International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 11, November-2013, pp: (11-16), Available online at: **www.erpublications.com**

A review paper on present status & various novel developments in OTEC plants and it's various applications

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Keywords: OTEC, novel methods, applications.

Introduction

The dire need in the present electricity generation is to resort to methods entailing lesser non-renewable resources. The present decadence of the conventional energy resources such as coal, petroleum indicate that soon the development and the innovation in the Non-Conventional Energy Resources would be the man's only recourse to the ever burgeoning demands in electricity. Thus a need for the development of such resources from the very present day is required. A lot of cerebration had already been given to the solar and the wind energy systems. In comparison to them, Ocean Thermal Energy Conversion looks in a germinal state and thus gives a lot of scope to scientific thinkers to ruminate over novel innovations.

The concept of Ocean Thermal Energy Conversion evolved, when in 1881, a French scientist J.A. d'Arsonval propounded a concept of the withdrawal of thermal energy from oceans. In 1926, the French engineer Georges Claude made Ocean Thermal Energy Conversion a reality. Although, his plant consumed more power than it created, he certainly succeeded in edifying the world with an alternate source of energy. Since ocean's form a major portion of the Earth they, being left aside in the course of withdrawing energy from Non-Conventional Energy Resources sounds unlikely. Thus the present review is an attempt to project collectively, the present status of Ocean Thermal Energy Conversion systems, some novel technological innovations in Ocean Thermal Energy Conversion technology and the various other applications where Ocean Thermal Energy Conversion phenomenon can be used.

Since the advent of Ocean Thermal Energy Conversion (OTEC) phenomenon and its implementation, a number of OTEC plants have developed in the regions of the world which are found to be the most prominent location for the extraction of such energy. Also, a number of sophisticated technological alternatives have been implemented within the rudimentary OTEC model. This section presents a status of some of the OTEC plants and discovered or invented alternatives within OTEC Plants.

The concept of SWAC is one of the most important concepts in OTEC. It was first developed by National Energy Laboratory of Hawaii Authority (NELHA) in 1983. Also, it was the same organisation which built the first Cold Water Pipe in U.S. in 1981. Since then the SWAC systems have been developed drastically over conventional cooling methods which has bolstered the cause of OTEC which after its invention has been even more feasible. Today, Lake Source Cooling and Deep Lake Water Cooling methods have also developed as its complementary. The status of SWAC is thus growing and in a way improving the design perspectives of the OTEC itself. In a paper [1], it was discussed that the SWAC can offset electrical demands by 75%-85%. Today, in countries like France, Canada, U.S. and many others cold water systems are used for air-conditioning of the buildings.

The status of deep well has been drastically improving as a potential and viable alternative to OTEC. In the paper [2]-[5], it was featured that in Florida a Boulder Zone was identified at a depth of 3000 feet having cold sea water wells formed by the water coming from the Florida Straits. More than 30 deep wells were identified and in the paper [2]-[5], it was delineated that 5 power plants were proposed making deep wells as effective alternative for OTEC applications.

The Ballistic Cold Water Pipe has been extensively exalted with the latest calculations. Although, it is a new concept, in a paper [6]-[8] its mechanism and some assumed data were presented. The water therein is projected upwards into the empty pipe from a nozzle at a high speed of 100m/s. For a 670m-deep pipe it was shown in the same paper, that a 15 cubic meter/second of the flow will cause a frictional loss of 2-m (head loss). In the same paper it was also stated that research on the pipe walls also needs to be conducted which should be able to withstand such an external pressure. It was also shown in the paper that it was less expensive and much more rugged.

The navy views the OTEC technology as a technology to reduce dependence on the fossil fuel and the associated release. In the U.S. Navy, the command (NAVFAC) is promoted and established to promote technical viability and the commercialisation of OTEC. It is required to promote certain key technologies which include offshore platforms, deep water anchors and moorings. At present, the Federal Government is involved in the development, inspection and the demonstration of OTEC subsystems. These subsystems include the Department of Energy funded apparatus development and the Cold Water Pipe development. Also, the NAVFAC took a strident stand for the congress-funded heat exchanger design and at the same time, American Recovery and Reinvestment Act (ARRA) funded OTEC pilot plant design and critical component design. Moreover, presently the navy is involved in developing commercialisation of OTEC and roadmaps to support and implement the progressive steps-[9].

Hawaii has an abundant energy resource in wave energy. It is perfectly situated in an area having a high potential of OTEC. According to the Hawaii electricity profile by 2030, 40% of the state should be fed with Non-Renewable energy resources. The University of Hawaii National Energy Institute (HNEI) was listed among the three institutes for renewable energy centres in the state by the U.S. Department of Energy. In the paper[10]-[11], it was projected that HNEI is conducting test and also implementing projects for inspecting interconnection systems for wave energy Laboratory of Hawaii Authority. The state has also framed a process wherein the energy projects of more than 200 Mega Watts are automatically eligible to enter into Renewable Energy Facility Siting Process (REFSP). Because there are a number of occlusions in the way of Renewable-Energy Resources so the state drafted a procedure to streamline the flow of all activities to promote the growth of OTEC. Moreover, in the paper [10]-[11], it was also projected that a number of people were also pursuing R&D education in Hawaii for OTEC and in that a number of private companies are also proposing their pilot plants in Hawaii. All such edifying facts presented in the paper [10]-[11], are a harbinger of OTEC success in Hawaii.

Some Novel Innovations in OTEC Plants and Technology

Since the advent of the OTEC technology a number of small and big technological innovations have been done to make this phenomenon a glaring reality with the expanse towards commercialisation. This section is an attempt to focus on some of the most important technical innovations in OTEC that mark the face of today's OTEC systems. Thus some of the important innovations within the OTEC technology are as follows.

OTEC energy is derived from oceans. Currently, the research in OTEC plants is focussed basically on potential energy concentrated in the temperature gradient between the warm and the cold water. But the theoretical efficiency of the plant designed on such a concept is relatively low. The efficiency given by the Rankine Cycle is

$$\eta = 1 - \frac{T1}{T2}$$

Where, T1=condenser temperature

T2= Hot vapour temperature

In the paper [12]-[13], a novel method was discussed in which an external system supplying heat to the Rankine Cycle was introduced. With an external heat supplied to the Rankine Cycle the efficiency of the cycle was found to increase considerably. In this method a TIS was introduced externally to the Rankine Cycle in which ammonia reacted with water to produce ammonium hydroxide producing heat. This heat was supplied to the Rankine Cycle to increase temperature. Since no vapours of ammonia were involved in the production of electricity, so heat was only considered in the rankine Cycle and this increased efficiency. A basic scheme of such a system is given below.

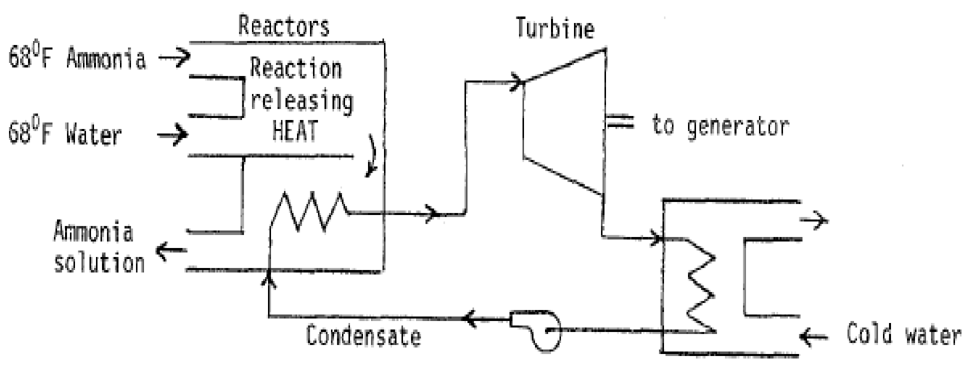

Figure 2. TIS assisted OTEC plant

In this scheme, ammonia gas from the fractionator is passed to the heat exchanger where it meets with mild ammonia from the reactor. The ammonia is absorbed by water in the solution to liberate heat at higher temperature. The remaining ammonium hydroxide is passed again to the reactor where it reacts with the mild ammonia from the fractiontor and thus releases more energy. As the solution proceeds it becomes concentrated with ammonia which is removed with the help of fractional distillation with heat from sea water. The maximum thermal efficiency, the overall thermal efficiency, all these factors favour TIS whose efficiency is 3.2 times the efficiency of the conventional OTEC systems.

Also in the design of such a system, because of the similarity in the design of the cold water pipe and platform the cost remains almost similar. Because of the less dependence on sea water, TIS system has much higher heat with only 61% surface of the heat exchanger as compared to conventional OTEC.

In an OTEC system the cold water pipe is of utmost importance. The deep cold water pipe allows a higher temperature gradient and thus a better efficiency of OTEC systems. But building such pipes with traditional methods seems uneconomical and challenging. With the burgeoning demands of electricity and the increasing dependence on Non Conventional Energy Resources it becomes mandatory to develop methods to increase efficiency of OTEC Systems.

In the paper [14]-[15], a novel design for Cold Water Pipe was propounded which could be lowered upto 3000 feet and has a diameter of 30 feet. This was called a Fibreglass Reinforced Plastic (FRP) sandwich material. Three test projects were undertaken to estimate their performance in OTEC systems. It was found that such Cold Water Pipe design was suitable for moored OTEC platform. A basic design for FRP sandwich Cold Water Pipe is as under:

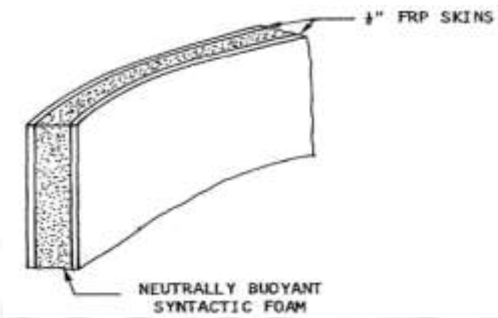

Figure 3: A basic FRP design Cold Water Pipe cross-section

In this design there is a neutrally buoyant foam core which separates the two FRP laminates. The function of the core is to isolate two laminates of variable thickness. This is to avoid buckling. A spherical bearing at the platform provides angular motion. The fabrication of the pipe was done with fibre glass inner skin which was wounded to circumfentially rotating ring containing spools. This ring had 30 feet diameter. The tape possessed biaxial distribution of fibres resin. With such a design it was assumed to have a compression and tensile strength of 6000 psi and shear stress of 5000 psi. Thus proposed design was effective for the strength and for the fact that it could be fabricated at the shore.

The man's capacity to draw large amounts of water from the ocean depths give way to a thought that there is an impending source of energy still to come from oceans. In case of OTEC a temperature difference of 20°C between the hot and the cold water is considered suitable. Hence OTEC can prove a valuable source of energy therein. For the commercial feasibility of the OTEC there should be an effective heat exchanger and a technology to draw cold water from large depths. It is being calculated that for producing 1 MW of power 5 cubic meters of cold water is required. Moreover, for the maximum efficiency of OTEC flow rate of water should be minimum and the friction between water and pipe wall should be minimum. Thus there is a requirement of a Cold Water Pipe with large diameter and a long length. With existing materials there is a problem of buckling. Hence a new concept of Cold Water Pipe is required.

In paper [16]-[17], a novel Cold Water pipe design was propounded by the name of Inflatable Pipe. Such a pipe had the advantages of the ease of installation and non-destructive Buckling. The design of such a pipe is as under.

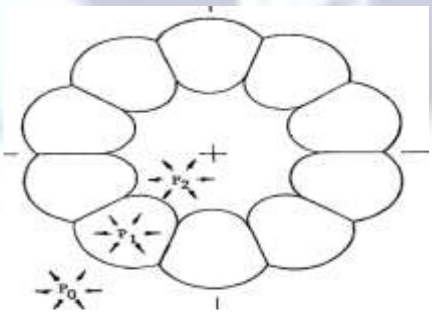

Figure 4. Cross-section of the proposed Inflatable Pipe

The pipe had a double wall and a honey combed structure. The material used in the pipe was flexible. The middle cavity of the pipe was proposed to carry the cold water and the outer cavity was one which was pressurised by filling the water. In the same paper, the analysis of the pipe was done assuming it to be a part of 10MW OTEC plant located at Keyhole point at Hawaii. After the analysis the graph of the pipe's inflation induced tensions was plotted against the pipes outer diameter. The tension was plotted by taking the ratio with the outer skin tension T_1. By the graph it was concluded that there was no optimum pipe configuration for such a pipe if the inner diameter was fixed to 5m. Also, in the same paper, it was shown that since the ocean current speed as 1m/s and just induced a pressure of 0.04 atmosphere on both the upper and the lower surfaces, so they could be neglected and thus were neglected during tension calculations.

A prototype was also constructed with a 6 mil polyethylene plastic sheeting material. It had 10 equally spaced radial webs which had thin strips that connected the outer and the inner skins. The ten outer cavities it had were individually filled with an air pump which was centrally connected. The overall model dimension were 1 meter (outer diameter), 0.7 meter (Inner Diameter), 4.6 meter (length).

One of the most common technical problems associated with the OTEC plants is the problem of Bio-Fouling. The heat exchanger of the OTEC operates on a very low temperature differential, so bio-fouling in heat exchanger, which increases the thermal resistivity and reduces the amount of heat transferred, needs to be controlled. In a paper [18]-[19], the impact of bio-fouling on heat exchanger performance was listed in the form of a table. In a standard, the critical bio-fouling in a 60 MW plant should not be more than 0.002 thick. Along with this the paper also presented some control strategies for controlling the bio-fouling as well as their evaluation.

Advantageous Features	Chlorine	Amertap Balls	M.A.N. Brushes	Biocidal Soak	Toxic Coating
Major Considerations					
1. Proven countermeasures for marine heat exchanger	X	X			
2. Minor capital expense			X	X	X
3. Minor parasitic power consumption		X	X	X	X
Considerations					
4. Affords biofouling control between screens and tubes	X			X	X
5. Major design innovations not required	X		X	X	X
6. No adverse environmental impact predicted		X	X		
7. Not sensitive to debris entrainment	X			X	X
Minor Considerations					
8. Infrequent maintenance and repair required			X	X	X
9. Effective against inorganic fouling		X	X		
10. Compatible with enhanced tube surface designs	X		?	X	X

Figure 5. Different control strategies and their evaluation

In the OTEC systems shelf platform designs are common by the name of shelf-mounted OTEC plant. They require a Cold Water Pipe at 40° inclination and up to 1000 meters long. In the paper [20]-[23] several novel shelf platform designs were discussed. It was mentioned that the National Oceanic and Atmospheric Administration (NOAA) sponsored conceptual studies that provoked interest in Shelf-mounted OTEC platforms. This gave rise to a number of designs of OTEC platforms. NOAA analysed all such platforms and performed comparative studies on them. All the concepts were found to be technically feasible and a selection of a particular design depends upon net power requirement, energy generation, housing of equipments, design of the heat exchangers and environmental loading effects. The various designs proposed are presented below with a basic design of the shelf-mounted OTEC platform.

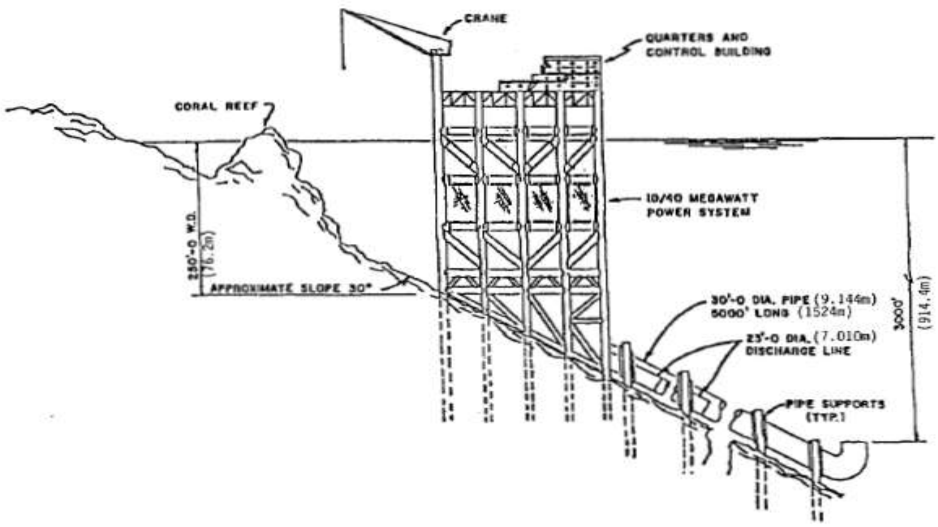

Figure 6. Basic design of shelf mounted platform

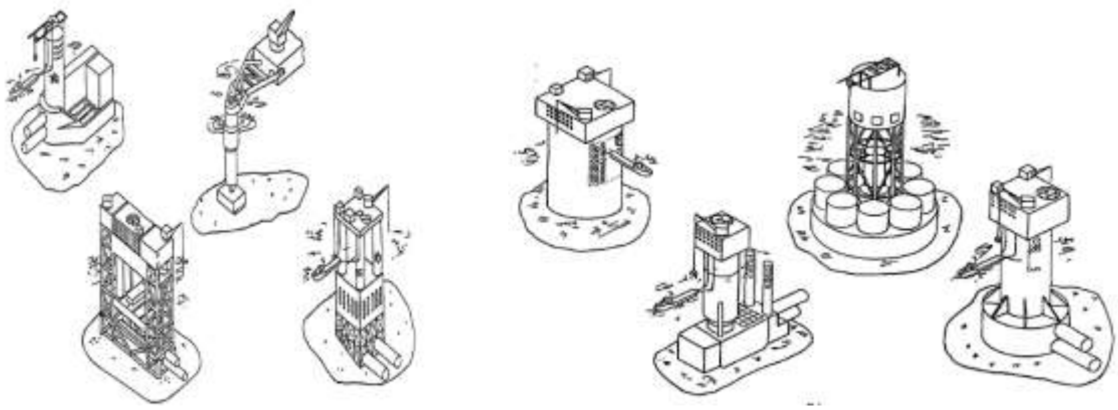

Figure 7. Eight novel designs proposed for Shelf Mounted OTEC plants

Applications of OTEC

The OTEC systems except from producing electricity can be used in other applications. Some very major applications where they can play a significant role are as follows.

The hurricane formation takes place over the ocean when a low pressure is created due to warm water. Sea Surface Temperature (SST) for hurricane formation is suggested as 27℃-29℃. In the paper [24]-[25], a strategy to overcome the problem of SST was presented. In the same paper the study was focussed on the Gulf of Mexico. This paper suggested that the SST can be reduced by bringing up deep cold water from the ocean depths by the help of OTEC pumps. This cold water can be distributed at surface with the help of fabricated perforated hoses. In the same paper such a strategy was discussed for the Gulf of Mexico. In the proposed design of the pump, it was assumed that if the 200 meter isobath having a constant depth contour was taken where the bottom temperature was 13.5℃, the cold water flow of 3m/s can be considered through a pipe of 5m delivering 58.9 cubic meter /second. The hose diameter required could be 5m and can be kept at the surface. The hose can be 1km long. In such a situation if the cold water be mixed to the warm water of 27℃ then the heat exchange rate was found to be 3.42 GW. The average density of the 200m column water outside the pipe was 1025.73kg / cubic meter, which required a pressure of 2296 pa to raise the water in the pipe.

If the cold water is pumped up from the deep ocean and is used to cool the surface of the ocean, it will absorb more CO_2 from the atmosphere, facilitating photosynthesis, and hence more phyto-planktons and thus acceleration of the bio-life in the oceans which will also have an impact on increased production of food on the Earth's surface, as they produce a lot of oxygen. This pumping of the cold water can be achieved by OTEC pumps with some design modifications. The pumping plants in OTEC are big and according to the paper [26]-[27], it would take 100000 of them to lower Caribbean current temperature by 3℃. Thus pumps with great strength are required. Thus in the same paper it was concluded that there is a of designing a pump station having the cold water flow of less than 10 cubic meter / second and less volume. It proposed a radical design where the pump ports will be arranged around the periphery of the Cold Water Pipe. This would require around 6 pumps for the forgoing arrangement of 12 side by side groups.

References

[1]. Jan C. War, "Seawater Air Conditioning (SWAC) A Renewable Energy Alternative", 0-933957-39-8 ©2011 MTS.
[2]. James C. Huggins, David L. Block, "Deep Wells For OTEC Application", CH2363-0/86/0000-0196 $1.00 Q 1986 IEEE.
[3]. Block, D.L., J.C. Ruggins, B. Patel, J. Valenzuela, etal , Thermo-economic Optimization of OC-OTEC Electricity and Water Production Plants, FSEC-CR-108-84, September 1984.
[4]. Heath, Richard C., and Clyde S. Conover. Hydrologic Almanac of Florida. U.S. Geological Survey Open-File Report 81-1107. Tallahassee, FL, 1981.
[5]. Kohout, F.A., A Hypothesis Concerning Cyclic Flow of Salt Water Related to Geothermal Heating in the Floridan Aquifer Water Resources Division, U.S.Geological Survey, Miami, FLY presented at a meeting of the USGS Section of Geological Sciences on April 5, 1965.
[6]. Stuart L. Ridgway, "The Ballistic Cold Water Pipe", CH2363-0/86/0000-0685 $1.00 0 1986 IEEE.
[7]. John J M c M u l l e n A s s o c i a t e s , I n c , New York, N.Y., Review of Reports by Gibbs and Cox, Inc, et al., on 400 MWe Commercial Plants, Report o DOE C00-4931- 3 J u n e 1979.
[8]. S.L. Ridgway, C. K. B. Lee , and R.Phillip Hammond, Mist Lift Process, RDA report TR 110901, ORNL 761311, April 1980.
[9]. Brian Cable, William Tayler, Chris Tindal, Robert Varley, Lee Brissey, "The Navy's Ocean Thermal Energy Conversion Program".
[10]. A.T. Gill, R.E. Rocheleau. "Advances in Hawaii's ocean energy RD&D," EWTECH 2009 Procedings, Uppsala, Sweden, September 2009.
[11]. Department of the Navy, "Environmental Assessment, Proposed Wave Energy Technology Project, Marine Corps Base Hawaii, Kaneohe Bay," 2003.
[12]. Dugger, G. L., R. Richards, J. F. George and W.H. Avery, "Ocean Thermal Energy Conversion", JHUI APL Report AEO-81-13, Feb. 1981.

[13]. P a n d o l f i n i , P. P . , J. L. Keirsey, G. L. Dugger, W. H. Avery and H. D. Foust, "Alclad-Aluminum, Folded-Tube Heat Exchangers f o r Ocean Thermal Energy Conversion", JHU/APL Report AEO-81-32, March 1981 .
[14]. Hove, D., et al., "Materials Project Test R e p o r t , " SAI-464-820-011-LA, April 1981.
[15]. Hove, D., et al., 'r Deployment Project Test Report," SAI-464-820-012-LA, April 1981.
[16]. James, A.L. and D. W. Murphy, “Kelp Support Substrate Structures for Use in the Ocean Food and Energy Farm Project”, Naval Undersea Center, ERDA/USN/1027/3, September 1976.
[17]. Hughs, W.F. and S . A . Brighton, Theory and ProbZems of FZuid Dynamics, New York: Schaum’s Publishing CO., 1967, pp. 119-120.
[18]. De Palma, John R . , "Fearless Fouling Forecastin g , " Proceeding Third International Congress on Marine Corrosion and Fouling, 1972.
[19]. R i t t e r , R. B. and J. W. Suitor, "Fouling Research on Copper and I t s Alloys – Seawater Studies," INCRA Project 214A, April 1976.
[20]. “NOAA OTEC research aims at future payoffs,” Sea Technology Maguzine, pp. 10-16, July 1983.
[21]. Kalvaitis, F. McHale, and L. Vega, “Design, fabrication and at-sea test of a large scale OTEC pipe,” in Proc. OCEANS 83 Conf., Aug.
[22]. “Preliminary designs for ocean thermal energy conversion (OTEC) station keeping subsystem (SKSS)-Task I: Design requirement, final rep.,” Lockheed Missiles and Space Co., Inc., Sunnyvale, CA, Rep. LMSC-D673832, June 1979.
[23]. “Concepts for a bottom-mounted buoyant, stab-in cold water pipe for the OTEC program,” ORI, Inc., Silver Spring, MD, Rep. TR-1485, Mar. 1979.
[24]. Colling, Ocean Circulation, 2nd ed., Butterworth-Heinemann, Oxford, 2001, p.32.
[25]. K. Emanuel, "Limits on Hurricane Intensity," http://wind.mit.edu/~emanuel/holem/holem.html, Retrieved March 2006.
[26]. R. LaRosa, "Hurricane Suppression by Sea Surface Coolinge, in IEEE twenty-five-million-dollar prize offered by ir Richard Branson for a method Long Island Systems, Applications and Technology Conference, LISAT of removing carbon dioxide from the atmosphere. 2006 CD-ROM Proceedings, Charles P. Rubenstein, Editor, Farmingdale State University, Farmingdale NY 11735.
[27]. R. LaRosa, "A Macro-Project to Reduce Hurricane Intensity and Slow Global Sea Level Rise," in Macro-Engineering - A Challenge for the Future, V. Badescu, R.B. Cathcart, and R.D. Schuiling, Eds., Dordrecht: Springer, 2006, ch. 5.