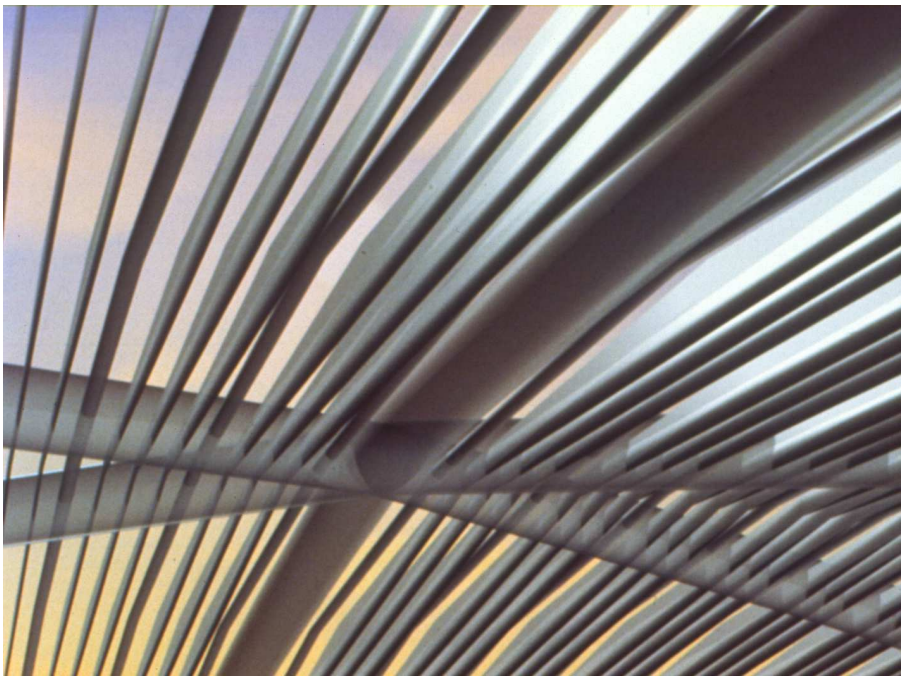

Figure 4 **Shade Tubes for Sunlight Control**
Domes are raised progressively as plants grow. Shade tubes, two meters in diameter, can be individually inflated to vary the amount of shade provided.

On level ground, water is distributed through a cluster from the central Mechanical Core outward by means of a canal system. During site preparation, before a cluster is erected, the system of canals is prepared by scooping out a

central channel, building banks beside it and covering banks and channel with plastic sheeting. The resulting canal holds the bulk of its water above ground level, but retains a residual supply below ground level. From the main supply received at the central Mechanical Core, water is delivered to the primary canal system, 2 meters wide, which radiates out from the Core to the centers of the six adjoining domes in the first ring. From there, the water in each canal divides into two 1-meter-wide channels of the secondary canal system to supply the twelve domes of the second ring. Throughout the cluster, a tertiary water irrigation system delivers water from the canals to the plantings. This system, made up of soaker hoses fed by siphon from the canals, automatically ceases to function if the canal water level falls below ground level.

If a cluster is constructed on uneven ground, the canal system is altered to correspond to the ground disposition. Water from the Core is pumped to the high ground, from which the canal system descends through the cluster. Tertiary irrigation under these conditions is always down-hill, and individual canal segments may be terraced to control the flow of water.

**Operations**

Operations for a Dome Cluster normally are automatic. The system is designed for low intervention operations. Routine inspections and monitoring visits are conducted by a small staff rotating through the clusters on a once-every-three-months basis. General inspection is also conducted from above by blimp and helicopter. For visits, part of the Mechanical Core space is laid out as a helipad, and a mooring tower can be erected for blimp operations.

The progressive envelopment of a desert area begins with a line of clusters. When the seedlings in the clusters have grown to a point requiring the domes to be raised, a new line, or layer, of clusters is added. When the clusters in this layer are ready, in turn, for adjustment, another layer is added. This process usually continues until five layers have been created, by which time the seedlings of the first layer have reached maturity. At the time of the next adjustment, the domes of the first layer clusters are dismantled and moved to the front of the envelopment as the new seedling layer.

Domes are moved and installed with the help of a blimp fitted with helicopter pods as outriggers for positioning and fine movement control. Before transport, a dome' s six radial support tubes are isolated from the central hub, sealed and inflated. Now stiffened, the tubes act like ribs in an umbrella to control the shape of the nearly 200,000 square meters of fabric. For installation, a dome is simply lowered onto location, spread open, inflated and anchored down with poles, cables and wall structures. When a dome is removed, however, it must be handled carefully so that it does not injure the new trees under it. In this operation, guidelines from the six corners are released under winch control as the blimp lifts the dome vertically away from the trees.

**Floating Wetlands**

The second macro-designed system envisioned by ***Project Phoenix,*** in a sense, "greens" the oceans. The sea holds a great quantity and variety of life, but a preponderance of it lives near the coastlines. The mid-ocean areas are comparatively barren. In these open spaces, free of political competition and pressure from other strongly entrenched ecosystems, ***Project Phoenix*** projects a floating "coastal" environment to engage both the carbon dioxide reduction problem and the problem of vanishing habitats for wetland-dependent sea life.

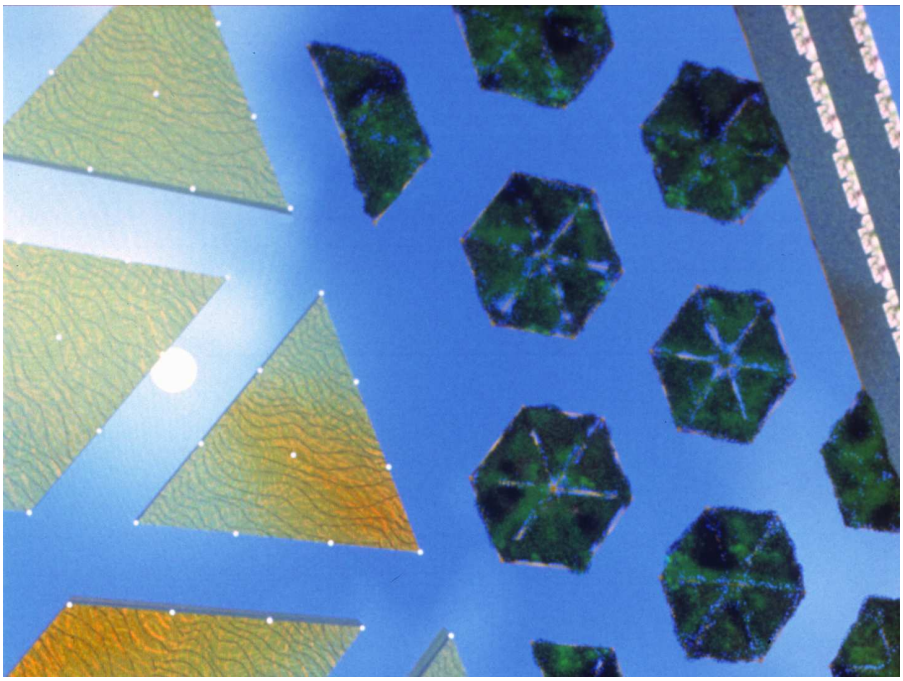

Figure 5 **Floating Wetlands**
Floating Wetlands are systems of floating Mangrove Islands, Mollusk Farms and Kelp Beds covering areas as large as 1,000,000 square kilometers.

The strategy is to create living conditions for aquatic and coastal plant and animal species in an area in which they are not otherwise prepared to grow. Species of plants of particular interest are giant kelp (***Macrocystis pyrifera***—a form of algae), the red mangrove tree (***Rhizophora mangle***—a "land forming" tree that grows in salt water), species of sargassum (a genus of floating algae), and mollusks—particularly mussels, oysters and related bivalves that grow in attached colonies. These plants and animals have the capacity to contribute structurally to a skeletal base set up for them in the open ocean. Simulated island and ocean bottom structures can be assembled in patterns covering as many as 1,000,000 square kilometers (an area approximately three times the size of Japan). At this scale, they have the potential to remove .5 billion metric tons or more of carbon from the atmosphere each year.

**The Structural System**

Underlying all floating elements is a triangular grid of cables suspended below the ocean surface at a depth of 20 meters. Supported by buoys and floating island elements, it acts as the floor of the system, the spacing grid for building, the connection location for moorings, and the site for the holdfasts of Kelp Beds. A triangle 50 meters on a side is the module for the system.

To maintain position and orientation, a Floating Wetland is anchored to the sea bottom by a long-line anchoring system. This system consists of deep water anchors to which are connected long mooring lines weighted in an "N" shaped counterbalance arrangement. Sharp changes in strain, as may be experienced in severe storms, are relieved by the counterbalancing weights, which ride up as the Floating Wetland stretches out, opposing gravity and water resistance to the energy of the storm.

Other structural features are deployed for Wetland stability. On sides normally facing wind and waves, there is a continuous double line of floating Breakwaters. Each Breakwater unit is 50 meters long and 14.5 meters wide, with two

18-meter-long by 8-meter-wide wave power generators on its leeward side. The face of a Breakwater rises 2.5 meters above the surface and is specially curved to break the force of an oncoming wave crest. As waves pass under the Breakwater,

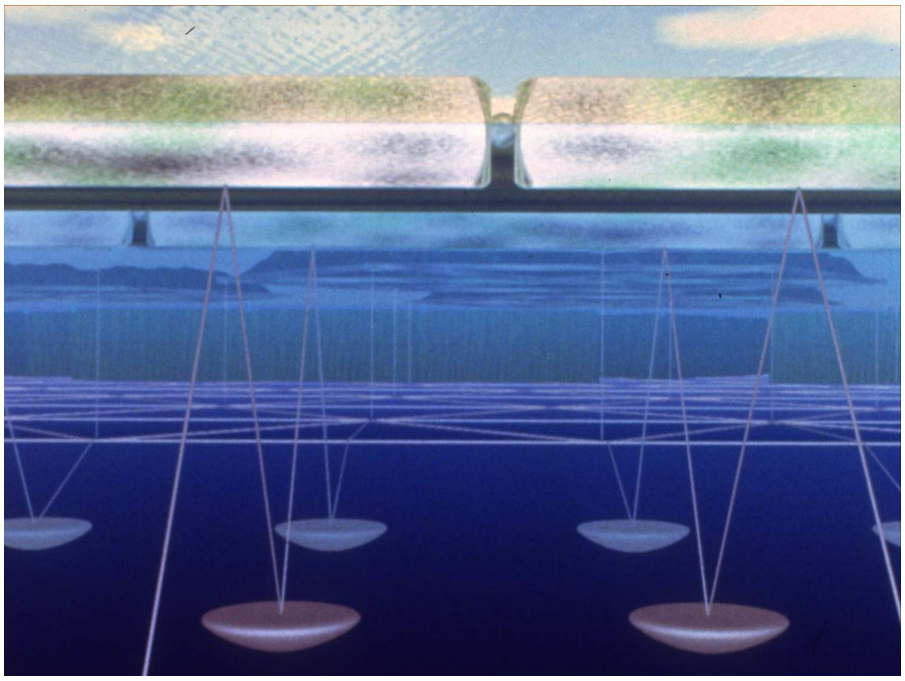

Figure 6 **Wetland Anchoring system**
A long-line anchoring system consists of deep-water anchors to which are connected long mooring lines in an N-shaped counter-balance arrangement. Severe storms can move the system, but strain is reduced by the hydrodynamic resistance generated by the underwater weights

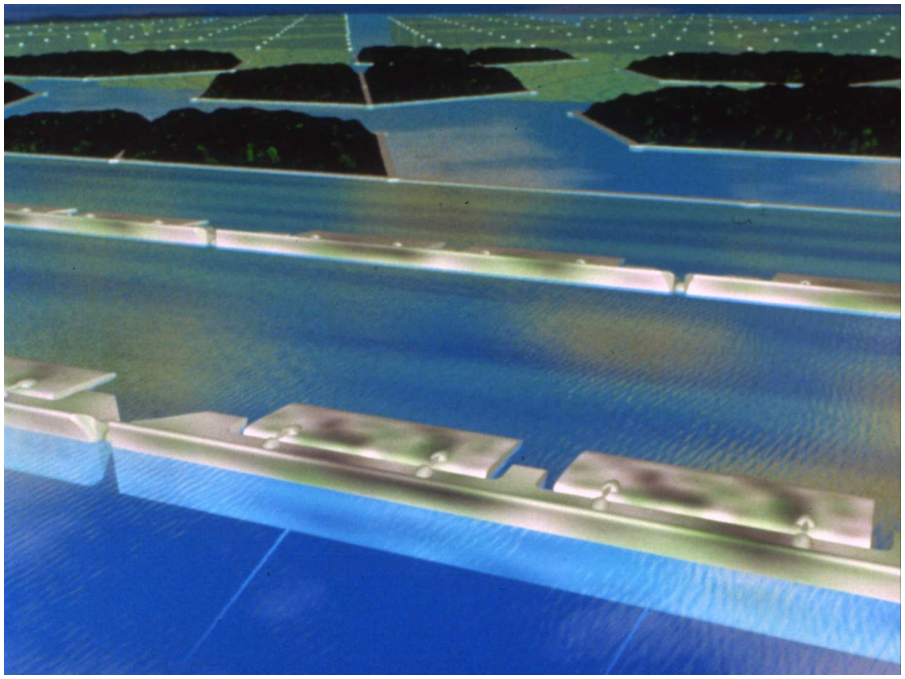

Figure 7 **Floating Power-Producing Breakwaters**
Floating Breakwaters protect the Wetlands from breaking waves and provide power from wave motion. Mangrove Islands mix air-oriented, salt-tolerant plants with water-based algae. Mollusk Farms around them convert $CO_2$ in the water to solid calcium carbonate.

their crests and troughs flex its forward and after sections relative to each other. This motion is harnessed by pumps to drive generators in the Breakwaters, converting some of the wave energy to electric power.
Behind the Breakwaters, reduced energy waves travel 43 meters over an open stretch of water heavily seeded with sargassum seaweed. This floating alga is a third protective feature, blunting the tendency of waves to break. Following this is a second line of Breakwaters, similarly sized and outfitted with wave energy power generation equipment, and directly behind them, a final band of sargassum seaweed also approximately 43 meters wide.

**Mangrove Islands**

Floating islands inside the Breakwater bands act as the next barrier to wind and wave. These islands, hexagonal in plan, cover six modules of the 50 meter triangular grid. To support mangrove trees whose mass is primarily above water, each island is surrounded by a floating perimeter. Floats in this structure measure .87 meters vertically and are trapezoidal in vertical cross section: 1.5 meters wide at the top; .5 meters wide at the bottom. Made of foamed plastic with a hard exterior plastic surface, the floats produce geometrically greater lifting forces as they are pushed deeper into the water by the increasing weight of growing mangrove trees. Floats at the corners and center of an island (on the 50 meter grid) help hold the grid 20 meters below and, in addition, join with the perimeter floats to support another net system designed to hold the root systems of the mangrove trees. This net system, which substitutes for land, consists of five layers of nets in a vertical space spanning .87 meters. Nets in the descending layers have decreasing mesh sizes to engage the roots of the mangroves as they spread out and grow down. Mangrove seedlings, implanted or dropped from growing trees, float trapped in the wide mesh surface net while their roots descend to more suitable anchorage. As the mangroves grow, their trunks thicken to fill out the mesh in the upper level nets, and their increasingly complex root systems interlock to provide ever denser structures and greater stability.

Oyster clumps cling to the mangrove roots and thicken the structure. Leaves and leaf mold from the mangroves and drifting sargassum fill in the interstices and slowly turn the root structure into a floating island.

**Kelp Beds**

Kelp Beds form the heart of the other island-like element of the Floating Wetlands. Kelp grows an average .67 meters per day and absorbs 1,000 to 2,000 grams of carbon per square meter annually. From a holdfast securely anchored to the ocean floor, kelp grows vertically in stalks with leafy frond offshoots supported by gas-filled, ball-like floats. In the Floating Wetlands, Kelp Beds are seeded in the grid structure 20 meters below the surface, allowing the stalks to grow as much as 30 meters, including lateral growth on the water surface. A wide range of valuable commercial uses makes regular kelp harvesting economically desirable—and increases the amount of carbon dioxide removable.

A Kelp Bed is built from 50 meter triangular modules by sinking "holdfast nets" seeded with kelp. These nets, weighted to offset the kelp' s natural floats, ride down on snap rings over the vertical cables connecting the grid to its buoys. The snap rings, which can be released from the buoy cables by a lanyard tied to the buoy above, make it possible for any individual Kelp Bed net to be raised independently for maintenance, although as many as six may be connected to the same buoy. Boats powered by water pumps are able to move freely over the horizontal cables between buoys to harvest the fully grown kelp.

Another economically valuable mariculture activity is mollusk farming. Extensive mollusk farming is encouraged in the Wetlands for the ability of

mollusks to remove carbon relatively permanently from the active carbon cycle. To build their shells, these bivalves combine carbon from the plankton they ingest with calcium from the sea water and convert it to calcium carbonate. Mollusks are grown on looped Mollusk Lines strung in rings between buoys

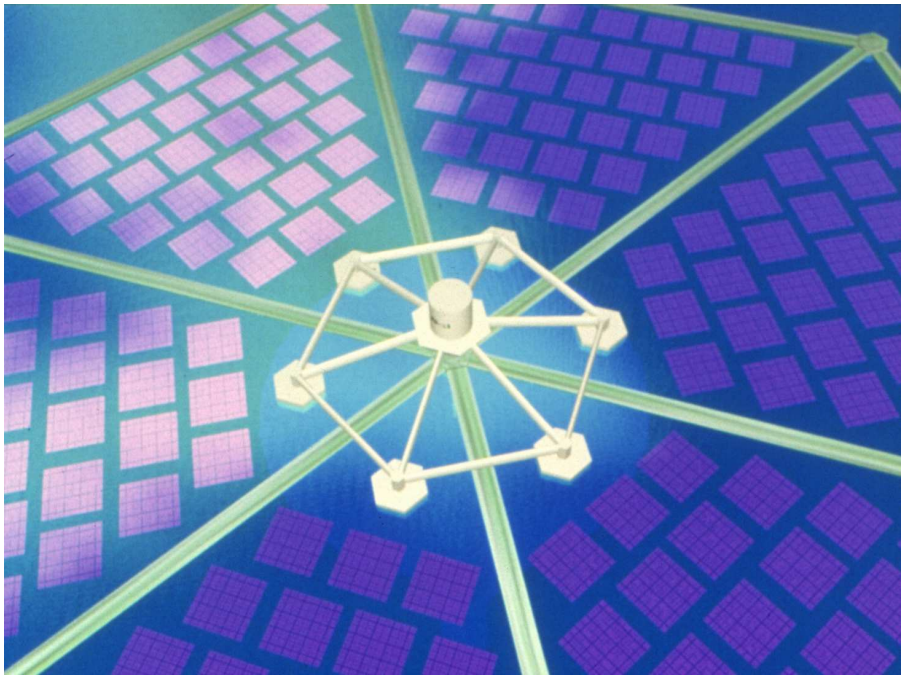

Figure 8 **Pump Islands**
Pump Islands are equipped with general Wetlands maintenance facilities, solar panels for the supply of power, and simple, slow-moving propeller pumps for bringing to the surface a steady flow of cool bottom water rich in nitrogen and phosphorus compounds.

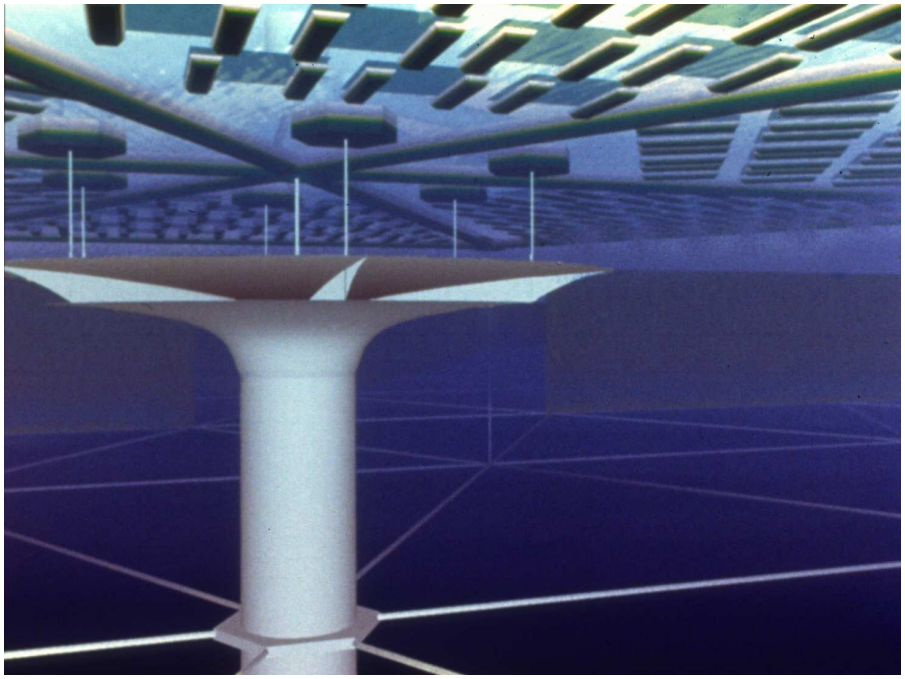

Figure 9 **Artificial Upwelling**
Pump Islands supply the phytoplankton and plants of a Floating Wetland with nutrients from deep below. As specialized islands, they are positioned strategically with concern for prevailing wind and current.

around Kelp Beds. Continuous harvesting and reseeding is done by reeling in lines while the harvesting boat is moving around a Kelp Bed, removing the attached mussel or oyster clusters, and reseeding the lines with "spat" as they are replaced.

Some deep ocean surface waters are well supplied with nutrients by upwelling currents from the bottom. Most deep ocean waters are not. To supply the plants and animals of a Floating Wetland with nutrients, specialized pump islands can be located at strategic locations within the environment. These islands are equipped with general Wetlands maintenance facilities and simple propeller pumps for bringing a steady flow of cool, nitrogen-and-phosphorus-rich bottom water to the surface. Power for the pumps comes from the breakwater generators and solar power arrays on the pump islands. The long pipes necessary to reach from the pump islands to waters near the ocean floor are neutrally buoyant and are held in position by cables to the anchor lines.

Kelp Beds are constructed in arrangements of diamond-shaped beds of 32 triangles and triangular beds of 16 triangles. Mangrove Islands are interspersed periodically to break up long wind and wave paths. Channels, 43 meters wide for boat movement, separate Kelp Beds from each other and from Mangrove Islands. The regular forms of these elements and their arrangement in regular patterns help to maintain a grand plan of Wetland geography that is easy to navigate.

## Conclusions

As the two facets of ***Project Phoenix*** show, there are positive Greenhouse options available. In fact, antidotes for global warming could also speed a successful transfer to other energy sources before fossil fuels run out. As well, they could resolve some of the other environmental crises we face, such as loss of wetland habitats, acid rain and desertification.

Problems that take centuries to create will not be wished away or altered by scattered local and individual efforts. They require orchestration on a national and international level and on a scale that will inherently take time. The sheer size of the effort will require sacrifice by all. To bring recognition and consent for the massive effort required, the international public will have to be shown the options. The design disciplines have a critical role to play here in conceptualizing and visualizing these options for both leaders and public.

The Greenhouse problem should be treated as an insurance problem, not as a public works problem. If action must await proof of necessity, proof may take too long. Action as insurance, although bought under uncertainty, will justify the risk in the worst case—and, if well conceived, will show benefits in any case. Best of all, well-conceived projects have the potential for contributing to the world economy and world well-being.

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