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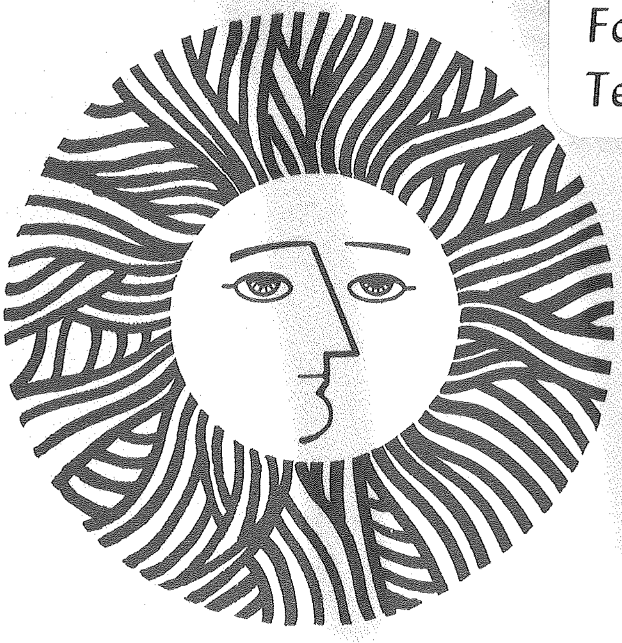

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INTRODUCTION

The assessment of energy-related impacts in the coastal zone has focused primarily on thermal power plants and outer continental shelf (OCS) petroleum development. However, a growing number of energy resources and conversion systems within the coastal environment are currently being proposed. Marine biomass is one of the most recent entries on this list of coastal energy resources.

A marine biomass farm is one of the few biologically-based systems that has the potential to contribute large quantities of synthetic gaseous fuels to the nation's energy supply. This is especially true because large surface areas are available on the ocean, and large amounts of plant nutrients are available in the ocean waters. The California giant kelp (_Macrocystis pyrifera_), which is well established as a valuable coastal resource and a source of chemical products (algin), is a prime candidate for energy conversion because it is efficient in converting sunlight into a fixed source of energy. In turn, kelp can be processed into methane by anaerobic digestion or other procedures. Furthermore, other by-products such as food, fertilizer, ethanol, and industrial material can be obtained.

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This paper describes an ocean farm system that has been designed and used as an ocean test facility by the Energy from Marine Biomass Program, jointly sponsored by the Gas Research Institute and the Department of Energy and managed by the General Electric Company (Leone, 1979).

The analysis of the ocean farm system includes a description of the types of impacts that might occur if large scale operations become available, such as the production of environmental residuals, conflicts with the fishing and shipping industries, and other legal/institutional impacts. Finally, a discussion is given of the relationship of the marine biomass concept and coastal zone management plans.

OCEAN FARM DESCRIPTION

Overall Concept

The basic concept of a marine biomass system is to culture and harvest seaweed plants that are attached to a grid of polyethylene lines suspended fifty to one hundred feet below the ocean surface. These lines are supported by buoyancy-control structures embracing thousands of acres (Wilcox, 1975).

Marine plants require light, carbon dioxide, water, and nutrients from the surface layers of the ocean. However, many of the areas along the southern California coast, which could support marine algae, may be nutrient-limited for as much as six to nine months each year because of a lack of upwelling (North, 1977). Therefore, fertilizing operations are clearly necessary to produce good yields of kelp on ocean farms. The selected process for fertilization is to pump up nutrient-rich waters from depths of a thousand feet or so. While not a general consensus among researchers, it is expected that resultant photosynthetic conversion efficiencies of marine systems will be higher than current terrestial crops.

Design and deployment of the upwelling system has provided the major engineering challenge to the overall farm concept. In order to maintain the adequate nutrient concentration, especially nitrogen, the test farm system uses upwelled water from a depth of 1500 feet through a two foot diameter polyethylene pipe at approximately 9000 gallons/minute. In a prototype or commercial farm, a depth of 300-500 feet would suffice because nutrient concentrations are relatively constant at depths below 300 feet (Seligman, 1976). The requirement of providing continuously upwelled deep water from the open ocean is similar to the concept required in another energy system, O.T.E.C. (Ocean Thermal Energy Conversion), which is being tested off the coast of Hawaii.

Finally, the seaweed are to be harvested periodically and converted to methane and other by-products (fertilizer, food supplements, etc.) at a processing facility located at an onshore coastal site. Figure 1 shows a generalized diagram of the marine biomass system used in this analysis.

Production system

The California giant kelp (Macrocystis pyrifera), which grows along the coasts of California, Mexico and New Zealand, was selected as the biomass source because it is one of the world's fastest growing plants and has been cultivated on an artificial substrate. The reproductive cycle is well understood and it believed that, in nature, the plant will reproduce its own weight every six months or so (North, 1971). Macrocystis kelp beds have been harvested mechanically along the southern California coast for over sixty years. In the biomass farm system, the plants will be harvested every three months, with no replanting expected to be required.

Of primary importance to the basic system is the determination of yield. In general, all aquatic plants have the same basic physical requirements for growth including nutrients, which are controlled by water circulation, and light, which is affected by plant density and water temperature.

The practical value for aquatic biomass production, on a full year basis, is reported to be eight dry ash-free tons/acre/year, which includes 6.7 tons of organic matter/acre/year (Clendenning, 1971). Klass (1977) reported from laboratory efforts, however, that anchored giant kelp may be

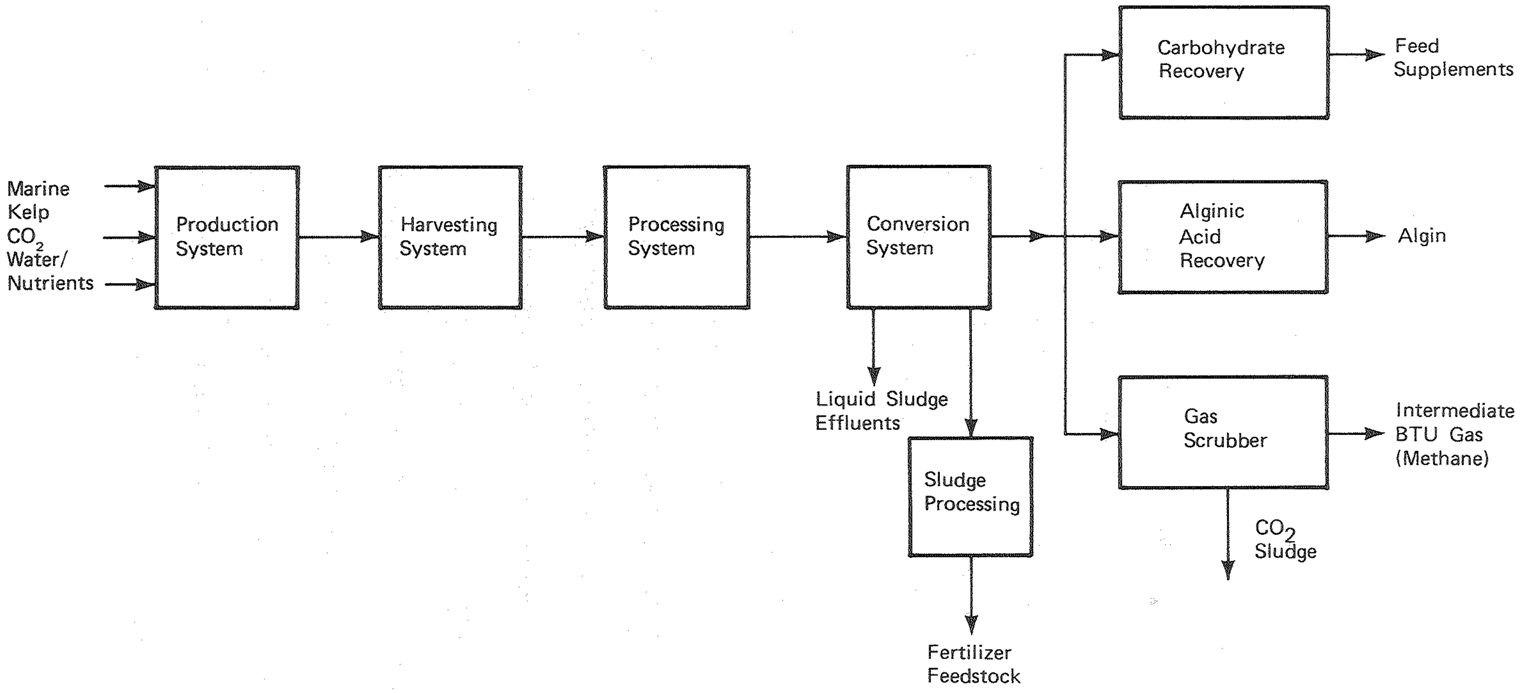

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Figure 1. Complete Marine Biomass System

expected to yield as high as 50 dry ash-free tons/acre-year. This assumes that nutrients are supplied by the upwelling of deep nutrient-rich water. Nitrogen, an element which most often limits the growth of marine plants, is required at levels exceeding three microgram-atoms per liter (North, 1977). Trace quantities of other micronutrients, such as manganese and iron, may also play a major role in obtaining maximum kelp growth and yield.

The controlled cultivation of Macrocystis pyrifera in water that is deeper than its natural habitat has been successfully accomplished (North, 1979). The test bed, however, is not intended as a miniature version of a commercial farm, but rather is designed to gather data for determining the growth, yield, and nutritional requirements of kelp.

Harvesting

In the marine farm designed by Wilcox (1975), the standing crop is harvested by special ships about six times per year. These vessels are patterned after the Kelco Company design used for commercial harvesting along the California coast for many years. Some pre-processing, e.g., removal of water and grinding, could be accomplished on the harvesting ships prior to transporting the kelp to onshore processing plants.

Since this part of the ocean farm system has not been tested, it will be assumed that some processing is conducted on the harvesting vessels with the final phases occurring at an onshore processing site. One limitation to the harvesting concept, in general, is the availability of harvesting shops, since the commercial vessels currently used are scheduled long in advance.

Processing

The degree of processing necessary to prepare kelp for conversion into usable fuels is related to its water and ash content. *Macrocystis* typically has a high water content, about 87.5 percent (Wilcox, 1975). The ash content of dry seaweed is typically about 40 percent, which may cause difficulty in subsequent conversion to various products (Leese, 1976).

A substantial reduction in water content would minimize shipping costs. If such processing is done at sea, a reduction in the capital costs associated with onshore sites would result because of the reduction in storage requirements.

A problem may arise, however, in drying kelp for transport. Since about 35 percent of the carbohydrate content is dissolved in water, most of it is lost in the drying process. If the food value of kelp is as much as 15 times greater than the energy resource value, capital might be saved on one process while losing it on another (Schneider, 1978).

With regard to ash content, it may be necessary to reduce the level of ash in order to maintain a viable culture for subsequent digestion or fermentation (Hart et al., 1978). Because kelp ash consists principally of water soluble salts, some market may exist for such products as potassium, calcium, and magnesium. Further incremental system costs for removing these chemicals from the process stream would not be large.

The degree of mechanical and chemical pre-treatment necessary for increasing kelp separation and digestion has not been fully defined. A process developed for this analysis begins by shredding the wet, harvested kelp by means of hammermill-type grinders. Leone (1979) estimated that about

1.1 kWh/ton of raw kelp is required to produce properly-sized particles from wet kelp. Next, the shredded kelp is treated with a calcium chloride solution heated to 95°C. The material is then pressed (100 pounds pressure) to remove salts and excess water. The resulting mixture acts as feedstock and is fed into the anaerobic digester.

Conversion

The conversion of kelp to methane has been described in previous studies (Wilcox, 1975; Chynoweth, et al., 1978; and Leone, 1979). As mentioned above, there is no standard procedure for pretreating the kelp. Several separation steps are usually used to segregate the electrolytes, carbohydrates, water, and volatile solids. The soluble sugars that are pressed out could be fermented to ethanol. The volatile solids (60 percent) go into a heated air-tight digester where methane and carbon dioxide are produced. The feedstock is decomposed over a period of seven or more days by bacteria in the absence of oxygen. A waste sludge, high in nitrogen, will also result. This material, after further processing, could be used as fertilizer feedstock.

Energy recoveries of methane, on the order of 4.9 to 5 standard cubic feet per pound of volatile solids (SCF/lb. VS), have been obtained with 55-60 percent conversion of volatile solids (Chynoweth, et al., 1978). This yield represents approximately 75 percent of that which is theoretically attainable and, on the average, exceeds those of any other known biomass source including feedlot waste or sewage sludge.

In addition to the goal of maximizing methane yields, research is underway in the Marine Biomass Program to increase the digester loading rate and reduce detention times. Digesters have been stabilized at a loading rate of 0.2 lb. VS per cubic foot and 10 days detention time. This rate is compared to earlier values of 0.1 lb. VS per cubic foot and 18 days detention time. It is estimated that a loading rate of 0.3 lb. VS per cubic foot, a detention time of six days, and a methane yield of 5.5 SCF/lb. VS are achievable (Leone, 1979).

Although this study emphasizes the production of methane gas as the primary product, other by-products are possible. In fact, if the marine biomass system is to make a major contribution to the energy sector, it will require that these other products be processed and marketed as well. Potassium chloride, sodium sulfate, sodium carbonate, and other salts are possible moderate value products. Several industrial gum materials such as algin, fucoidan, and laminarin are available. Algin has been extracted from kelp for profit for many years and has many uses in the food and chemical industries.

All of the carbohydrates in Macrocystis are polysaccharides containing sugar molecules that may become economically viable food products. Preliminary studies have suggested the potential of the digester solid effluent as an animal feed supplement (Leone, 1979). The data from these investigations indicate that the effluent has a crude protein content of approximately 37 percent and therefore has good potential as an animal feed supplement.

Table 1 lists the baseline design parameters for a marine biomass farm system. Since there is no prototype system in existence, the parameters given are average values.

Table 1. Baseline design parameters for a marine biomass farm system.

Parameter	Average Value	
Kelp composition (dry weight)	Ash	38 - 45%
Volatile solids composition	Volatile solids	55 - 62%
	Carbohydrates	~28%
	Algin	13 - 24%
	Cellulose	3 - 8%
	Protein	5 - 7%
	Fats	0.5%
Biomass yield	50 dry ash-free (DAF) tons/ acre-year	
Energy content	8000 Btu/ lb. (DAF)	
Upwelling depth	300-500 feet	
Surface water temperature	20°C (or less)	
Nitrogen (NO_3) at 300 ft. depth	25-30 µg-atoms/liter	
(Biomethanation Parameters)		
Methane yield	4.9-5 standard cubic feet/pound volatile solids	
Retention time	10-18 days	
Volatile solids converted	65-75%	
Loading rate	0.1-0.3 lb. VS/ft^2	
Temperature	35°C	
Volume	65% methane - 35% carbon dioxide	
Energy recovery	55.5%	

Source: J. Leone, 1979

POTENTIAL IMPACTS OF OCEAN FARM SYSTEM

Every energy conversion system has various impacts. This section provides information on the types of impacts that might occur from an ocean biomass system that converts marine algae to methane gas. Since there are no full-scale systems in operation, the data represent a compilation of potential impacts from bench-scale experiments, test farms, and from the conceptual plans for production, harvesting and processing.

Environmental Impacts

The impacts of a massive open-ocean farm operation have not been explored. There is a potential for significant climatic modifications. The anticipated climatic changes stem from the massive artificial upwelling that will be required to stimulate kelp growth and maintain it at high rates. When large amounts of cold deep water, which are rich in nutrients and supersaturated with carbon dioxide, are brought to the ocean surface to fertilize the plants, events might occur that could lead to regional and global changes in climate. The culture and harvesting of seaweed over several thousand square miles of ocean surface could result in changes in albedo, air-sea exchanges of materials, and altered ocean surface roughness. The farm structures themselves will reduce or change prevailing weather patterns and create additional fog banks, subsequently may have some effect on the productivity of the kelp beds. The possible climatic changes resulting from large scale marine plant culture have been recently reviewed by NOAA (Lehman, 1980).

A potential problem associated with the farm structure itself is the release of numerous chemicals into the ocean from the supports and synthetic lines used to hold the algae. Hruby (1978) noted the possibility of a slow release of toxic metals from the antifouling paints and organic chemical used on the farm structures. The seriousness of this chemical pollution is unknown. Dissolved organic chemicals, such as phenols, will be released by the marine kelp. Sieburth (1969) estimated that these organic compounds could be exuded by the algae at rates as high as 40 percent of the net carbon fixed. Calculations based on available data suggest that the release of extracellular organic compounds by *Macrocystis* will be a problem (Hruby,1978). The exudations from brown algae have been found to be toxic to some marine organisms.

The upwelling system, which is designed to provide an abundance of nutrient-rich water needed for kelp growth and development, could present several environmental problems. The temperature differences between upwelled waters and those present on the ocean's surface might form large fog banks as warm moist air is blown over the cooler deep water. One consequence of such fog banks is reduction of sunlight reaching the surface which, in turn, could affect the rate of productivity.

The upwelling of water may alter salinity, temperature, dissolved oxygen, turbidity, and nutrient levels. While artificial upwelling may support increased biological production in the kelp beds, it may also increase the growth of less desirable planktonic species that may have long term effects on the resident biological communities.

Furthermore, the upwelling of deep water will entrain marine organisms that cannot resist the vertical inflow velocities. Organisms that are entrained will be subject to mechanical pressure and sheer stresses. The survival rate of mesopelagic organisms in the upwelling streams is species-specific.

A final problem with the upwelling system is related to the use of diesel-powered pumps. Several possible air pollutants, e.g., particulates, nitrogen oxides, and hydrocarbons, would be emitted to the atmosphere from the pumping operations. The level of emissions corresponds to the type of system selected.

Harvesting of the marine biomass system will be done with ships of Kelco Company design. These ships will create some environmental impact by their emissions during normal operation. The Kelco ships burn diesel as a fuel, resulting in the production of particulates, nitrogen oxides, and hydrocarbons as primary air pollutants. These pollutants, however, will be diffused over larger area than the kelp farm itself, since they are released as the ships travel to and from the farm. In addition to the air emissions, there may be liquid effluents (brine), formed during on-ship processing, that will require special handling and disposal. The level of waterborne effluents depends on the degree of processing that is conducted aboard the vessels during harvesting.

Two methods are available for unloading the kelp, depending on the size of the systems involved. For the ocean farm system, the kelp will probably be shredded and pre-processed on the ships prior to reaching the processing plant, In a second system, a slurry of chopped algae mixture will be piped from the ship to the shore-based facility. Since some pumping will be necessary to move the slurried mixture, a potential exists for the release of certain air pollutants from the diesel-powered engines. The consumption of diesel fuel is low, however, and this environmental impact should be minimal.

The waste water generated from the shredder, presser, and digester during the processing phase will eventually be discharged into the sewer system. The composition of this effluent and the degree of pollution control necessary are unknown at this time. It is assumed, however, that the processing plant will conform to EPA discharge permit standards regarding waste water effluents.

As a final step in the marine biomass system, the processed algae is fed into the anaerobic digester. The gas mixture from the digester must be passed through a scrubber to separate carbon dioxide, which is about 40 percent of the gas, from methane. The major environmental residual resulting from this stage of the process is sludge from the scrubber that must be collected for subsequent disposal. The composition of the sludge from the scrubber, as well as from other phases of processing/conversion, is also unknown. However, since marine algae will concentrate various heavy metals, the sludge may possibly contain considerable levels of these metals. If any of this sludge is to be used for fertilizer feedstock, it will require some detoxification.

The final concentration of heavy metals and other toxicants and the biological oxygen demand and organic loading of the aqueous discharge cannot be anticipated without specific measurements from test, demonstration, or prototype facility. Until that information is available, only potential environmental impacts can be identified.

Other residues from the ocean farm may find their way to onshore locations. For example, the potential exists for an increased amount of kelp debris to break loose from the farm structure and be washed ashore. In turn, there may be a resultant impact on local recreation or on other beneficial uses of the coastal zone.

Legal and Institutional Impacts

Algal farms, depending on their size and location, may have a negative impact on commercial shipping if they disrupt existing shipping lanes. At a projected biomass yield of 50 dry-ash free tons/acre-year, it has been estimated that about 55,000 square miles of ocean surface might be needed to supply the nation's current requirements for natural gas (Leone, 1979). This area (approximately 235 miles by 235 miles), if concentrated off the California coastline, might provide an additional hazard to ocean commerce.

In addition, because such large marine biomass farms may adversely affect access to and utilization of coastal fishing locations, the potential exists for impacts on recreational and commercial fishing in the farm area. Because the kelp farms themselves will probably attract certain fish species, the legal issue of trespassing on the marine farm and other liability questions arises.

Several institutional and legal issues are likely to accompany the research, development, and commercial phases of the open ocean system if they are located beyond the 12 mile (territorial seas) or 200 mile (high seas) limit. The current biological test farm is deployed about 4.5 miles offshore from Laguna Beach in southern California. The prototype and commercial farms may be located as far as 20 miles or more offshore. Not only will the international and domestic legal status have to be analyzed, but a regulatory framework also will have to be established to guarantee the various uses of marine resources.

Legal questions include, but are not limited to, liability for: collisions between ships and the substrate or associated fixed structures; blockage of fishing rights and lanes; interference with shipping and navigation; residuals released from the farm structure; and the impact of the cold water plume on coastal areas or fishing grounds.

RELATION TO COASTAL ZONE PLANNING

The federal Coastal Zone Management Act (CZMA) of 1972 established the Coastal Zone Management Program, which gives states federal help to prepare and then administer management programs that "preserve, protect, develop, and where possible, restore coastal resources." Under the 1976 CZMA amendments, state programs are required to include a planning process for identifying energy facilities likely to be located in or significantly affecting the coastal zone and for anticipating and managing the impacts from these facilities. With these coastal zone planning requirements in mind, we will consider how the introduction of a new energy technology, such as marine biomass conversion, related to the planning process.

The ocean farm concept can be divided into offshore and onshore components. Offshore requirements include the farm site, which probably will be located outside the legal boundaries of the coastal zone. It is believed that the first commercial farms will be sited about 20 miles offshore of southern California. The harvest ships, however, will follow transit routes through the coastal zone to their onshore terminals. Just how the coastal zone planning process at the local, state, or federal levels will affect the offshore activities is undefined at this time.

An immediate question is whether the federal government would establish a permit or licensing system for offshore biomass operations. Which federal agency would be given overall lead regulatory authority if a system was established? There are various possibilities, including the following current responsibilities. Any alteration to the coastline or harbor area, under law, requires an Army Corps of Engineers permit. Vessels, including industrial ships such as mobile drilling rigs, are subject to close regulatory supervision by the Coast Guard. Fixed structures used in oil/gas exploration and development on the OCS are monitored by the U.S. Geological Survey and the Coast Guard. The U.S. Department of Energy, which supports most biomass research, development, and commercialization efforts must comply with the National Environmental Policy Act and probably would have to prepare one or more environmental impact statements. Finally, discharge of pollutants from the farm structure would probably require a National Pollution Discharge Elimination (NPDE) permit under the provisions of the Federal Water Pollution Control Act. These overlapping roles between various federal agencies will require some degree of clarification.

Another uncertainty of offshore operations involves the federal consistency provision of the CZMA (Section 307), which has become an important issue with OCS petroleum development. Many states are presently concerned because a federal agency may be its own judge as to whether its action affecting the coastal zone complies with regulations. State coastal management programs may not be equipped to adequately determine if the proposed offshore energy activity is in compliance with state or local coastal plans.

An additional concern is ways for local coastal governments to plan for and mitigate any of the ocean farm impacts previously mentioned. The Coastal Energy Impact Program (CEIP), which is part of the 1976 amendments to the CZMA, is designated to help states minimize the social, economic, and environmental disruptions that result from new or expanded coastal energy activities. It is assumed that CEIP assistance can be used for exotic coastal energy resources such as ocean kelp.

Planning for onshore activities, such as the offshore operations, may pose a set of different problems for coastal planners. Onshore requirements for a marine biomass system include terminals for the harvesting ships, port support facilities, farm fabrication plants, biomass conversion plants, and pipelines for gas supply and distribution. These facilities are not unlike those already included in a natural gas system or in the commercial kelp processing industry.

Although ocean kelp farms and their supporting facilities are not mentioned specifically in most state or local coastal plans, there are usually general policies that favor expansion areas within the coastal zone. In California, for example, ocean-dependent coastal development is encouraged, especially at existing sites. Industrial areas for kelp processing plants because of the already existing kelp industry are presently zoned in the ports of San Diego and Port Hueneme.

An important and unresolved issue with onshore activities is again related to which lead agency is responsible for planning, regulating, and mitigating the potential impacts of marine kelp energy conversion. The possibility exists that local jurisdictions would act eventually as the lead agency. Until that time, there may be some confusion with this issue.

With regard to potential air and water quality impacts, it is expected that the air and water quality standards would be satisfied through the issuance of permits by an appropriate federal, state, or local agency. The regulation and mitigation of air and water impacts from most onshore energy facilities are adequately considered within existing environmental protection provisions.

In conclusion, the main objective of energy planning in the coastal zone with any energy resource--oil, natural gas, coal, nuclear, or marine kelp--is to promote a timely transfer of pertinent information between the federal, state, and local levels of government as well as with the industrial sector where possible. State and local agencies that are responsible for coastal planning (under the provisions of the CZMA), implementing the energy development, and bearing the environmental and socioeconomic impacts inherent to a particular technology must be kept abreast of the plans and potential consequences of the energy technology in question.

SUMMARY

The coastal regions of the United States are relatively unique, biologically important, and vulnerable to human perturbation. The coastal zone has been and will probably continue to be important in the industrial development of the nation. The placement of energy facilities along the coast, however, generates environmental impacts and creates conflicts in the use of our coastal resources.

Marine biomass has been suggested as an energy resource, since it has the potential to contribute significant quantities of gaseous fuels to the nation's energy supply. As part of another project, an ocean farm system, using the California kelp (Macrocystis pyrifera) has been designed and used as a test facility off the southern California shore. This ocean farm concept, includes production, harvesting, processing, and conversion systems.

Possible impacts of the marine kelp system include: the potential for climatic modification; the release of numerous chemicals from the farm structure itself; possible consequences of the upwelling system, such as changes in various physical parameters and entrainment of marine organisms; the generation of air emissions from the diesel-powered harvesting vessels; the waste water discharges from the processing and conversion stages; and the digester waste sludge, which may contain considerable levels of heavy metals. Legal and institutional impacts associated with large ocean farm systems are: the hazards to ocean commerce; the obstruction of access to and utilization of coastal fishing locations; the questions of liability; and the international and domestic legal status of such an offshore operation.

Major concerns with the offshore aspects of the ocean farm concept exist, including the overall lead regulatory authority; the question of federal consistency; and impact planning and mitigation by local coastal governments. Onshore activities will probably pose fewer problems, since the proposed facilities are not unlike those already sited in the coastal zone.

It can be concluded that the proponents of a biomass energy system should start early to promote a timely transfer of information between the various institutions (federal, state, and local) involved in coastal zone planning. The accurate prediction of environmental impacts and their mitigation as required by law, demands a fully-coordinated energy planning and coastal resource management process.

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