COUNTRY NOTES

The Country Notes on OTEC compiled for previous editions of the *Survey of Energy Resources* have been revised, updated and augmented by the Editors, using national sources, other information and personal communication. Valuable inputs were provided by Don Lennard of Ocean Thermal Energy Conversion Systems Ltd.

American Samoa

In mid-2006 it was reported that the country's Power Authority was being supported by the US Department of the Interior in an investigation into using its available OTEC resource to replace fossil fuel-generated electricity.

Antigua

At the beginning of 2006 the Chief Environment Officer of Antigua announced that an MOU for an OTEC feasibility study was being prepared with an American organisation.

Australia

At an ocean energy workshop held in Townsville, northern Queensland in September 2005, discussion concentrated on developing OTEC energy in the region. It was suggested that the city could act as the 'launch pad' for plants in the South Pacific and also, in time, become a centre of excellence in the technology.

To date the plans have not progressed owing to environmental concerns for any such scheme and also a greater interest in other alternative energy sources.

Barbados

With the high petroleum product prices of recent years, Barbados is considering substituting a fossil fuel-based power supply for one utilising the renewable energies. In late-2004, an American developer announced that it was interested in helping Barbados establish an OTEC plant for electricity generation and mariculture purposes.

Cayman Islands

Caribbean Utilities Company (CUC) stated during 2006 that it was exploring the possibilities of utilising the country's ocean thermal resource for the production of electricity and fresh water. An American developer would plan for a prototype plant to be installed but purchase agreements between CUC, Cayman Water Authority and/or Cayman Water Company would need to be settled prior to any deployment.

Côte D'Ivoire

A French project to build two open cycle onshore OTEC plants of 3.5 MW each in Abidjan was proposed in 1939. The experimentation was eventually undertaken after World War II, with the main research effort occurring during 1953-1955. The process of producing desalinated water via OTEC proved to be uneconomic at that time and the project was abandoned in 1958.

Cuba

This was the site of the first recorded installation of an OTEC plant and the island remains a very desirable location in terms of working temperature difference (in excess of 22^{o}C). Georges Claude, a French engineer, built an experimental open cycle OTEC system (22 kW gross) at Matanzas in 1929-1930. Although the plant never produced net electrical power (i.e. output minus own use) it demonstrated that the installation of an OTEC plant at sea was feasible. It did not survive for very long before being demolished by a storm.

Fiji

This group of islands has been the subject of OTEC studies in the UK and in Japan. In 1982 the UK Department of Industry and relevant companies began work on the development of a floating 10 MW closed cycle demonstration plant to be installed in the Caribbean or Pacific. The preferred site was Vanua Levu in Fiji.

At end-1990 a Japanese group undertook an OTEC site survey on the Fijian island of Vitu Levu. Design work on an integrated (OTEC/DOWA) land-based plant was subsequently undertaken.

The studies have not given rise to any firm construction project. However, when the tourist industry grows further, the Vanua Levu site will

again be ideal, with cold deep water less than 1 km from shore. The development of the tourist industry will require substantial electrical power, potable water and refrigeration.

French Polynesia

Feasibility studies in France concluded that a 5 MW land-based pilot plant should be built with Tahiti as the test site. An industrial grouping, Ergocean and Ifremer (the French institute for research and exploitation of the sea) undertook extensive further evaluation (of both closed and open cycle) and operation of the prototype plant was initially expected at the end of the 1980s, but the falling price of oil caused development to be halted. Ifremer continues to keep the situation under review and has been active in the European Union.

Specifically, Ifremer with various partners has examined DOWA desalination, since a much smaller (1 m diameter) cold water pipe would be needed. Techno-economic studies have been completed but further development is on hold.

Guadeloupe

Experimental studies on two open cycle plants were undertaken by France between the mid-1940s and the mid-1950s in Abidjan, Côte d'Ivoire. The results of these studies formed the basis of a project to build an OTEC plant in Guadeloupe (an Overseas Department of France) in 1958. This onshore 3.5 MW OTEC plant was intended to produce desalinated water but the process proved to be uneconomic at that time and the project was abandoned in 1959.

India

Having an extremely long coastline, a very large EEZ area and suitable oceanic conditions, India's potential for OTEC is extensive.

Conceptual studies on OTEC plants for Kavaratti (Lakshadweep Islands), in the Andaman-Nicobar Islands and off the Tamil Nadu coast at Kulasekharapatnam were initiated in 1980. In 1984 a preliminary design for a 1 MW (gross) closed Rankine Cycle floating plant was prepared by the Indian Institute of Technology in Madras at the request of the Ministry of Non-Conventional Energy Resources. The National Institute of Ocean Technology (NIOT) was formed by the governmental Department of Ocean Development in 1993 and in 1997 the Government proposed the establishment of the 1 MW plant of earlier studies. NIOT signed a Memorandum of Understanding with Saga University in Japan for the joint development of the plant near the port of Tuticorin (Tamil Nadu).

During 2001 the Department of Ocean Development undertook an exercise to determine the actions required to maximise the country's potential from its surrounding ocean. The result was a Vision Document and a Perspective Plan 2015 (forming part of the 10th 5-year plan) in which all aspects of the Indian Ocean will be assessed, from the forecasting of monsoons through the modelling of sustainable

uses of the coastal zone to the mapping of ocean resources, etc.

It has been postulated that most of India's future fully-commercial OTEC plants will be closed cycle floating plants in the range 10-50 MW (although 200-400 MW plants are not ruled out). Working with Saga University, NIOT had planned to deploy the 1 MW demonstration plant in March/April 2003. However, mechanical problems prevented total deployment and the launch was delayed. Following testing, it was planned to relocate the plant to the Lakshadweep Islands for power generation prior to full commercial operation from scaled-up plants. No further progress has been reported.

Indonesia

A study was carried out in the Netherlands for a 100 kW (net power) land-based OTEC plant for the island of Bali, but no firm project has resulted.

Jamaica

In 1981 it was reported that the Swedish and Norwegian Governments, along with a consortium of Scandinavian companies, had agreed to provide the finance required for feasibility studies towards an OTEC pilot plant to be located in Jamaica.

In a reference to OTEC, the National Energy Plan (circa 1981) stated that 'a 10 MW plant was envisioned in the late 1980s'. Although this project never came to fruition, a plan remains in place for an offshore 10 MW plant producing energy and fresh water. For implementation to take place, purchasing agreements from the power and water utility companies need to be in place.

There was further discussion regarding Jamaica's ocean thermal resource at the beginning of 2005 and the Ministry of Industry, Technology, Energy and Commerce continues to list OTEC as a possible energy supply to the island, but to date there has been no development.

Japan

Research and development on OTEC and DOWA has been carried out since 1974 by various organisations (Ocean Thermal Energy Conversion Association of Japan; Ocean Energy Application Research Committee, supported by the National Institute of Science and Technology Policy; Japan Marine Science and Technology Center, Deep Seawater Laboratory of Kochi; Research Institute for Ocean Economics and Toyama prefectural government; Saga University; Electrotechnical Laboratory and Shonan Institute of Technology).

Saga University conducted the first OTEC power generation experiments in late-1979 and in early-1980 the first Japanese experimental OTEC power plant was completed in Imari City.

During the summer months of 1989 and 1990 an artificial up-welling experiment was conducted on a barge anchored on the seabed at 300 m offshore in Toyama Bay.

With the establishment in 1988 of the OTEC Association of Japan, now the Japan Association of Deep Ocean Water Applications (JADOWA), the country has placed greater emphasis on products that use deep ocean water in the manufacturing process. Such products (food and drink, cosmetics and salt) have all proved commercially successful.

In March 1996, a Memorandum of Understanding was signed between Saga University and the National Institute of Ocean Technology of India. The two bodies have been collaborating on the design and construction of a 1 MW plant to be located off the coast of Tamil Nadu in India.

In mid-2003 Saga University's Institute of Ocean Energy (IOES) inaugurated a new research centre for the study of OTEC.

During 2003 it was reported that Saudi Arabia had shown great interest in working with Saga University to develop the Kingdom's OTEC potential.

If the OTEC projects the university is helping to implement are proved to be viable, the enormous potential of Japan's own EEZ could be exploited in the future.

Kiribati

During late-1990, an OTEC industrial grouping in Japan undertook detailed research (including the water qualities of the ocean, seashore, lagoon and lakes) on Christmas Island. Following on from this research, the basic concepts were improved but no developments have ensued.

Kuwait

In May 2007 Kuwait National Petroleum Company signed an MOU with Xenesys of Japan for the application of OTEC technology to power generation and water desalination, using waste heat from KNPC refineries.

Marshall Islands

In the early 1990s the Republic of the Marshall Islands invited proposals from US companies to undertake a detailed feasibility study for the design, construction, installation and operation of a 5-10 MW (net) OTEC power plant to be located at Majuro. The contracted study was carried out by Marine Development Associates of California between April 1993 and April 1994 but no project resulted.

At a forum convened prior to the World Water Forum (Kyoto, March 2003) by Japan's Saga University and the Government of Palau (a group of Pacific Islands to the east of the Marshall Islands), interest was renewed in the possibility for OTEC installations. The success of the planned project in Palau could well prove to be the impetus required for development in the Marshall Islands and other Pacific Islands.

Mauritius

With its heavy dependence on imported fossil fuels for energy supply, Mauritius has increasingly been looking at developing the

renewable energies available to the Republic. In 2005 Xenesys, and Saga University, both of Japan and working on the development of OTEC systems, were represented at the UN conference for Small Island Developing States held in Mauritius. Although much interest was shown in utilising the Republic's ocean thermal resource, there has to date been no development.

Nauru

In 1981, the Tokyo Power Company built a 100 kW shore-based, closed cycle pilot plant on the island of Nauru. The plant achieved a net output of 31.5 kW during continuous operating tests. This plant very effectively proved the principle of OTEC in practical terms over an extended period, before being decommissioned.

Netherlands Antilles

A feasibility study carried out by Marine Structure Consultants of the Netherlands and funded by the Dutch Government for the Netherlands Antilles Government examined the competitiveness of a 10 MW floating OTEC plant. No development ensued.

New Caledonia

Ifremer (the French institute for research and exploitation of the sea) has re-examined a previous proposal to establish a test site for OTEC/DOWA in New Caledonia.

Northern Marianas

Using the islands' ocean thermal resource for power generation continues to be considered. A Memorandum of Understanding was signed in 2003 for the future development of a 10 MW plant, but to date the plan has not progressed.

Palau

In a plan to obviate a future need for diesel-generated electricity, Palau could utilise its ocean thermal resource to provide electricity supply.

In Spring 2001 the Government of Palau, Japan's Saga University and Xenesys Inc. (a Japanese private company) entered into an agreement that resulted in research and feasibility studies being undertaken for the identification of suitable sites for OTEC installations. Seven such sites were located on the biggest island in Palau (Babeldaob). It was stated that a pilot project would have a capacity of 3 000 kW that could ultimately reach 30 000 kW, an increase in excess of 50% from the current diesel-generated supply.

In addition to the production of power, the by-products of salt and fresh water could be used for organic farming.

It was reported that under the ACP-EU Partnership Agreement, the European Commission and the Government of Palau had drawn up a Country Strategy Paper and an Indicative Programme for the period 2002-2007. The EU was to provide financial assistance to Palau in order to expand the utilisation of renewable energy sources. However, to date no development has taken place.

Philippines

The aim of the New and Renewable Energy Program (NRE) of the Department of Energy (DOE) is to accelerate the development, promotion and commercialisation of new and renewable energy systems. The Philippines is well-endowed with a range of renewable energies and the Philippine Energy Plan (2005-2014) plans to utilise them in an effort to reduce fossil fuel consumption. To this end the DOE working with Japanese scientists has identified sixteen areas that could be suitable for the development of OTEC systems.

Puerto Rico

A resource assessment conducted in 1977 studied the potential for a nearshore OTEC plant. In 1997 a new evaluation concluded that a closed cycle, land-based OTEC plant of up to 10 MW was feasible, especially with the inclusion of DOWA. The headland of Punta Tuna on the south-east coast of the island satisfied the criteria for such a plant.

Saudi Arabia

It was reported in early 2003 that there had been high level governmental discussions between Japan and Saudi Arabia with a view to OTEC technology being utilised for water desalination and electricity production. To date, there has been no development.

Sri Lanka

Interest in OTEC and DOWA has been revived by the National Aquatic Resources Agency in Colombo, in the context of making use of Sri Lanka's EEZ, which is some 27 times its land area.

Three submarine canyons (Panadura, Dondra and Trincomalee) have been identified as highly suitable sites for OTEC plants and the production of electricity. The results of successful experiments conducted during 1994 were presented to the Government but political unrest in the area of Trincomalee has resulted in unsafe working conditions.

The Oceanography Division of the National Aquatic Resources Research & Development Agency (NARA) maintains contact with Japan's Institute of Ocean Energy (Saga University) and the Mitsui Corporation. Following the announcement in January 2007 of the establishment of an Alternative Energy Authority, it is hoped that in the future OTEC will play a significant role in Sri Lanka.

St. Lucia

In 1983, as a part of a commitment to develop alternative energy systems, the Government of St. Lucia welcomed the opportunity to be part of an OTEC initiative that included the design and construction of a 10 MW closed cycle floating OTEC demonstration plant off Soufriere. Hydrographic surveys in 1985 confirmed that the 1 000 m contour was less than 3 km from shore, with cold water in the volcanic canyon adjacent to Petit Piton and Gros Piton. This landfall was also close to the electrical grids. The surface temperature of the sea on that part of the west coast never falls below 25^{o} C, reaching 27/28^{o} C in summer.

The UK-designed plant was provided with a fully costed proposal by a merchant bank, which showed that with construction commencing in 1985, and operation from 1989, the OTEC plant would show a cost benefit over oil-fired plant from 1994, the higher capital cost of OTEC being balanced by the 'free fuel', whereas there were ongoing fuel costs for the diesel plant. However, the final decision was to go for a diesel plant, with the whole of the capital cost being funded by another country.

Taiwan, China

The seas off eastern Taiwan are considered to be highly favourable for OTEC development. Following preliminary studies during the 1980s, three nearshore sites were selected and the steeply shelving east coast was thought to be able to accommodate an onshore OTEC plant. However, only one site (Chang-Yuan) was deemed suitable for further investigation by the Institute of Oceanography.

In 1989, the Pacific International Center for High Technology Research in Hawaii prepared a development plan for the Taiwanese Multiple Product Ocean Thermal Energy Conversion Project (MPOP). The intention of the MPOP was to construct a 5 MW closed cycle pilot plant for generating power and also the development of mariculture, desalinated water, air conditioning, refrigeration and agriculture. It was thought that the operating data obtained from the pilot plant could be used in the building of a 50-100 MW commercial plant. In 1993 it was assumed that 6 years would be required for site preparation and 5 years for construction, with the plant having a 25-year life cycle.

During the 1990s the concept of MPOP changed to a Master OTEC Plan for R.O.C. (MOPR), with the objective of ultimately establishing eight 400 MW floating OTEC power plants.

With its positive interest, Taiwan was the initiator, in 1989, of the International OTEC/DOWA Association (IOA). Until around 2004 a permanent Taiwanese secretariat worked to ensure a higher international profile for OTEC/DOWA but both the organisation and plans for OTEC within the country have, at present, somewhat stagnated.

United States of America

Hawaii remains the focus of US activity in OTEC/DOWA, primarily through work carried out at the Natural Energy Laboratory of Hawaii (NELHA) facility at Keahole Point.

In 1979 'Mini-OTEC', a 50 kW closed cycle demonstration plant, was set up at NELHA. It was the world's first net power producing OTEC plant, installed on a converted US Navy barge moored 2 km offshore: it produced 10-17 kW of net electric power.

In 1980 the Department of Energy constructed a test facility (OTEC-1) for closed cycle OTEC heat exchangers on a converted US Navy tanker. It was not designed to generate electricity.

In the early 1980s a 40 MW OTEC pilot plant was designed. It was to be sited on an artificial island off the Hawaiian coast. However, funding was not forthcoming and the plant was not constructed.

An experimental 210 kW (gross electrical) open cycle OTEC plant was designed and operated by the Pacific International Center for High Technology Research (PICHTR) at Keahole Point. It produced a record level of 50 kW of net power in May 1993, thus exceeding the 40 kW net produced by a Japanese OTEC plant in 1982. The plant operated from 1993 until 1998 and its primary purpose was to gather the necessary data to facilitate the development of a commercial-scale design. Following the experiments, the plant was demolished in January 1999.

A further PICHTR experiment at NELHA employed a closed cycle plant to test specially developed aluminium heat exchangers. It used the (refurbished) turbine from 'Mini-OTEC' to produce 50 kW gross power. During initial operation in May 1996, corrosion leaks developed in the heat exchanger modules; the plant had to be shut down and the units re-manufactured. From October 1998, when the new units were received until end-1999 - the end of the project - data were collected on the heat exchange and flow efficiencies of the heat exchangers and thus on the economic viability of competing types of heat exchangers.

In addition to research into ocean thermal energy, NELHA has established an ocean science and technology park at Keahole Point. Cold deep seawater is pumped to the surface and utilised for the production of energy, air-conditioning, desalination, fish farming, agriculture, etc.

NELHA has reported that during fiscal year 2006 a letter of understanding had been signed with Ocean Engineering & Energy Systems (OCEES) of Honolulu to construct an OTEC plant utilising the 55 inch pre-existing cold water pipes. At the beginning of 2007 negotiations were continuing, with an expected operational date of 2009 for the 1-1.2 MW plant.

Virgin Islands

The island of St. Croix has been found to be a suitable site for the development of OTEC-produced electricity and desalinated water.

In the early 1990s an agreement was drawn up between the US company GenOtec and the Virgin Islands Water and Power Authority (WAPA). The plan was to obtain 5 MW of OTEC-produced electricity and 1.5 million gallons/day of desalinated water from a land-based, closed cycle OTEC plant. Additionally, various mariculture industries were planned. The project did not come to fruition.