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Proceedings of the International Workshop on Clean Ocean Energy

Varadero, Cuba. April 23–25, 2008

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For more information, please contact:
Daniel Whittle
dwhittle@edf.org
edf.org/cuba

Prepared by:
Dr. Rod Fujita and Courtney Scarborough, Ocean Innovations, EDF
Dr. Julio Ernesto Díaz Díaz, University of Matanzas

Please cite as Fujita, R., C. Scarborough, and J. Díaz Díaz, editors. Proceedings of the International Workshop on Clean Ocean Energy. April 23–25, 2008, Varadero, Cuba. Environmental Defense Fund 2010, 38 p. Available online at www.edf.org/cuba

Acknowledgments

Environmental Defense Fund would like to thank the following organizations for their generous support of this workshop: The Christopher Reynolds Foundation and the J.M. Kaplan Fund. We would also like to thank the following for their excellent interpretation services during this workshop: Julia Rosa Martínez García, Idanerys Avila Caballero, Sadienys Naranjo Trujillo, Leydis Laura Guitart Baró, Odaymis Gómez Martínez, and Pedro Enríquez Pérez Oliva.

Environmental Defense Fund

Environmental Defense Fund is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

Cover photo: Site of the world's first Ocean Thermal Energy Conversion Plant

The complete report is available online at edf.org/cuba.

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EXECUTIVE SUMMARY

Proceedings of the International Workshop on Clean Ocean Energy

Cuba and other island states of the Caribbean are looking to develop more energy to fuel economic development. Rising oil prices, air pollution associated with fossil fuel combustion, and concern about global climate provide the impetus to explore cleaner, alternative sources of energy. Abundant energy potential resides in the waves, tides, currents, and temperature differentials (between cold deep water and warm surface waters) throughout the Caribbean.

Cuba has embarked on a national strategy to increase the efficiency of energy use and develop alternative clean energy sources. This workshop was convened by the University of Matanzas, which hosts Cuba's expert group on Ocean Thermal Energy Conversion technology, the Cuban Ministry of Science, Technology, and Environment (CITMA), the Cuban Ministry of Basic Industries, and Environmental Defense Fund to review scientific research and other information concerning the status and trends of ocean energy development in the world, potential adverse impacts on coastal and marine environments, and mitigation strategies. Over 50 scientists, economists, and policy experts from Cuba, St. Kitts, the United States, Canada, and Japan participated in the workshop.

Vice-Minister of Basic Industries Juan Manuel Presa provided the keynote address. He described Cuba's growing need for more reliable electrical power, and the national effort that is underway to increase energy efficiency, develop cleaner energy technologies, and develop renewable energy sources.

A number of attendees presented results of many field studies on the energy potential contained in Cuba's tides, waves, currents, and temperature differentials. Cuban scientists and engineers are focusing on ocean currents, waves, tides, and temperature differential because these sources exhibit less variability than wind and solar. Although tidal amplitude is relatively low in Cuba, tidal currents can reach speeds up to 5.18 km/h, particularly in the narrow mouths of bays such as Bahía de Banes, Bahía de Nipe, Bahía de Nuevitas, and in the northern keys and under bridges. Demonstration projects are under way to test the viability of harnessing currents to produce electricity.

Wave energy potential is highest on Cuba's northern coast, which has wave heights averaging 1.44 m, with a maximum of 2 m. Wave energy potential depends strongly on site conditions; estimates range from 500 kW to 750 kW.

Ocean Thermal Energy Conversion (OTEC) uses the temperature difference between warm surface seawater and cold deep seawater brought to the surface to vaporize and recondense a working fluid with a low boiling point, which drives a turbine. Optimal OTEC sites on land are close to deepwater because deepwater pipe length, installation costs, and maintenance problems can all be reduced. According to Cuban experts, in some places in Cuba the 1000 m isobath lies 0.5–2 miles from the coast, creating ideal conditions for OTEC energy generation all year round.

Papers on all of these ocean energy sources were given, providing insights into science, siting, engineering and environmental issues. OTEC in particular requires the use of a complex technology that can yield multiple benefits, including electricity, biodiesel, freshwater, seafood, seaweed, and refrigeration/air-conditioning. These potential benefits were discussed in breakout sessions. A poster session included feasibility studies of various OTEC configurations designed to suit the needs of populations in a variety of settings ranging from small remote islands to urban areas. The current voluntary and mandatory markets for carbon credits was also described, noting that Cuba is eligible for both kinds of credits as a signatory to the Kyoto Protocol, and that Cuba has already received financing with a carbon credit for the Energas Varadero combined cycle power plant project.

While participants acknowledged the important benefits of renewable ocean energy with respect to reducing pollution, increasing energy security, and helping to stem global climate change, the potential adverse environmental impacts of ocean energy were also a primary focus of this meeting and the principal reason for the participation by scientists from Environmental Defense Fund. These include: siltation and direct destruction of habitats during construction; leaks of toxic materials during operations; discharge of nutrient-rich cold water from OTEC plants into warm, nutrient-poor surface waters; and impacts incurred during the decommissioning of ocean energy facilities. Mitigation strategies were also discussed, including the promulgation of performance standards. Papers on the use of aquaculture to increase the temperature and reduce the nutrient levels of OTEC discharge water prior to discharge were also presented.

With good environmental standards and policy, it seems clear from this workshop that ocean energy could make Cuba a model for clean energy development in the Caribbean. Replication of this model would reduce transboundary pollution and reduce GHG emissions at significant scales, as well as provide for the sustainable development of the Caribbean region.

Recommendations

1. Conduct additional studies on tidal currents to specify suitable locations.
2. Form an international collaborative group on ocean energy.
3. Conduct studies of OTEC environmental impacts.
4. Continue to facilitate the exchange of information between Saga University, the University of Matanzas and others.
5. Identify other countries in the Caribbean interested in developing ocean energy.
6. Integrate new energy resources such as biodiesel produced from microalgae.
7. Strengthen the exchange of information with Xenesys.
8. Establish working relations between the Canadian firm Nisymco and the OTEC Group (Matanzas).
9. Strengthen the coordination of work related to ocean energy by GeoCuba, MinBas and the OTEC Group (Matanzas).
10. Promote scientific studies of OTEC applications.
11. Conduct economic studies of ocean energy and potential carbon offsets.
12. Install with urgency a cold seawater pipe in Cuba to rapidly provide tangible social benefits such as freshwater, refrigeration, and air-conditioning at relatively low cost; these benefits have already been demonstrated elsewhere. This installation could also be used to study the feasibility of producing various OTEC secondary products such as microalgae for biodiesel production, seafood and seaweed via aquaculture, as a step toward demonstrating OTEC feasibility.
13. Environmental Defense Fund should collaborate with the University of Matanzas and CITMA on summarizing proceedings and circulating contact information.

SECTION 1

The conveners

University of Matanzas. The University of Matanzas "Camilo Cienfuegos" is a leading Cuban academic institution and hosts the national group on Ocean Thermal Energy Conversion development, an important part of the Cuban Energy Revolution program. The OTEC group of the University of Matanzas is actively engaged in numerous field research projects, modeling, and software development efforts related to assessing the feasibility of OTEC in Cuba and in other Caribbean countries.

Ministry of Science, Technology, and Environment (CITMA). The Ministry of Science, Technology and Environment is the institution in charge of directing, executing and controlling the Cuban government policies regarding the scientific and technological activities, the environment and the peaceful use of nuclear energy. It fosters the coherent integration of all these activities to contribute to Cuba's sustainable development.

Ministry of Basic Industry (MinBas). The Ministry of Basic Industry is the governmental organization responsible for three important sectors of the Cuban economy: Energy, Geology and Mining, and Basic Chemistry. The Ministry is in charge of the work on production, research, projects, maintenance, construction, internal commercialization, raw material imports, and export of finished products. Over the 35 years of work of MinBas, the Ministry has created an important industrial base and support infrastructure.

Environmental Defense Fund (EDF). A leading national nonprofit organization, Environmental Defense Fund represents more than 750,000 members. Since 1967, Environmental Defense Fund has linked science, economics, law and innovative private-sector partnerships to create breakthrough solutions to the most serious environmental problems. EDF also has several institutes for performing specialized work, including our Corporate Partnerships Program and Ocean Innovations which works with outside specialists to conduct research and to ensure that we are working on the highest priority problems with the best possible tools. EDF relies on good science, economics, innovation, and policy expertise to craft lasting solutions to environmental problems that accommodate economic and social goals.

EDF's Oceans Program is focused on protecting coastal ecosystems and creating sustainable fisheries. EDF has been working on a variety of projects in Cuba since 2000.

SECTION 2

Rationale for the workshop

Disclaimer: These proceedings are based on notes taken at the workshop, and on reviews of the presentations themselves. While every effort was made to faithfully communicate the content presented, not all presenters reviewed the proceedings; hence, statements in these proceedings should not be attributed to any presenter without their permission. It is also not our intent that these proceedings provide a comprehensive report on the information presented, but rather a summary of some of the main points made and issues discussed.

Cuba, along with all of the other nations in the world, faces an unprecedented challenge: how can energy needs be met while reducing greenhouse gas emissions and air pollution? Cuba is developing a comprehensive energy strategy to meet this challenge. This strategy includes efforts to increase energy use efficiency, to reduce pollution associated with fossil fuel combustion, and to develop renewable sources of clean energy. Interdisciplinary teams of Cuban experts have been mobilized to conduct research and develop strategies to address these major issues. Preliminary research suggests that Cuba has a relatively high potential for ocean energy due to its proximity to the powerful Gulf Stream current and to the Cayman Trench, which presents an opportunity to exploit the temperature difference between surface waters and deep waters to produce electricity, food, freshwater, and refrigeration with Ocean Thermal Energy Conversion (OTEC) technology. It may also be possible to use waste heat from coastal industries to produce energy from thermal differentials.

Ocean energy technologies have clear advantages over fossil fuel combustion. They produce no fine particulate pollution, which has been linked to respiratory disease; no sulfur or nitrogen dioxides, which contribute to smog, accelerate weathering of building materials, and create acid rain and nitrogen deposition; and no greenhouse gases. Some ocean energy technologies have the potential to produce secondary benefits as well. However, if developed at a commercial scale, ocean energy technologies may have adverse impacts unless they are mitigated.

The Cuban Ocean Energy Workshop was held to tap the expertise of ocean energy experts from around the world, and to review scientific information relevant to ocean energy production, secondary products, and environmental impacts. The international community has an interest in exploring opportunities to avoid greenhouse gas emissions; the development of ocean energy in Cuba presents such an opportunity. There is also interest in developing methodologies for documenting carbon offsets via ocean energy technologies. In addition, international interest in Cuban energy use patterns and strategies is also generated by ecological linkages between Cuba and other Caribbean nations, as well as with the United States, and the potential for Cuba to become a leader and center of ocean energy expertise.

SECTION 3

The energy situation in Cuba

Cuban Vice-Minister of Basic Industry Juan Manuel Presa provided an overview of energy supply, demand, and projected supply and demand. He also articulated the national goal of increasing the stability of energy supply. Blackouts have had large economic effects, and have led to social disruption, as recently as 2004 and 2005.

Cuba's energy needs have increased dramatically. Population has increased from 6 million to 11.2 million people since 1959, 96% of whom have electricity in their homes. To meet these needs, and to increase the stability of energy supply and improve the environmental performance of energy facilities, Cuba has instituted a broad program called the Cuban Energy Revolution. Subprograms deal with energy efficiency, new generating capacity, clean fossil fuel use, increased oil production, and renewable energy development.

In the area of energy efficiency, Cuba has replaced all lightbulbs in the country with compact fluorescents and replaced 2.3 million old refrigerators with more energy efficient models. Current efforts are focused on increasing the efficiency of energy use in the industrial sector. Cuba estimates oil savings of 1 million tons of oil as a result of these measures in 2006–2007.

Oil and gas fuel about 48% of Cuba's energy. Efforts to reduce pollution associated with fossil fueled power generation include the first combined cycle plant in Cuba, located in Varadero.

Dr. Julio Díaz (on right) welcomes workshop participant

This project is also Cuba's first project to be financed in part by carbon offset credits. In addition, Cuba is collaborating with international partners to explore domestic oil and gas reserves.

Total Cuban energy demand varies by season:

- Winter: 2700–2800 MW
- Summer: 2400–2500 MW
- Average 17 million MWh/yr
- Range 1000–2800 MW

Diesel fuel costs on average 13 cents/kWh, with average costs across all fuels at about 10 cents/kWh. Gas costs about 2 cents/kWh. In Cuba, electricity requires an average of 280 grams fuel/kWh; by 2010, Cuba expects this to come down to 230 grams fuel/kWh.

Cuba is also seeking to increase renewable energy as part of its national energy portfolio. Cuba's renewable energy program includes 11 national groups dedicated to the development of renewable energy and cogeneration. They are examining many potential energy sources, including photovoltaics, solar thermal, biomass, biogas, biofuels, wind energy, fuel cells, geothermal, and ocean energy.

The vice-minister also noted that in Cuba, foreign investment is governed by special legislation. Financing of energy projects can proceed under B.O.T. (Buy-Own-Transfer) or B.O.O.T (Buy-Own-Operate-Transfer) protocols. After loan instruments are completed, all property reverts to Cuba but investors may stay involved with projects after ownership is transferred. Cuba is already investing in wind power with experimental wind farms but recognizes that ocean energy and Ocean Thermal Energy Conversion (OTEC) in particular will likely be more capital intensive, with estimated costs for a 1 MW OTEC plant at $10–15 million.

Cuba has signed and ratified the Kyoto Protocol, but as a non-Annex I Party it has no domestic greenhouse gas reduction obligation under the Protocol. Nevertheless, Cuba's domestic programs are reducing greenhouse gas emissions through conservation and transition to clean energy production. In addition, Cuba has national approval for Clean Development Mechanism carbon offset credits, and has an approved project under way (combined cycle plant at Varadero) that is already receiving carbon credits under the Clean Development Mechanism (CDM). No Cuban projects are presently receiving carbon credits from the voluntary market.

SECTION 4

Cuban national effort to increase energy efficiency, clean energy production, and renewable energy production

Dr. David Pérez Martín of CUBAENERGIA and Gestor Area Energia provided an overview of the International Scientific and Technological Cooperation for the Development of Ibero-america (CYTED), a cooperative program for the Portuguese- and Spanish-speaking countries of the Caribbean. CYTED has seven areas or themes of investigation: health, development, nutrition, climate change, sustainable development, science and society, energy, and technology. Proposals are solicited and evaluated in each of these areas. CYTED also engages in collaborative projects in other areas with different institutions.

In the energy arena, CYTED is considering six projects from six different countries, including one from Cuba regarding the use of geothermal energy to enhance temperature gradients in order to generate electricity.

CYTED is in the process of creating a network of energy experts in the Caribbean—such a network would add value because many groups are investigating energy technologies, but there is insufficient information exchange between these groups. In addition, this network and the integration of research with national priorities may reduce the number of investigations that result in doctoral dissertations and publications with no practical applications that improve quality of life.

CYTED is focused on adapting energy technologies to each country's conditions and national interests. Primary approaches include Technology Prospecting (a process to identify emerging technologies and strategic research with the highest probability of producing economic and social benefits) and Vigilance (a process for organizing and systematically selecting information to make it useful for decision making).

CYTED energy research is expected to result in reports on solar, wind, solar thermal, and thermal electric technologies presented at a national energy workshop in June 2008; 500 participants are expected. In addition, researchers are working on reports related to biomass and ocean energy.

SECTION 5

Clean production

Juana Junca Horta, Director of the Center for the Study of the Environment in Matanzas, provided insights into how to reduce the environmental impacts of a broad range of economic activities.

In 1989, the Programa de Naciones Unidas sobre el Medio Ambiente (United Nations Environment Programme) initiated a new form of life cycle analysis of industrial processes that takes into account the prevention or minimization of environmental impacts by preventing contamination from the start (virgin material extraction) to finish (residuals). Industrial processes should conserve materials and energy, eliminate toxic materials, and reduce the quantity and toxicity of emissions and residuals. This will result in both environmental and economic benefits, improving competitiveness. Prevention is better than a cure, because contamination of the environment requires remediation.

The basic components of clean production are the diffusion of information and the evaluation of the production process. This process should be applied to ocean energy technologies to prevent environmental harm and maximize economic benefits.

In order to encourage the diffusion of information on clean technologies, **Marlen C. Alfonso Lorenzo of the Cuban Institute for Sugar Investigation (ICINAZ)** discussed the research of her group on the cultivation of microalgae for the extraction of biodiesel.

Ocean Energy Workshop participants

Because the price of oil is increasing rapidly, other sources of liquid fuel are needed. The use of crop plants for conversion to biodiesel presents many problems, ranging from the intensive use of resources including fossil fuels to runoff and the use of arable lands that could be used for food crops.

Microalgae can be up to 30 times more productive than corn or soy crops; hence, much less energy and resources may be required for microalgal cultivation. In addition, these types of microalgae are not used as food and so microalgae cultivation does not involve a tradeoff between food and fuel.

Chlorella vulgaris is one species of microalgae currently under investigation. This species produces fats and fatty acids, sometimes in concentrations as high as 30%, which can be converted to biodiesel. The production of fats and fatty acids is influenced by nutrient inputs, light intensity, and photoperiod (cycles of light and shade) as well as by other factors.

Microalgae cultivation is well suited to Cuba's environment. Moreover, in Cuba there is an emphasis on technologies that can use residuals (waste) and create residuals that can be used by other industrial processes to increase efficiency. Microalgae are capable of growing well on residuals (e.g., waste nutrients from agricultural drainage water). Residuals from microalgal production (e.g., algal paste) may serve as a food source for aquaculture crops. In addition, Cuba's highly educated labor force is well suited to microalgae production, which can be automated.

Another way to use the microalgae as a substitute for fossil fuels is through the conversion to biocombustibles and to burn them in traditional boilers. **Julio Díaz, Coordinator of the OTEC Group of Matanzas,** presented a poster depicting the potential use of OTEC technology in combination with microalgal biocombustion. This would involve a closed cycle in which the residual heat from the combustion gases would be used in a modified OTEC cycle and later would be used to enhance the growth of the microalgae.

There are several issues that still need to be resolved in order to commercialize microalgae production. Research is needed on different species of microalgae, on growth rates using different kinds of residuals, on the extraction of fatty acids, on the separation of microalgal biomass from culture water, and on the conversion to biodiesel. In addition, detailed analyses of the costs will be necessary.

SECTION 6

The potential for ocean energy in Cuba

Fermín Vega, Director of the Institute of Marine Studies and Vice-Coordinator of the National Ocean Energy Group, presented the results of over 40 studies based on 37 transects of the energy density of currents, waves, tides, and thermal gradients in Cuba.

Offshore wind

Because currents, waves, tides, and temperature differential exhibit less variability than wind, Cuba is focusing on these potential sources of energy production.

Tides

Cuba has semidiurnal tides, with two highs and two lows. The average amplitude is 70 cm; however, the highest tidal amplitudes are in the north, ranging from 90 cm–1.5 m. The tides pulse flow for 6 hours in each direction, at speeds ranging from 3.7 km/h to 5.18 km/h. There are winter and summer patterns. Higher current speeds that can yield increased energy can be found in narrow mouths of Cuba's bays, such as the Bahía de Banes, Bahía de Nipe, Bahía de Nuevitas, and in the Cayería Norte and under bridges. Current power research projects are under way.

Waves

The northern coast has the biggest waves because it is exposed to the Atlantic Ocean. In Cuba, wave heights average 1.44 m, with a maximum of 2 m. Wave energy potential depends strongly on site conditions; estimates range from 500 kW to 750 kW.

Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy Conversion uses the temperature difference between two sources of seawater to vaporize and recondense a working fluid with a low boiling point, which drives a turbine. Usually, warm surface water is used to heat up the working fluid and vaporize it, while cold deep water is used to recondense the working fluid. Optimal OTEC sites on land are close to deep water because deep water pipe length, installation costs, and maintenance problems can all be reduced. Even for floating OTEC facilities, locating them close to shore (i.e., over deep waters that are close to shore) has many advantages, including reduced facility (including power transmission cable) installation and maintenance costs. In some parts of Cuba suitable for OTEC, the 1000 m isobath lies 0.5–2 miles (0.8–3.2 km) from the coast. At Fosa de Oriente, Santiago de Cuba and Fosa Cienfuegos, Cienfuegos cold deep water lies close to shore and its temperature is about 4 degrees C at 1200 m. There is an annual cycle in the temperature gradient between surface and deep waters, during which the gradient ranges from 24.7 to 25.8 degrees C, up to a maximum of 29 degrees C. Because the southern coast is warmer than the northern coast, the temperature gradient is about 1 degree C higher in the south. Given these observations, it is apparent that OTEC potential exists in Cuba all year round.

SECTION 7

Wave, tide, and current technologies

Many different technologies are under development to harness the power of waves, tides, and currents. **Felíx Santos García of the Center for Environmental Technology Study at the University of Matanzas and George Boehlert of Oregon State University's Hatfield Marine Science Center** described some of these technologies.

Wave energy

Point absorber systems move up and down with waves, compressing a hydraulic fluid which drives a piston and generator. Wave attenuator systems are long, snakelike systems of floating booms deployed perpendicular to the beach which move back and forth, compressing hydraulic fluid and driving a generator. Overtopping devices allow waves to spill and use the falling seawater to drive a turbine.

Current energy (currents and tides)

Current energy systems are typically large propellers deployed underwater either horizontally or vertically to harness either unidirectional currents or tidal currents (which change direction twice each day). The horizontal units are more efficient and are generally easier to deploy; however construction processes can be quite complex and costly. Turbines can also be deployed by constructing platforms or co-locating them with existing underwater infrastructure.

Most experts agree that costs can be reduced significantly with commercialization. Vertical units are highly reliable even with changes in direction of the current, and are attractive economically because construction processes are relatively straightforward and maintenance costs are low. However, efficiency is 5–10% lower than that of horizontal turbines. Turbines can also be manufactured and deployed such that they can extract energy without reducing pressure on the rotor. Marine species can avoid contact with these turbines more easily, and hence this technology will likely have less adverse environmental impact. However, they are less efficient than other designs.

Because Cuba has many different sites where power could be produced from tidal or current energy with different characteristics, different technologies may be required. The open cycle turbine may be appropriate for deployment around bridges and where the coast juts into the sea, where currents and tidal flows are more rapid. At shallow depths and lower current speeds, the Turbina Helocoidal Gorlov (Helical Gorlovian Turbine) may be a more appropriate technology. Yet another technology (e.g., Verdant Turbines) may be necessary for the entrances of bays, where depths reach 40 m.

Currently the Center for Research at the University of Las Villas is focusing on assessing the characteristics of each area selected and choosing the most appropriate technology that will maximize environmental and economic benefits. Cost analysis has already been conducted. The center recommends starting with a 2 kW pilot plant. It is estimated that costs will approach $2000/kW for small plants.

Ocean Thermal Energy Conversion

OTEC is a very old technology with a variety of pros and cons, and is described in more detail below. It is thought to be very expensive.

Tidal, wave, and current energy employ relatively new technologies that in the last four years have undergone rapid development. It is estimated that such technologies can feasibly produce power in Cuba, using an average current speed of eight meters per second. This projection is based on the continuing development of technology and the expectation that costs will go down during commercialization.

Further analysis and a detailed proposal will be necessary to fully assess the feasibility of current, tidal, and wave energy in Cuba. Decision makers should invest in detailed studies aimed at coming up with definitive recommendations.

SECTION 8

Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion technology (often referred to as OTEC) has a long history. The first OTEC plant in the world was built in Matanzas Bay, Cuba in 1930, by the French scientist George Claude. A few years later, Mr. Claude built a floating 1200 kW OTEC plant in Brazil, with the objective of supplying ice for tourism facilities. More recently, in 1993, a 210 kW plant was built in Hawaii; and in 1984, a 75 kW plant was built at Saga University, Japan.

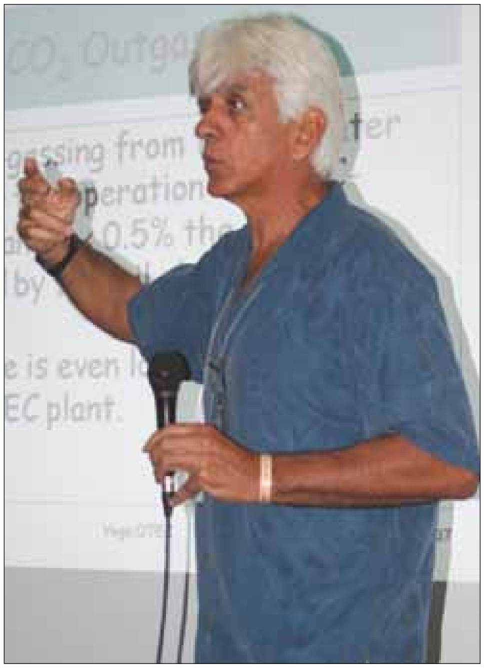
The OTEC operating conditions present in Cuba are among the best in the world. Cuba has an ample temperature gradient of 22°C year round, with deep cold water available in some places within 0.5–2 miles (0.8–3.2 km) of the coast. In addition, energy demand is higher in the summer months, which conveniently coincides with the highest OTEC production capacity.

Luis Vega of Pacific International Center for High Technology Research provided an overview of OTEC technology and presented information derived from experiments and engineering calculations in Hawaii, the Marshall Islands, American Samoa, and the U.S. Naval base on the island of Diego Garcia.

According to Vega, a 50 MW OTEC facility would be cost competitive in Hawaii presently because the avoided cost would now be $0.15–0.20 per kWh (compared to only $0.06 in the 1990s, when oil prices were lower). A 100 MW plant using a ship as a platform (also known as a plantship) delivering 800 million kWh/yr and 32 million gallons of freshwater per day (through condensation of atmospheric water on the cold seawater pipes or through flash evaporation) could produce electricity at levelized costs below current avoided costs. A power purchase agreement at 17 cents/kWh would provide an ample return on investment in the short-term.

Vega also suggested that air-conditioning loads could be met by OTEC using only 1/10 of the energy required for conventional systems, leading to an investment payback period of 3–4 years.

It is important to note the failures, in order to learn lessons. Plans were developed for a 1MW OTEC demonstration project in Tuticorin (southern India), 34 km from the shore. However, during deployment, two pipes were lost due to inexperience going to sea with the technology. Pipe construction and deployment problems also plagued OTEC experiments in Hawaii.


Dr. Luis Vega's presentation

Bob Nicholson, President of Sea Solar Power (SSP), provided information on OTEC energy production cycles, including SSP's plans to introduce specialized modifications to increase efficiency. Both 10 MW land-based and 100 MW plantships (using large ships as platforms) have been considered for OTEC implementation in Cuba. Plantships have certain advantages over land-based plants. For example, the cold-water pipe (often the most difficult and costly component of OTEC) can be much shorter (hanging straight down from the plantship into the deep water). According to SSP's calculations, an SSP plantship could theoretically produce 32 million gallons of freshwater a day; a total of 14 plantships could satisfy all of Cuba's current energy needs. They would be unanchored and thus rely on louvers to maintain position, while using an underwater cable to transmit energy to shore. These plants would employ fiberglass pipes and utilize multiple turbines to increase redundancy, reliability and efficiency.

The United States has focused on two specific OTEC designs, the Department of Energy design and the SSP design. The 100 MW DOE design is a heavier design, at 200,000 tons, while the 100 MW SSP design is considerably lighter, at 25,000 tons. The DOE design would use 15,000 cubic feet per second (CFS) cold-water flow, and 15,000 CFS warm-water flow, with a cold-water pipe 50 ft in diameter. This would result in an increase in the necessary power needed to operate the system and thus a lower net output of energy. In contrast the SSP design would use 8,000 CFS warm-water flow, and 5,000 CFS cold-water flow. A 28-foot diameter cold-water pipe is necessary for this design. The SSP design would demand less power to operate and might provide higher overall net output. Six to seven of SSP OTEC plants of 10 MW capacity have been proposed in various tropical islands.

Recent OTEC performance improvements have been developed by the **University of Saga in Japan,** including refinements of the basic Rankin OTEC power cycle that, when combined, make up the Uehara cycle. Results were presented by **Jitsuhara Sadayuki** and **Michinaga Takeda** of Xenesys, a Japanese technology application company. **Yasuyuki Ikegami** of Saga University provided an overview of efforts to facilitate OTEC development throughout the Pacific Ocean.

The Uehara process uses an ammonia/water mixture as working fluid as well as a heat recovery system and a high performance plate type heat exchanger. These modifications resulted in a 50% improvement in heat efficiency compared to the conventional Rankin cycle. The plate heat exchanger in particular improves efficiency and needs less installation space. These exchangers are made of titanium, which decreases the weight and corrosion potential, while increasing the strength and heat transfer rate. However, with these improvements come other complications in terms of higher costs and a more complex manufacturing process. Xenesys has exclusive rights to the technology and is devoting resources to research and development in improving the manufacturing process.

In the early 1990s most of the research devoted to OTEC involved the closed cycle Rankin design. Problems associated with this method involved large capital costs in terms of materials as well as high costs associated with pumping. Oil prices were also relatively low at this time, making OTEC a less competitive option. One way to increase the cost viability of OTEC projects is through temperature enhancement via increases in the warm/cold seawater differential. Available power increases with the square of the temperature differential (delta T). By increasing this temperature differential it is possible to get 10 times more power with the same plant and water flows. Increases in delta T may be achieved through deeper pipelines, utilization of waste heat, and/or solar energy.

Solar Ocean Power's George Lockwood presented an overview of a potential OTEC plant with temperature differential enhancement through solar ponds in Jamaica. Heat gain would be achieved through the use of solar covers on 5-acre ponds, which transmit 80% of energy into the water, raising the seawater temperature to 60°C. Cuba has a high level of solar flux (200 watts/m^2) making it an excellent candidate for solar temperature enhancing methods.

Lessons learned from previous OTEC pilot scale tests provide some excellent learning tools for future projects in Cuba and throughout the Caribbean. Problems with pipeline installation, gasket, hose and brass failures, as well as issues with the ammonia engineering must be overcome for successful OTEC implementation. Refrigeration grade, not agriculture grade ammonia is necessary in such cases, as well as hydrophobic lubricants and no-leak seals. Further recommendations have come out of the project to keep the cold-water pipeline at a depth less than 2500 m. If solar ponds are used flat, low relief areas would be needed—approximately 20 ha for a 2.5 MW plant and 1600 ha for 200 MW plant.

This Jamaica project has also reinforced the feasibility of such temperature-enhancing ventures. Certain costs (capital and operating costs such as the cost of oil) are avoided by using OTEC technology; estimated avoided costs depend on the price of oil (e.g., at $20/bbl oil, avoided costs = 9 cents/kWh; at $100/bbl oil, avoided costs = 22 cents/kWh).

Lockwood projects that many Caribbean countries have high ocean energy production potential. In summary, Lockwood suggested that several elements will be required for successful OTEC:

- Learn from mistakes
- Motivated entrepreneur
- Favorable government
- Willing and cooperative customer
- Favorable power purchase agreements
- Need to overcome opposition by fossil fuel interests
- Well respected sponsor for initial studies and design
- Adequate financing on favorable terms
- Carbon credits to reduce costs

Secondary products associated with OTEC can further increase both social and economic benefits. Power generation costs for small OTEC plants are relatively high. As such, to increase the productivity of the project as a whole, deep ocean water may be used for other purposes. The cold water that is pumped up from depth for use in OTEC power production is ideal for aquaculture; it is rich in nutrients, and free of both pollution and disease. Ideal temperatures for growth and health of cultured organisms may be easily maintained at low production costs.

Japanese scientists have been studying OTEC since 1973 and have greatly advanced the innovative use of the associated secondary products. Japan has installed 10 deepwater pipes to study secondary OTEC products. Studies have shown the cold water to be highly useful in fish fertilization (i.e., the use of nutrient-rich deepwater to fertilize surface waters, resulting in increased fish production), agriculture, refrigeration, air-conditioning and lithium extraction. There are also desalination products such as freshwater, hydrogen and ocean minerals that further increase the utility of OTEC projects. A 10 MW land-based plant may be ideally suited for tropical islands, where deepwater is located close to shore. Such a plant could potentially produce 3 million gallons (over 11 million liters) of freshwater per day, which may also be sold for profit. The air-conditioning units associated with deep seawater pipes have shown to have a cooling load of 480 USRT with 11 kW of consumption. This results in 1/10 of the power consumption of conventional air-conditioning processes. An innovative floating platform to bring up deep ocean water has also been in operation in Sagami Bay, Japan since 2003. Aimed at enhancing the fishery production, this plant upwelled 100,000 tons of deep ocean water per day. Research reports that 5,000 tons of anchovies wet weight per year can be resulted with 1 million tons of deep ocean water. The Sagami Bay plant was built using an innovative pipe construction and deployment system: the pipe was built on land, towed to sea in a horizontal position, attached to the plant, and then slowly lowered to a vertical position. This method appears to have overcome most of the obstacles normally associated with OTEC pipe construction and

Workshop participants

deployment. Notable too is the fact that this plant has survived several typhoons per year, suggesting that OTEC marine engineering has advanced considerably.

Capital costs associated with OTEC are related by a strong inverse exponential correlation to plant size; costs are reduced dramatically as plant size and capacity increases. It is estimated that initial capital costs are $30,000–50,000 per kW installed at 5 kW, and range from $10,000–15,000 per kW for 30 MW and above. However, even at large capacity, OTEC capital costs are relatively high, and so the economic feasibility of OTEC projects is highly related to the cost of fossil fuel and secondary products. Fuel prices are currently on the rise, and the costs of using diesel is now reaching 24 cents per kWh, while OTEC may result in prices from 1–24 cents per kWh, depending on the capacity and conditions. Currently in Cuba the average price of diesel is 10 cents per kWh because of subsidized oil from Venezuela.

In terms of construction, engineering studies suggest that floating offshore plants may prove to be more cost-effective for plants over 30 MW. Capital costs for OTEC are a function of the size of the plant, but on average for offshore plants the cold-water pipe requires 14.9% of the total investment, while for shore-based plants this average jumps to 37.3%. The cost of the pipe for a 5 MW OTEC plant would be $5 million, 11% of the total investment, according to estimates made by the **OTEC Group of Matanzas.** This also takes into consideration other proposed modifications that can reduce total costs. **Julio Díaz** explained that a new method for obtaining cold deep ocean water may be feasible in Cuba. Instead of installing a flexible pipe on top of the seafloor, modern horizontal and slanted drilling techniques (adapted from the oil industry) can be used to drill through the crust into the seafloor of the deepwater zone. This method has not been proposed or applied for use in OTEC; however it holds promise for reducing costs significantly, reducing corrosion, and increasing the stability of cold seawater supply. The five million dollar valuation was offered by the Cuban Enterprise for Oil and Gas Exploration and Development and is the highest estimated value. **A. Díaz, G. Beruvides, Y. Zamora** and **D. Machado** presented a poster with possible trajectories for the slanted drilling in a zone within the Bay of Matanzas.

Even with subsidized oil prices, it is becoming clear that the economic feasibility of OTEC continues to increase as fossil fuel prices continue to rise and secondary products from OTEC plants become more socially and economically attractive. The use of deepwater for aquaculture ventures, as mentioned previously, has proven quite feasible in Japan and Hawaii. However, the discharge of cold, nutrient-rich water from OTEC plants would be highly problematic, especially in warm tropical environments. Coral reefs, seagrass systems, and other ecosystem types characteristic of the tropics are highly sensitive to cold temperatures and nutrient inputs.

Charles Yarish of the University of Connecticut described the utility and feasibility of growing seaweeds, which can clean up the nutrients of OTEC cold water while producing valuable byproducts and food. The OTEC water can also be warmed up to surface water levels during the aquaculture process. Hence, combining seaweed aquaculture with OTEC has the potential for producing economic outputs as well as discharge with virtually no environmental impacts. For example, in an Israeli experiment, seaweeds were able to produce a final effluent with very low nitrogen from fish farm effluent—88% of the nutrients were removed—at a flow rate of 4 cubic meters/hr. In another calculation, **Yarish** estimates that the red seaweed, *Porphyra* could remove all of the phosphorus and nitrogen pollution associated with salmon aquaculture. Approximately 7 kg P and 49.3 kg N are released per ton of salmon per year; at measured N and P uptake rates, 27 aquaculture nets stocked with *Porphyra* could remove all of this N and P. Furthermore, Cuba has had a very positive experience in Varadero with the cultivation of Gracilaria seaweed for agar-agar; production rates were higher than in Asia, according to the experiments of **Carmenatis,** working with the **OTEC Group of Matanzas.**

According to **Yarish,** worldwide seaweed aquaculture production has reached a commercial scale, worth ~US$7.1 billion per year. Chile is the leading country in the production of *Gracilaria* in the Americas. Seaweed constituents may be used in a variety of ways. The use of seaweeds in the nutraceuticals (nutritional supplements), cosmoceuticals (cosmetics) and pharmaceutical industries is increasing exponentially and is currently valued at more than ~US$30 million per year, while colloids are valued at a fairly stable ~US$670 million per year. Also, seaweeds contain many amino acids, vitamins, and minerals and are used in many human food products and animal feeds. For example, the seaweed *Porphyra* (which is used to make nori) can be comprised of up to 50% protein (very rich in protein relative to many other foods), and is currently valued at ~US$1,024 per ton. It has fairly high growth rates of up to 24% per day; Japanese researchers have found that strains of *Porphyra* are capable of growth rates of up to 48% per day in nutrient enriched deep seawater. *Eucheuma* is currently valued at ~US$118 per ton. Also, a new area of research that is drawing much attention is the use of microalgae being explored as a source of biogas. Yarish suggested that Cuban scientists should be assaying their local marine flora to assess lipid (oil) content. Some species of the green seaweed *Codium* have up to 6–21% lipids! Cuban scientists are currently investigating the potential of integrating microalgae production with OTEC facilities to produce biofuel (see Section 6 of these proceedings).

Cuban scientists at the **University of Mantazas** group have conducted numerous modeling studies of OTEC feasibility, presented by Julio Díaz and **Juan Landa of the University of Matanzas.** These studies were also presented in the poster session by various students from the School of Chemical and Mechanical Engineering of the University of Matanzas.

Landa stated that although cost estimates are subject to many variables, including whether the plant is shore-based or offshore, distance from shore, whether it is single purpose or multipurpose, and whether the temperature differential is enhanced or not, the OTEC group estimates that for a 100 MW OTEC plant, an initial ~US$78.24 million investment would be required, at a unitary cost of ~US$0.77 million/MW, yielding an investment recovery time of 1.1 years. They noted that secondary OTEC benefits such as freshwater recovery, biodiesel production from microalgae, refrigeration/air-conditioning, and aquaculture could reduce the investment recovery time. They also note that the use of aluminum heat exchangers, if technically feasible, could reduce initial costs.

The OTEC Group of Matanzas simulated a number of different OTEC scenarios, focusing on the use of waste heat to enhance the temperature differential. These scenarios assumed that ammonia would be used as the working fluid in a modified Rankin cycle OTEC plant. They found that the use of an additional heat exchanger increases efficiency of the thermodynamic cycle. For example, if waste heat from a sugar cane plant was used to heat OTEC water to 50 degrees C, with a flow rate of 0.515–2.325 cubic m/s, a single sugar mill could theoretically produce 70 MW of power at a cost of about ~US$15–40 million (~US$1.5–3 million/MW) with investment recovery in less than a year. If all 56 of Cuba's sugar mills converted to this technology, they could conceivably produce 3000 MW/yr.

With ocean energy, Cuba has an excellent opportunity to make a valuable contribution to reducing global warming pollution and thus to generate emissions credits through the installation of an OTEC plant. Carbon credits have become valuable commodities as the market for them has developed, and with the coming of OTEC, Cuba may offset some of the investment cost by selling carbon credits. This marketplace is currently voluntary in countries that have not ratified the Kyoto Protocol; however in places that are Kyoto Annex 1 nations, like the European Union, cap and trade regulations are mandatory. The average price of carbon credits is approximately ~US$35 per ton. More details on the carbon credit market are provided in Section 12.

SECTION 9

Environmental impacts of ocean energy and opportunities to reduce and minimize them

Doug Rader and Rod Fujita of Environmental Defense Fund (EDF) described some of the ecological values of Cuban marine ecosystems and of the larger ecosystem comprised of U.S. and Caribbean waters, and the need to comprehensively reduce threats to these shared ecosystems. They also discussed the potential environmental benefits and impacts of ocean energy, and ways to minimize adverse impacts.

Cuban marine ecosystems are highly connected to the ecosystems of other Caribbean countries and of the United States. Caribbean countries and Florida share a shallow water coral reef tract. The U.S. and Caribbean countries also share a deepwater coral ecosystem dominated by Ophelia colonies, which are very fragile, ancient corals up to 2000 years old that form spectacular pinnacles on the seafloor. These corals serve as a priceless record of environmental change.

The Florida Current contributes to the Gulfstream, one of the most stable and powerful currents in the world. Some studies estimate that technologies that tap only 1% of the energy contained in the Gulfstream would yield 4–8 GW (4000–8000 MW) of energy potential. These currents move larvae and fishes from where they are born to where they mature. Models and field studies indicate that fish larvae are carried by currents for 4 weeks until they settle on coral reefs.

Migratory birds also link Caribbean and U.S. ecosystems by using them for nesting and feeding, and by transporting energy and materials throughout the region. Many migratory birds use Cuban ecosystems.

The United States and the Caribbean also share some environmental problems. We share a problem with ozone near the ground. Ozone is a powerful greenhouse gas and a health threat.

The potential environmental benefits from ocean energy are large and obvious, notably a reduction in local air pollution and greenhouse gas emissions. However, as is the case with any large-scale technology, there are potential environmental impacts associated with ocean energy. Construction of ocean energy platforms

Dr. Rod Fujita's presentation

in coastal ecosystems and on the seafloor is likely to result in some level of direct impact on ecosystems as well as siltation which can reduce seagrass productivity and result in coral and seagrass mortality. Ongoing operation of ocean energy facilities could result in leaks of working fluids and other substances harmful to marine life. Tidal energy can obstruct flows, thus disrupting the natural transport of animals, larvae, sediment, and nutrients. Such disruption can have severe impacts on the structure and resilience of marine ecosystems, reducing their ability to provide ecological goods and services. Offshore wind energy facilities at large scales can affect wind patterns and migratory birds, as well as reduce access to marine areas by users like fishermen and tourist operations. Entrainment of animals and larvae in OTEC uptake pipes results in direct mortality, and can have significant effects on populations particularly in embayments and coral reefs which have synchronized spawning events. Releases of nutrients and cold water from OTEC plants would no doubt result in coral bleaching, eutrophication (the overgrowth of coral reefs with less desirable species, and in extreme cases, mass die-offs of marine life due to low oxygen conditions), and other impacts. Sensitive ecosystems must be protected, including coral reefs, mangroves, seagrass beds, and important nursery and rookery areas for marine mammals, seabirds, and sea turtles.

In addition, the deep ocean must be protected from the effects of ocean energy, in particular with regard to OTEC which relies on the withdrawal of large amounts of water from the deep ocean. The deep ocean is not a desert—it is full of life and very rich in biodiversity, including slow-growing species that take decades or even centuries to recover from damage.

Although it is often assumed that discharges become well mixed rapidly upon entry into ocean receiving waters, this is not always the case due to small-scale circulation and the fact that water residence times can vary greatly from place to place along a coastline. Embayments and protected coves often have long residence times and hence are usually more vulnerable to pollution than open coastal areas exposed directly to the ocean. Areas with seagrass meadows or patch reefs have complex circulation patterns that often include eddies that trap discharge water and keep pollution concentrations high for extended periods of time.

The best way to guide industrial development along a sustainable path while encouraging technical innovation and the improvement of environmental and economic performance is by promulgating performance standards, such as water quality standards, instead of prescribing technologies or mitigation approaches. This approach allows creative entrepreneurs to develop new ways to meet standards while cutting costs. While environmental standards for coastal waters do not yet appear to be available for Cuba, research in other tropical countries suggests potential ranges that can serve as starting points for the development of appropriate standards for Cuba (Table 1 and Table 2).

Thresholds for coral reef ecosystems with respect to Nitrate and Ammonium are thought to be quite low. Phosphate thresholds are extremely low, because productivity in coral reef

TABLE 1

Environmental standards (EDF)

Chlorophyll	.5 ug/l	ANZECC, 2000
Dissolved oxygen	90% saturation	ANZECC, 2000
Temperature	31ºC	Delcan, 1994
Salinity	30–38 ppt	Delcan, 1994
TSS	5 mg/l	Delcan, 1994
Sed. Rate	5 mg/cm^2/d	Delcan, 1994
Turbidity	1.5 NTU	Delcan, 1994

Australian and New Zealand Environment Conservation Council, Delcan, *1994 Report to Government of Barbados.*

TABLE 2

Nutrient thresholds for tropical marine ecosystems (EDF)

$NO+NO_2$	9.8 µgN/l	Delcan, 1994
NH_4	9.8 µgN/l	Delcan, 1994
NO_3+NH_4	1 µM (0.014 ppm N)	Lapointe, 1997
Total N	100 µg/l	ANZECC, 2000
PO_4	2.48 µg P/l	Delcan, 1994
PO_4+DOP	0.1 µM (0.003 ppm P)	Lapointe, 1997
Total P	15 µg/l	ANZECC, 2000

Lapointe, 1997. *Limnology and Oceanography.* 42: 1119–1131.

waters is often limited by phosphate availability; as a result, even very small amounts of phosphate stimulate the production of algae, which can overgrow corals. Algal growth can also reduce the transmission of light through the water, reducing growth rates of seagrasses and coral reefs, which depend on very clear waters that transmit light well. Reduced seagrass growth in turn reduces habitat for conch and other valuable species, while reduced coral growth reduces habitat for myriad species and fisheries. Moreover, vigorous coral growth is essential for keeping pace with erosive forces such as parrot fish grazing and dissolution (more rapid now as the ocean becomes more acidic as a result of carbon dioxide emissions from fossil fuels) and with an accelerating rate of sea level rise which threatens to "drown" slow-growing reefs (if reefs cannot keep up with sea level rise, water depth becomes too great for sufficient photosynthesis to occur for the maintenance of the reef). Nutrient discharge associated with OTEC could potentially be partially mitigated with macroalgal or microalgal aquaculture.

Another potential concern with respect to OTEC technology arises from the fact that this technology draws deep, CO_2-saturated water to the surface. Upon contact with the atmosphere, some amount of this CO_2 will outgas into the air. However according to calculations by L. Vega, CO_2 outgassing from an OTEC plant would be expected to be only 0.5% of that released by an oil-fired plant. This could potentially be mitigated by discharging the cold OTEC water at depth, or mitigated in part by using seaweeds to absorb the CO_2 and convert it into biomass. Similarly, sea surface temperature anomalies could result from the direct discharge of cold OTEC water into surface waters, which could result in coral bleaching and other adverse impacts on warm-water adapted species, if residence times are long enough (e.g., in embayments or lagoons with restricted circulation). This impact could be mitigated by either discharging at depth or by using aquaculture or other systems to allow the water to reach to surface water temperatures. Some workshop participants also expressed concerns about the discharge of salty brine as a result of freshwater production by OTEC, because this is a concern with conventional desalination technologies. However, other participants noted that one method for OTEC freshwater production—condensation from the atmosphere—will result in no brine and will not affect the chemistry of the cold seawater in any way. And that the other method—flash evaporation—would have negligible effects on salinity due to the very small volume of freshwater that would be evaporated relative to the large flows of seawater that OTEC requires.

EDF recommends the adoption of Best Practices and performance standards to minimize the potential adverse impacts of ocean energy development, and the development and enforcement of performance standards that apply to site development, construction, operation, and decommissioning. As is the case with any construction near the coast, it is advisable to avoid sensitive habitats, avoid other major impacts, minimize unavoidable impacts, characterize the residual impacts, mitigate or offset minimized impacts, and monitor for verification.

Ocean energy offers excellent opportunities for clean energy production, as well as numerous ancillary benefits such as freshwater, food, seaweed crops, and refrigeration/air-conditioning in the case of OTEC. The development of ocean energy—if done thoughtfully and in the context of strong environmental standards, enforcement, and incentives—is an unmatched opportunity to help build a healthier world, meeting human needs while at the same time protecting and restoring ocean ecosystems.

SECTION 10

Potential environmental impacts of wave energy

George Boehlert, Director of the Hatfield Marine Science Center, Oregon State University, presented the results of a recent workshop on the potential environmental impacts of wave energy off the Oregon coast.

Nearly half of Oregon's electricity supply comes from hydropower. Wind and geothermal energy only account for 1% of the supply. Oregon needs a better renewable energy portfolio, and so the state is exploring the potential of wind, solar and wave energy.

Wave energy can be more predictable than other forms of renewable energy such as solar and wind, because waves form constantly. Predictable supplies of energy are useful for utility companies, which must plan for meeting demand which also varies over time.

Wave energy varies in space; there are some areas that have particularly steady and large waves such as southern Alaska. However, there is low population density in this area; hence, the demand for electricity is relatively low. The east coast of the U.S. is dominated by a shallow continental shelf, which reduces wave strength and energy potential. In contrast, the west coast of the United States has fairly high wave energy potential due to the long reach afforded the Pacific Ocean as well as large population centers with high energy demand.

To date, seven wave energy sites have been identified in Oregon. Wave energy is highest in the winter and decreases in the summer when the water is calmer, but there is potential throughout the year. The distribution of wave energy throughout the year is similar to the distribution of power demand along the Oregon coast, which is high in the winter and lower in the summer.

Challenges for the development of wave energy in Oregon include:

- **Education and outreach:** Many people are worried about what can happen when new equipment is installed in the ocean.

- **Existing use conflicts:** Fishing, recreation, and other activities may conflict with wave energy facilities.

- **Regulatory framework:** Because ocean energy is a relatively new use of the ocean, jurisdiction and oversight responsibilities are not clear; two agencies are vying for jurisdiction. **The Federal Energy Regulatory Commission (FERC)** has developed a process to assess requests for permits to use areas of the ocean for wave energy. Projections suggest that up to 5 MW of power may be generated from wave energy along the west coast of the U.S.

- **Research and development: The Oregon Wave Energy Trust (OWET)** is a $4.2 million fund to build and share expertise needed to accelerate the development of the wave energy industry. The **National Wave Energy Demonstration Center** is available for testing wave energy devices in a location that already has a permit.

In October 2007, Oregon held a workshop on wave energy with two main goals: (1) to conduct an initial assessment of the potential ecological impacts of wave energy; and (2) to develop a general framework for analyzing wave energy environmental impacts. Fifty U.S. scientists, academics, and representatives of nongovernmental organizations (NGOs) gathered in Newport, Oregon for the workshop, which was funded by government agencies, foundations, and NGOs.

After the presentation of background information on wave energy technologies (summarized in Section 7 in these proceedings), scientists with specific expertise worked in small groups to assess impacts.

Potential impacts of wave energy include:

- Wave energy at scale may significantly reduce wave and current strength, with subsequent impacts on shore processes such as the transport of sediments, water, nutrients, heat energy, organisms, and propagules.
- Wave energy structures may act like artificial reefs and attract organisms.
- Cables and tether lines associated with wave energy facilities could entangle marine animals.
- Wave energy platforms and structures could result in changes in benthic habitat. Changes in flow (current) associated with such structures will affect larval distribution and settlement.
- Wave energy could have effects on community structure and impacts on migration corridors for many different species. There is concern in Oregon about the potential effects of wave energy on the salmon and green sturgeon, and with respect to the ability of fishermen to access good fishing grounds.
- Wave energy could have effects on seabird migration patterns, and lighting on buoys may attract birds.
- Overtopping wave energy devices can trap organisms.

The Oregon Wave Energy Workshop showed that scientists want to help society understand the ecological effects of wave energy. Participants identified the need to link wave energy data collection to other ocean research and activities. Because wave energy technology is advancing rapidly, there is a need for ecological impact assessment that adapts to new information. Measurements and monitoring will be essential for understanding the impacts of wave energy. Finally, there is a need to coordinate research and create a clearinghouse for wave energy information. For example, a great deal of research on wave energy has been conducted in Scotland. There is a need to determine which studies from other places can be applied generally, and when it will be necessary to do site-specific studies.

The proceedings of that workshop will be available at http://hmsc.oregonstate.edu/waveenergy.

SECTION 11

Greenhouse gas reduction credits

Denise Choy of Environmental Defense Fund (EDF) provided an overview of the market for greenhouse gas reduction credits (often referred to as carbon credits).

The facts of global climate change are well established. Increased carbon dioxide (CO_2) and other greenhouse gases have warmed the Earth. Greenhouse gas (GHG) concentrations are increasing because of human activities such as fossil fuel combustion. The rate and extent of future warming and the severity of its impacts depend on future emissions and sinks of CO_2 and other GHGs.

Carbon credits can play an important role in reducing GHG emissions. Cuba can make a valuable contribution by demonstrating that clean ocean energy is a feasible way to prevent or offset fossil fuel emissions.

Carbon credits can be part of financing packages to support clean energy production.

With increased awareness of climate change, GHGs (usually translated into carbon equivalents) have become commodities that carry value and can be traded like rice or sugar. They are traded in a carbon marketplace—the buying and selling of CO_2 reductions and other global warming pollution credits. As nations put caps or limits on these pollutants, companies that reduce emissions beyond requirements can sell their "excess" reductions as credits. This is a *voluntary* marketplace in countries that do not have a formal cap on GHG emissions such as the United States. However, in places that do have a cap on GHG emissions (Kyoto Annex I nations) such as the European Union this is a *mandatory* carbon marketplace to date. Mandatory and voluntary markets can coexist in the same country (e.g., the U.K).

Examples of carbon offset projects include:

- Reforestation and forest management (which increases carbon sinks, thus reducing GHG concentrations in the atmosphere, or reduces emissions by reducing deforestation and slash burning)
- Agricultural techniques (which increase carbon sinks by preserving the ability of the soil to store carbon)
- Carbon capture and geological sequestration (which reduce GHG emissions by turning them into forms that can be sequestered for long periods of time)
- Methane capture: animal waste and landfills (methane is a powerful GHG)
- Renewable energy (which can reduce GHG emissions directly by replacing existing oil, gas, or coal power plants or indirectly by offsetting future projected emissions that would occur if the renewable energy were not available)

For Cuba to generate and sell carbon credits there are two main options. Cuba could sell carbon offsets on the mandatory Kyoto protocol market through the Clean Development Mechanism. Alternatively, Cuba could sell offsets into the voluntary marketplace that has emerged as a result of individual and corporate interest in reducing GHG emissions.

The Kyoto Protocol requires developed country signatories to reduce their GHG emissions below levels specified for each of them in the protocol. These targets must be met within a five-year time frame between 2008 and 2012, and add up to a total cut in GHG emissions of at least 5% against the baseline of 1990 emissions. The targets cover emissions of the six main greenhouse gases, namely:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)

Review and enforcement of these commitments are carried out by United Nations–based bodies. The protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities" for two main reasons. First, those countries can more easily pay the cost of cutting emissions. Second, developed countries have historically contributed more to the problem by emitting larger amounts of GHGs per person than in developing countries.

In order to give parties to the protocol a certain degree of flexibility in meeting their emissions reduction targets, the protocol contains three innovative mechanisms—known as Emissions Trading, Joint Implementation, and the Clean Development Mechanism (CDM).

Emissions Trading and Joint Implementation allow developed parties to earn and trade emissions credits through projects implemented either in other developed countries or in developing countries, which they can use toward meeting their commitments. These mechanisms help identify lowest-cost opportunities for reducing emissions and attract private sector participation in emissions reduction efforts. Developing nations benefit in terms of technology transfer and investment brought about through collaboration with industrialized nations.

The Clean Development Mechanism (CDM) recently announced that it registered its 1000th project. To be eligible for a carbon offset credit under the CDM, the project proponents:

- Must show how the offset will be different from a business-as-usual (BAU) scenario
- Provide extensive documentation and calculations
- Gain approval for projects and methodologies (for calculating the offset) by the CDM Executive Board at the United Nations

There are no currently approved methodologies for calculating offsets for ocean energy projects.

The Gold Standard is a Swiss NGO with the goal of helping CDM meet objectives by providing widely accepted methodologies for calculating carbon offsets. The Gold standard is endorsed by 49 NGOs led by the World Wildlife Fund. To obtain accreditation by the Gold Standard, project proponents must provide both CDM documentation plus additional Gold Standard documentation, and submit to a review and approval process conducted by an independent accreditation organization.

Cuba is already eligible to receive carbon credits and associated financing under the CDM. The first threshold test has been passed; Cuba is a signatory and ratifier of the Kyoto Protocol. Cuba is a Non-Annex I country, along with many of the neighboring Caribbean nations; hence it is not subject to a binding cap on GHG emissions. The designated national authority in Cuba for CDM registration is CITMA. Cuba has already benefited from the CDM by registering the Energas Varadero project (to convert a power plant to combined cycle operation) in June 2007, one year after the project started (CDM project 0918, represented by Sr. Jorge Luis Fernández Chamero and Sr. José Antonio Díaz Duque). The project is expected to offset 342,235 metric tonnes of CO_2 equivalents per year (http://cdm.unfccc.int/Projects/DB/DNV-CUK1170423186.13/view). The average American emits 12–20 tons per year, so the Energas Varadero project alone would offset the annual emissions of about 17,000 Americans.

While carbon credits from the mandatory market command a higher price than voluntary carbon credits, the voluntary market offers some advantages. In the voluntary marketplace, a bilateral agreement between the project developer (seller) and the buyer is negotiated to set the terms of the offset financing. The terms of offset certification and verification are also negotiated in this agreement. Thus, the complex and sometimes difficult process of developing a CDM or Gold Standard approved methodology and certification of the project's carbon offset can be avoided.

It is EDF's position that even voluntary credits should meet certain minimum standards to ensure that they are of high quality so that they do not end up doing more harm than good.

Here are the criteria that we believe make good quality offsets:

1. Only direct emissions reductions are eligible (e.g., energy efficiency).
2. The emissions reductions must demonstrably exceed business-as-usual projections (additionality) (i.e., they would not occurred without the emissions-offset investment).
3. Quantification of emissions reductions must be reliable and accurate.
4. Permanence of emissions reductions must be clearly explained and demonstrated.
5. The time frame for emissions reductions must be clearly identified. For example, if the emissions-reduction plan is to plant trees, the time lags resulting from tree growth and the rates at which CO_2 is removed from the atmosphere must be taken into consideration.
6. Offset providers should be able to demonstrate clear ownership of the claimed emissions reductions.
7. The emissions reductions must be serialized and tracked to assure that they are not reoffered for sale.
8. All claims should be independently verified by a third party.
9. The emissions reductions should be generated in ways that produce net positive environmental and community impacts. For example, methane capture on hog farms, if the farmer uses the traditional spray field and lagoon system, and simply places a tarp over the lagoon to capture the methane, results in a GHG saving but does not address the other community and human health impacts of the lagoon system and, in fact, may worsen those impacts by institutionalizing traditional systems.

The International Finance Corporation (IFC) Carbon Finance Unit provides another way to finance GHG emissions-reduction projects. The IFC finances carbon projects by buying certified carbon credits from them. To be eligible for this program, projects must take place in an emerging market country that has either ratified the Kyoto Protocol or is in the process of doing so; must generate a minimum number of carbon credits which varies by project; must meet IFC environmental and social criteria; must obtain host country approval; and must be subject to an independent evaluation of project design. Renewable energy projects such as ocean energy are eligible and are of particular interest to the IFC.

In summary, there are no accepted OTEC or other ocean energy carbon project methodologies yet. The size of the offset potential from Cuban ocean energy projects must be carefully determined. Cuba already has the domestic institutions in place for CDM projects, and selling to the voluntary market is also possible. In either case, there is the potential for a valuable revenue stream.

In an ad hoc meeting, a group of workshop participants made a preliminary calculation of the conservation benefits for 2 MW and 5 MW ocean energy facilities (Table 3). Using a conservative estimate of current carbon credit prices ($20/ton of carbon; current prices have reached $35/ton), a 5 MW ocean energy project could potentially generate $337,500 per year by selling carbon credits, save about 118,750 barrels of oil over 20 years ($11,875,000 at $100/bbl), and offset about 16,875 metric tonnes of carbon per year. These participants estimate that the potential carbon credit for a 5 MW ocean energy facility (at $20 per ton of carbon) would range from $215,000 to $337,500.

TABLE 3

Preliminary calculation of conservation benefits for ocean energy facilities

	Estimates based on number of BTUs in a Jamaica example (280g of fuel/kWh)			
Specifications	**Million barrels of fuel saved**	**Tonnes of carbon saved**	**Tonnes of sulfur saved**	**Tonnes of particulate matter saved**
20 year life 2 MW	950,000	135,000	4,800	160
20 year life 5 MW	2,375,000	337,500	12,000	400
Per year 5 MW	118,750	16,875	600	20

SECTION 12

The Cuba OTEC database

Dailin Arzola and **J. García** demonstrated a web site that they have developed. Users can register and gain access to technical information on OTEC. Users can also specify parameters of an OTEC project (e.g., power capacity, single or multiuse, flow rate, water temperature differential, etc.) to drive an automated analysis that calculates the temperature of the working fluid, characteristics of the water exiting the heat exchangers, and changes in nutrients and salinity among other factors.

SECTION 13

Recommendations

Workshop organizers agreed on the following recommendations:

1. Conduct additional studies on tidal currents to specify optimal locations.
2. Form an international collaborative group on ocean energy.
3. Conduct studies of OTEC environmental impact.
4. Continue to facilitate the exchange information between Saga University and the University of Matanzas.
5. Identify other countries in the Caribbean interested in developing ocean energy technology.
6. Integrate new energy resources such as biodiesel produced from microalgae.
7. Strengthen the exchange of information with Xenesys.
8. Strengthen the coordination of work related to ocean energy by GeoCuba, MinBas and the OTEC Group (Matanzas).
9. Promote scientific studies of OTEC applications.
10. Conduct economic studies of ocean energy and potential carbon offsets.
11. Install a cold seawater upwelling pipe in Cuba to rapidly provide tangible social benefits such as freshwater, refrigeration, and air-conditioning at relatively low cost; these benefits have already been demonstrated elsewhere. The upwelling could also be used to study the feasibility of producing various OTEC secondary products such as microalgae for biodiesel production, seafood and seaweed via aquaculture, as a step toward demonstrating OTEC feasibility.
12. Environmental Defense Fund will collaborate with the University of Matanzas and CITMA on summarizing proceedings and to circulating contact information.

Ocean Energy Workshop participants

SECTION 14

Concluding remarks

Roberto Vizcón, Vice Dean of the University of Matanzas, provided concluding remarks. He stated that the workshop has resulted in increased scientific knowledge and improved relationships. George Claude pioneered ocean energy in Cuba. Continuing the development of ocean energy in Cuba reflects the reality that humanity cannot support development with one source of energy. Coal use dominated the 19th century, and oil dominated the 20th century. The use of fossil fuels is not sustainable.

In theory, OTEC could provide up to 5,000 MW of electricity, enough to supply all the electricity in Cuba. According to Dr. L. Vega, OTEC could also produce all of Cuba's freshwater needs. But drawing on the lessons of history, Cuba does not want this to be the only source of electricity.

Cuba has 15 national groups studying different ways of saving energy and developing other renewable energy resources. In 2008, Cuba made a substantial financial investment in renewable energy. These technologies may be able to generate power at lower cost than currently installed capacity. The growth of renewable technologies is comparable to that of other state of the art technologies such as electronics and informatics and biotechnology. It is up to us to transform the environmental/energy culture in Cuba. Cuba has embarked on an effort to transform its environmental and energy culture.

George Claude began this transformation in the 20th century when he demonstrated the Ocean Thermal Energy Conversion process, and it is up to us to complete this progression. Claude once said that in the age in which he lived men behaved like hares that spent their money indiscriminately. In our current age, where unsustainable development practices are all too common, it is these words that continue to ring all too true. Today we are reminded that people do not inherit the Earth from their parents, but borrow it from their children. A new world is possible with everyone and for everyone. We will continue working for world peace, human solidarity and sustainability.

Finding the ways that work

National Headquarters
257 Park Avenue South
New York, NY 10010
T 212 505 2100
F 212 505 2375

Austin, TX
44 East Avenue
Austin, TX 78701
T 512 478 5161
F 512 478 8140

Bentonville, AR
1116 South Walton Boulevard
Bentonville, AR 72712
T 479 845 3816
F 479 845 3815

Boston, MA
18 Tremont Street
Boston, MA 02108
T 617 723 2996
F 617 723 2999

Boulder, CO
2334 North Broadway
Boulder, CO 80304
T 303 440 4901
F 303 440 8052

Raleigh, NC
4000 Westchase Boulevard
Raleigh, NC 27607
T 919 881 2601
F 919 881 2607

Sacramento, CA
1107 9th Street
Sacramento, CA 95814
T 916 492 7070
F 916 441 3142

San Francisco, CA
123 Mission Street
San Francisco, CA 94105
T 415 293 6050
F 415 293 6051

Washington, DC
1875 Connecticut Avenue, NW
Washington, DC 20009
T 202 387 3500
F 202 234 6049

Beijing, China
c-501, East Building of Yonghe Plaza
28 East Andingmen Street
100007 Beijing, China
T +86 106 409 7088
F +86 106 409 7097

La Paz, Mexico
Revolución No. 345
E/5 de Mayo y Constitución
Col. Centro, CP 23000
La Paz, Baja California Sur, Mexico
T +52 612 123 2029