Farming the Ocean

Michael Markels, Jr.
Ocean Farming, Inc.
McLean, Virginia

"It is clear that the return to the world from the success of this endeavor leading to the farming of selected portions of the almost three-quarters of the earth covered by the oceans, will be great indeed."

Executive Summary

Ocean Farming is the modification of the ocean surface by the addition of nutrients to greatly enhance the productivity of the resource. When applied to large areas of the barren tropical seas, ocean farming can increase the phytoplankton, the base of the food chain, bringing the productivity up to the level that occurs naturally off of the coast of Peru. This can result in an increase in fish catch by a factor of 400 or more. A 53,000 square mile ocean area might see the fish catch go to 50 million tons per year. The carbon dioxide absorbed initially could exceed the production by the United States from the burning of fossil fuels. While the concept of farming is well accepted on land the extension to the ocean is new. It requires the investment in the resource to increase productivity so the “commons” approach which has been the tradition in the ocean fisheries does not suffice. A measure of private property rights are needed, at least within the national exclusive economic zone (EEZ) of the host states.

U.S. Governmental interest so far has been minimal. Other governments have found it difficult to step up and say “yes” to these activities in their jurisdiction. Environmental regulators consider adding anything to the ocean “dumping,” in which case overriding advantage must be available to move forward. Small tropical Pacific island nations with large EEZ areas have been the most welcoming of all possible host states. Therefore, we intend to concentrate initial commercialization efforts in those areas.
The response of much of the oceanographic community has been negative, but after careful study some key oceanographers have endorsed the validity of the project. Some are on our Advisory Board or have consulting contracts with us. At this point, initial seed capital has been raised, a fertilizer system developed and laboratory testing is underway. Open ocean tests in the Gulf of Mexico are planned for late spring.

Success of the commercialization of ocean farming will increase the fish production and biodiversity of the barren tropical ocean, sequester C02, and feed our increasing world population with high quality protein from a completely renewable resource.

**Background**

The earliest history of the human race shows us as hunter-gatherers taking what the land produced but being a part of the natural scene, rather than changing it to our purposes. Some ten thousand years ago in the Middle East, this changed with the domestication of wild animals, i.e. the cow, pig, goat, sheep, and dog. Now our ancestors became herdsmen, moving their domesticated animals to the best pastures with the changing seasons. They continued to hunt and gather but found herding more productive.

Then, about 5,500 years ago, a new invention swept the then-civilized world, the moldboard plough. This increased the productivity of the farmer by a factor of seven. It also changed the way we looked at the land, from passive acceptance to active intervention. This resulted in planting of favored crops, rather than accepting what had always grown there, and making additions to the soil of water and nutrients to further increase productivity.

The transition of people from hunter-gathers to using present farming methods has greatly increased the food output of the world. Half of the increase can be measured by the population increase from about six million to six billion people and the other half by our higher protein diet from feeding grains
and leafy materials to animals to produce milk, eggs, meat and aquaculture fish.

These transitions were not always smooth or without controversy. The USA had free range in the western states for many years. For some, there was an almost religious quality to it, and they argued strongly against fences, roads, houses, farms, and railroads. Let these things happen and cities will follow they argued, and they were right.

While these transitions are largely complete on land, they have hardly begun on the three quarters of the earth's surface covered by oceans. We can start a similar change there with a similar return for our efforts.

The fishermen of the world have known for many years that there is great variation in the productivity of the different areas of the oceans. Within the last 10 years, the extent of this variation has been measured and the reason for it determined. The necessary nutrients to support a phytoplankton bloom only occur in a very small fraction of the ocean surface. This gives us a picture of the ocean as a vast desert with only a few verdant zones where life abounds. It is easy to spot the difference. For most of the ocean, you can see 150 feet through the water as you can in the Gulf Stream. In the productive zones, you can see only a few feet, the living matter is so dense. This is the case in the upwellings off the coast of Peru.

These zones have been sampled and the difference is now obvious. The productive zones are rich in iron, phosphorous, trace metals, silica, and nitrate. Each ocean zone must be sampled and the nutrient requirement ascertained to bring it to the level of the Peruvian upwelling. In the barren tropical oceans we expect the main fertilizer to be iron with some phosphate.

It is estimated and now well accepted, that 60% of all the life in the ocean arises from 2% of the ocean surface. Therefore, if all the ocean was like the 2% verdant zone we would have 0.6/.02 or 30 times the present ocean life. If all the ocean was like the 98% nutrient poor zone we would have .4/.98 or .41 times the present ocean life. The ratio of the
verdant to nutrient poor is therefore 30/.41 or 73.5 times. That is, if we fertilize a nutrient-poor region of the tropical ocean to conditions such as exist off of Peru, we should get an increase in phytoplankton production of 73.5 times.

A recent paper (Nature, March '95) by Pauly & Christensen gives a measure of the "primary production ratio" including catches and discards. This is the pounds of fish caught per pound of phytoplankton produced. The open ocean value is 1.8%, but the tropical upwellings value is 25.1%. For ocean farming we would use the 25% value. This gives us a picture of transfer of biological material between trophic levels that is much more efficient than previously thought. Fish farming gives values of pounds of fish produced per pound of feed of 50% to 90%. The key is to be sure that the fish expend minimal energy to obtain their next meal. In order to achieve the 25% value the efficiency of transfer between trophic levels must be between 50% and 70%. This is only possible in a very dense ecosystem where the energy loss for capture is small as occurs in fish farming. The highest value from the Pauly paper is for non-tropical shelves at 35.3%.

The increase in fish catch per 100 pounds of phytoplankton from the Pauly paper is from 1.8 for the open barren ocean to 25.1 for the tropical upwellings, a multiple of 14 from extra nutrients. Multiplying this increase times the increase in phytoplankton gives 14 X 73.5 or 1025.

Some confirmation of these trends can be obtained from data on the effects of the El Nino event of 1982-3. The anchovetta catch was reduced to 1/600th of its normal value. Since the fishing effort per ton of catch went up during the event we expect that the fish stock went down by a factor of about one thousand. This gives a reasonable check with the factor of one thousand to one estimated above. It is interesting to note that these large changes in productivity at all levels of the food chain took place in a time scale of a year or two indicating the likelihood of a similarly rapid response to ocean farming in the tropical ocean. There is also a rough check with the 2,000 times increase in food production from farming on land.
Farming the Ocean

The ocean differs from the land in several regards: (1) there is never a drought, (2) it moves, and (3) it mixes both vertically and horizontally. The first difference means that we only have to add minor constituents. The second difference means that where we add nutrients and where we harvest are likely to be many miles apart depending on the current. The third difference means that we must do our farming in the open ocean on a large scale or we will never be able to find the results. Finally, we must do our fertilization in deep water so that the deep ocean currents can process the rain of organic materials produced without becoming anoxic, leading to conditions that will kill the very fish we wish to produce.

What are the parameters of ocean farming? First and foremost it must be done on a large scale relative to farming the land because of the movement and mixing of the ocean surface. There is a size where the edge-to-area ratio becomes so small that the fish are essentially trapped within it. All except migratory fish tend to remain in the verdant waters. Secondly, it differs from aquaculture in that it is based on the enhanced production of plant life in the ocean waters. The Redfield ratios describe the response of the ocean plant life to critical nutrients. One pound of available iron can lead to the production of 100,000 pounds of biomass. To the iron we must add some phosphate, a float material to keep the fertilizer in the photic zone and, perhaps, a seed material of phytoplankton to fix the nitrogen required. By the time we have done all this, one pound of fertilizer produces about 10,000 pounds of biomass. The ocean is not a controlled, uniform resource. Therefore, we estimate, conservatively, that one pound of fertilizer will produce 4,000 pounds of biomass in barren tropical waters.

The productivity per acre should be higher in a nutrient-rich ocean than on land. However, we use 40 tons per acre per year, which is the same as for sugar cane cultivation. That calculates out to be 25,600 tons per square mile per year.

We are familiar with planting and fertilizing in the spring and harvesting in the fall where we deal with land farming. In
the ocean, under ideal conditions the phytoplankton double every day or two producing a bloom of 20 to 30 times in about five days, seven hundred to one thousand times in 10 days. Then the zooplankton graze on the phytoplankton, the bait fish eat the zooplankton, and on up the food chain to the large mammals and apex predator fish whose life cycles approach decades. We plan to fertilize in areas of the open ocean where the currents maintain the fertilized water within our control for at least twenty days, consistent with the life cycle of the upwelling-fed blooms off of Peru. Longer available time for the blooms will reduce the seeding requirements for both plants and fish, and therefore increase productivity of the resource.

The credibility of these predictions has been greatly enhanced by the publication of the results of the IronEx II experiments in *Nature* of October 10, 1996. In this experiment ferrous sulfate was added to the waters of the tropical Pacific ocean in an area of high nitrate, low chlorophyll, HNLC, water. Page 497 of *Nature*, reproduced here as Figure 1, shows the variation in chlorophyll, nitrate, C02, and iron over 17 days from the first iron addition (day 1), second iron addition (day 3) and third iron addition (day 7). The chlorophyll bloomed on days 5, 6 and 9, as shown in green. Nitrate was used up as shown in pink where darker is lower nitrate concentration. Carbon dioxide was also used up as shown in blue, where darker is lower concentration of C02. The chlorophyll concentration increased by a factor of twenty-seven times by day 9 in spite of a loss of about 95% of the iron to precipitation. We expect to achieve essentially 100% utilization of the iron by phytoplankton growth in our fertilizer system. These results are the first that show that iron is the controlling nutrient in these high nitrate low chlorophyll open ocean waters.

While not its primary purpose, ocean farming may affect how we think about the atmosphere C02 balance. The U.S. produces about 1,340 million tons of C02 per year from burning of fossil fuels (gas, coal, and oil). One ton of fertilizer produces 4,000 tons of biomass and removes (initially) 5,500 tons of C02 from the ocean. Therefore, to equal the U.S. fossil
fuel CO$_2$ production we need to spread about 250,000 tons of fertilizer. This amount of CO$_2$ can be taken out of the ocean initially by fertilizing an area about 100 miles wide and 530 miles long, about the same area as the Chesapeake Bay. The algae produced by fertilization will remove CO$_2$ from the water and indirectly from the air. Thus the food chain organisms will "lock up" CO$_2$ at all trophic levels up to and including the large, apex predator fish, and whales. The animal life will oxidize the
biomass and return some $\text{CO}_2$ to the ocean as well as some to the atmosphere. Some of the biological material will descend to the ocean bottom in the form of droppings and shell carbonates, where it will ultimately be picked up by the bottom currents and eventually recycled into upwelled water on a geological time scale. The total carbon that becomes part of this cycle is thus removed from the ocean waters and the atmosphere for substantial periods of time, giving us an avenue of positive action to ameliorate our concern with regard to the effects of burning fossil fuels.

While we do not now know all of the environmental impacts of converting areas of the ocean from barren deserts to verdant blooms we can outline some of the expected effects. Since the plant life will be dense, fish will expend less energy to get to their next meal and the ratio of pounds of fish per pound of phytoplankton will increase greatly. The whales and porpoises will increase in the fertilized area gaining weight rapidly during the time they spend there. These are migratory species and we expect them to congregate where the food supply is plentiful. Over a long period of time the total world count of porpoises and whales will increase, but slowly due to the long doubling time for these species. This positive trend due to ocean fertilization could, of course, be reversed by adverse actions in other parts of their habitat. The effect on large pelagic and migratory fish will be similar. Tuna, for example, increase rapidly in mass during the time they are in verdant waters. They then move to breeding grounds where they spawn. The increased food availability will increase the numbers of tuna, bill fish and dolphin in the fertilized area as they seek new food sources. They will be very happy fish.

There are other ecosystems in the fertilized area that may not be as happy. Coral reefs have evolved to be able to grow in low nutrient ocean waters. When the nutrient levels are increased they grow faster until a level is reached where the nutrients produce so much algae that it shades the coral and kills it. We do not know where our nutrient level will fall, but it may happen that some coral must be shaded in order to achieve
the increased productivity that we seek. In the commercialization of ocean farming, large areas of the tropical ocean will be involved. Therefore, some adverse effects on local corals could occur. We will endeavor to minimize any such adverse effects.

The great environmental plus for ocean farming is that, unlike erosion on land, none of the changes are permanent. We only have to stop fertilizing and all traces of the nutrients are gone in a short time.

The overall effect of ocean farming will be to greatly increase the amount and diversity of the marine ecosystem in the fertilized zone. This is a positive answer to the worldwide problem of over fishing, since we will always create more fish than we harvest. This will be done in the context of private property rights so that conservation and the creation of value will be a part of everything that is done.

**Technology Development**

The proposed fertilizer materials will have special features such as: particle size, dissolution rate, density, and ratios of critical nutrient constituents. Since sea life appears ultimately able to process nutrient materials regardless of chemical makeup or form as long as it remains in the photic zone, we believe that the least expensive, most readily assimilable forms of raw materials having the appropriate chemical compositions should suffice. The fertilizer must not contain traces of toxic chemicals, especially those known to bioaccumulate in marine organisms, as they move up the food chain, and they must also be free of pathogens that could be passed up and ingested by fish destined for human consumption. It appears that many present-day waste streams offer possibilities to produce nutrient constituents at low cost, with concurrent benefits to both public and industrial community recycling programs.

The fertilizer design concept is to obtain a rapid phytoplankton bloom that fixes nitrogen and further promotes accelerated growth of oceanic biomass at successively higher trophic levels. To do this, the buoyant fertilizer system should
contain the limiting nutrients such as iron, phosphate and other trace nutrients. A strain of phytoplankton specifically selected to initiate the process may also be seeded in the broadcast stream. There are difficult technical problems associated with the design of the fertilizer. The added nutrients must be in a form that permits them to remain in the ocean surface water for an extended period and not sink to the bottom as a precipitate. The optimum ratio of phosphate to iron and any other missing nutrient must be determined in order to design the fertilizer system for the ocean area selected.

**Experimental Program**

A three phase technology demonstration program has been designed and is presently underway.

**Phase I. Fertilizer Development**

This phase is to design the ocean fertilizer materials and to assure that they meet the requirements of density, solution rates and performance. The ability of the fertilizers to support a phytoplankton bloom under laboratory conditions is tested. This phase is now nearing completion.

**Phase II. Fertilizer Evaluation and Refinement**

This phase will test the phytoplankton response to fertilizers developed in Phase I in open barren tropical ocean. The plan is to use nine square mile test areas in placid waters away from coral reefs. The results will be used to perfect the distribution and seeding protocols. We expect to begin testing this spring in the Gulf of Mexico.

**Phase III. Full-Scale Fertilized Ocean Testing**

This phase is to demonstrate the production of fish from fertilization of barren tropical ocean. This will require the fertilization of a larger area than Phase II and for a longer time. The fertilized area will be seeded with filter-feeder fish that live on the phytoplankton produced and their growth rate determined. The fertilized area will be about 500 square miles, depending on the currents and mixing of the ocean surface and
will be away from coral reefs. The test will last about six months.

Suitable ocean areas have been selected for Phases II & III in the Gulf of Mexico. Experienced organizations are under contract to carry out the three phase program. With the successful completion of these experiments the fertilization of the ocean will be demonstrated and the resulting increase in fish production documented. The commercialization of Ocean Farming can then begin.

**Commercialization**

The ocean is an economic "commons." That is, if there is one fish left, it is to my advantage that I catch it and not you, and there is no advantage to me to invest in enhancing ocean productivity for you to catch the extra fish. Both aspects of the "commons" problem must be solved in order to enhance the ocean resource.

We have arrived at a situation in the ocean where we have the technological and economic capacity to decimate any fishery within a year or two given the necessary effort, dedication and perseverance. Once this has happened the open "commons" approach to exploiting the resource can no longer be sustained. The fishery will always be over fished and the stock reduced to an uneconomic level. This has already happened in the Georges Bank of the U.S. and to other fisheries around the world.

One method of dealing with this problem for countries with a history of commercial fishing is to use government regulation. This has been tried in New England and many other fisheries with uniformly poor results. It is always to the fisherman's advantage to ignore or circumvent the regulations since he gets no return for fish left in the sea. Also, government regulators respond to political pressures and have no stake in maximizing the output of a resource.

The answer that has worked wonders on land is the introduction of private property. For the oceans this has taken the form of longterm individual transferable quotes or ITQ's.
These give the owner the right to a percentage of the allowable catch for that fishery and hence a financial stake in its health and productivity. The only other way for investment to occur is for the current owner, the government, to sell or lease the rights to the resource to a private entity. The lease would have to be longterm and would have to be for a large area of ocean, possibly in the range of 200,000 square miles. This is a real possibility for island nations, many of which already lease fishing rights within their EEZ.

Among these nations that do not have a “Commons Problem” a search can be made for tropical ocean areas within their Exclusive Economic Zone (EEZ) that have suitable properties to be an area for Ocean Farming. These properties include a large contiguous area, preferably over 500,000 square miles of barren tropical ocean; ocean depth of at least 1,000 feet but preferably greater; benign currents that allow the fertilized ocean water to stay in the host country EEZ for at least 20 days and preferably 60 days in spite of storms; and an indigenous artisanal, but not commercial, fishing tradition. The creation of private property rights in the EEZ will require licensing, purchase or leasing of a large area of ocean of up to 200,000 square miles. It will also be important that the host nation be willing to use its sovereignty to control poaching.

There are several island nations in the tropical Pacific that meet these criteria. These nations are characterized by large barren ocean areas, small land areas, small populations and low national income. Therefore, there is a real incentive for their government to say “yes” to new initiatives. Where the incentive is missing a “no” or “not now” is always the easy answer.

The host nation can look forward to a steep increase in available jobs for its nationals as companies locate there to service the new industry. It should be possible to start commercial ocean farming by using foreign vessels to spread the fertilizers, foreign commercial fishing boats to catch the fish produced and foreign factory ships to process the catch.

On the technical side, we expect that there will be a long period of learning associated with the commercialization of
Ocean Farming. We will be optimizing the selection of the areas for fertilization as a function of weather, time of year, etc. and the selection of the optimum fertilizer composition and amount. We will also be optimizing the amounts and varieties of plants and fish to seed the fertilized areas to obtain the maximum return from our investment.

Like any farmer, we will be faced with conservation decisions. How much of the resource is available for today's catch and how much should be left for tomorrow? The answer to these questions will demand a much more detailed understanding of the conditions of the fishery than is customarily available so that the management of the fishery can lead to optimization of the financial returns from the resource. This is a dynamic system and steady state results may not be approached for some years.

**Expected Results**

The fertilization of 100,000 square miles of barren tropical ocean is estimated to produce 2,000 million tons of phytoplankton per year and require about 500,000 tons of fertilizer per year. The ratios from the Pauly paper would predict a catch, including discards of 500 million tons of fish. Since this has never been done before and we have only marginal control of the ocean we predict a catch of 100 million tons. This is a very large number, essentially equal to the current world catch. Even if the fertilizer costs $1,000 per ton delivered, the cost of fertilizing is $500 million per year. The value of the U.S. fish catch is now about $0.37/lb at the dock. If we use a value of the expanded catch of $.30/lb the catch for 100,000 square miles is $60 billion per year. We get about $120 worth of fish per dollar of fertilization cost. The cost of fishing and processing should be much lower than for barren open ocean fishing due to the higher concentration and greater predictability of the fish stocks, perhaps $0.05 to $0.10 per pound. We would probably not reach these large numbers for some years as we gradually expand our fishery and the migratory fish became accustomed to the new conditions.
These are very big numbers indeed. The current world fish catch is approximately 100 million tons, so we would be doubling the current world catch in a few years. We would try to reach this level by slow increments. However, commercialization cannot be accomplished on small patches. The normal storms and turbulence of the oceans would destroy our small farm and we would not be able to find the results of our efforts.

Many environmentalists will contend that anything that mankind puts in the ocean is dumping and they are against dumping. Fortunately, some realize that ocean farming will create new verdant habitats for their favorite species.

Many oceanographers have a hard time with the Ocean Farming concept. One view is that the ocean is so complex that you cannot tell what will happen when you change one part (like fertilizing). A second more profound viewpoint comes from the fact that oceanography is an observational rather than an experimental science. That is, the natural ocean is there only to be studied and understood. Any change is to be resisted. In this view man can only do bad things to the ocean. None of his actions can result in longterm good, like more and happier fish, whales, dolphins and turtles.

Upon long reflection, some senior oceanographers have agreed to advise the project because they really can’t find anything wrong with the scientific logic and all the latest findings support the general thesis. They are excited by the impact that ocean farming may have on the science of oceanography and the positive effect on food supply.

**Financing**

Whenever a really new enterprise is launched there is always the difficulty of raising the necessary capital to fund the technological development and launch the commercialization. This is often a daunting task, filled with hard lessons learned.

After working on the concept for about a year, I interested some friends in backing the launching of a new company, Ocean Farming, Inc. (OFI) to license the patents that were about to issue and get the technology development and
demonstration phases underway. One of my previous patents had lead some of these same people to found a company for its exploitation which is now quite successful, making a profit of several million dollars per year. I had also founded an environmental company, grew it to about 800 employees and taken it public. Some of my associates in this venture are the providers of the seed money for OFI.

The first approach was to look for U.S. Government funding for the development. After all, projections showed that fertilizing the Gulf Stream off the Atlantic coast could create a new industry with over half a million new jobs along with all the other advantages mentioned. The key agency is NOAA and we had an all day symposium including the key NOAA, Navy and National Science Foundation personnel. No support was forthcoming and no more effort was wasted in seeking support from the U.S. Government.

The second attempt to obtain backing was from the U.S. fishing industry and the U.S. Congress. The Congress was needed to address the common problems. The fishermen could then, through the regional fishery management councils, be the focal point to attract funding for the project. This seemed like a good approach given the state of the New England fisheries. An article was published in the Commercial Fisheries News and the executive directors of the Atlantic Coast councils were contacted. No interest was expressed by anyone at any time. Evidently, small scale day-to-day problems were so overwhelming that no time or energy remained to address a possible solution to the larger problem. Without a solution to the common problems or some sort of help from the government or the fishing industry, the U.S. EEZ was deemed unattractive and effort was directed elsewhere.

With the issuance of the first two patents which teach increasing the productivity of the open ocean by the addition of missing nutrients, a creditable management and a compelling story, initial capital was raised and the enterprise got underway.

The ocean are planned for the Gulf of Mexico outside of the EEZ of any country so that no one had to say “yes.” It is
planned to commit three to five million dollars to the Technology Development and Demonstration Program. The key contractors are International Fertilizer Development Center in Muscle Shoals, Alabama, for fertilizer development and pilot production and the University of South Florida for oceanographic support. When significant results are available we look forward to a public offering of about $100 million. This will carry OFI until revenues commence with successful commercialization. The OFI corporate structure is planned for a small technical and management team that then contracts with the various entities that make commercialization possible. We envision a long term lease of all or part of the EEZ of one or more tropical island nations. We plan to contract the manufacture of the fertilizer materials to our specifications, the seeding of the area with phytoplankton and fish, the catching of the fish to OFI’s resource management plan, the processing of the catch, and finally transportation and sale to wholesale markets.

The current average value of fish at the dock, worldwide, is about $0.37/lb. We expect this to fall to $0.30/lb for the increased catch. Since we will have a managed resource concentrated in a predictable area we expect significant economies of scale that will more than outweigh the cost of fertilizing and host country licensing. We will also be able to design our processing to utilize every part of every fish caught. Non-edible materials will be processed into fish meal, fish oils, and fertilizers. There should be no by-catch and no waste. We expect the cost of the fish at the dock to be between $0.10/lb and $0.15/lb, including license fees and host state charges, providing a favorable profit margin.

This is a new concept, based on new technology. There is much to be learned as we apply it to the ever changing ocean. It is clear that the return to mankind from the success of this endeavor leading to the farming of selected portions of the almost three-quarters of the earth covered by the oceans, will be great indeed.
Ocean Microcosm: Elements of an Ecological and Freshwater Buoy Design

Victoria Rechtenwald
Kailua, Hawaii

Abstract

The ocean microcosm is a modification of a basic buoy directed toward mitigating some of the deleterious effects of invasive ocean development. It specifically employs creature friendly materials of glass and concrete, it utilizes passive energy of the sun and wind, and promotes marine colonization. This design expands the range of the structure beyond its singular human service of floatation or aggregation site to one capable of cultivating and sustaining a resident ocean population. Given the reality of offshore development, the need to conserve the common heritage of the oceans, and the involvement of the international community in legislating ocean degradation, the microcosm is designed to increase integration and stewardship, and comply with the most stringent environmental regulations.

"... People have lived naturally since time began ... the sooner they do it again, the less dependent they will be on imported oil and nuclear energy ..."

*The New Wind Power* by Jon Naar.¹

Concept

Enough ocean structures require floatation to make the study of modified buoy design worthy of consideration. All offshore structures need to minimize their disruptive impact on the ocean envrironment.

Figure 1. Ocean Microcosm. Solid modelling modifications of spherical buoy. Concrete hull with glass portholes, variable ballast, internal planter, and protective projections. Sphere diameter: 120 ft. Internal lagoon surface: 66 ft. depth.
Because the ocean is a common heritage resource, there is the obligation to insure all structures placed there respect the interests of local populations when being exploited by nonlocals, and preserve the oceans' resources for populations distant in time and space.

The ocean microcosm is a merging of ecology and engineering in order to transform a buoy or caisson used in service for floating human enterprises offshore, into a similar structure that is illuminated inside and that can now cultivate a food web; a transformation that is relatively low-tech. The choice of concrete and glass materials for the hull imparts to the buoy cavity the capacity to increase phytoplankton production and to generate freshwater through solar desalination. while wind pumps can aerate and circulate deep ocean water for condensate production. Furthermore, the actual form of the hull can be modified to collect and contain rain. Thus by providing sunlight and establishing a freshwater source, new niche space is conveyed to the ordinary buoy that converts it into a multifunctional subsurface greenhouse that can reside in the open ocean in compliance with environmental and international standards.

Size and Logistics

Ideally no man-made objects have permission to be stationed or disposed in a region held in common with others such as the ocean frontier, without universal consent. Although it is an international crime for an entity to degrade foreign property as well as that which is held in common², this crime is being perpetrated in modern times by entities whose capital and technology are in greater abundance than vision, integrity and dicipline. Already, large scale coastal and offshore developments are underway in a style that is in disregard of other contemporary nations and future generations. Some mega-enterprises are not in the best interests of a planet whose

evolution is dependent on adaptability, which is dependent on diversity... the diversity of human and creature populations, and the natural environment. Mega, in the form of nuclear waste, in the form of offshore urban-sprall landfills, in overfishing and deforestation, in overproduction and, in general, in the over-consumption of world resources by developed countries, is a largess that cannot be humanely sustained nor ethically promoted. Well educated citizens are equipped to pursue saner options. According to Tawney, the most obvious facts are the most easily forgotten. Both the existing economic order and too many of the projects advanced for reconstructing it break down through their neglect of the truism that since even quite common men have souls, no increase in material wealth will compensate them for arrangements which insult their self respect and impair their freedom. A reasonable estimate of economic organization must allow for the fact that unless industry is to be paralyzed by recurrent revolts on the part of outraged human nature, it must satisfy criteria which are not purely economic.\(^3\) For the ocean frontier, those criteria involve cultural and environmental integrity. The international community is pressed to devise a means to both advance modern human enterprise on the ocean front and to simultaneously safeguard resources essential to the support of all present and future life on the planet. There is an urgency to provide alternative designs for prospective development and management that reflect a more universal environmental application.

Some decision makers, with the power of capitol and public influence, but lacking the understanding of environmental consequence, have been making choices designed to sustain existing abuses of petroleum and nuclear energy in disregard of appropriate reductions and alternatives. Without intervention of the international community and global perspective, they deliberately continue to effectively diminish the collective resources of mankind, to defy and to undermine

---

saner and more humane management. As Naar puts it, "If the mainstream of wind power research and development since the 1970s has been dominated by the high technology world of aerospace and the Dept. of Energy, a minor but important tributary is the diffuse movement known variously as alternative, appropriate, intermediate, or soft technology with its antecedents in Schumacher's Small is Beautiful, and the teachings of Buckminster Fuller, and Amory Lovins. For this movement, which is particularly strong in the universities in the Pacific NW and in New England, solar wind, and other forms of renewable energy are seen not merely in terms of bottom line accounting but truly alternative forms of energy that are valid because they are in harmony with the environment." The value in designing for a scale that is humane and sustainable has economic viability.

The microcosm is an ocean structure design that invites more harmony with the natural environment, that complements the flow of nature rather than attempting to resist it or control it. Unlike the conventional expenditure of energy combating inexorable natural processes like fouling and condensation on a surface, the microcosm incorporates them into its design. Encrusting will strengthen the concrete while enriching the habitat, and the freshwater will broaden the range of aquatic life cycles. In the same vein, the wind and ocean currents that impinge on offshore structures can be turned into a source of circulation energy.

The ocean microcosm is intended to support a climax marine community on passive energy and expand human space with its buoyancy. It's designed to evolve relatively naturally to a size and level of productivity well below that of mega operations yet above the norm. A fish aggregation site that can be cultivated is one way of moving agriculture offshore on a small scale, that is as natural and benign as a family farm. When the international Law of the Sea evolves to reflect

---

genuinely effective environmental standards and global stewardship of the high seas, the ocean microcosm style buoy will already be in compliance.

**Passive Energy Systems**

**Solar radiation** entering the cavity of the microcosm buoy is the source of energy that powers the process of desalination through evaporation and condensation. It is the force stimulating photosynthesis and increasing primary production of algae in the area; productivity that can be enhanced by introducing deep, nutrient rich water to photic zone layers, along with limiting agents like iron. After increasing the primary productivity of the buoy field, secondary consumers and members of the food chain can colonize the area. Designing the habitat to favor plant life is also a means to oxygenate the internal air cavity.

The **thermal** properties of the structure, atmosphere and ocean affect the dynamics and production of the freshwater system. The difference in temperature of the surface and deep water can be a source of energy for desalination, pumping, and OTEC. Wind and wave energy can also serve to pump and circulate air and water. Various propellers and pistons for both mediums have been developed that have improved output.

The interplay of light, temperature, winds, creatures, stable materials, and environmental purpose are what distinguish the microcosm from conventional buoy structures and recommend it to offshore development.

**Freshwater Sources**

**Solar Desalination**

Like a simple solar still, the microcosm buoy traps solar energy and converts it into latent heat of vaporization within the air cavity. Water inside the buoy is warmed, the cavity air

---

becomes saturated, and the vapor condenses on the inside surface of the hull and flows downward toward the internal sea surface. Being less dense, it will eventually form a lens of freshwater over the ocean water. Some major factors influencing the amount of condensation within the buoy are: insolation intensity, ambient temperature, brine depth, slope of glass, vapor tightness of the cavity, and heat losses through the elements. The atmospheric pressure of the air cavity is reflected in the depth of the internal sea surface. This elevated pressure on the surface of the lagoon influences evaporation because of the resistance thus offered to the escape of the vapor. The ocean microcosm is affected by the ocean regime, being 9/10ths submerged in the ocean temperature that varies little around 68° F in the tropics. On the other hand, a much larger change in apparent extraterrestrial radiation is caused by the seasonally changing path of the sun through the sky. Other heat loss, some trivial, depends on wind velocity, or rather, ocean current velocity, air, sky, ocean temperatures, angle of incidence, size of aperture, density of glass, heat capacity of the various materials and water... Actual measurements and predictions about performance are difficult for collectors in which the geometry is not simple enough to permit a closed form solution of convective heat losses. The sun is intermittent, and designs can be modified to reduce heat losses, increase condensation surface area, etc. Suffice to say, the variables affecting performance are numerous.

---


7 Ibid.


Condensation Enhanced by Deep Ocean Water

Rough estimates indicate that two liters of freshwater per day are sufficient for human subsistence, and that the conventional stills produce from 1-3 liters/m² on the average. Given the tempering effect of the ocean immersion and near steady 68°F surrounding waters, the microcosm is expected to produce only a small fraction of what its terrestrial counterparts are capable. A more continuous source of freshwater can be obtained by pumping cold subthermocline water to the surface and through materials in the saturated air upon which condensation can take place and drain into an area where it can form a lens above the denser salty layer. Cultivation of terrestrial plants by the condensation from DOW pipes has been successful and yielded surprising results at Hawaii’s Natural Energy Lab at Keahole Point. The ocean microcosm is designed to drain into an area for the cultivation of terrestrial species (see “planter” in illustration) in the central region of the buoy cavity. This is to be further terraced to the water level in a series of ponds of increasing salinity.

Rain Catchment

A remaining source of freshwater is the collection and containment of rain. Although it is possible to design basins to save the rainwater, it remains to make them secure from inundation by storm waves. Recuperation from what is unavoidable is also a design strategy, such as having deep, open-ended catchment holds with vertical depth that would retard dilution and enable denser water to settle out. There are many modifications that can be attached to, or made in the hull of, the microcosm to receive and channel rainwater, such as spiraling, and grooving of the collection surface, while

---

11 Ibid.  
12 Craven, Presentation at Ocean Cities '95 Symposium, Monaco.
conforming the shape to a torus provides an open ocean lagoon separated horizontally from the ocean waters.

By the methods of solar desalination, DOW condensation, and rain catchment, the ocean microcosm can establish its own independent freshwater source. As mentioned in size and logistics, the maximum production is on a small sustainable scale. This is not an obstacle for the ecosystem evolution being cultivated for the microcosm habitat. Although slow, it eventually can provide a gradation of fresh, brackish to saline waters, so that the buoy acquires the capacity to serve as a hatchery site for those marine species whose larvae spend time in estuarine waters.

Circulation System

Wind Pumps

Circulation of the water and air will affect the climate of the microcosm habitat. While still waters promote vertical stratification, they also promote the blooms of nuisance algae. Nutrients are available in deeper waters that are depleted at the surface. Old fashioned wind powered piston pumps can lift water from a hundred meter depth. Other passive pumping can be generated by wave motion. The low output of this sort of alternative energy is less an obstacle for the microcosm than it is for mega operations. What more than compensates is that it is free, virtually inexhaustible, and clean. In the long run, this dependence on nature's bounty, and not human capital, better serves a structure that's designed to endure centuries.

A different version of the pumps compresses air and can be employed to adjust buoyancy and to circulate air in the cavity. In fact, mechanical motion derived from wind power can be used to drive heat pumps or to produce heat from the friction of solid materials or by the churning of water ...

stored in materials having high heat capacity, such as water, stones, eutectic salts so the heat can be used directly\textsuperscript{14}... Ideally, the microcosm can be designed to be self evolving and self sustaining with the minimum of post-inception management. Mechanical devices like pumps and compressors have a shorter lifetime than the microcosm and will involve human maintenance. One desirable feature of the microcosm buoy is its absence of artificial noise. The pumps are an exception to this plan and as with most equipment, should be dispensed with where possible and minimized where not. In fact, the microcosm should be serviced by sailing vessels rather than motorized ones.

Conclusion

The ocean microcosm demonstrates some of the advantages of designing structures with ecology in mind. A basic common object like the buoy, with a few simple modifications in materials and form, can be transformed from a relatively inert object to one that is virtually organic. By scale and by resource impact, such modified structures recommend themselves to offshore placement because they possess features that render them relatively non-invasive in the human or environmental realm. The merit in this type of design lies in the savings made preserving what is irreplaceable and doomed to perish if disregarded ... the vitality of the world's oceans.

References


\textsuperscript{14} Eldridge, Frank R. Wind Machines. 1980 Van Nostrand Reinhold Company.


Craven, J. Presentation at Ocean Cities '95 Symposium, Monaco.