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SUBSTANTIVE PREPARATIONS FOR THE CONFERENCE

Report of the Technical Panel on Ocean Energy on its second session

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* A/35/43 (Part II) and Corr.1, para. 67.

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INTRODUCTION

1. The Technical Panel on Ocean Energy of the United Nations Conference on New and Renewable Sources of Energy held two sessions. The first session was held in Paris from 5 to 9 November 1979, and the second was convened at Geneva from 22 to 26 September 1980.

2. The Panel was composed of six members appointed by the Secretary-General of the Untied Nations from among candidates nominated by Governments. The terms of reference of the Panel are outlined in document A/34/585, annex II, which is based on General Assembly resolution 33/148. Decision 5 (II) and resolution 2 (II), taken at the second session of the Preparatory Committee for the Conference further defined the form of the present report.

3. The second session was opened on behalf of the Secretary-General of the Conference by the Assistant Director of the Ocean Economics and Technology Branch, Department of International Economic and Social Affairs. In his statement he recalled the three principal questions which the Secretary-General of the Conference had presented at the second session of the Preparatory Committee on the central issues for the final reports:

(a) What are the technologies which can be utilized significantly in the next 20 years and beyond?

(b) What are the major constraints preventing the development of those technologies? (The examination of this question was to serve as a basis for the discussions of the ad hoc expert groups.)

(c) What are the means of overcoming those constraints and of reinforcing the utilization of the technologies in the next 20 years and beyond?

4. Mr. J.-C. Pujol (France) continued as Chairman and Mr. S. Varas (Chile) acted as rapporteur. The meeting proceeded to the adoption of the provisional agenda, which was slightly amended and appears as annex I. The Panel had before it a number of background documents, listed in annex III. A complete list of participants and observers is contained in annex II.

I. ORGANIZATIONAL MATTERS

A. Review of intersessional work (agenda item 3)

5. The Panel reviewed the results and recommendations of its first session and expressed its satisfaction with the studies and reports prepared during the intersessional period.

B. Ocean Energy Panel priorities and goals (agenda item 4)

6. The results of the Preparatory Committee at its second session, held at Geneva from 21 July-1 August 1980, were presented. The Panel reviewed decision V (II) dealing with the reports of the technical panels, which it felt gave it strong direction for its work. In addition, the need to provide the *ad hoc* group of experts and the synthesis group with adequate information and guidance was noted. Each participant, having prepared intersession documents, presented his principal conclusions. This led to a valuable exchange of views concerning the focus of the Panel's efforts on ocean thermal energy conversion (OTEC), tidal and wave energy. In the light of the Preparatory Committee directives, the Group attempted to examine technologies which might be commercially available immediately or in the forthcoming 15 years.

C. Draft report of the Panel (agenda item 5)

7. The Panel considered the documents before it and the revised outline of its final - that is, present - report. In the course of its discussions, it was agreed that a draft report would be completed, subject only to editorial and minor revision at a later date by the Secretariat. The scope and purpose of the work of the Panel at its second session was set forth at the second session of the Preparatory Committee of the Conference, in decision V (II).

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II. OVERVIEW OF OCEAN ENERGY SYSTEMS

8. Of all the ocean systems, the Panel judged OTEC to be its primary focus, on the basis of projected viability and significance in the near term and amenability to international action. The advantages of OTEC are summarized below:

(a) Economics: Cost estimates show early promise for OTEC to replace oil economically for electricity generation.

(b) Technical:

(i) Baseload electricity capability - no energy storage requirement;

(ii) Large-unit scale, possibly leading to meaningful impact;

(iii) Expected availability in the near term: technology not dependent on any basically new scientific advance; engineering development judged amenable to normal engineering scaling and conventional construction; can be designed in a wide range of sizes appropriate to multiple applications;

(iv) Multiple concepts and applications, including production of fresh water.

(c) Environmental: The environment can be protected through design.

(d) Resource availability: Large accessible resources,are predominantly in the equatorial belt, and there is potential for co-operative programmes in international waters.

(e) Internationally accessible technology: Essentially conventional construction and technology are currently found in off-shore oil and refrigeration industries. Further, partial integration of developing countries into production is possible, especially since OTEC is an emerging industry. Multiple national development programmes exist, and there is some potential third-party ownership and finance.

9. Secondary emphasis was placed on tidal energy because it is a proven system, albeit with a limited number of sites.

10. Wave energy was not considered of immediate applicability, although it should be reviewed after two to three years of continued research and development.

11. While ocean wind and biomass are dealt with more directly by other technical panels, certain information was felt to be worth communicating.

12. Ocean currents and salinity gradients do not appear to be significant before the year 2000.

13. Ocean energy is only one of the many types to be examined at the Conference. There is reason to believe that OTEC can soon make a significant contribution to islands and certain coastal States. The over-all importance of ocean energy should be emphasized.

A. Ocean thermal energy conversion (OTEC)

1. OTEC significance

14. The OTEC thermal resource is vast and in the United States alone a goal of 10,000 MWe of OTEC power has been set for the year 2000. A total of 99 nations and territories have direct access to an OTEC thermal resource with an average monthly ΔT exceeding 20° C within their exclusive economic zones - 200 nautical miles. Of this total, 62 are developing countries. One ongoing study indicates that 25 of those nations are projected to have installed capacities greater than 1,000 MW by 2010. The size of the electrical energy demand argues for a large potential for OTEC in developing countries. For the other 27 developing nations, a great potential exists for the installation of smaller-scale plants (less than 100 MWe), which are already becoming competitive with diesel-powered plant in many locations. Estimates for the global installed OTEC capacity have ranged from 10,000 to over 100,000 MWe; a realistic figure probably lies closer to the lower end of that range.

15. Prospective sites exist throughout the equatorial belt from 30° S to 30° N but prospective sites cannot be judged on that basis alone. Peculiar coastal characteristics can enhance or degrade the ΔT, while local costs for energy, particularly in remote islands, may be so great that OTEC can compete even at a relatively high unit cost.

16. Fresh water as an end product can critically affect system viability; small plants producing less than 5 MWe, which may be inconsequential for energy, can contribute significant amounts of fresh water. The inclusion of schemes such as the solar pond can increase warm water temperatures greatly and can open areas more distant from deep cold water to OTEC applications.

2. Technological state of the art

17. Some of the major parts of the OTEC system are well tested, reliable and should be amenable to normal engineering scaling. These include the heat exchangers, turbines and generators, platforms and pumps. A few major components which require development work include the cold water pipe, underwater electrical cable and floating platform mooring.

18. The heat exchanger for the closed-cycle OTEC utilizes either conventional "shell and tube" or "plate and fin" type heat exchangers with ammonia as a working fluid and anti-fouling measures on the water side to increase the total heat transfer coefficient to a value greater than 1,000. Although its cost represents a large component of OTEC plant costs, titanium is the preferred heat exchanger material because of its resistance to ammonia corrosion and its long life in contact with sea water. The high cost and limited availability of titanium may lead to new approaches, which could significantly reduce the cost of OTEC installations. The turbines required are larger than any yet built and while no major design problems are anticipated, some concern has been expressed with regard to the enthalpy drop through the turbine which would reduce the efficiency of the system. The platforms required for an OTEC plant are not dissimilar to existing

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off-shore structures found in the North Sea and other activities on outer continental shelves. The pumps, too, pose no special problems except for the requirement that they operate in parallel.

19. The 1,000-metre cold water pipe, which might have a diameter of 10 metres for a 40 MWe plant, presents an engineering challenge which is being seriously and directly addressed by industry. Mooring and electrical cabling to shore are issues of unique significance to OTEC and have required detailed engineering concerning stationary positioning in depths greater than 1,200 metres and under-sea electrical swivel joints for installation greater than 10 MW.

20. In summary, OTEC installations consist principally of larger-scale applications of existing commercial technology which needs to be redesigned to withstand the environmental and operational forces to be encountered by a facility over its projected 25-year life.

3. OTEC project characteristics and assessment guidelines

21. The most important factors to consider in assessing the potential application of OTEC are physical and environmental issues, sizing, end use and by-products, design configurations, centralized *versus* non-centralized use and institutional and economic issues.

(a) Physical factors

22. The major factor in determining the degree of utilization of OTEC for power production will be the availability of a thermal resource adequate to support operations. A temperature difference of at least 18° C between surface waters (0-100 m) and deeper waters (900-1,100 m) is essential, coupled with proximity of the 1,000-metre isobath to the coastline. A first approximation of the location of adequate thermal gradients is presented in figures I and II, and a preliminary list of developing countries with adequate ocean thermal resources is found in table 1. Caution should be used in interpreting those figures and tables because physical suitability is very site-dependent, and detailed site descriptions will dictate whether a moored, land-based, shelf-based or floating plant ship configuration is preferred. Furthermore, although the temperature profile is easily measured at a site, it may vary because water masses move and other physical processes alter the structure of the water column.

Table 1. Developing nations with adequate ocean thermal resources

Region/nation	Latitude	Longitude	Delta T(°C) between 0-1,000 m	Distance from resource to shore (km)
Africa				
Angola	6°S-18°S	11°E-14°E	18-22	65
Benin	6°N	3°E-4°E	22-24	50
Congo	4°S-5°S	11°E-12°E	20-22	50
Gabon	2°N-4°S	9°E-11°E	20-22	50
Ghana	5°N-6°N	3°W-1°E	22-24	50
Guinea	9°N-11°N	14°W-15°W	20-22	80
Guinea-Bissau	11°N-13°N	15°W-17°W	18-19	50
Ivory Coast	5°N	3°W-8°W	22-24	30
Kenya	2°S-5°S	34°E-41°E	20-21	25
Liberia	5°N-17°N	8°W-12°W	22-24	65
Madagascar	10°S-25°S	45°E-50°E	18-21	65
Mozambique	10°S-25°S	35°E-40°E	18-21	25
Nigeria	4°N-6°N	4°E-9°E	22-24	30
Rio Muni	2°N-3°N	10°E	20-22	30
Sao Tome and Principe	0°N-2°N	7°E-9°E	22	1-10
Senegal	13°N-17°N	16°W-17°W	18	50
Sierra Leone	7°N-9°N	12°W-14°W	20-22	100
Somalia	10°N-2°S	41°E-50°E	18-20	25
Togo	6°N	2°E-3°E	22-24	50
United Republic of Cameroon	3°N-4°N	9°E-10°E	22-24	65
United Republic of Tanzania	5°S-10°S	35°E-40°E	20-22	25
Zaire	5°S-6°S	12°E	20-22	50

Table 1 (continued)

Region/nation	Latitude	Longitude	Delta T(°C) between 0-1,000 m	Distance from resource to shore (km)
Latin America				
Bahamas	25°N	77°W-79°W	20-22	15
Barbados	13°N	58°W-60°W	22	1-10
Belize	16°N-17°N	87°W-88°W	22	50
Brazil	4°N-32°S	35°W-55°W	20-24	75
Colombia	2°N-12°N	63°W-79°W	20-22	50
Costa Rica	8°N-12°N	83°W-85°W	21-22	50
Cuba	20°N-23°N	75°W-85°W	22-24	1
Dominica	15°N-16°N	61°W-62°W	22	1-10
Dominican Republic	18°N-20°N	68°W-72°W	21-24	1
Ecuador	2°N-4°S	81°W-79°W	18-20	50
El Salvador	13°N-14°N	87°W-90°W	22	65
French Guiana	4°N-5°N	50°W-52°W	22-24	130
Grenada	13°N	61°W-62°W	27	1-10
Guatemala	14°N-17°N	88°W-94°W	22	65
Guyana	5°N-8°N	58°W-60°W	22-24	130
Haiti	18°N-20°N	72°W-75°W	21-24	1
Honduras	14°N-16°N	83°W-88°W	22	65
Jamaica	18°N-19°N	76°W-78°W	22	1-10
Lesser Antilles	12°N-18°N	61°W-65°W	22-24	1
Mexico	17°N-22°N	104°W-108°W	20-22	32
Nicaragua	11°N-14°N	84°W-86°W	22	65
Panama	8°N-9°N	76°W-83°W	21-22	50
Saint Lucia	13°N-14°N	61°W-62°W	22	1-10
Saint Vincent and the Grenadines	13°N-14°N	61°W-62°W	22	1-10
Suriname	4°N-5°N	52°W-58°W	22-24	130
Trinidad and Tobago	11°N	61°W	22-24	10
Venezuela	8°N-12°N	60°W-73°W	22-24	50
United States Virgin Islands	18°N	65°W	21-24	1

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Table 1 (continued)

Region/nation	Latitude	Longitude	Delta T(°C) between 0-1,000 m	Distance from resource to shore (km)
<u>Indian and Pacific Oceans</u>				
American Samoa	12°S	165°W	22-23	75
Australia	10°S-40°S	115°E-155°E	18-22	100
Burma	5°N-30°N	95°E-100°E	20-22	75
China	21°N-40°N	108°E-122°E	21-22	50
Comoros	1°N-3°N	43°E-45°E	20-25	1-10
Cook Islands	18°S-22°S	155°E-165°E	21-22	1-10
Fiji	15°S-20°S	175°E-180°E	22-23	1-10
Guam	13°N	145°E	24	1
India	10°N-25°N	70°E-90°E	18-22	65
Indonesia	5°S-10°S	95°E-127°E	22-24	50
Kiribati (Gilbert)	5°S-5°N	172°E-178°E	23-24	1-10
Maldives	2°N-8°N	72°E-74°E	22	1-10
Mauritius	20°S-21°S	57°E-58°E	20-21	1-10
New Caledonia	20°S-22°S	165°E-168°E	20-21	1-10
Papua New Guinea	0°-11°S	131°E-151°E	22-24	30
Pacific Islands (Trust Territory)	15°N-20°S	135°E-150°W	22-24	1
Philippines	18°N-5°N	120°E-127°E	22-24	1
Samoa	10°S-16°S	168°W-175°W	22-23	1-10
Seychelles	1°S-7°S	53°E-57°E	21-22	1
Solomon Islands	4°S-12°S	155°E-165°E	23-24	1-10
Sri Lanka	6°N-10°N	80°E-82°E	20-21	30
Thailand	5°N-10°N	96°E-100°E	20-22	75
Vanuatu	11°S-20°S	160°E-170°E	22-23	1-10
Viet Nam	12°N-23°N	105°E-108°E	22-24	65

ΔT(°C) BETWEEN SURFACE AND 1,000 METRE DEPTH

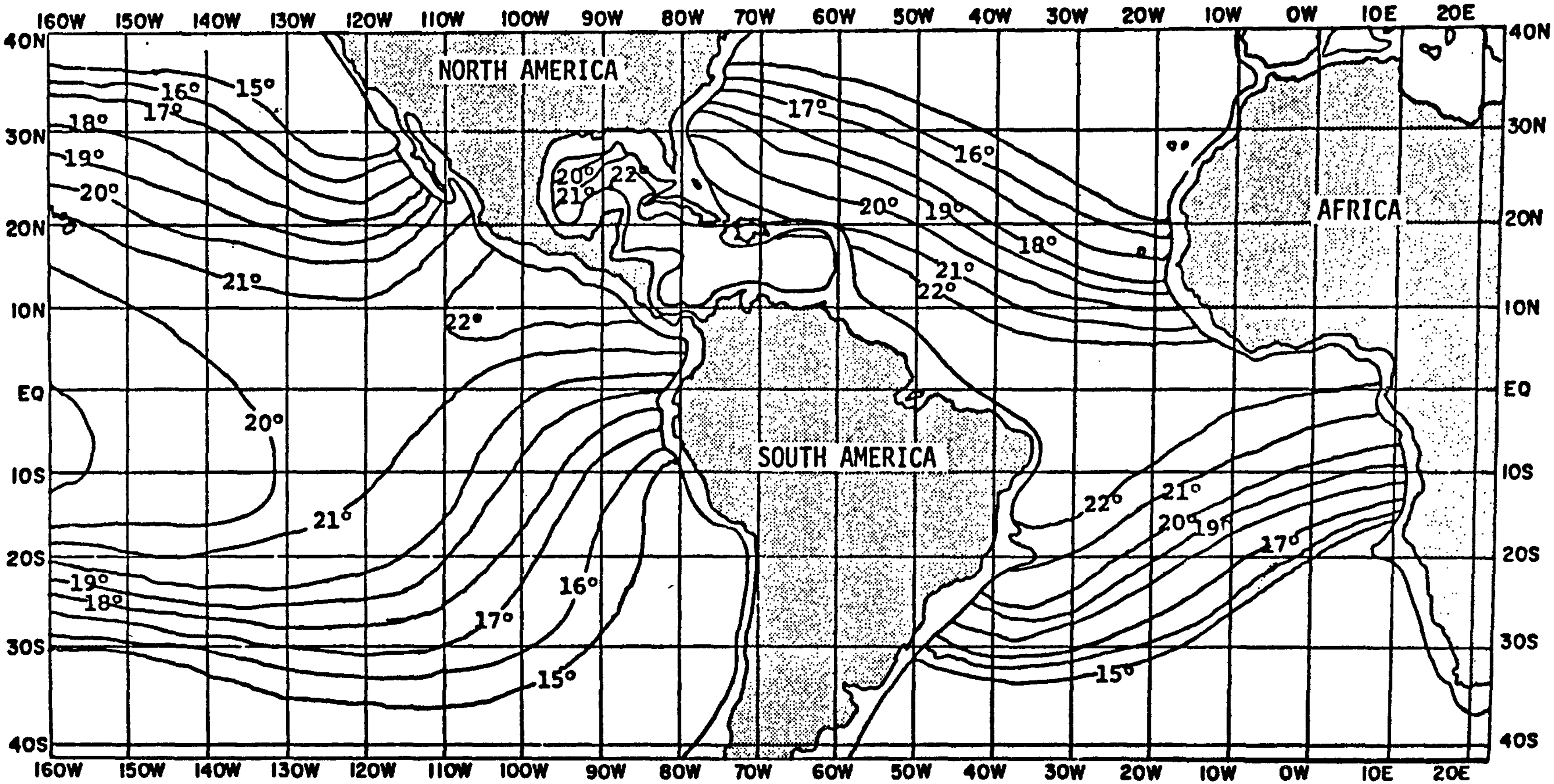

Figure I

ΔT(°C) BETWEEN SURFACE AND 1,000 METRE DEPTH

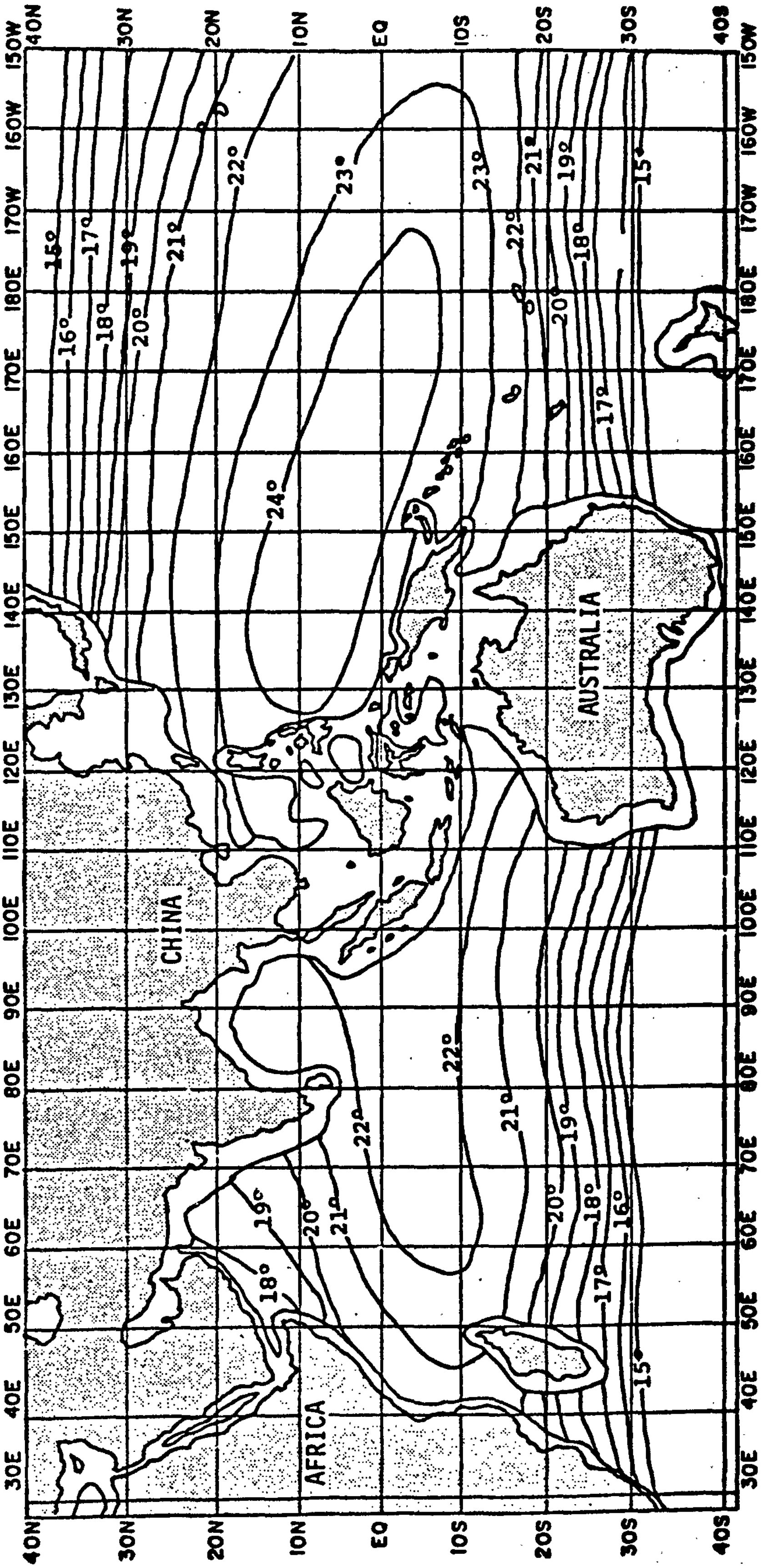

Figure II

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Table 2. OTEC project studies

Project characterization	Caribbean island		Caribbean island		Pacific Island		
	United States Virgin Islands	Floating	Land-based	Floating	Land-based		Floating
Study contractor	Westinghouse Electric Corporation (United States)	Johns Hopkins APL (United States)	EUROCEAN combined ODA plant	Netherlands Hollandische Beton Group	CNEXO	Todden Sekkei Co., Tokyo Electric Power Service Co.	Sunshine Project MITI (Japan)
Plant type	Hybrid closed	Closed cycle	Closed cycle	Closed cycle	Closed and open	Closed	Closed
Working fluid	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia sea water	R-22	R-22 or ammonia
Proposed location	United States Virgin Islands	Puerto Rico	Curaçao	Curaçao	Tahiti Nauru	Nauru	Okinawa
Net plant power capacity (MWe)	2-5	40 BUSBAR 33.8 net onshore	1	10	3-15	0.1 (100 KW) Total demonstration	1
Capital investment (Millions of $US, 1980)	50-70	206 (including 10 per cent profit, 10 per cent contingency	9.1 for power alone, 17.7 for combined ODA plant	73.0	60 for 3 MW, 150 for 15 MW	...	50, including research
Unit cost/KWe	...	$6,110	$9,100	$7,300	$20,000 for 3 MW, $10,000 for 15 MW	...	
Electrical cost mills/KWh	...	66-83	70 internal calculation for plant	61	175 for 3 MW, 112 for 15 MW	...	
Production cost at present mill/KWh	170	80-100	75	75	175		
Output	1. Fresh water 2. Electricity	1. Electricity	1. Electricity 2. Fresh water 3. Aquaculture	1. Electricity	1. Electricity 2. Fresh water	1. Electricity	1. Electricity
ΔT (mean)°C	21°	22.4°	20°	20°	23°		
Freshwater estimated production cost/ton	$1.39	...	$1.80	...	$1.25	...	...
Present production cost/ton	$2.00-2.50	...	$2.60	$2.60	...	...	...
Time-table to full operation (years)	3	3	5	5	3	1	5
Availability factor (percentage)	80-90	90	90	80	90		

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23. Other physical characteristics of the site are required, including certain kinds of ocean currents and meteorological and sea-bottom conditions. Strong ocean currents are expected to place a severe strain on the cold water pipe and on the mechanisms for mooring or holding position. Additionally, the frequency of severe meteorological disturbances such as typhoons, hurricanes or other tropical storms needs to be tabulated and evaluated in relation to possible interruptions of operations or damage to the installation.

24. Geological, engineering and topographical data are also needed to define the slope, roughness and suitability of the area for submarine cable installation and platform anchoring.

(b) Environmental factors

25. All studies, to date, are very favourable to single-plant OTEC deployment, indicating that no significant environmental impacts are anticipated.

26. The full range of environmental issues pertaining to OTEC development, demonstration and commercialization have been described in various ongoing research studies, including, notably, the Environmental Development Plan for OTEC of the United States Department of Energy. 1/

27. Current environmental research programmes are addressing the question of potential impact at smaller facilities, and their findings will be used to predict the impact at larger facilities. Environmental assessment activities should be undertaken at each potential OTEC site. Future larger-scale deployments should be the subject of studies to assess optimal platform-siting distances for minimizing impact. Environmental concerns relate to the following areas:

(a) Changes in oceanic properties:

(i) Destruction of marine organisms (by impingement and entrainment);

(ii) Ocean water mixing;

(iii) Local climate alteration;

(b) Chemical pollution:

(i) Biocide discharge;

(ii) Working fluid leaks;

(iii) Corrosion products discharge;

1/ United States Department of Energy, Environmental Development Plan: OTEC, DOE/EDP-0034 (Washington, D.C., United States Government Printing Office, 1978).

(c) Structural effects:

(i) Artificial reef;

(ii) Nursery and migration impacts;

(d) Secondary impacts:

(i) Construction effects;

(ii) Operational effects;

(iii) Legal and institutional impacts.

28. Environmental acceptability of OTEC also requires a determination of the size of the installation and its design configuration, in order to assess siting conflicts. Typical ocean uses in the selected area might include commercial and artisanal fisheries, transportation, mining, petroleum development, recreation, and waste disposal.

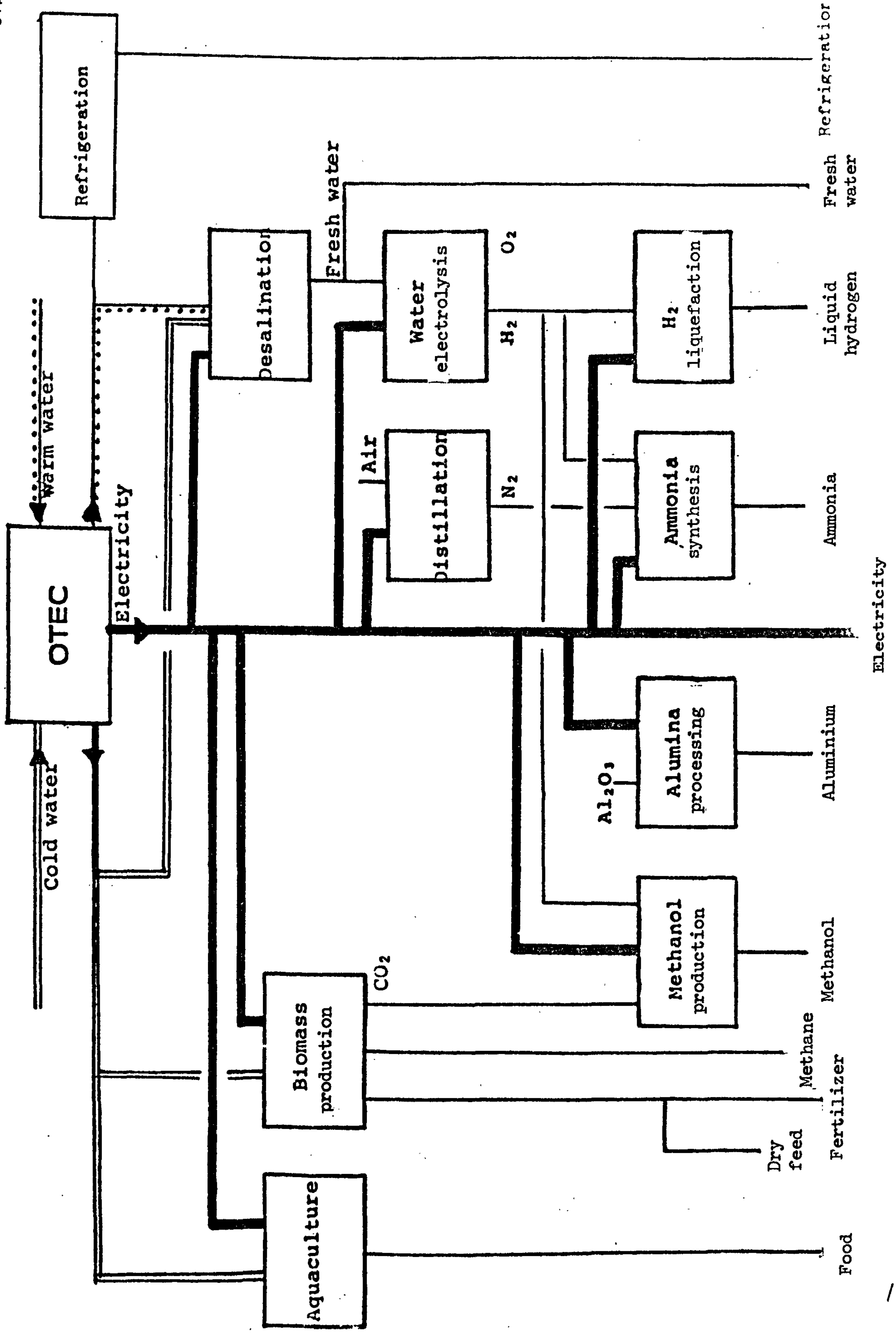
(c) <u>Plant size</u>

29. Proper sizing of OTEC electrical output is a function of energy demand, available alternative supply, demographics and economic penalties associated with down-scaling. Using a basic international rule stating that no one power facility should represent more than 15 per cent of the power grid, numerous developing countries with nominal demand would either need to create a high reliance on one source or incur possible economic penalties from down-scaling the size of optimally designed OTEC plants. The development of smaller-scale plants is currently under way and is critical to improving OTEC applicability in developing countries. The case studies in chapter IV indicate the need for OTEC plants of less than 25 MW, although developing countries have a higher growth rate in energy demand, and in the future it is expected that larger OTEC plants will be required.

(d) <u>End use and by-products</u>

30. Energy from OTEC can be converted into either electrical, chemical or protein form. Figure III, prepared by EUROCEAN, depicts the different forms of energy products and by-products that may result. Industries may be developed at OTEC sites where other natural resources are present or can be transported.

Figure III. OTEC energy forms and by-products



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(e) Design configurations

31. The selection of the appropriate configuration for a given project will be largely a function of the site's depth and proximity to shore, the mission and product(s) produced, and other physical parameters such as ocean current speed and adverse weather. The four configurations for commercial-scale OTEC plants are moored, land-based, shelf-based and plant-ship facilities.

32. The moored facility is kept relatively stationary with either cables and anchors or dynamic positioners such as propellers or thrusters. Such positioning would be expected in ocean regions with depths of 500-1,500 metres in order to accommodate the cold water pipe. The moored configuration best lends itself to electrical and/or by-product (for example, ammonia) transmission to shore via submarine cables or pipelines.

33. For those areas having a thermal resource relatively close to shore, it is possible to locate the OTEC operating plant either on shore or on the continental shelf. The advantages of those two configurations are the elimination of mooring and cabling costs, a reduction in the cost of the cold water pipe (which could be laid along the off-shore slope), less exposure to adverse weather conditions and a greater flexibility in the use of the energy produced. Many islands and certain continental sites are suitable for land-based or shelf-based plants.

34. The plant-ship configuration is free of any mooring or stringent positioning requirements, for it "grazes" at sea for the maximum ocean thermal gradients. The plant-ship therefore trades off the direct connexion to shore against higher thermal gradients, no mooring costs and no submarine cable or pipeline costs. The plant-ship's mission is somewhat constrained, though, for it becomes necessary to utilize all the OTEC-produced energy at sea by engaging in either an energy-intensive industrial process (for example, ammonia production or alumina reduction) or an energy-conversion process.

(f) Economic and associated factors

35. Small-scale OTEC plants in the 1-10 MW range now appear to be competitive with diesel generators in remote islands and could significantly benefit local economies, particularly since coastal areas have traditionally been the focal points for economic growth and human settlement. OTEC may provide not only a source of electricity but also the means to develop new industries which are energy intensive, and that could have a considerable impact on the creation of "energy islands", which currently have extremely limited prospects for industrial development.

36. An important consideration is the effect of OTEC adjunct activities, particularly fresh water production in areas of water deficiency. In a feasibility study undertaken by EUROCEAN for Curaço, fresh water and fish production made OTEC economically viable even though OTEC electricity alone was not competitive at current costs.

37. Large-scale OTEC installations may be appropriate for the electricity needs of large urban centres and areas where industrialization and urbanization require the development of centralized supplies of energy. Where the infrastructure and market are present, a primary energy source for electric power generation, such as OTEC, may be added to the grid system to reduce the dependence on oil.

38. Cost-effective OTEC deployment could have an effect upon economies proportional to the savings in the balance of payments from decreased reliance on oil importation. In addition, certain indirect benefits may result - for example oceanographic exploration may increase information on other off-shore resources such as minerals, and lead to a better understanding of coastal water circulation, sediment movement and possibly fisheries as well. The advanced nature of OTEC technology and the limited need for maintenance would probably have less bearing on a country than would the existence of facilities to use the end product produced.

39. Transfer of technology for the design and construction of power plants has been taking place in developing countries through licensed engineering services of transnational engineering firms, and collaboration agreements have been signed by local firms with foreign manufacturers for the provision of know-how to make equipment needed for the project. The success of the technology transfer will depend not only on economic and legal conditions but also on the availability of skilled labour, the domestic production of equipment and other components, and on the effects made to assimilate, adapt and develop local technologies to mate with OTEC.

4. Case studies

40. OTEC is currently in a rapid stage of development in several industrialized countries - notably, France, Japan, the Netherlands, Sweden and the United States of America. With the exception of the United States and Japan, those countries do not have a thermal resource and are pursuing OTEC for international markets in developing countries.

41. Site studies reflect the focus of interest of those industrialized countries: both France and the Netherlands are considering their overseas island territories for initial projects; the United States has pursued an "island strategy" for initial installations in Hawaii, Puerto Rico, the United States Virgin Islands and its Pacific Ocean territories because of the more favourable economics compared to continental sites.

42. It is important to note that in the present examples the product of OTEC operations may be critical in determining initial and long-range economic favourability. Because no fully tested and proven full-scale system has ever operated or been tested, current cost projections for electricity is expected to be higher for the first plants than for subsequent plants. As a consequence, fresh water and aquaculture production are especially attractive components of current project concepts.

43. No land-based OTEC plant has ever been operated, with the exception of a 22 kW experiment built by Claude in Cuba in 1930. The extremely successful "Mini-OTEC" experiment was a 50 KW floating power plant which successfully operated for the planned few months in 1979 during a first deployment. A second deployment is planned for 1981.

44. Because no actual commercial experience exists, estimates of costs and time are considered not definitive but only indications of ranges. This is apparent in the case studies considered, which reveal large differences in cost estimates, reflecting not only differences in technology but in approach and philosophy as well. It is clear that while OTEC is becoming competitive with other energy sources, each site must be considered individually and a large flexibility should be built into the evaluation process. A developing country can make the most effective choice by being well informed and involved in the early stages of project formulation. Particularly now, there is an opportunity to influence the direction of technological development towards the needs of specific developing countries.

45. The case studies summarized in chapter IV are representative of current interest. They include:

(a) Curaço, Caribbean - a feasibility study undertaken by the European Oceanic Association (EUROCEAN). Completed in March 1980, the study includes a small power plant producing fresh water and aquaculture in addition to electricity; it has wide applicability beyond the reference site.

(b) Tahiti, Pacific Ocean - a report prepared by le Centre national pour l'exploitation des oceans (CNEXO) for the United Nations. Land-based and floating plants are considered for small to medium-sized plants (3-15 MWe). Closed and open cycles are discussed. The results can be adapted to other isolated island sites.

(c) United States Virgin Islands, Caribbean - a study prepared by a major private industrial concern for the United States Department of Commerce to determine the commercial potential of open-cycle OTEC water plants. The report provided interesting insight into basic considerations, including the value of fresh water to the enterprise, and a methodology for site evaluation and selections. The preferred system is actually a closed-cycle plant with a desalination unit.

(d) Punta Tuna, Puerto Rico, Caribbean - a study undertaken by the Johns Hopkins University, Applied Physics Laboratory. It projects costs for electricity and by-products from commercial-size, moored facilities and floating plantships. The conclusions indicate that OTEC electricity delivered to shore by undersea cable will be economically viable for tropical and semi-tropical islands as soon as plants can be built and that ammonia produced on cruising plantships will be fully cost-competitive with that produced from natural gas in new on-shore plants by about 1990.

(e) Nauru, South Pacific - a project to construct a land-based 100 KW "demonstration plant" for Nauru has been initiated by a private Japanese company in co-operation with Tokyo Electric Power Company. A 1-MW floating plant is also under consideration.

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46. In addition, it was noted that several OTEC projects were in varying stages of development. The following examples were cited:

(a) Ivory Coast - a proposal to undertake a feasibility study for a 25 MWe OTEC plant complex with mariculture has been submitted by a United States company; the European Economic Community will be sponsoring a general OTEC feasibility study in 1981.

(b) India - Proposals from private concerns for studies relating to OTEC development are under consideration.

(c) Jamaica - bilateral discussions are taking place with the Swedish OTEC group concerning an OTEC plant and how to finance it.

47. The OTEC programme in the United States was felt to be important to OTEC development globally. During 1980 several policy decisions were made by the United States with regard to OTEC. Public Law No. 96-310 established a national goal of 10,000 MW of OTEC capacity by the year 2000, and directed that two or more pilot plants be constructed to produce 100 MW by 1986. Public Law No. 96-320 declared OTEC plants seaward of the high water mark to be subject to maritime law, and established a $2 billion fund to provide ship mortgages, guaranteed by the United States Government, for OTEC demonstration plants. In addition, laws were passed to provide a 15 per cent investment tax credit for OTEC, and to require utility companies to purchase the output of privately owned OTEC plants.

48. The United States OTEC programme has arrived at the stage of development at which a pilot plant of intermediate electrical generating capacity is necessary in order to demonstrate the potential for commercial applications. It can do so by developing design and construction methodology, acquainting user industries with the operating requirements and product potential, and determining the potential for cost reduction. Studies have shown that commercial OTEC plants can provide electrical power for 70 mills per kilowatt hour by 1987 (in 1980 dollars). This is competitive with combined-cycle, oil-fired plants on United States islands, which project 140 mills per kilowatt hour within the same time frame. Similar projections made for OTEC ammonia production, as an energy-intensive process alternative, show a cost to produce ammonia of $160 per ton (in 1980 dollars). This compares with today's selling price of ammonia at $165 per ton and the 1987 projection of $360 per ton. Thus, a 40 MWe pilot plant could conceivably serve as both a pilot and a demonstration plant if located to serve island or energy-intensive markets. OTEC commercial plants of 100-400 MWe capacity for the Gulf Coast market would follow. Such commercial plants are of a size suitable for meeting the market demand, and appear to be technologically attainable within the next decade.

5. Impediments to OTEC utilization

49. The major impediments to OTEC utilization relate to the lack of demonstrated reliability at full scale and the need for greater awareness and understanding of the benefits that can be realized by developing countries.

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50. The Panel interpreted "constraints" as impediments that would require resolution by external actions, and defined "issues" as impediments that would be removed naturally as the OTEC market develops. The constraints and issues are discussed below and are summarized in table 3, which also contains a guide for assigning the subjects to ad hoc panels. 2/

51. The Panel determined that although current OTEC technology is sufficient for the construction of small-to-medium-sized plants in prototype form, such construction is not yet possible, for reasons discussed below. A critical point in the OTEC development programme has thus been reached, for international co-operation could overcome the constraints and make OTEC a reality for developing countries. Such international co-operation could be of great benefit to developing countries, even though national OTEC programmes exist in the United States, France, the Netherlands and Japan. The Panel feels that widespread application of OTEC could significantly reduce the need for imported petroleum.

(a) Undemonstrated OTEC reliability and economics (Constraint No. 1)

52. Although OTEC does not require scientific or technical breakthroughs, in order to achieve commercial application, utility companies and international lending institutions will not commit their resources to commercial plants until they have seen either a commercial plant in operation with reasonable promise of economic success or a full-size demonstration plant operating successfully under working conditions that approximate commercial operations. The Mini-OTEC demonstration, while proof of the OTEC concept, was not designed to provide the long-term operation or commercial application that would produce a proof of OTEC economics.

(b) Lack of prototype plant funding (Constraint No. 2)

53. The demonstration of OTEC reliability and economics requires the construction and operation of at least one prototype plant that is appropriate for the needs of developing countries. At the present, the funding for such a project is not available through commercial or development banks.

(c) Lack of commercial OTEC funding (Constraint No. 3)

54. After the successful demonstration of OTEC reliability and economics at a prototype plant, a reduction in the obstacles to expanded utilization, particularly in developing countries, can be expected. Nevertheless, there will still be risks associated with the introduction of OTEC into each additional developing country. Consequently, some tapered developmental funding assistance may be required for the initial installations.

2/ The distance from shore of the OTEC resource currently reduces the number of countries that can have economic OTEC systems. Engineering developments on undersea cables are expected to make such distant off-shore resources more usable in the future.

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(d) Lack of awareness and understanding of OTEC technology and potential (Constraint No. 4)

55. Lack of awareness and understanding was felt to be a most important constraint to OTEC utilization in developing countries. The problem can be divided into three categories:

(a) Operating philosophy: a lack of understanding of OTEC includes the fact that OTEC is a marine technology and is operationally different from land-based power plant operations; that fixed costs dominate variable costs due to the zero-cost fuel, and that OTEC power can be despatched in a different fashion; and that multiple uses of OTEC are possible, including desalination, mariculture, and captive electrochemical and electrometallurgical activities;

(b) Investment philosophy: an emphasis on cost/benefits as made by decision makers in appraisal of conventional fuel-burning plants must be countered by increased use of and appreciation for long-term financial analyses and techniques appropriate to a zero-cost energy source;

(c) Resource assessment and management: guidelines for evaluating sites are being refined continually, and the oceanographic and socio-economic criteria are changing as well. In addition, the necessary data for assessment may not exist or may not be available.

56. A full appreciation of OTEC opportunities requires training and must exist at all levels of industry and government management if the correct decision is to be made. In addition, small-scale OTEC plants may be situated on islands or remote coastal areas, and will interact with rural and agricultural needs, or they may be coupled to captive industrial parts. Many developing nations lack the qualified personnel to evaluate those industrial and rural applications.

(e) Requirements for high technical risk-acceptance or risk-sharing (Issue No. 1)

57. Undemonstrated reliability and the lack of operating experience indicate that the risks of an OTEC venture may exceed an acceptable level in countries with limited resources to commit to new energy systems. Some equilibration of risk between the OTEC producer and OTEC user may be necessary; both parties may be required to accept and share some risks, to find ways to obtain insurance, or to negotiate acceptance for finance warranties. It is expected that this will be accomplished as a normal process by contract negotiators.

(f) Absence of a participatory role for developing countries in the fabrication, construction and utilization of OTEC systems (Issue No. 2)

58. The participation of developing countries in OTEC development is considered essential to its successful utilization by those countries, and several OTEC components could be manufactured or constructed using established industries in developing countries.

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59. In addition, information on OTEC planning and development is often delayed in reaching developing countries; consequently they do not appreciate its advanced stage of development. This further delays the initiation of a participatory role. Participation is expected to increase naturally after a successful prototype project has been set up.

(g) Immaturity of the OTEC industry (Issue No. 3)

60. Since OTEC is a new emerging industry, the infrastructure requirements and investment criteria are undergoing constant change. It is not yet clear how OTEC projects might be initiated and financed or what will be the proper role of each industrial participant. This uncertainty will be resolved after a successful prototype has been demonstrated and as the industry approaches normal commercial sales.

(h) Absence of any institutional framework (Issue No. 4)

61. The lack of a designated lead agency to co-ordinate government actions and to assign schedules and responsibility increases the risk involved in an OTEC investment owing to the prospect of bureaucratic jurisdictional disputes. Any ambiguity about the legal status of a plant may preclude long-term tenure on the site, which may preclude long-term financing. The absence of over-all energy planning, including projections of future supply and demand, may prevent the full assessment of the ability of OTEC to provide a meaningful contribution to the energy needs of the developing countries. As prototypes prove successful, and commercial negotiations are initiated, it is expected that developing countries will resolve these issues by policy decision or legislation.

(i) Uncertain market demand (Issue No. 5)

62. Lack of market research means there is little information on the extent of developing country needs that could be satisfied by OTEC. Estimates of the OTEC share of additions to current capacity suggest that there are significant opportunities for OTEC in many locations. This information does not reach the decision makers in international organizations and developing countries, and thus they may not realize the extent of the potential market. This impediment is expected to disappear as a result of education and training.

6. Measures to promote OTEC utilization

63. Having identified the impediments to OTEC, the Panel attempted to suggest a number of measures that would remove or mitigate them. The measures, grouped as in the section above, are further defined as either national and international remedies; they are summarized in table 3, which also suggests the appropriate ad hoc panels.

(a) Undemonstrated OTEC reliability and economics (Constraint No. 1)

64. At the national level, developing countries should examine their interest in OTEC and encourage and participate in the operation of an international OTEC

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prototype project. At the international level, the most effective measure to resolve the impediment would be to have a commercial-sized OTEC prototype plant built and operated, as much as possible, under commercial working conditions. The plant could be an international endeavour involving pooled financial and technical resources of industrial countries, augmented by international aid and funding sources, under the auspices of the United Nations, and located in a developing country. Initial operations would progress towards a demonstration phase, simulating commercial operation while providing the international community with training and research opportunities for OTEC applications.

(b) Lack of prototype plant funding (Constraint No. 2)

65. Measures at the national level would provide encouragement for actions at the international level. They would also include the offer of a site and other local resources and services and contributions in kind. At the international level, no single action would encourage the flow of capital to OTEC projects more than the successful operation in a developing country of an OTEC plant designed for that country's needs. The United Nations should consider the development of such a pilot project, with funding from an international trust fund. Although such an undertaking would be larger than the typical UNDP-sponsored project, it is comparable to the world-wide fisheries project of $170 million - of which UNDP provided $85 million, and to the minerals exploration project of $130 million - of which UNDP provided $80 million.

(c) Lack of OTEC development funding (Constraint No. 3)

66. Measures at the national level should provide encouragement for actions at the international level where the Panel feels that a consortium of interested countries, international institutions and private concerns - that is, a development bank - could provide the initiative and expertise necessary to facilitate co-financing, or another financing arrangement, for an OTEC project. The consortium would represent interested financial participants and arrange and negotiate financing packages. (There are precedents for that type of arrangement.) The consortium or a member of the consortium could actively solicit co-lenders and prepare and appraise the project. A consortium that serves the interested financial participants would also help to lend credibility to the proposal and ensure that the lenders' requirements were being adequately addressed.

(d) Lack of awareness and understanding of OTEC technology and potential (Constraint No. 4)

67. At the national level, several measures were suggested. Developing countries should participate in current OTEC development programmes in order to involve energy planners, engineers and decision makers. Developing countries should be encouraged to write their own OTEC specifications, with technical assistance, if necessary.

68. Developing countries should also undertake studies of the substitution possibilities and the range of possible rural and industrial applications of OTEC

according to site availability and local needs. The application of OTEC energy to agriculture and irrigation in coastal areas should be examined. The local manufacturing or construction of OTEC system components may be possible in many developing countries.

69. Managers and skilled personnel should be developed by means of international training programmes. Countries should be encouraged to identify the OTEC requirements that could be met with local personnel, and the tasks for which training programmes should be created. Joint use of training facilities by several countries should be encouraged. Training should address the following needs:

(a) Operating philosophy: the sharing of experience among developing countries in regard to dealing with new technologies such as OTEC and maritime industries should be encouraged. Industrial nations should orient their public relations efforts towards informing users in developing countries about OTEC;

(b) Resource assessment and management: basic oceanographic information should be collected and analysed in order to determine site parameters and thermal resource capability;

(c) Investment philosophy: energy planners and decision markers in developing countries should obtain information indicating how long-term investment analyses could be undertaken, and compare long- and short-term costs/benefits.

70. Finally, universities should present science and engineering students with OTEC case studies and examples of OTEC applications and problems. Engineering organizations should be encouraged to participate in regional and international programmes. Once the planners and decision makers in developing countries have become convinced of OTEC and its benefits, public awareness should be encouraged.

71. At the international level, a programme of research should be initiated to examine the adaptation of OTEC technology to the needs of developing countries. The programme should identify the rural and industrial applications of OTEC which have potential cost/benefit advantages. In many cases the OTEC resource is available at sites where there is no demand for industrial electricity. This offers an opportunity to establish new industrial facilities. Specific opportunities include desalination, mariculture, electrochemical and electrometallurgical apparatus. These concepts are described in more detail in the case studies (chap. IV).

72. A training and educational programme should be established to provide instruction in OTEC technology, resource assessment, project evaluation and operation. A study of short-term and long-term cost/benefits should be prepared, and information should be provided to describe how OTEC operations differ from conventional power plant operations. The latest OTEC resource assessment guidelines should be circulated to Governments and discussed in workshops and seminars.

(e) <u>Requirement for high technical risk-acceptance or risk-sharing (Issue No. 1)</u>

73. Measures at the national level would include attempts by the developing country to secure performance warranties from the producer of the OTEC system. At the

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international level the developing country and the industrial producer should, during the initial development phase, receive some risk protection through an international funding agency.

(f) Absence of a participatory role for developing nations in the fabrication, construction and utilization of OTEC systems (Issue No. 2)

74. At the national level, potential user countries should inform producers or an international co-ordinator of their desire to participate in the OTEC development programme. The joint use of training facilities and/or demonstration projects should be encouraged.

75. At the international level a programme should be initiated to identify in and among developing countries suppliers of equipment, materials and services that could be used in the OTEC programme. Oceanographers, marine engineers and energy planners should participate in training programmes through working fellowships created by industrial producers.

(g) Immaturity of the OTEC industry (Issue No. 3)

76. At the national level, prospective OTEC users should seek to inform themselves about the structure and nature of the emerging OTEC industry through examination of relevant documents from conferences and technical journals. At the international level, the United Nations should prepare a descriptive note on the OTEC industry, its components and its methods of operation.

(h) Absence of institutional framework (Issue No. 4)

77. At the national level, over-all energy planning should be initiated; a lead agency for OTEC evaluation and development would be desirable. It may be necessary to co-ordinate various skills and disciplines within the developing country to address properly the full range of issues involving the law, resource management, and environmental protection. At the international level, several international issues will have to be resolved, including safety zones, codes and standards, insurable risk studies, and possibly vessel registration. Those issues are discussed in the case studies and are being dealt with by the Inter-Governmental Maritime Consultative Organization.

(i) Uncertain market demand (Issue No. 5)

78. At the national level developing countries should examine their OTEC resource potential and communicate their interest in OTEC to suppliers of OTEC systems. At the international level, studies of the international market are currently in process and, when completed, should be widely circulated. They should be comprehensive and make few a priori restrictions about possible sites.

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Table 3. Summary of constraints and issues, and measures to overcome them

Constraints	Measures	Ad hoc panel
1. Undemonstrated OTEC reliability and economics	Build and operate at least one prototype OTEC plant	Research and development
2. Lack of prototype plant funding	Establish an OTEC demonstration fund	Finance
3. Lack of OTEC development funding	Establish an OTEC development fund	Finance
4. Lack of awareness and understanding of OTEC technology and potential	Increased information flow Education and training programme Improved communications	Information education Industrial/rural
Issues		
1. Requirements for high technical risk-acceptance or risk-sharing	Establish an OTEC demonstration fund and OTEC development fund	Information Industrial Finance Research and Development
2. Absence of a participatory role for developing nations in the fabrication, construction and utilization of OTEC systems	Encourage open planning Identify in-country work Sponsor fellowships Assist developing countries to unite specifications	Research and Development Infcrmation Education
3. Immaturity of the OTEC industry	Analyse and recommend procedures and standards	Industry
4. Absence of an institutional framework	Designate lead agency Define legal status Domestic policy decision	Industry
5. Uncertain market demand	Undertake surveys	Research and Development Information

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B. Tidal power (agenda item 5B)

1. Status

79. Unlike most of the other "new" energies, ocean- or land-based, tidal energy represents an existing industrial reality. The French tidal plant of La Rance, which produces some 240 MW, is considered very successful, having confirmed all previous expectations. Although its use has gone far beyond the stage of research and development, it remains unique in the world, except for an experimental mini-power plant of 400 kW capacity located north of Murmansk in the Union of Soviet Socialist Republics. Currently, the Republic of Korea, Canada, India and the United Kingdom are pursuing new studies, some of which may lead to experimental plants, and later to commercial plants. This reveals a renewed interest in tidal energy.

2. Global potential

80. The sites at which the construction of an installation having a capacity of over 200 MW is likely would have to meet certain criteria: favourable geographical location, in order to minimize engineering work; an average tide of 5-12 metres; the possibility of linkage to a grid, in order to allow the variable output of the tidal plant to be accommodated; and favourable socio-economic and ecological conditions. Some 40 sites in the world meet those conditions; at only half could a plant having a capacity of over 1,000 MW be considered. Those sites are generally located in industrializaed countries.

3. State of the art

81. Tidal energy has been used for more than 15 years. The power plant at La Rance has proved the reliability of its engineering structure in the marine environment, as well as that of the bulb-generating unit and the general conditions of optimum utilization. France expects to publish an over-all report soon. It is quite possible that new technologies will reduce the time and cost of civil engineering work and increase the rating of each generating unit. From an economic point of view, based on 1980 price evaluations, the cost would be 1.45 billion French francs for a power plant of 240 MW, which would represent $1,500 per kW and a total cost of production of 80 mills/kW. Those costs are in the same range as estimates made in 1975 by EUROCEAN, the United States Department of Energy and scientists in the United Kingdom - namely $800-$3,470 per kW and 25-106 mills/kWh. The cost of 80 mills/kW is comparable to the cost of present production from a fossil-fuel power plant of 900 MW established in a country without national sources of fossil energy. Recent studies conducted in the United Kingdom and France suggest that tidal power could produce electricity at a cost comparable to that of coal and better than that of oil in those countries. However, those conclusions at present apply only to those sites with the highest tidal range and, in any event, cannot compare with nuclear power.

82. Preliminary studies concerning micro-tidal plants in areas of average tidal range (5 metres) having power outputs of a few MW show that the production costs would be very large and, in any case, greater than 70 centimes/kWh (175 mills/kWh.

Those studies lead to the conclusion that such an establishment cannot be justified except in very particular cases - when electricity from other sources could be produced only under particularly unfavourable conditions, or the plant would find justification in being part of a larger programme, including aquaculture and coastal area management.

4. Constraints

83. Besides the high cost on investment, the major constraint which hampers the development of tidal plants in some locations is potential harm to the environment. While a tidal power plant does not present any major risk and does not itself lead to pollution, it entails a complete change of natural hydraulic conditions over a large surface area and interferes with a number of activities (navigation, fisheries, marine culture). Such changes have multiple effects on the marine ecological system, water drainage, water quality and pollution control and many other associated matters of local concern. Landfill sites might also cause local environmental problems.

5. Recommendations

84. It is important for studies to be pursued on tidal energy because it can be compared favourably with fossil sources of energy in some particularly suitable sites. The studies should, however, give priority attention to possible effects on the environment. This aspect should be developed in agreement with the support of the local population. It is recommended that the studies pay particular attention to the development of appropriate technology for micro-tidal plants in special sites.

C. Off-shore wind energy

85. Wind energy systems are being evaluated by another technical panel, and the present Panel had only a brief discussion of their special off-shore aspects. Three groups represented on the Panel had carried out relevant studies - the United Kingdom, the Netherlands and EUROCEAN. While the groups studied somewhat different cases, their broad conclusions were not greatly dissimilar. They can be summarized as follows: since the wind off shore is stronger than on the adjacent land (hilltops aside, it is perhaps 10-14 per cent higher 20-30 km off shore), off-shore units should be capable of providing greater output than on-shore ones. Further, they can often be placed in larger arrays than is environmentally acceptable on many land-based sites. Estimates suggest that resulting off-shore electricity units might be in the range of 50-100 mills/kWh for large machines between 5 and 10 MW each at wind speeds around 10 m/s. Since civil engineering and underwater cables account for a significant proportion of the cost, reductions will depend on technolgical developments in areas that are also being studied extensively in the wave and tidal programmes. Close co-operation and information exchange is therefore important, and is recommended by the Panel.

D. Wave energy (agenda item 5 (d))

1. Status

86. Wave energy technology is at an early and quite rapidly changing state of development. Cost estimates for wave-generated electricity have halved in the past two years as a result of detailed design studies and small-scale experiments. Such studies and experiments continue and could well result in further cost reductions in the next two years.

87. Wave energy has a number of attractive features. For example, in some locations it may provide energy from storms and winds occurring thousands of miles away. Waves from distant areas thus supplement those caused by local winds to provide a greater stability of output than would be obtained from the local winds alone. Further, some designs are modular in construction in units around 1 MW each and lend themselves to the use of modern techniques of mass production applied on a civil engineering scale. On environmental acceptability, they can be located at a sufficient distance off shore so as not to impinge on visual amenity. Physical impact on the shoreline is minor or even beneficial (for instance, providing coastal protection). However, wave energy also has some important constraints both generally and on its application to developing countries.

2. Constraints

88. Present designs assume that wave energy devices are to be placed in a vigorous wave climate (45-50 kW/m mean annual value) such as found predominantly beyond 30°N and 30°S. Since the developing countries do not, on the whole, lie in those regions, such devices are not often applicable to them.

89. There are, however, geographical exceptions - for example, the West African coast between the equator and 20°S. Furthermore, it is not known whether economical systems would result if designs were placed in less vigorous wave climates. Some evidence may emerge from the Kaimei device in Japan, which is in a sea of 14 kW/m.

90. The Panel did not dwell on the possible geographical exceptions referred to above, for the following reason: even in the more favourable areas beyond 30°N and 30°S, potential customers for wave-generated electricity that costs 120-240 mills/kWh have not been identified. This is not because wave energy might not be economical - for example, on island sites that at present depend on diesel-generated electricity. It is, rather, that wave energy at its present cost is not the most economical alternative source of power.

91. Hence the Panel concluded that the most important constraint on wave energy was not reliable engineering (though that may apply to some designs), but poor economics leading to lack of potential customers. Hence wave energy must be regarded as still in the research and development stage.

92. The Panel recognized that their conclusions did not apply to small-size applications of wave energy devices - for example, lighted buoys, communication links, lighthouses or off-shore platforms that can afford premium prices for locally generated electricity.

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93. Various other constraints that might inhibit further progress to demonstration have been examined provisionally. These are:

(a) Technical: Mooring and anchoring could be a limiting constraint, expecially in view of the enormous size of the devices. Furthermore, down-time, exacerbated by problems of repairing units in the hostile off-shore environment, might offset the advantages of small 1-MW units, and any marine growths on structures could be expensive to remove.

(b) Environmental: Fish spawning grounds may need to be avoided.

(c) Economic and financial: High capital cost, common to other renewable sources of energy.

3. Solution and recommendations

94. The central solution is more research. The Panel recommends that the status of the technology be reviewed again in two to three years time.

E. Other sources

1. Ocean currents

95. The Panel reconfirmed the conclusion reached at its first session that, as far as can be determined at present, ocean currents produced too little energy at too high a cost, and no commercial development could be expected before the year 2000. Studies are currently under way in Japan and the United States, and the Panel recommended that developments in the field be followed in the future.

2. Salinity gradients

96. The Panel reconfirmed the conclusion reached at its first session that although scientific studies and laboratory experiments indicated that power could be derived from salinity gradients, the transition to practical applications was not in the near future - that is, before the year 2000. Although continued research on membrane technology was under way and methods without membranes might be promising, no change in the conclusion was anticipated.

3. Marine biomass

97. The Panel reaffirmed that there were two reasons for considering marine biomass, in association with the Technical Panel on Biomass Energy. The first derived from the fact that marine biomass had extremely high growth rates, which argued for a marine biological approach, while the second was related to the large amount of nutrient-rich water which would result from OTEC plant operations. The Panel encouraged continued research in the field of marine biomass for energy production. Particular attention should be paid to biological "getters" of uranium and other fuels, to the synergism of combining genetic engineering with the nutrient-rich cultivation medium of OTEC cold water, and to the combination of several ocean energy sources to stimulate biomass production (wave power and kelp cultivation, or OTEC and mariculture of biomass stock).

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III. SUMMARY AND RECOMMENDATIONS

98. One of the major energy problems facing the world today is the rapidly increasing demand for and price of oil. Later on, the same problem will occur with other fossil fuels and with uranium. Hence, renewable sources of energy are of increasing importance. They are especially important for the developing countries, many of whose economies are suffering very badly from the adverse balance-of-payment effects of oil imports. Among the renewable sources, the ocean resource is substantial. The following ocean resources were considered by the technical Panel: OTEC, tides, waves, ocean currents and salinity gradients. Ocean wind and biomass are dealt with by other Panels. The size ranges of ocean energy plants, their requirements in terms of capital investment and their electricity costs, compared to those aspects of other energy systems, are shown in Figures IV, V, VI, prepared by EUROCEAN.

99. Of the ocean technologies, there is only one that is commercially established - namely, tidal energy. There are a few prime tidal sites in the world where the technology is probably economic now compared to the cost of fossil fuels (oil and coal). Other sites may become economic as energy prices rise. While tidal energy will make a useful contribution to world energy supplies over the next 20 years, it is not large by global standards and will not make a major impact on the energy problems of the developing countries. The conclusion on wave energy resources is somewhat similar, though for different reasons. It is larger in extractable form than tidal energy, but is of most interest beyond 30° N and 30° S. Hence, it is applicable to only a few of the developing countries. Even in such countries it is unlikely to find wide application in the present century because its unit costs are too high; more research is needed before its ultimate economics can be assessed. Neither ocean currents nor salinity gradients were thought to have any prospect of commercial application in the century.

100. The Panel focused primarily on OTEC, on the basis of projected conceptual viability, significance for developing countries in the next 10-15 years, and amenability to international action. Its advantages and the constraints on its early exploitation are summarized below.

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Figure IV. Capital investment in ocean energy systems

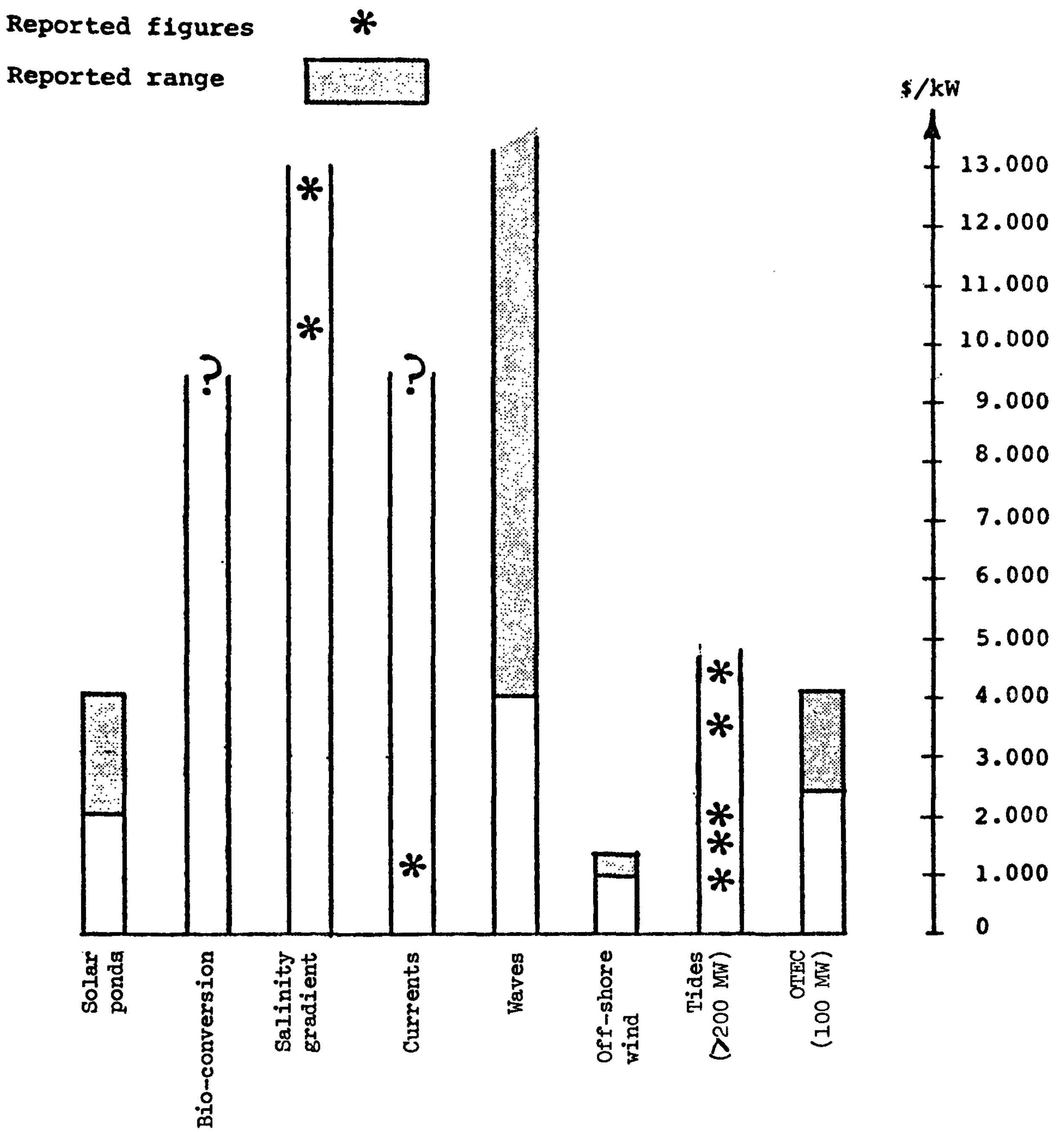


Figure V. Size ranges of single plants

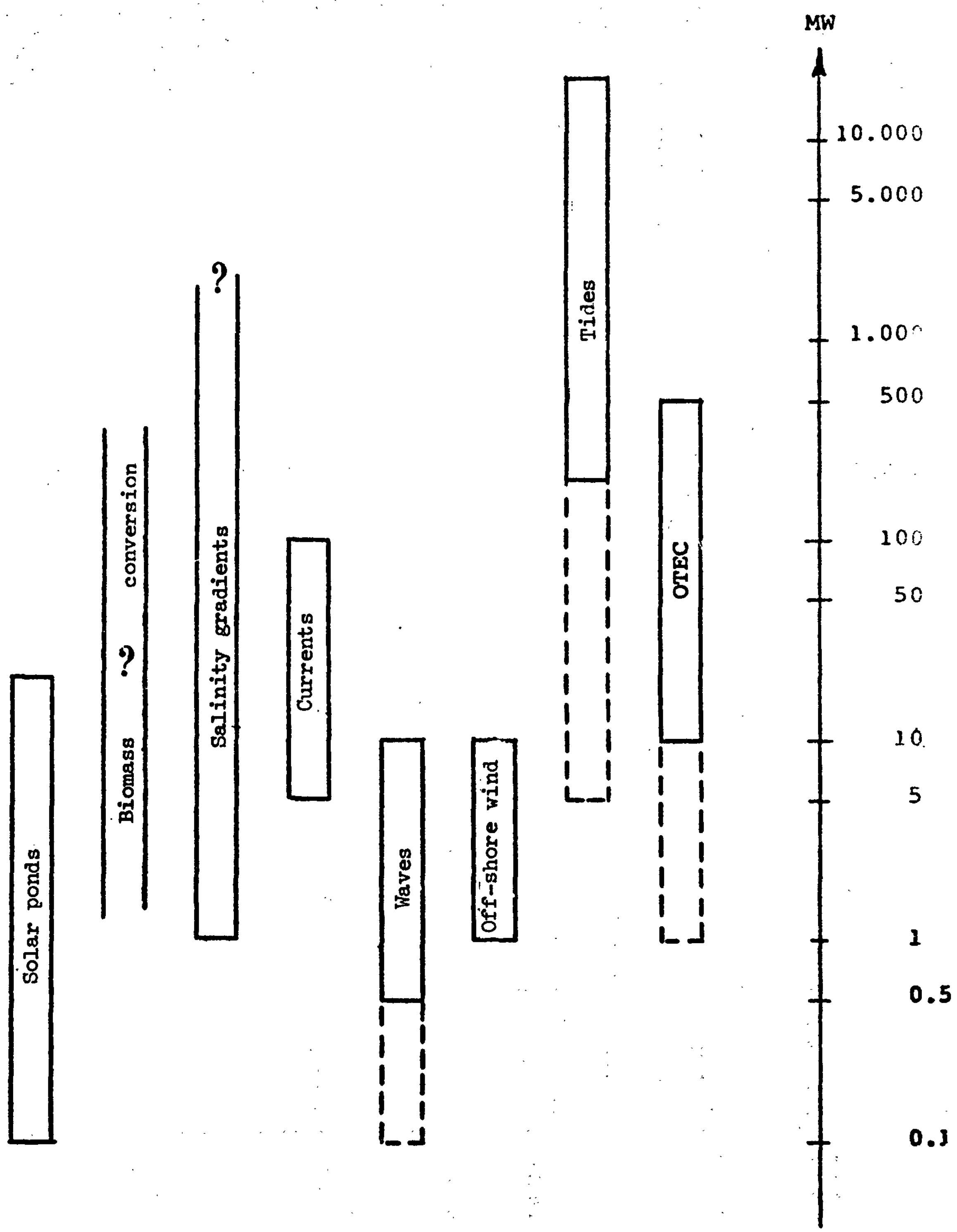
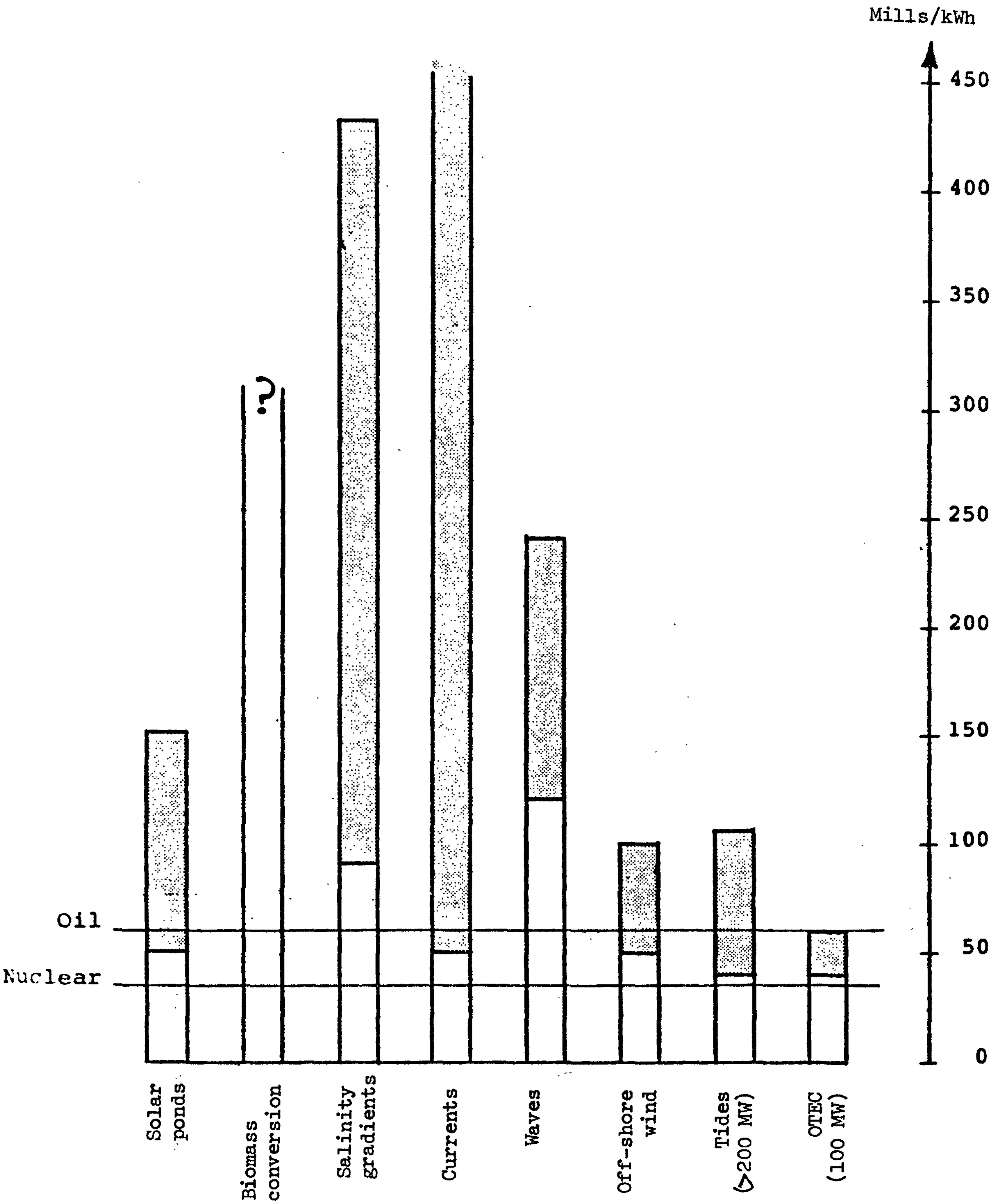


Figure VI. Electricity costs



A. Advantages of OTEC

101. On the basis of experimental trials on a small scale and of conceptual design studies on a much larger scale, the advantages of OTEC are clearly seen by technical experts. Those advantages were discussed in chapter II above, and relate to economics, technology, the environment, and resource and technological accessibility.

B. Constraints on OTEC development and exploitation

102. The idea of generating electrical energy from such small temperature differences and with such large structures somewhat strains the credibility of the non-specialist. Because it is not obvious that the process will work easily, lack of credibility is the first constraint to OTEC development. In fact, OTEC will not be fully credible to those responsible for purchasing and financing until its reliability has been demonstrated on a commercial scale.

103. There are also constraints involving OTEC technology and its potential. OTEC differs from conventional technologies; those likely to use it or invest in it do not fully take account of such factors as the effects of zero fuel-cost and of the maritime location on operating procedures and plant economics, or the need to develop an investment philosophy that credits the long-term benefits of those effects against the drawback of high capital charges. The resource, its management and its use are understood only in broad terms, inadequate for individual developing countries that may want to evaluate the full relevance of OTEC to their needs.

104. The Panel believes that OTEC is an emerging ocean technology of special potential significance for the developing world and that it should be given a high priority by the Conference. In order for OTEC to overcome the present constraints on its exploitation, the Panel makes the following recommendations:

(a) A demonstration project should be initiated in a developing country to demonstrate OTEC reliability and economics, under size and operating conditions appropriate to a commercial operation. It should be open to all who wish to participate. An international demonstration project under United Nations auspices would increase the understanding of OTEC and of the benefits of its application to developing countries.

(b) A special OTEC demonstration fund should be established to finance the project described in (a) above.

(c) An OTEC development fund should be established to support increased international awareness of OTEC and early projects in developing countries.

(d) An information, education and training programme should be established, with emphasis on resource and site assessment.

(e) Studies should be undertaken within existing United Nations programmes to address the following subjects:

(i) Developing country markets;

(ii) Research assessment and network integration;

(iii) Long-term OTEC cost/benefit;

(iv) Identification of manufacturing opportunities in developing countries;

(v) Multiple-use concepts, including the "energy island" concept;

(vi) International co-operative plantship projects;

(vii) Refinement of guidelines for resource assessment and site evaluation.

(f) Any demonstration project arising out of recommendation (a) should be linked with activities arising out of recommendation (c). This should be done in such a way as to provide an over-all United Nations focus for the participation of all countries interested in OTEC, including information advice and studies aimed at applications and markets, and the establishment of fellowships to advance and train developing country specialists in OTEC technologies.

(g) On tidal power, activities should continue within existing United Nations programmes to help evaluate its prospects in individual developing countries interested in it.

(h) The position on wave power should be reviewed again in about two years.

IV. CASE STUDIES

A. Curaçao (EUROCEAN)

1. Configuration and siting

105. A small land-based installation, which would produce electrical power, fresh water and such aquacultural products as shellfish and shrimps, was studied. Although many sites would qualify, for the initial investigation, Curaçao, Netherlands Antilles, was chosen as representative. Curaçao, located in the Caribbean close to Venezuela, has steep slopes on the south-west coast and a Δ T of 20° C at a depth of 650 m. All fuel is imported or bought from a local refinery.

106. Environmental conditions are good because the best sites are on the sheltered south-western side of the island. The infrastructure in Curaçao, which will become completely independent in 1990, is well developed, and industry has been present for many years. A Dutch energy research programme sponsors alternative energy research schemes in the Antilles.

107. The most important site requirements in the study included the three products: OTEC electricity, desalinated water, aquaculture (ODA). The site requirements are shown in table 4.

108. The most essential requirement is the presence of a 20° C Δ T, which can be obtained with a cold water pipe not longer than 3 km. High wave loads, hurricanes or other frequent natural hazards would, however, require costlier installations and pipe protection.

109. Because of local conditions and the small size of the plant - 1-3 MWe, the electrical output is not as critical to the venture as is the fresh water production. Aquaculture products are a helpful but not decisive factor in detailed site evaluation.

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Table 4. OTEC electricity-desalination-aquaculture (ODA)

Oceanographic	Water depth of 900 m within 3 km of shore
Geographical	Δ T 20° C within 3 km of shore
	Steep smooth underwater slope (30-45°)
	Shallow and smooth beach (sand or gravel)
	Nutrients in deep water 30 mg/litre
	Flat shore area at sea level (20-50 ha)
	Low wave loads, currents and tides
	No hurricanes or tsunamis
Local market situation	Growing demand and stable prices for electricity, fresh water, and fish products
Realization	Basic industrial background
Operation	Low land cost
	Easy access (infrastructure)
	Local labour available
Other	Political and social stability
	Good connexion with Europe

2. Costs

110. The following breakdown of costs was made.

Investment cost	
Cold water pipes and pumps	$US 4.2 million
OTEC equipment	5.3
Desalination unit	4.6
Aquaculture	3.6
Complete ODA installation	$17.7
Operational costs	
Labor costs	$137,000/year
Maintenance	
Labour, materials, chemicals	$486,000/year
	$623,000/year

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3. Revenues

111. Because both fresh water and electricity are public utilities, any projected sales price has to be compared with current production costs at potential sites. The price of electrical power was assumed to be 70 mills/kWh (10 mill=$US 0.1), and the fresh water price was $1.80/ton. The price of the aquaculture product is dependent on selected and local export markets; a sales price of $2.30/kg was chosen. Annual revenue is tabulated below.

Product	Quantity	Thousands of $US
Electrical power	No saleable amount	-
Fresh water	2,200 m^3/day	1,440
Shellfish	600 tons/year	1,380
Total revenue		2,820

4. Economics

112. A set of constant yearly increase rates for fuel cost, labour and maintenance were assumed over a 20-year plant lifetime. During the first years of operation the OTEC-powered ODA installation is not as cost effective as a diesel-powered plant. This effect reverses after a number of years because of the 12-15 per cent rise assumed in diesel fuel costs. OTEC electricity becomes more economic when the fuel price has risen higher than $420/ton (in 1979 $US) or when the yearly increase in fuel costs is over 20 per cent. Although both fresh water and aquaculture contribute about half the total revenue, the profitability goes up on 3 per cent, from 16 to 19, when aquaculture is added. Furthermore, the scaling-up of existing OTEC aquaculture experiments is perceived as facing major problems requiring considerable research and development. OTEC on this small sale has a much higher specific investment cost than larger floating plants.

113. An interesting result of the study is that a diesel-driven desalination unit can be a profitable first stage, with OTEC power production following at a later stage, together with aquaculture.

114. Assuming a scenario of inflation and rising fuel prices, EUROCEAN has constructed graphs showing OTEC to be less sensitive to write-up fuel price changes and varying inflation rates than is diesel power. The project return is much more sensitive to capital cost increases than operating cost increases.

B. Tahiti (CNEXO) I

1. Configuration, No. 1 siting

115. A land-based plant using the closed cycle OTEC system was examined because it had the following advantages:

(a) Great simplicity of operation requiring a small operating staff;

(b) Resistance to natural hazards such as cyclones;

(c) Proximity to many product users of fresh water and refrigeration;

(d) No requirement for electrical cable to shore.

The cost of the cold water pipe will be greater, however, but this will be less critical as size increases.

116. The Tahiti site is relatively calm with few cyclones or violent storms. The 1,000 m isobath is found at about 3 km from the shore, which is surrounded by a shallow lagoon in which the 15 MWe plant could be situated. The cold water pipe will traverse the shoreline through a tunnel built below the coast in order to avoid disturbances by large waves and swell. The closed-cycle plant would use ammonia as the working fluid.

2. Costs

117. The costs were calculated as shown below.

		Percentage of total		Percentage of total
Electro-mechanical installation: turbines; generators; condensers; pumps	17.5 a/	22.3	55.3 a/	33.5
Cold water pipe and material	42.3 a/	53.8	64.8 a/	41.5
Land-based installation: civil works	16.3 a/	20.7	32.8 a/	21.0
General engineering	2.5 a/	3.8	3.0 a/	1.9
Total	78.6 a/		155.9 a/	
Maximum power	3.9 MWe		15.63 MWe	
Price/kW	$20,000/KWe		$10,000/KWe	

a/ Millions of United States dollars; $US 1 = 44 French francs.

118. The cold water pipe is a major factor in the cost, varying from 42-54 per cent depending on plant size. The cold water pipe accounts primarily for the large difference in cost in comparison with the Curaçao costs.

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3. Revenues

119. The CNEXO study takes note of the fact that even after electricity is generated, a flash evaporation desalination system can be installed, producing fresh water for 3-5 French francs (FF)/m^3 (\$1-2/ton), which is below production prices for conventional units.

120. The cold water discharge might also be used for a major refrigeration installation which, in the CNEXO study, is another product in addition to aquaculture.

4. Economics

121. Investment costs of prototypes appear larger than those for conventional thermal plants, but the cost of exploitation, especially for land-based plants, is greately reduced owing to low operating costs. For 10 MWe plants and larger, cost of a kWh is less than it is for oil-fired plants. Even for 2.5-3 MWe plants, the cost is lower if petroleum prices are assumed to rise at 7 per cent per year.

C. Tahiti (CNEXO) II

1. Configuration, No. 2 siting

122. A floating plant of 3-15 MWe size was examined, with mounting on a barge structure. The plant could be built in France and floated to Tahiti; for strong seas, the power is reduced and in major storms, the barge may be disconnected from its anchorage. For Tahiti, the plant is expected to be operational 87 per cent of the time for the open cycle and 92 per cent for the closed cycle.

2. Costs

123. While the barge would be built in France, the cold water pipe and pumps would be built in Tahiti. The cost of a kWh takes into account the 87 per cent availability, the annual variation of warm water temperatures, maintenance, and operating costs as well as local factors.

Plant size (MWe)	Investment cost (Thousands of $US KWe)		Unit cost, closed systems (Mills/kWh)
	Open	Closed	
2	16.5	17.5	300
5	11.3	11.3	200
10	8.8	8.8	150

D. United States Virgin Islands (Westinghouse)

1. Configuration

124. The study was constrained to sites where fresh water demand was more critical than electricity. The most cost-effective concept was an open-cycle system which produces both electricity and fresh water rather than fresh water alone. When operating and capital costs are both considered, the open-cycle OTEC plant is more cost-effective than a typical multistage flash evaporator. Although the capital cost is about three times greater, a hybrid design may reduce the cost of water by a factor of about two.

125. The nominal plant capacity for St. Croix is 5 million gallons/day (MGD), or 20,000 m^3/day. Costs for a hybrid closed-cycle OTEC power plant with multistage flash evaporator and for an open-cycle plant are estimated at $US 45 million, while the larger 15 MGD open-cycle plant would cost $200 million.

126. The open cycle is more adversely affected by economics of scale and consequently small-scale appears more uneconomic. Given the state of the art in closed-cycle plants, they will probably be the first to be built.

2. Costs

127. The major contributions to the cost are the following:

(a) Closed-cycle power module;

(b) Multistage flash evaporator;

(c) Platform cost;

(d) Cold water pipe;

(e) Pumps;

(f) Water delivery system.

128. The platform suggested is made of steel, semi-submersible, incorporating a 2-MW closed-cycle OTEC power plant. Two cold water pipes can be of 1.5 m standard polyethylene, supported by a single anchor-leg mooring similar to that already developed by the off-shore petroleum industry for application in water depths of over 1,600 m.

3. Economic analysis

129. The economic attractiveness included a requirement for a 40 per cent discounted cash-flow rate of return on investment. This reflects interest in encouraging a private investor to participate in the development of a new technology. Even with the requirement, the resultant selling price of water, $1.39/$m^3$, is less than the current average cost of water in St. Croix.

130. The hybrid plant design produces only fresh water; all the power generated is used to overcome parasitic losses, operate all pumps and the air-removal compressor, and supply living accommodations.

131. It is suggested that the system can be well protected when threatened by severe storm conditions by rapidly disconnecting it from mooring, deballasting, retrieving cold and warm water pipes, and towing the system to a harbour of refuge. In order to assess costs involved in substantially avoiding the risk of total plant loss of a land-based or near-shore system in a severe storm, further investigation is required. The land-based facility was preferred by most island communities interviewed: it appears to be safer for personnel and equipment and improves plant accessibility for repair and maintenance. However, it may not be economical to locate the plant on or near shore because of increased costs of cold water pipe.

4. Methods of financing the OTEC plant

132. Because OTEC is capital-intensive, assembling sufficient money is a problem. The 1979 capital estimate for the plant studied is larger than the annual budget of the United States Virgin Islands for the same year. This implies that a combination of funding sources may have to be used from the United States Virgin Islands, federal, and private funds.

133. The largest scheme might include a reduction in unemployment as a result of increasing the industrial base in the United States Virgin Islands. The incentive for the federal Government would be to assist development in order to decrease financial dependence, by creating a reliable source of water and additional power, if needed.

E. Nauru (Toden Sekkei Co. and Tokyo Electric Power Co.)

134. Toden Sekkei Company, in co-operation with Tokyo Electric Power Company, initiated a project to construct an OTEC "demonstration plant" of 100 kW off Nauru and to conduct a series of experiments in preparation for future practical utilization of the system. Approval from the Government of Nauru was granted in 1979.

135. In the entire power-generating system, the heat exchangers of the evaporator/condenser have a particularly important effect on the cost of power generation. In fact, it is thought that they account for 30-50 per cent of the total construction cost. The choice of heat exchangers is therefore the first point of consideration in OTEC.

136. Toden Sekkei selected the plate and shell-type heat exchanger, taking into consideration the factors of landing, installation, maintenance, and economic efficiency.

137. Fiber-reinforced plastic was adopted as material for the cold sea-water intake pipe, taking into account the marine environment of the South Pacific, control of the sinking speed in the construction of the pipeline, and the impossibility of

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inspection and repairs in the deep sea. Construction of the pipeline will be based on a thorough investigation of the marine meteorological conditions, weather, and environment of the designated sea area. This will be reflected in the elaborate considerations regarding the structure and specifications at the landing spot.

138. The 100-kW demonstration plant is scheduled to start operating during the middle of 1982. Ultimately, there is a plan to install an OTEC plant with an output of 10,000 kW. The table below summarizes its specifications.

OTEC on Nauru

Total output	10,000 kW
Output per unit	2,500 kW/unit
Number of units	4
Thermal cycle	R-22 on-cycle
Annual power generation	38,200,000 kWh
Volume of warm sea water	32,400 m^3/h/unit (27.5°C)
Volume of cold sea water	28,000 m^3/h/unit (7.0°C)
Internal diameter of intake pipe	2,300 mm (FRP)
Auxiliary mobility	50 per cent
Utilization rate	90 per cent
Depth of cold sea water intake	500 m ca.
Intake pipeline	750 m ca. (under sea)

F. Puerto Rico (Applied Physics Laboratory, Johns Hopkins University)

1. Configuration

139. A plant-ship deisgn was prepared to produce 40 MWe net electrical power capability with a Δ T=23° C, in two versions:

(a) A moored plant which would deliver the power generated to on-island utility via undersea cable;

(b) A cruising plant-ship which would produce ammonia in an on-board process plant for transshipment. At Punta Tuna, Puerto Rico, an average Δ T of 22.4° C would lower the output to 33.8 MWe, because electrical power varies with the available temperature difference.

2. Costs

140. Detailed cost estimates for acquisition, construction and deployment have been made for the two configurations and are summarized below, in thousands of dollars.

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Work breakdown structure costs b/	Moored plant $\Delta T = 40.2°$ F 34.9 MWe on board (33.8 MWe to shore)	Grazing plant $\Delta T = 42°$ F a/ 40 MWe on board (42.9 each at 43° F)
Platform system	$ 66.4	$ 47.3
Hull structure	20.4	20.4
Position control systems	24.2	7.6
Outfit and furnishings	8.8	9.0
Sea-water systems (40 MW)	12.5	9.8
Corrosion control	0.5	0.5
Cold water pipe system	9.5	9.4
Power system (40 MW nominal) c/	45.2	45.2
Deployment and system test	12.7	11.6
Industrial facilities	3.7	1.7
Engineering and detail design	3.3	3.3
Subtotal	141.3	119.0
NH_3 plant or cable (deployed)	29.3	24.7
Total	170.6	143.7
$/kWe on board	4 049	2 980

a/ Does not include propulsion power. However, if 43° F is attained by grazing at 0.4 knots with an average propulsion power requirement of 1.4 MWe, net power would be 42.9 - 1.4, or 41.5 MW, and specific cost would be $2,870 kW on board.

b/ Estimated costs in mid-FY 80 dollars. No allowance for profit or contingencies.

c/ Based on the use of 4 power modules of the APL type, each of which is sized to produce 10 MWe (net) at a $\Delta T = 42°$ F.

Annex I

AGENDA OF THE TECHNICAL PANEL ON OCEAN ENERGY AT ITS SECOND SESSION

1. Opening

2. Adoption of the agenda and organization of work

3. Review of intersessional work

4. Ocean Energy Panel priorities and goals

   A. Results of the Preparatory Committee - second session, 21 July-1 August 1980

   B. Schedule of the Conference preparatory activities

   C. Presentation of intersessional contribution from experts

5. Final draft report

   A. OTEC

      (i) Significance

      (ii) Constraints

      (iii) Measures to overcome constraints

      (iv) Recommendations

   B. Tidal energy

      (i) Significance

      (ii) Constraints

      (iii) Measures to overcome constraints

      (iv) Recommendations

   C. Off-shore wind energy

      (i) Significance

      (ii) Constraints

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(iii) Measures to overcome constraints

(iv) Recommendations

D. Wave energy

(i) Significance

(ii) Constraints

(iii) Measures to overcome constraints

(iv) Recommendations

E. Other

(i) Significance

(ii) Constraints

(iii) Measures to overcome constraints

(iv) Recommendations

6. Recommendations - national/international/United Nations (To be transmitted by the Chairman to the synthesis group, 17-27 February 1981)

7. Other matters

8. Approval of final draft report

9. Closing

Annex II

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Members of the Panel

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Organisation des états Américains, Genève: F. E. Hurtado de Mendoza

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United Nations bodies

United Nations Conference on Trade and Development: Helen R. Argalias

United Nations Industrial Development Organization: Siro P. Padolecchia

Annex III

DOCUMENTS

UNERG/OP/II/1	Provisional agenda
UNERG/OP/II/2	List of documents
UNERG/OP/II/3	International issues and recommendations concerning ocean thermal energy conversion: paper prepared by Advanco Corporation, Los Angeles
UNERG/OP/II/4 English and French	Micro tidal power plant: paper prepared by SOGREAH, Ingénieurs conseils
UNERG/OP/II/5	Ocean Energy Utilization, paper prepared by Takeaki Miyazaki
UNERG/OP/II/6	Cost effectiveness of wave energy converters: note by F. J. P. Clarke
UNERG/OP/II/7	OTEC: a Jamaican source of energy: paper prepared by the Swedish OTEC group
UNERG/OP/II/8	1. Assessment of ocean energy projects 2. Summary of OTEC work: paper prepared by EUROCEAN
UNERG/OP/II/9 French only	Méthodologie d'étude d'un site propice à l'exploitation de l'énergie marethermique

Papers previously distributed

UNERG/OP/II/10	Absorption of ocean energy in power systems, by A. N. Singh, India
UNERG/OP/II/11 Spanish and English	Comments about the transfer of technology in "OTEC" power plans: contribution from Chile, prepared by Sergio Varas
UNERG/OP/II/12 French only	Energie thermique des mers, centrales à terre de petites et moyennes puissances à cycle fermé: rapport préparé pour le Centre national pour l'exploitation des océans
UNERG/OP/II/13 French only	Energie thermique des mers, centrales flottantes de petite et moyenne puissance: rapport préparé pour le Centre national pour l'exploitation des océans

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UNERG/OP/II/14	Living from the ocean - result of the EUROCEAN ODA feasibility study, March 1980
UNERG/OP/II/15	The development of ocean energy in the third world, by Frederick E. Naef
UNERG/OP/II/16	Wave energy technology, by F. J. P. Clarke
UNERG/OP/II/17	Utilization of tides energy - technical and economic aspects, by L. B. Bernstain

Annex IV

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