

Public Utilities Commission

Docket No. 05-0145

O`ahu Power Plant

Testimony of

Dr. Hans Krock

re: Ocean Thermal Energy Conversion (OTEC)

LOL T-9

1 **Testimony**

2 I am Professor Emeritus of Ocean & Resources Engineering at UH and President of
3 OCEES International, Inc.

4

5 **Education**

6 BS in Civil Engineering from Arizona State Univ. in Tempe, MS and Ph.D. in Civil and
7 Environmental Engineering with minors in Chemistry and Chemical Engineering from
8 the University of California at Berkeley.

9

10 I am a registered Professional Engineer (Civil) in Hawaii, served as PI for numerous
11 research projects at UH for twenty five years covering all aspects of ocean engineering,
12 ocean dynamics, water quality, OTEC, and environmental effects, hold two US Patents
13 related to gas exchange dynamics and open cycle OTEC, received letters of recognition
14 from two Governors of Hawaii, served as visiting professor at two foreign universities,
15 have been recognized as the leading authority on multi-product OTEC systems and
16 OTEC/hydrogen at the World Renewable Energy Congress and by the Chinese Academy
17 of Science.

18

19 **Professional Experience**

20 Conducted professional engineering work in Hawaii and numerous other islands in the
21 Pacific as well as in Arizona, California, Germany, the Indian Ocean, and the Caribbean.
22 Served as Professor of Ocean Engineering and Director of J.K.K. Look Laboratory of
23 Oceanographic Engineering and Ocean & Resources Engineering Departmental Chair at

1 UH. Established OCEES International, Inc.

2

3 **Professional Work**

4 The list of my professional work product is several pages long and I will provide it if
5 necessary as an attachment.

6

7 **Testimony**

8 The tropical ocean surface layer is the world's largest and most efficient (about 85%)
9 solar collector. Energy exchange from the ocean powers the hydrologic cycle and runs
10 the world's weather.

11

12 OTEC is a process that allows us to convert the solar energy stored in the tropical ocean
13 surface layer into electrical power using well established principles of thermodynamics.

14

15 OTEC was first proposed in 1881 by d'Arsenval, and first built by Claude in the late
16 1920's in Cuba. Hawaii has been the world center for OTEC development since the mid
17 1970's. Work in Hawaii has established the technical feasibility of both the open and
18 closed cycle OTEC power production processes as well as proven the feasibility of fresh
19 water production, cold water air conditioning, cold water pipe design and deployment,
20 floating OTEC plant operation, biofouling control, related aquaculture and other
21 secondary products.

22

23 Commercial installations are being planned for NELHA, Diego Garcia, Kwajelein,

1 Tahiti, and several other Pacific as well as Caribbean islands.

2

3 The energy flowing through the surface layer of the tropical ocean is about 10,000 times
4 greater than the energy used by human societies. As such it is the only energy resource on
5 earth that is large enough to replace fossil fuel.

6

7 Open- Cycle OTEC is a close copy of the hydrologic cycle in nature. The warm seawater
8 is evaporated in a vacuum chamber and the resulting fresh water steam runs a turbine
9 which in turn runs a generator to produce electricity. The steam is then condensed using
10 the cold seawater and the resulting liquid fresh water is pumped out for use as potable
11 water supply. Such a system was run at NELHA for about six years in the 1990's.
12 OCEES International, Inc. has improved on this design with a pre-deaeration and
13 reinjection system of the non-condensable gases that are in the warm seawater stream. As
14 a historical note, Claude used an open-cycle system for his installations in Cuba and off
15 Brazil.

16

17 In a closed cycle OTEC system a working fluid with a low temperature boiling point (e.g.
18 ammonia, propane or any other refrigerant) is vaporized in a heat exchanger using the
19 warm seawater. The working fluid vapor runs a turbine/generator to produce electricity.
20 The cold seawater is used to condense the working fluid vapor back to a liquid (in a
21 second heat exchanger) and the liquid is then pumped back to the evaporator to complete

1 the cycle. Such a closed cycle system has been successfully demonstrated in the Mini
2 OTEC barge, the OTEC-1 ship and at several on-shore installations.

3

4 The Rankine cycle is the closed cycle used by most power production facilities. It
5 contains four main components, an evaporator, a turbine, a condenser, and a pump.

6

7 The Kalina cycle is the most efficient closed cycle available for low delta T applications
8 such as OTEC and waste heat “bottoms cycles”. The Kalina cycle has been commercially
9 successful for more than 10 years with installations in the US, Japan, and Iceland.

10 Siemens is currently building a 50 MW Kalina cycle plant in Germany for a waste heat
11 application. OCEES International, Inc. has an agreement with the patent holder for the
12 Kalina cycle for OTEC applications.

13

14 Because of the relatively small delta T available for OTEC large quantities of warm and
15 cold seawater are required. This limits most on-shore installations to about 10 to 20 MW
16 unless waste heat resources are available to supplement the delta T. The largest OTEC
17 pipe that has been installed on-shore has been about 2.5 m diameter. Presently the largest
18 HDPE pipe commercially available is about 2 m in diameter. Makai Ocean Engineering
19 is the recognized world leader in deep cold water pipe technology. A bundle of five 2 m
20 HDPE pipes is being proposed for the Diego Garcia OTEC system.

1

2 The mini-OTEC barge and the OTEC-1 ship were off-shore OTEC systems and
3 Lockheed has proposed 500MW OTEC/hydrogen off-shore platforms. The system
4 proposed for Diego Garcia is an off-shore floating system. The most promising design for
5 such off-shore floating facilities is the honey-comb concrete platform system developed
6 by Alfred Yee of Applied Technology Corp.

7

8 Depending on distance, either a DC or AC underwater cable with a directionally drilled
9 shoreline crossing to a substation.

10

11 Relative to the ideal Carnot efficiency the Kalina cycle is about 50% efficient. The ideal
12 Carnot efficiency is simply a statement of the available delta T relative to absolute zero.
13 For example, for OTEC the Carnot efficiency is about 7 to 8% while for a windmill the
14 Carnot efficiency is much less than 1%. Such measures of efficiency are most important
15 when you have to pay for the fuel – such as with a fossil fuel fired plant. For OTEC (and
16 wind) the fuel is free.

17

18 The economics of OTEC are similar to those of hydropower -- relatively high initial
19 capital costs with very low operating costs. For large scale OTEC installations at present

1 interest rates the costs are comparable to oil fired plants when oil is more than about \$45
2 a barrel.

3

4 OTEC takes its energy out of a very large storage reservoir and hence is a base load
5 power source. For example, the OTEC installation at NELHA was much steadier than the
6 HELCO grid.

7

8 Since OTEC can be operated at near 100% capacity continuously it makes very efficient
9 use of its capital investment – unlike an intermittent resource. With OTEC there is no
10 problem with imbalance of payment since no import of fuel is required. The price of
11 electricity produced by OTEC is steady and predictable for the life of the project (usually
12 taken as 30 years)—unlike the expected rise in electricity costs associated with limited
13 fossil fuel based systems.

14

15 OTEC uses a reliable local energy resource and does not rely on a limited global resource
16 whose use has proven to be environmentally detrimental. There would also be much less
17 reason for international tension and war over limited resources.

18

1 OTEC systems can be designed to produce not only electrical power but also other
2 necessary and economically important products. Such systems produce jobs and increase
3 the economic well being of society as a whole.

4

5 Large scale use of OTEC systems would largely eliminate air pollution and the danger of
6 oil spills as well as warm water discharges.

7

8 Large scale use of OTEC will stop the excessive discharge of greenhouse effect gases.
9 However, the increase in global heat from anthropogenic sources is already so large that
10 even if all of human society's energy requirements were supplied by OTEC systems it
11 would take about 500 years to use the extra heat that has accumulated in the tropical
12 ocean surface layer in the last 50 years.

13

14 **All of the following excerpts are from the OCEES International, Inc Website**
15 **www.ocees.com**

16

17 **Ocean Thermal Energy Conversion: Power from the Sea**

18

19 **Sustainable Energy and Resource Solutions**

20

21 For nearly a quarter century OCEES International, Inc. and its corporate partners have

1 been actively involved in, and recognized as the world's leaders in, all aspects, from
2 theoretical to technical to design and operations, of Ocean Thermal Energy Conversion
3 (OTEC) technologies. Through extensive research and development experience and
4 commercialization alliances, OCEES International, Inc. can provide environmentally and
5 economically sound energy and resource solutions to tropical island communities across
6 the globe. OCEES' proven integrated energy and systems approach can provide
7 considerable savings for the producer and consumer while establishing energy and
8 resource independence for the communities it serves. This approach provides a buffer
9 against the long term uncertainties of a rapidly changing energy market by operating
10 predominantly independent of fossil fuels, thereby establishing clearly predictable
11 operating costs and eliminating nearly all adverse environmental impact; all while
12 providing an excellent and competitive return on investment.

13

14 Environmentally responsible, renewable energy has become an increasingly necessary
15 generation alternative, as industry restructuring, growing public concern over
16 environmental issues, and increased need for diverse supply portfolios create new
17 opportunities for renewable resources poised to make an immediate impact on local
18 energy development. In response to these market forces, combined with widespread
19 concerns over water and other resource needs, OCEES International, Inc. has focused its
20 efforts towards the effective commercialization of the integrated multi-product OTEC
21 energy system industry, today. In light of the recent maturation of several key system
22 requirements (i.e. a cost effective OTEC power system, cold water pipe designs and other
23 relevant technological advancements); an integrated multi-product OTEC system

1 providing clean energy (base-load, not intermittent, power), air conditioning, pure fresh
2 water, and sustainable food (via aquaculture and cold water agriculture applications) can
3 be confidently designed and constructed based upon proven, existing technologies.

4 Additionally, detrimental environmental impacts are virtually eliminated and only
5 renewable resources are utilized. Implementation of such a system will help establish
6 harmonious, self-sustaining island communities independent of fossil fuels, with a
7 complete infrastructure providing food, water, and electricity to effectively support or
8 sustain the development of industry, tourism, and trade.

9 OTEC technology is the best way to tap into the vast thermal reservoir of the tropical
10 ocean to produce hydrogen for the eminent hydrogen economy. Offshore OTEC plants
11 using techniques already developed for accessing deep-water oil fields can be adapted to
12 produce and liquefy hydrogen.

13

14 OCEES International, Inc. works directly with industry, governmental and resource
15 officials to customize integrated multi-product OTEC systems to meet local infrastructure
16 needs. Whether you are an energy producer, a public sector agency, government official,
17 or a consumer, if you are interested in knowing how an integrated OTEC system can
18 benefit your tropical island community, or can provide large quantities of hydrogen to
19 supply the developing hydrogen energy infrastructure, OCEES International, Inc. can
20 answer your questions and help you achieve your goals.

21

22 The Tropical Ocean — the world's largest — and most efficient solar energy collector
23 and storage medium - represents a vast and yet untapped natural resource which can

1 provide the globe with all of its required energy needs in perpetuity.

2

3 Each day, the solar radiation incident upon, and absorbed by, the tropical ocean is
4 significantly more than 1000 times the current global energy consumption over the same
5 twenty four-hour period. Thus, even anticipating the eventual industrialization of the rest
6 of the planet, we will likely never consume more energy than the natural daily fluctuation
7 of this enormous thermal resource, thereby ensuring an environmentally friendly and
8 sustainable energy economy for all peoples for many generations to come.

9 Ocean Thermal Energy Conversion is a process where we can tap into that natural cycle
10 and reap energy benefits from that natural fluctuation - with multiple peripheral benefits.

11

12

13 **An Abridged History of Ocean Thermal Energy Conversion**

14

15 During the latter part of the last century, the young sciences of Oceanography and
16 Thermodynamics had each separately developed past the initial rush of discovery to
17 attain a certain level of maturity. The science of Oceanography was being built upon the
18 results of measurements made in several voyages of discovery, under a number of flags,
19 towards a broad understanding of the structure and dynamics of the ocean.

20 Thermodynamics, after the development of theoretical underpinnings relating mechanical
21 and thermal energy and work, flowered into practical application in the form of the steam
22 engine and further, the growing Industrial Revolution.

23

1 Jaques-Arsène d'Arsonval, a famous French scientist, noted for his numerous
2 contributions to the physical, physiological, and medical sciences, bridged the two
3 sciences of Thermodynamics and Oceanography with his realization that the ocean and
4 atmosphere acted like a giant steam engine. In the natural solar energy cycle, heat flows
5 horizontally from the sun-warmed tropics to cooler temperate zones. This same heat flow
6 could be tapped vertically in the tropical regions of the ocean via human technological
7 means. This concept could, in effect, be actualized to harness a potentially limitless
8 amount of energy.

9

10 Ocean Thermal Energy Conversion uses the world's largest renewable energy resource,
11 the ocean. Solar energy stored in the warm tropical ocean is converted to electrical
12 energy using a modified refrigeration technology and cold, deep ocean water. All heat
13 engines collectively share the principle that energy will flow from an area of higher
14 temperature to an area of lower temperature. All modern power plants use temperature
15 differences to produce electricity. Geothermal, coal, nuclear and diesel power plants all
16 employ a high temperature gaseous medium to spin a turbine, which turns a dynamo,
17 which generates electricity. These power plants use a medium with a temperature
18 difference of several hundred degrees.

19

20 On the other hand, an OTEC energy generation system uses a temperature differential of
21 far less- approximately 20oC to 24oC Ocean waters in the equatorial region of the earth
22 have the necessary temperature gradient. Surface water is kept warm all year via the
23 radiation of an ever-present tropical sun.

1

2 Below the surface, the water remains at Arctic temperatures of approximately 40C. The
3 degree of difference in temperature is adequate to power a thermal engine of a relatively
4 low efficiency. Most modern power plants have a resource to electricity conversion
5 efficiency approaching 30 to 40 percent. An OTEC plant operates at a much lower
6 efficiency, but it works with such a large volume of water, 24 hours a day, 365 days a
7 year, that it produces substantially large amounts of energy, negating the apparent
8 disadvantages of operating at a perceived lower efficiency. In reality, the net positive
9 effect is substantial. The fact that the Ocean Energy Resource is extremely large and free
10 makes the importance of technical efficiency less dominant.

11

12

13 One of d'Arsonval's students, Goerges Claude, took this idea to application, first in 1928,
14 in what is now known as a bottom cycle application. He used warm cooling water from a
15 steel plant in Belgium, and cool Meuse river water from near the plant as the operating
16 medium for an Open-Cycle OTEC plant that produced electricity. It was the first of it's
17 kind to operate at the scale. Modern designs for OTEC plants provide continuous, base-
18 load electric power because ocean water temperatures are stable, unlike other renewable
19 energy sources such as wind and solar which are inherently intermittent in nature. Using
20 the sun for its heat source, the OTEC process is free of any kind of pollution or
21 emissions.

22

23 Claude favored the use of open-cycle OTEC and he developed a system of pre-deaeration

1 (taking out dissolved gases from a liquid prior to evaporation.), to remove the non-
2 condensable gases and thus, to improve the efficiency of the whole process. d'Arsonval
3 had suggested the use of a closed cycle system in line with theoretical descriptions of
4 such a cycle by Carnot and later, more realistically, by Rankine. Recently, Exergy, Inc.
5 has developed a new cycle, the Kalina Cycle®, which considerably improves upon the
6 efficiency of the OTEC concept.

7

8 The OTEC idea lay largely dormant during the period of artificially inexpensive and
9 readily available oil and was resurrected after the OPEC oil crisis in the 1970's. Hawaii
10 became the world center for exploring the potential for development and application of
11 the OTEC concept. In the last 25 years, numerous OTEC relevant research efforts have
12 been conducted in Hawaii. Included in these efforts were MiniOTEC and OTEC-1 that
13 demonstrated power generation, and the development by PICHTR of an operational
14 freshwater producing OPEN-CYCLE OTEC prototype. Other technological
15 advancements included biofouling and corrosion solutions in heat exchanger design;
16 problems that were inherent in previous OTEC designs.

17

18 What has occurred at the research facilities in Hawaii is the realization that not only can
19 electric power be produced using the ocean's natural thermal gradients, but also
20 abundant, clean, and potable drinking water. In addition, cold, deep seawater is nutrient
21 rich and pathogen free, ideal for aquaculture and mariculture applications such as fish and
22 shellfish farming. The cold seawater causes natural condensation in the soil enhancing
23 growth rates for agriculture. Further, an OTEC power system pumps a large amount of

1 very cold seawater to the surface and therefore can provide air-conditioning which is
2 extremely cost effective. By providing air-conditioning as a separate sub-system within
3 an OTEC facility, electrical load requirements and maintenance costs are drastically
4 reduced. Additionally, through the process of electrolysis, fresh water from the OTEC
5 process can be the basis for a hydrogen production system, of which commercial scale
6 quantities could be constantly produced. This realization has thus led to the development
7 of an OTEC systems approach that can be implemented to produce various optimized
8 amounts of all of these products for a particular installation. The systems approach results
9 in extremely favorable economic conditions for a profitable governmental or commercial
10 entity, energy corporation, division, or consortium.

11

12 An Integrated OTEC System can create harmonious, self-sustaining island communities
13 independent of imported fossil fuels and their associated costs. Pollution and emission
14 free energy with reduced, predictable and stable operational costs largely independent of
15 foreign imposed pricing and politics. Island communities can now create a complete
16 infrastructure providing food, water, and electricity which can reliably support industry,
17 tourism, and trade - effectively bolstering their developing economies.

18 The specific market needs for this technology are quite extensive. Commercial OTEC
19 facilities must be located in an environment that is stable enough for efficient system
20 operation. The natural ocean thermal gradient necessary for OTEC operation is generally
21 found between latitudes 20oN and 20oS. Within this tropical zone, are portions of several
22 industrial nations (i.e. United States, Taiwan, Japan, etc.), as well as 29 territories and 66
23 developing nations and nearly a dozen U.S. Department of Defense operated military

1 installations (i.e. Diego Garcia, B.I.O.T.; Guantanamo Bay, Cuba; AUTECH, Bahamas;
2 Kwajalein, etc.). Of all these possible sites, tropical islands with growing power
3 requirements and a dependence on expensive imported oil are the most likely areas for
4 initial OTEC development. Most of these military installations, developing countries and
5 territories have significant needs for reliable, sanitary potable water and/or food sources,
6 afforded through cold water agriculture and/or aquaculture application, adding to the
7 social and political desirability of an integrated OTEC system.

8

9 **OTEC Technological Innovations**

10

11 **Recent Advancements**

12

13 The last evaluation of OTEC was based on the technology demonstrated by the mid-
14 1980's. Technical advances since that time include:

15

16 The development of the Kalina Cycle® which is significantly more efficient than the
17 previous closed-cycle system based on straight ammonia. Several Kalina Cycle®
18 installations have been constructed to take advantage of waste heat from conventional
19 power plants and steel plants. These installations have an excellent history of availability
20 and reliability – much better than other power plants. OCEES International's strategic
21 partner Exergy, Inc., the company which possesses the seventeen (17) patents associated
22 with the Kalina Cycle®, is responsible for all operating commercial Kalina Cycle®
23 installations globally.

1

2 The discovery that dissolved gases exchange more rapidly from seawater than from fresh
3 water. This allows for more efficiency and lower costs for open-cycle OTEC and for
4 fresh water production from seawater in a hybrid Kalina Cycle® configuration as well as
5 fresh water production in general. OCEES International, Inc. principals performed the
6 research leading to this very important realization and hold two (2) U.S. Patents on this
7 process and its integration into an OTEC system.

8

9 The development of better heat exchangers and heat exchanger operation with respect to
10 bio-fouling control (on the warm water side) and corrosion control. Accomplished
11 through research performed in Hawaii at the Natural Energy Laboratory of Hawaii
12 Authority (NELHA) research facility at Keahole Point, Hawaii by the Solar Energy
13 Research Institute (SERI) and Pacific International Center for High Technology Research
14 (PICHTR). Principals of OCEES International, Inc. participated in the research leading to
15 these advancements.

16

17 The demonstration of an open-cycle plant with fresh water production and the
18 development of an open-cycle turbine. Research performed by PICHTR at NELHA in
19 Hawaii demonstrating OC-OTEC with fresh water production included participation with
20 OCEES principal. OC-OTEC turbine designed by Swedish Turbine company, ALSTOM,
21 after consultation and discussions with OCEES principal.

22

23 The demonstration of cold water air conditioning. Research performed at NELHA in

1 Hawaii and commercially applied by Cornell University in conjunction with OCEES'
2 strategic partner, Makai Ocean Engineering. OCEES personnel participated and/or
3 consulted in each project.

4

5 The development of reliable cold water pipe designs and deployment methods. All
6 successful cold water pipe installations as well as the very recent successful deployment
7 of a 55" deep water pipeline (December, 2001) reaching 800 meter depths to service
8 NELHA in Kailua-Kona, Hawaii have been designed and deployed by OCEES' strategic
9 partner, Makai Ocean Engineering.

10

11 The development of drilling platforms for deep ocean oil exploration. This technology
12 has been primarily developed for oil exploration and procurement applications in 3,000+
13 feet of water; however, it can also be directly applied to future floating OTEC plant
14 designs.

15

16 The demonstration of efficient hydrogen production using electrolysis of water with
17 KOH addition. In addition, the use of liquid hydrogen for fuel cell powered vehicles.

18

19 Advances in instrumentation and control technology which allows for multi-product plant
20 operations which are reliable, optimum, and responsive to change. This will let us install
21 complex facilities even in remote locations.

22

23 The application of systems engineering for optimum designs and optimum economics of

1 multi-product OTEC systems. This is an original concept of OCEES International, Inc.
2 and represents the primary commercialization strategy for OCEES to introduce OTEC to
3 tropical island applications.

4 These technical advances bring OTEC systems to the point of development where
5 projects can be confidently designed, constructed, and operated. Each component exists
6 and has been shown to work reliably. No significant technological questions remain in
7 OTEC systems. This is in contrast to other renewable energy systems, such as nuclear
8 fusion, which also have the potential to replace fossil fuel on a large scale. We at OCEES
9 International, Inc. applaud the efforts of all involved in researching these various aspects
10 of OTEC technology. This combined effort, building upon the work of d'Arosnval,
11 Claude, and Lockheed, in conjunction with the research conducted in Hawaii, will lead to
12 the commercialization of OTEC.

13

14 Many of these technological advances over the past decade are directly attributable to the
15 principals of OCEES International, Inc. and/or its consortium of corporate partners intent
16 on commercializing this extremely important technology. OCEES and its partners
17 represent the world's foremost experts in this field with substantial experience in design
18 and practical application of OTEC systems and ancillary technologies. OCEES has
19 positioned itself through research, partnerships, governmental relationships and
20 experience to take a leading role in the imminent global commercialization of the OTEC
21 systems technology.

22

23 **Power Systems**

1

2 The innovation to the power cycle which OCEES International, Inc. employs is provided
3 by OCEES strategic corporate partner Exergy, Inc. in the form of their patented Kalina
4 Cycle®. The Kalina Cycle® is a variation of the more conventional closed-cycle OTEC
5 system incorporating aqueous ammonia (ammonia/water mixture) as the working fluid
6 instead of the conventional ammonia or propylene working fluid employed in earlier
7 designs of closed-cycle OTEC power systems. The Kalina Cycle® is a break-through
8 technology for OTEC power systems providing a nearly 80% increase in efficiency over
9 previous closed-cycle designs. Because the ammonia/water concentrations can be varied
10 throughout the system to optimize according to system temperatures (sort of a "designer"
11 working fluid) and by adding an extra component – the recuperator, heat losses generally
12 experienced in other closed-cycle designs can be minimized and recovered, thereby
13 improving the overall efficiency of the power cycle.

14 The Kalina Cycle® is a modified Rankine cycle with increased efficiency resulting from
15 the altered properties of its ammonia/water working fluid, rather than the pure water or
16 ammonia working fluid in a standard Rankine cycle. The Kalina Cycle® specifically
17 exploits the variable boiling and condensing temperatures of a variable concentration
18 working fluid since an ammonia/water mixture can more closely follow the straight-line
19 temperature change of the heat source or condensing medium in a counterflow heat
20 exchanger.

21

22 Compared to a conventional Rankine cycle, the temperature rise of the cooling water for
23 the ammonia/water can be higher than that for condensing the more traditional anhydrous

1 ammonia, thereby minimizing the cold deep seawater requirements saving capital costs
2 and increasing the net power output of the plant over previous OTEC system designs! By
3 utilizing the more efficient Kalina Cycle® in the integrated OTEC system design,
4 OCEES International, Inc. is able to reduce costs of power generation and provide
5 emission free energy to the tropical island communities it services.

6

7 The OTEC Kalina Cycle® uses the four typical Rankine cycle phases: evaporation,
8 expansion, condensation and feed. The evaporator and condenser components in an
9 integrated OTEC Kalina Cycle® system consist of numerous large plate heat exchangers
10 with titanium plates for maximum corrosion resistance against seawater and maximum
11 life-time efficiency. An additional piece of equipment, the recuperator, recovers heat
12 from the warm but unvaporized liquid leaving the separator vessel. A brief simplistic
13 process description follows.

14

15 Generally, for OTEC applications and system temperatures, a mixture of approximately
16 60% ammonia – 40% water (by weight) enters the counterflow evaporator where it is
17 heated by the warm surface seawater. The warmed vapor/liquid mixture travels to the
18 separator where high quality ammonia vapor goes to the turbine. Warm "lean" liquid
19 from the separator drains through the recuperator and heats an incoming quantity of
20 60/40 mixture working fluid.

21

22 The high quality ammonia vapor from the separator enters a radial flow ammonia turbine
23 and expands creating mechanical energy which is then converted into electrical energy

1 via the attached generator system. Design of such ammonia turbine/generator systems is
2 well established with system efficiencies approaching 85% or greater for OTEC
3 applications.

4

5 The turbine exhaust vapor is recombined with the cooled post-recuperator lean mixture.
6 Both condensation and ammonia absorption then occur inside the counterflow condenser
7 cooled by the cold, deep seawater supplied by the Cold Water Pipeline. The 60/40 liquid
8 mixture then flows to the condenser hotwell where feed pumps take suction from the
9 hotwell and pump the ammonia/water mixture back into the evaporator, completing the
10 cycle.

11

12 OCEES International, Inc. utilizes integrated OTEC systems power cycle designs which
13 are scalable and modular for implementation into nearly every tropical island application
14 with suitable access to cold, deep seawater. Sufficient redundancy of components is
15 incorporated into every design to ensure periodic maintenance and repair procedures can
16 be performed without compromising the supply of base-line power to the local
17 community or power grid. Likewise, the modular nature of the system ensures proper
18 "down stream" protection of discharge water streams (either to aquaculture applications
19 or system discharge streams to the ambient ocean) from ammonia contamination, should
20 an unlikely leak in the system occur, without compromising the plant's performance and
21 availability. Instrumentation and sensors to protect against any leakage is standard in
22 OCEES International, Inc. OTEC system designs.

23 Top

1

2 OTEC Pipe Systems

3

4 Ocean Thermal Energy Conversion (OTEC) requires huge quantities of deep cold
5 seawater and warm surface water to operate. The fabrication and installation of deep-
6 water pipelines to provide this water represents the single most expensive portion of any
7 OTEC plant and the highest risk during construction. Because of these associated costs
8 and risks, it is the least demonstrated major component of a large OTEC plant.

9

10 Hawaii has been the center for OTEC development in the United States over the past
11 twenty years and OCEES and its strategic partners have been an integral part of that
12 research and have gained very valuable experience in cold water pipe technology. The
13 State of Hawaii is currently operating several pipelines at the Natural Energy Laboratory
14 of Hawaii Authority (NELHA) , the largest of which is 55" OD.

15

16 Pipelines as large as 8' OD have been tested at the facility in both down-the-slope mode
17 and suspended mode. In fact, all of the world's large deep seawater pipelines have been
18 deployed at NELHA. All phases of design, manufacture and deployment of each of these
19 pipelines have been overseen by OCEES International, Inc.'s strategic partner Makai
20 Ocean Engineering. The techniques learned and experience accumulated through the
21 deployment of the deep water pipelines at NELHA and the research accomplished on
22 large diameter pipelines performed in Hawaii have led to the confident conceptual design
23 and deployment scenarios for OTEC pipelines up to three (3) meters in diameter. These

1 segmented pipes of fiber-reinforced plastic can be deployed with the same controlled
2 submergence techniques that have already been implemented in Hawaii and can be
3 installed in either the gravity anchor mode, pendant mode or the long, inverted catenary
4 mode.

5 Pipeline configuration design and development requires analysis of the pipeline under
6 two very differing environments: the near shore region and the deep-water pipeline.

7 Near Shore Region

8 We define the near shore region as the shore landing through to a depth of approximately
9 60 — 80 feet. In this region a designer is faced with a variety of challenges including
10 severe current and wave loads, aesthetic and environmental considerations, pump station
11 interface and offshore pipeline interface. Because the pipeline is in shallow water, wave
12 action on the pipeline can be quite extreme, especially in areas susceptible to hurricane
13 activity. This is where experience in ocean related design cannot be understated - OCEES
14 International, Inc. and it's strategic partner's all possess the necessary ocean training and
15 experience to confidently design, deploy and construct a working plan in nearly any
16 ocean environment.

17 Large hurricane waves and associated large design wave heights, as are common to
18 tropical island communities, place very high lateral and lift loads on exposed pipelines
19 and effectively eliminate consideration of a near shore traverse using gravity anchors
20 alone. Several near shore crossing techniques are available for consideration, including:

21 Trenched pipelines

22

23 **Bolt down pipelines**

1

2 **Tunneled pipelines**

3

4 Buried or Trenched Pipelines are well protected from the environmental loads and, for
5 multiple pipes, are the most cost effective approach for the near shore route. However,
6 digging and blasting the trench can be environmentally damaging to reefs and the near
7 shore region; therefore should only be pursued if other, more environmentally attractive
8 means of traversing the near shore region prove unrealistic.

9 Bolt Down Pipelines are sometimes utilized in applications where the near shore region is
10 exposed to extreme wave conditions thereby exposing a hard seafloor or large boulders
11 partially submerged in the sand of sufficient size to stabilize the attached pipeline under
12 extreme wave conditions (hurricanes, etc.). Under these conditions, bolt down pipelines
13 become extremely cost effective. Rock bolts are relatively inexpensive and divers can
14 accomplish maintenance through periodic replacement of the sacrificial zinc anodes for
15 corrosion protection. The disadvantage of this technique is that the seafloor is highly
16 irregular and it is difficult to design in advance the exact location of each rock bolt and
17 clamp on the pipeline.

18 Tunneling consists of two differing techniques for accomplishing the same effect — slant
19 drilling and micro tunneling. Slant drilling uses oil drilling techniques with a drill oil rig
20 onshore pressing a drill bit and drill pipe through the soil at a fairly shallow angle to the
21 approximately 60 foot depth. In the micro tunneling approach, a large dry jacking pit is
22 constructed onshore reaching well below sea level. A micro tunneling machine with a
23 drill bit equal in size to the outer diameter of the desired tunnel is pushed through the

1 vertical wall of this onshore pit and continues to drill by adding drill pipe sections until
2 reaching the offshore regions of 60 — 80 foot depths. Under each of these tunneling
3 configurations, the shoreline and seafloor regions are relatively undisturbed and prove the
4 best protection for the near shore pipeline as well as the most environmentally favorable
5 means of traversing the fragile shallow water region to a shore mounted OTEC facility.

6

7 **Deep Water Pipeline**

8

9 The deep-water portion of any pipeline sees smaller environmental loads than the near
10 shore region. Waves have less impact upon this portion of the pipe, there are less visible
11 environmental concerns, and currents diminish with depth. In general, the design
12 approach and installation procedures are completely different than the near shore region.

13 Three different techniques for mounting deep-water pipelines have been developed in
14 Hawaii, they are:

15 Gravity anchored pipelines

16

17 **Pendant anchored buoyant pipelines**

18

19 Inverted catenary buoyant pipeline

20

21 In many deep pipeline applications, it is necessary to incorporate a combination of the
22 above approaches to accommodate different deep-water terrains.

23

1 Gravity Anchored Pipelines are most appropriate in regions where the seafloor is
2 relatively smooth over a gentle slope. Gravity anchoring consists of attaching a series of
3 cement bottom anchors at regular intervals before deployment over the length of the
4 pipeline with sufficient clearance to prevent damage to the pipe from the seafloor. A very
5 detailed survey route and precise deployment of the pipeline is imperative in this
6 technique to prevent damage to the pipeline during deployment — a pipelines most
7 vulnerable moment. Because of its simplicity in design and minimal cost, it is the
8 preferred method of anchoring the deep-water pipelines associated with an OTEC
9 facility. However, since ideal conditions rarely exist in reality, as mentioned previously,
10 this method is often combined with the other techniques over the course of the pipeline.

11

12 Pendant Pipelines are utilized under buoyant pipe conditions to traverse rugged bottom
13 environments (sharp rocks, etc.) by allowing the pipeline to float above the bottom at
14 considerable spacing to avoid damaging the pipe during deployment and periods of very
15 large waves which may cause some lateral motion to the pipeline. A pendant system
16 consists of a buoyant pipe attached to anchors via a cable system allowing the pipe
17 motion flexibility without permitting contact with the seafloor. One drawback of this
18 approach is the cost of buoyancy, which, if utilized over large portions of the pipe length,
19 can become cost prohibitive.

20

21 Catenary Pipelines take advantage of the deep water pipe's natural buoyancy and
22 flexibility to traverse very rugged and often very steep bottom terrain. When this
23 technique is to be employed, detailed route surveys of the bottom are not necessary (only

1 at the two ends of the catenary). Like the pendant pipeline, the catenary does not
2 experience high inertial loads and, being mostly detached from the seafloor is not
3 susceptible to earthquake damage.

4

5 The catenary approach cannot be implemented everywhere, it is not suitable for shallow
6 water applications or gentle slope considerations where the peak of the catenary could
7 approach the ocean's surface.

8

9 **Pipeline Deployment**

10

11 The design of the installation process of the pipeline is the single most important aspect
12 of the overall pipeline design. The most formidable obstacles to the installation of a deep-
13 water pipeline are the extreme depths, currents and waves that the installer will encounter
14 during installation. A pipeline will often experience its most extreme lifetime loads
15 during deployment and certainly the highest risk of loss. The proper design process of a
16 deep-water pipeline must constantly involve the deployment procedure.

17 In most cases in engineering the role of designer and installer are clearly separated.

18 However, this is not the case in deep water pipelines — it is unlikely the contractor hired
19 to deploy the pipe has installed such an instrument, therefore, it is up to the designer to
20 make sure the pipeline can be constructed and deployed both reliably and economically.

21 It is inherently necessary for the pipe designer to provide detailed deployment plans and
22 specifications together with the final design in order to make sure the contractor fully
23 understands the intended installation procedure. Because of the extreme expense

1 associated with marine construction operations, it is also necessary that the pipelines be
2 designed for fast and efficient deployment as well.

3

4 Most of the work on pipeline construction is performed on land or in a nearby harbor. All
5 weights, pendants, and other attachments are attached to the pipeline with shore crews.

6 Often the pipeline is assembled right at the shoreline in a harbor and as each section of
7 pipe material is added to the pipeline, the other attachments are added and the pipeline is

8 "pushed" into the harbor. The pipeline is designed to float when air filled; it supports the
9 weights and other pipeline attachments. Therefore the whole pipeline is assembled and

10 pushed into protected waters while using a minimal amount of marine equipment.

11 At the time of deployment, the pipeline is towed to the site and aligned over the design

12 pipeline path. The shore end of the floating pipeline is anchored in about 60 feet of water

13 and attached to a set of flooding pumps at the shore end. While the pipeline is under

14 tension (being pulled by barges at pre-designed speeds and directions), water is being

15 pumped into the pipeline at the shore end. The non-flooded buoyant section of the

16 pipeline supports the heavy flooded end at any given point and the pipeline takes on an S-

17 shape. By carefully monitoring the pull of the pipeline, the internal pressure, the

18 distribution of weight on the pipeline, and the temperature and time of deployment, the

19 pipeline can be safely placed on the bottom to depths up to and exceeding 3000 feet. The

20 alignment and flooding of a mile-long pipeline can be accomplished in one day.

21

22 As one can imagine, careful deployment design and detailed planning is critical to the

23 success and installation of a deep-water pipeline. The deploying contractor needs to pre-

1 analyze all conceivable problems and be prepared for any contingency. Therefore,
2 experience in the design and deployment of such a project requires the best, most
3 experienced companies available — OCEES International, Inc.'s strategic partner Makai
4 Ocean Engineering represents that experience and possesses the expertise necessary to
5 confidently design and deploy the large diameter cold water pipelines necessary for the
6 successful implementation of an integrated OTEC system.

7