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Aquatecture. Macro-design Projects on the Theme "Water": *Patterned Energy*

Edited by Charles L. Owen

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Three additional **Aquatecture** project reports are available under the subtitles:

Floating Fields
CrossRoads in the Sea
Mobile Offshore Industry

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

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Aquatecture. Macro-design Projects on the Theme "Water": Patterned Energy
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Preface

Mankind is inextricably bound to the water. Beyond our own obvious physiological needs, there are its associations with other life forms of concern to us, its importance as a medium for transportation and commerce and, above all, its very omnipresence. Three quarters of the Earth's surface is covered by water, and a great percentage of the world's population lives close to large bodies of water.

The contrast between development of the resources of land and sea, however, is sharp. The disparity suggests that, as we near the new millennium, we consider thoughtfully how to extend to the seas the understanding we have gained in developing the land for human habitation and support of our societies. Activities that were conceived for and evolved on land might now be better conducted on the waters, given the maturation of our technological knowledge and the crowding of our land base.

Aquatecture is a conceptual systems design project. Drawing on the computer-supported techniques of Structured Planning, it explores possibilities for uses of water resources for food production, transportation, energy development and manufacturing. Four subprojects: **Floating Fields, CrossRoads in the Sea, Patterned Energy** and **Mobile Offshore Industry**, deal individually with these subjects. In separate project reports, each speculates on how a "macrodesigned" environment might be developed using known technology to expand the uses of the seas, lakes and rivers as space, media and sources of energy, food and raw materials. This report describes **Patterned Energy.**

All four projects were done in the Fall 1986 Systems and Systematic Design course at the Institute of Design. This course is the final course in a three-course sequence for product design students beginning with Product Design, continuing with Environmental Design, and ending with the Systems and Systematic Design course. The Systems course is concerned with products working in concert to achieve goals; the development of comprehensive design concepts; the problems of teamwork in design; and the use of systematic, computer-supported design techniques (Structured Planning) for handling complex problems.

The topic for the fall 1986 course was the Japan Design Foundation's Third International Design Competition. Within the competition theme of "water", four study areas were set out: food production, transportation, energy and materials processing. Research in these areas evolved projects, collectively entitled "Aquatecture", which explore visions for uses of the oceans, lakes and rivers.

The projects were completed in four months and submitted to the competition in January, 1987. From a field of 2,281 entries representing 58 countries, 1,144 projects were actually submitted from professionals and students in 48 countries. All four of the Institute of Design projects survived the first round to be among 59 finalists. After another month of work to prepare final presentations, a second submission was made in June. Final competition results were announced in August: the four Aquatecture projects were together awarded the Grand Prize of 10,000,000 yen ($78,500). The award, made in Osaka on October 30, 1987, marked the second time in three competitions that Institute of Design students had won the Grand Prize.

The projects received considerable attention in the world press. Perhaps the best presentation of them was in the Italian international magazine of architecture: ***L'ARCA***. Its April 1988 issue (No. 15) contains a ten page article with a number of drawings and color photographs.

Charles L. Owen, Advisor and Editor

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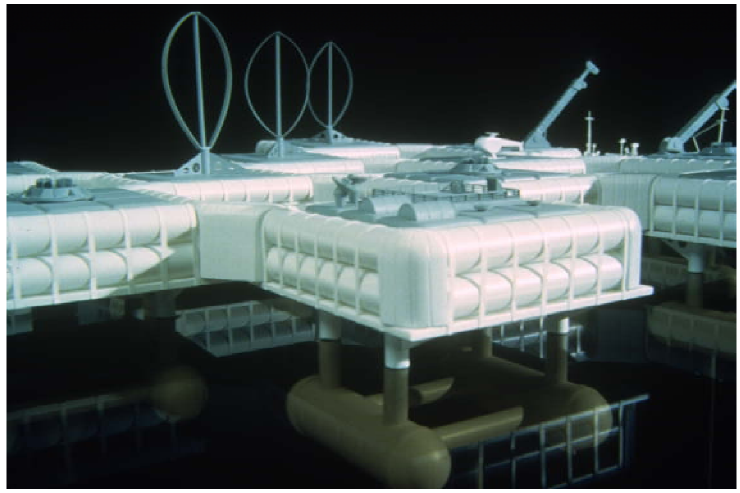

Figure 1 **Patterned Energy**
Floating energy production modules, matched in numbers to community requirements and in kind to local ocean characteristics, can be assembled rapidly to meet emergency or developmental needs.

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Patterned Energy

Overview

As the world's resources of fossil fuels dwindle, the value of alternative natural energy sources grows. Natural sources, however, are not particularly reliable in the consistency of their output—all days are not sunny, and the wind does not always blow. Combinations of power sources are an effective answer, and a water environment for major energy systems is a location of choice for several reasons: (1) wave action and temperature differentials in large bodies of water add additional sources of energy; (2) water pathways connect the great majority of urban settlements, making the transportation and relocation of large energy systems a realistic possibility; and (3) a large percentage of major cities are on or near large bodies of water—land near them is both scarce and expensive, while water locations offer advantages of performance, cost, safety and security.

The "Patterned Energy" system is a mobile water-borne energy conversion facility. The system can be established on the oceans and seas of the world to convert alternative natural energy resources such as wind, wave, solar and thermal gradient energy into electrical energy. It is designed to adapt advantageously to the environmental conditions available, drawing efficiency from special conditions as diverse as the energetic waves of the North Sea and the thermal gradients of the Northwest Pacific.

general Description

The Patterned Energy system is assembled from standardized 24-meter square Floating Platforms mounted on SWATHs (Small Water-plane Area Twin Hulls). The Platforms serve as bases for 18-meter square functional units, which include capabilities for energy conversion, habitation, docking, storage and repair. With suitable choices of functional components, an energy production system can be assembled that is appropriate for virtually any location.

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The energy conversion systems available as functional units in the Patterned Energy system are:

(1) Wind
(2) Wave
(3) Ocean Thermal Energy Conversion (OTEC)
(4) Fuel Cell
(5) Biomass
(6) Nuclear Fusion
(7) Solar

These units can be combined to form different patterns of energy production. Five example configurations of the Patterned Energy system are discussed below:

(1) Emergency Energy Center
(2) Deep Sea Energy Center
(3) Tropic Zone Energy Center
(4) Offshore Energy Center
(5) Metro/Industrial Energy Center

Tropic Zone, Deep Sea and Off-Shore energy centers are designed to take advantage of the environmental conditions typical of the area in which they are stationed. The Emergency and Metro/Industrial energy centers are designed specifically to meet needs created by man-made environments.

Emergency Energy Center

This energy center is configured to provide emergency power to a disaster-stricken area that has lost its own ability to provide electrical service or requires additional support. The center uses Conversion Modules that are not dependent on the climate or prevailing weather conditions in order to provide uninterrupted service at any location where it might be needed. Environmentally dependent Modules may be added to the configuration as additions if prevailing conditions allow. A typical configuration will produce approximately 1300 megawatts of electrical energy.

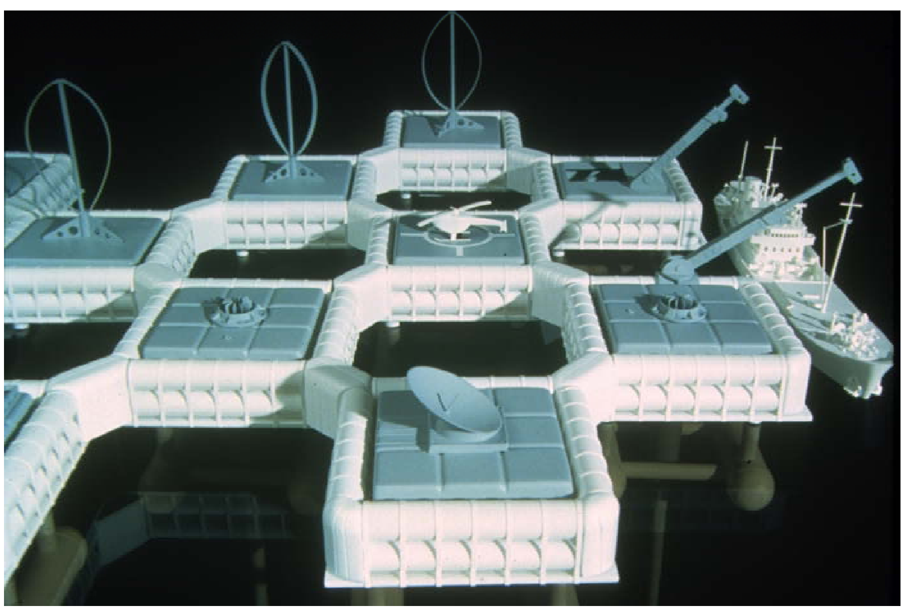

Figure 2 **Deep Sea Energy Center**
A floating energy center custom assembled for use where deep ocean water temperature differentials exist and winds are unimpeded. Three Darrieus wind turbines and two OTEC modules are visible along with auxiliary equipment for communication and cargo receipt and handling.

Deep Sea Energy Center

The Deep Sea Energy Center is a configuration which derives electrical energy from the sources available on the open sea. This center uses Conversion Modules which take advantage of the temperature differentials found between surface waters and waters at deeper levels as well as the abundance of wind and wave action. The Ocean Thermal Energy Conversion (OTEC) Modules that use thermal differentials achieve maximum output when positioned near equatorial or semitropical regions such as the Coral Sea, the the northern coast of Africa, the Arabian Sea, the southern coast of Japan, the West Indies and the East Indies. Wind and Wave Conversion Modules are most efficient when placed in areas of steady winds and consistent wave activity. Some of these locations are the North Atlantic Ocean, the North Sea, the northern coast of Africa, the east coast of Japan and the Tasman Sea near New Zealand. The configuration shown in Figure 2 will produce approximately 300 megawatts of electrical energy.

Tropic Zone Energy Center

The Tropic Zone Energy Center produces electrical energy from renewable sources in warmer tropical regions. Conversion Modules in this center take advantage of the prevailing sunshine as well as the water temperature differentials found in the tropics. Here, again, the OTEC Modules are used to take advantage of the thermal differentials. In addition to the previous listed regions of operation, the OTEC Module can be used extensively in any of the tropical regions of the world. To convert the energy of the bright sunshine directly, Solar Conversion Modules are employed. These Modules can be used the world over, provided that the area has a climate which is primarily sunny. A normal configuration will produce approximately 400 megawatts of electrical energy.

Offshore Energy Center

The Offshore Energy Center derives electrical energy from sources available closer to land. This configuration employs Conversion Modules which take advantage of the energy resources usually found near shore. Augmented with Solar Conversion Modules, the this system is configured for coastal areas which have substantial wave activity as well as continuous prevailing winds. Depending on the exact pattern, this version is capable of producing approximately 8 megawatts of electrical energy.

Metro/Industrial Energy Center

The Metro/Industrial Energy Center is configured to provide electrical energy to a metropolitan or industrial area which requires considerable energy. Since natural Conversion Modules take advantage of the energy resources available at a particular geographical location, specifying the location with regard for man's activities rather than nature's resources may lessen the efficiency of the natural conversion processes. Nuclear Fusion Modules may be a good choice where large power requirements exist; they can be supplemented with natural conversion units appropriate to the efficiency potential of the site. An appropriate configuration will usually be expected to produce approximately 1100 megawatts of electrical energy.

Modules

Conversion Modules

The Patterned Energy system has seven Functional Modules for the conversion of energy:

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Wind. Since stability and positioning are major issues in the establishment of a Patterned Energy installation, the Darrieus wind machine design was chosen for the wind power portion of the system. Its advantages include an ability to work in high winds, a capacity to utilize wind forces from any direction and a simple mounting process, all vital to overall system constraints.

The vertical blades of a Darrieus machine are constructed from aluminum and are shaped much like the wings of an airplane, with the leading edge slightly thicker than the trailing edge, to create an aerodynamic form which can respond to winds from any direction. With blades 50 meters in height, the system delivers 500 KW of direct current. For initialization, the blades must be driven by motor to a minimum speed, but thereafter the system is self-sustaining and has the ability to shut down momentarily in gusts of very high wind velocity.

Wave. Wave energy is harnessed by converting the motion of the waves into electricity. Performing this function is a system that employs three vertical, parallel plates. The first plate, which is placed one-quarter wavelength ahead of the second, faces the oncoming wave. Approaching wave crests push plate #1 inward, providing a forward pumping stroke. This motion is coupled to a series of pumps mounted on plate #2 which, in turn, drive turbines to produce electrical energy. This "paddling" movement allows the water between plate #1 and #2 to be set up as a standing wave. As the crest of the incoming wave falls, the pressure against the front face of the first plate is reduced, allowing the weight of the standing wave between the two front plates to force the first plate forward for a reverse pumping stroke. This cycle repeats with every successive wave. The third plate has a fixed spacing of a half-wavelength. It stabilizes the assembly in rough waters by containing a standing wave of changing amplitude between it and the second plate. The amplitude of the standing wave is always the opposite of that of the wave striking the first plate.

A single Module such as this may produce as much as 800 KW of electrical energy at an estimated 70% efficiency.

OTEC (Ocean Thermal Energy Conversion). OTEC exploits the thermal difference between the upper (warm) layers and lower (cold) layers of the sea. Solar energy is stored in the form of heat on the surface of the ocean, creating thermal gradients between the deep water layers and the surface.

Throughout the tropical belt around the earth, thermal gradients exist ranging from approximately 20 degrees Celsius to 28 degrees Celsius in water columns extending from 600 to 1000 meters in depth. Transformation of the thermal energy into electrical energy is performed in a thermodynamic cycle.

An OTEC Module is 18 x 18 x 6 meters in size. The system consists of an evaporator, turbo generator, condenser, warm and cold water piping and pumps. The warm water inlet takes in surface water; the cold water intake reaches down to depths as great as 800 meters for cold cooling water. In an open cycle OTEC system, warm sea water turns to vapor as it passes through the evaporator; its thermal energy is transformed into mechanical energy to drive a turbogenerator. Cooled by the cold sea water, the exhausted vapor condenses to fresh water as it passes through the condensers. The OTEC Module generates approximately 100 MW of power.

Fuel Cell. A Fuel Cell Module produces electricity by an electrochemical reaction between hydrogen and oxygen. The typical fuel cell power plant consists of three highly integrated major components: a fuel processor, a fuel cell power section and a fuel conditioner. Hydrogen is extracted from methane fuel

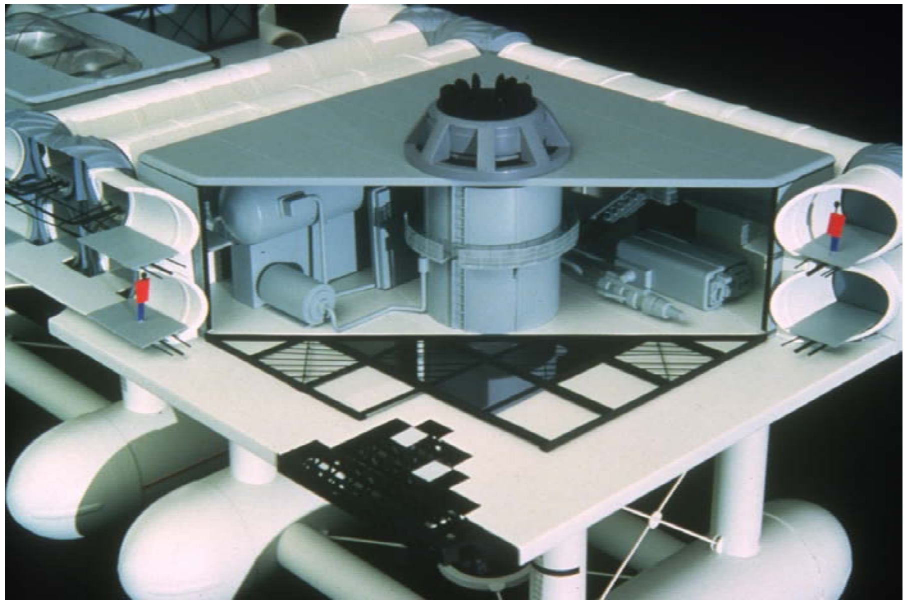

Figure 3 **OTEC Module**
An OTEC (Ocean Thermal Energy Conversion) module produces electricity from the temperature differential between surface waters and deep waters. In the open cycle OTEC process, thermal energy from evaporated warm sea water drives a turbo-generator; cold deep sea water condenses the water vapor.

(produced by the Biomass Module) in the fuel processor and fed into fuel cells in the power section. This series of cells is the core of the power plant. The power conditioner transfers the direct current output of the fuel cells into alternating current. This allows the power to be fed into the electrical grid and to be used by AC motors.

The fuel cell power section is housed in an 18 x 18 x 6 meter Module. These units are relatively inexpensive to maintain, and have a lifetime of 20 to 30 years with periodic overhaul. Output of the component is estimated at 500 KW (DC), which translates to a slightly lower AC voltage because of conversion losses.

Biomass. The Biomass Module produces methane by an anaerobic digestion process. A water slurry, or solution, of biomass material interacts with microorganisms and is enzymatically converted to methane (land and water-based vegetation and photosynthetic organisms are all categorized as biomass material). The Biomass Module uses aquatic biomass, particularly micro and macro algae, which are more efficient at converting incident solar radiation to chemical energy than most biomass species.

The Biomass Module measures 18 x 18 x 6 meters. It houses fermentation equipment consisting of hydrolysis units, anaerobic digesters, and gas cleanup and dehydration units. Methane storage tanks are located on the roof of the Module. The output of the Biomass Module is methane, usable in fuel cells.

Nuclear Fusion. The Nuclear Fusion Module consists of a reaction chamber in which a fusion device fuses hydrogen into helium under extreme forces generated by directed energy beams. Once initialized, the reaction is self-sustaining. Heat from the fusion reaction is converted into usable electrical energy by the heat transfer and steam turbine conversion system accompanying the reactor in the Module. The 18 x 18 x 6 meter Module can be located virtually anywhere within an installation. A single Module would be capable of producing as much as 1000 MW.

Solar. Solar energy converters are mounted atop 18 x 18 x 6 meter Modules. Each 18 x 18 meter solar panel is connected to the Base Frame by means of hydraulic jacks, which raise the panel to its best orientation toward the sun. A bellows protects the jacks from salt and water spray that may harm their functioning. The arrays themselves are made of photovoltaic cells, and are mounted on a steel frame and encased in durable plastic to provide protection against salt, wind and water. Output of the Module is expected to be 400 KW.

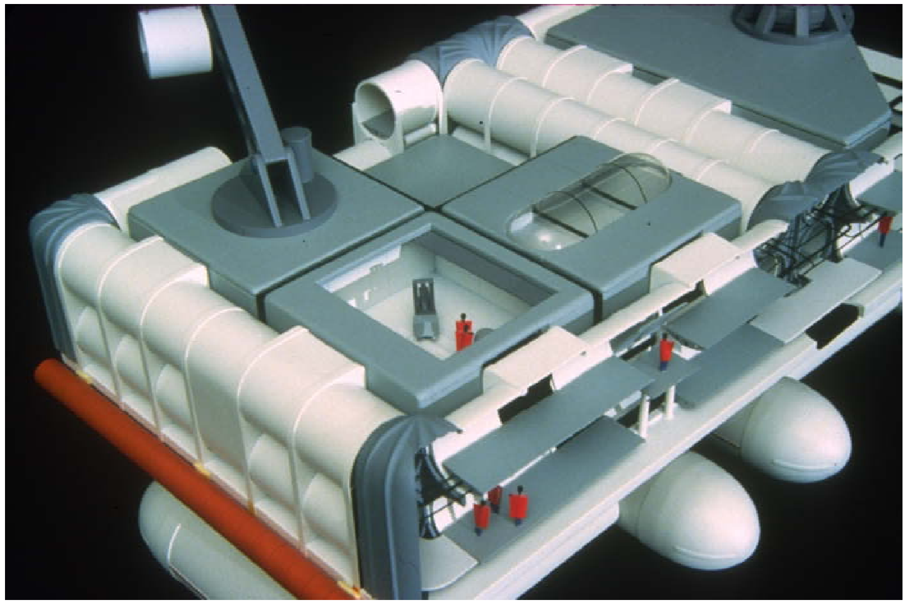

Figure 4 **A System Support Center**
Maintenance and operational support for energy centers of all kinds is provided through the System Support modules, each of which can be individually configured to meet service requirements.

System Support Modules

Cargo Receipt and Transfer

The receipt and transfer of cargo and supplies takes place at the Docking Module. Supplies arrive at a Patterned Energy installation by ship and are transferred from the ship to the Docking Module by cranes. The Docking Module is organized vertically as two 18 x 18 x 3 meter decks. The upper deck is a staging area for incoming and outgoing cargo. Supplies are temporarily held for storage on the lower deck, or are sent directly to another Platform if the need is immediate.

Heliport Module

The Heliport Module allows helicopters and other VTOL (Vertical Take Off and Landing) aircraft to land at a Patterned Energy installation. Personnel can be flown to and from the installation at scheduled intervals or when emergencies occur. The Heliport uses a 18 x 18 x 3 meter Module, which contains aircraft communications facilities, maintenance equipment and a refueling depot.

Habitation Module

The 18 x 18 x 6 meter Habitation Module serves the personal needs of the system's crew. The Module contains facilities for rest, dining, entertainment, hygiene, medical, and physical fitness activities. The Habitation Module requires a "skeleton crew" during routine operations; during reconfiguration activities or emergencies the Module houses a full crew.

Energy Distribution Module
The Energy Distribution Module transmits energy from the production site to end users. The Module has four basic components: a transmitting antenna, a relay satellite, a rectenna receiving device and a transmission cable. The transmitting antenna's function is to beam microwave energy from the production site to the end user. The transmitting antenna is 10 meters in diameter and can transmit 100 MW of power. The relay satellite directs the microwave beam to rectennas—.arrays of microwave receivers on land that convert electrical energy from AC to DC for use in a conventional power grid. The transmission cable is an alternative used when the energy center is near the end user.

Construction

Floating Platform
Floating Platforms are the building blocks of the Patterned Energy system. Their selection and placement determines the function of the system. The Floating Platform is made up of six major components:

(1) SWATH Units
(2) Base Frame
(3) Base Frame Connections
(4) Service Tubes
(5) Tube Connectors
(6) Modules

SWATH Units. SWATH Units serve as a floating foundation for the Patterned Energy system. The units come in two versions: one for flotation alone, and one which also contains propulsion units.

The SWATH hulls are connected to the bottom of the Base Frame by means of tubes and cross supports. Hulls are 5 meters in diameter and 21 meters in length. Caps on the ends of the hulls improve hydrodynamic characteristics during navigation of rough waters and protect the structure from wave damage. Ballast tanks are housed inside the hulls to provide the Platform with stability control for trim, some vertical positioning control to reduce pitching and rolling during relocation, and to help Platforms to match heights during linkups.

The propulsion hulls have the specialized function of providing system maneuverability; they are located only in key positions within a configuration. A water intake port supplies water to a jet pumps for propulsion. Water leaving a pump exits through an omni-directional port to create a force vector that can be controlled to make positional changes or resist current and wind-induced movements. The pumps may also be used to move water in the ballast tanks.

Base Frame. The Base Frame is the main support for the Modules and the Service Tubes. In outside dimension, it measures 24 x 24 x .5 meters; its inner square opening measures 12 x 12 x .5 meters. Extensions of 1.5 meters hold the Service Tube and Fence structures which, in turn, support the Modules.

The Base Frame is made from structural sections triangulated to add rigidity and strength. It is connected to the SWATH hulls by means of 9 meter long tubes, which have a diameter of 2 meters. Access to the hulls is through these tubes.

Base Frame Connections. Base Frame Connections hold a configuration of the Patterned Energy system together. The Connections protect Base Frames from damage by allowing individual Platforms freedom for limited roll and pitch motions without danger of impact between Frames.

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Service Tubes. Service Tubes provide crew and vehicular passage between Floating Platforms. The Tubes also protect the crew and equipment from the elements and provide a buffering barrier between Modules or between Modules and the external environment.

Service Tubes are mounted in two tiers around the outer edge of the Base Frame to allow access to both levels of the inner Modules. Constructed from six 3-meter-long tubes, three meters in diameter, Tube stacks for each side of a Module are held together by braces that surround the combined circumference of the two Tubes.

Assembly, repair and loading activities are supported by the presence of the Service Tubes. The cavity section underneath the Tube flooring houses the utility lines for the Module. Transportation between upper and lower Tubes is by an elevator system that raises a section of flooring. Entering and exiting Modules is possible through canister doors located at various points along the Tube. Tubes for Platforms are linked by Tube Connectors to allow access to the entire Patterned Energy installation.

Service Tube Connectors. A Service Tube Connector links Tubes, either on a single Platform or across Platforms. Single Platform Connectors are simple in concept, providing continuity around Platform corners. A multiple Platform Connector holds Platforms together via a horizontal disc flexibly mounted to permit differences in motion of two (or more) Platforms. Segmented bellows cover a Connector for weather protection, and utility lines pass through them so that a common utility service can supply all Platforms of an installation. There are five types of Tube Connectors:

(1) Diagonal Connector

(2) Single Platform Connector

(3) Two Platform Connector

(4) Three Platform Connector

(5) Four Platform Connector

Modular Infrastructure. Functional Modules for the Patterned Energy system include facilities for habitation, supply, storage, repair and maintenance as well as several kinds of energy conversion units. A versatile system of Roof Panels and a Fence structure of internal dividers allow placement of Modules of more than one size within the same system subunit.

Modules are available in three sizes: 18 x 18 x 6 meters, 18 x 18 x 3 meters and 8.75 x 8.75 x 3 meters. The Module structure is a frame with cross bracing for support and vertical bars for door frames.

Roof Panels perform a number of functions. The standard Roof Panel simply provides protection for the Modules from weather elements—salt, water, snow and wind. Panels can also be equipped with skylights to provide natural lighting and can be made adequate structurally to support such equipment as transmitting antennas, wind converters and solar arrays. To work with the crane system, panels open to furnish access to docking and storage facilities.

The Fence structure allows housing of four 8.75 x 8.75 x 3 meter Modules within a system subunit. Constructed from two 18 x 3 meter intersecting truss panels, it has the form of a "cross", enabling it to support four small Modules from the inside and supply them with utilities from the Service Tubes.