OTEC AFRICA

OTEC Africa Conference 2013
Oct 15-16, Univ. of Borås, Sweden

The Future of OTEC

– An new step towards commercialization from Okinawa, Japan –

OTEC Africa Conference, University of Boras
Boras, Sweden
October 15-16 2013

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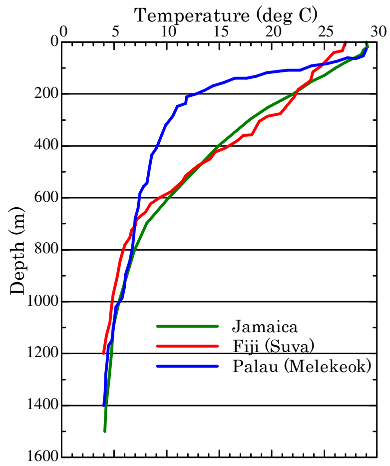
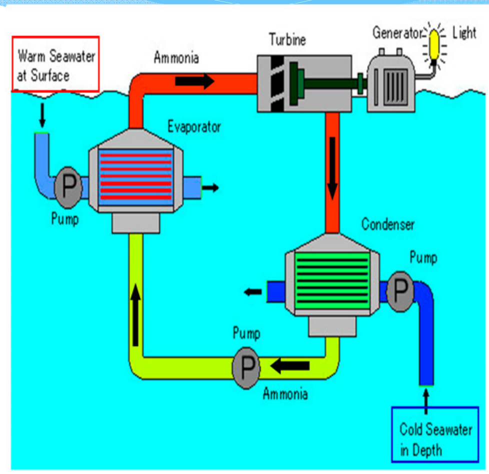
Characteristics of OTEC

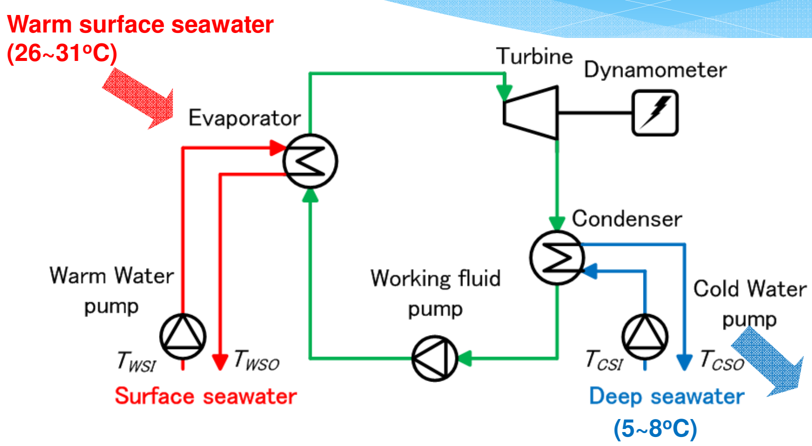
- Clean & Renewable Energy
  OTEC uses only seawater as energy resource.
- Inexhaustible Energy
  Applicable in 98 countries in the world.
- Supply Energy at Constant Rate
  Stably day and night throughout the year.
- Zero Emission
  No CO2 & other Green house gas, SOx, NOx and any wastes.

Principle of OTEC



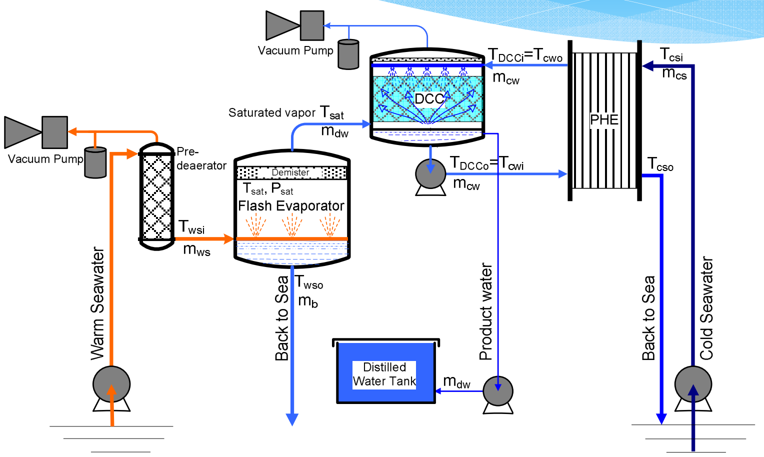


Single-purpose Power generation

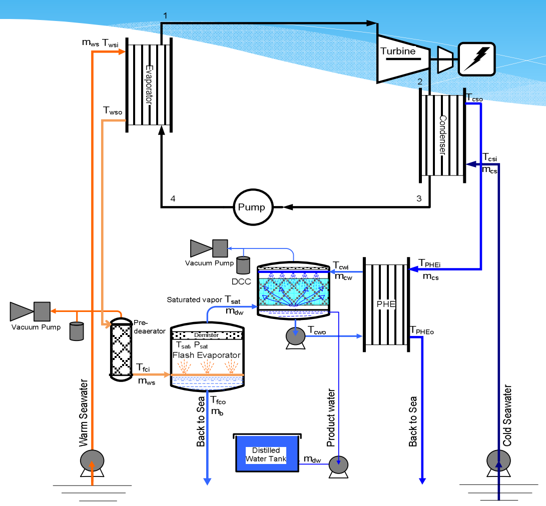


Closed cycle Ocean Thermal Energy Conversion system

Single-purpose LTTD Process

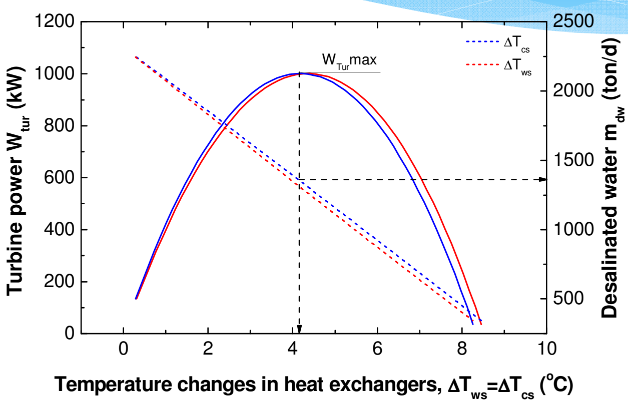


Dual-purpose OTEC-LTTD principle



Schematic of Integrated OTEC-LTTD process

Typical temperature changes in OTEC heat exchangers



Effect of temperature changes in heat exchangers on turbine power and desalinated water flow (Mws=Mcs)

Overview on energy requirements for different desalination technologies

	MSF	MED-TVC	MED	MVC	RO
Typical unit size $m^3 d^{-1}$	50,000 - 70,000	10,000 - 35,000	5,000 - 15,000	100 - 2500	**24,000**
Electrical Energy Consumption kWh m^{-3}	4 – 6	1.5 – 2.5	1.5 – 2.5	7 - 12	**3 – 5.5**
Thermal Energy Consumption kJ kg^{-1}	190 (GOR =12.2) – 390 (GOR =6)	145 (GOR =16) – 390 (GOR =6) #1	230 (GOR =10) – 390 (GOR =6)	None	**None**
Electrical Equivalent #2 for Thermal Energy kWh m^{-3}	#3 9.5 – 19.5	#4 9.5 – 25.5	#5 5 – 8.5	None	**None**
Total Equivalent Energy Consumption kWh m^{-3}	**13.5 - 25.5**	**11 - 28**	**6.5 - 11**	**7 - 12**	**3 - 3.5 (Up to 7 with Boron treatment)**

Source: WANGNICK CONSULTING (2010) http://www.desware.net/desa4.aspx

Desalinated water presents and added value to any OTEC project

Example:

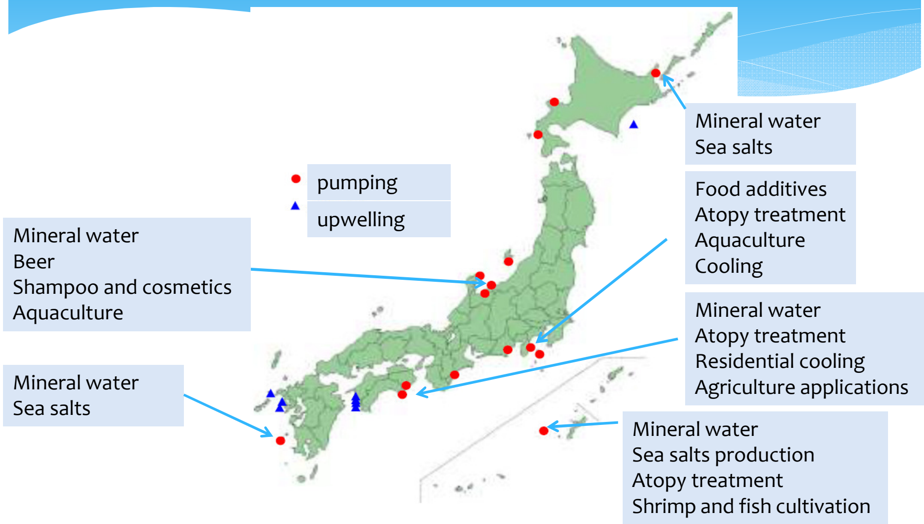
1 MW (Turbine power) OTEC plant would produce:

- A net power of **675 kW**
- Fresh water at a rate of **15 *kg/s*** **(54 *t/h*)**

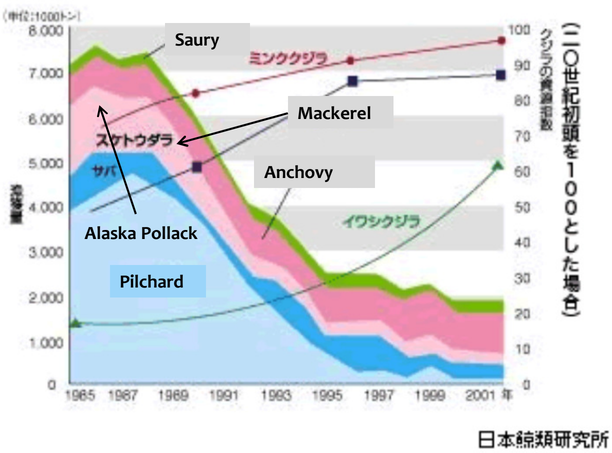
Energy requirement to produce 54 t/h using the most energy-efficient desalination process would be:

$$54\ m^3/h \times 3.5\ kWh/m^3 = \underline{189 kW}$$

Deep Ocean Water Application in Japan

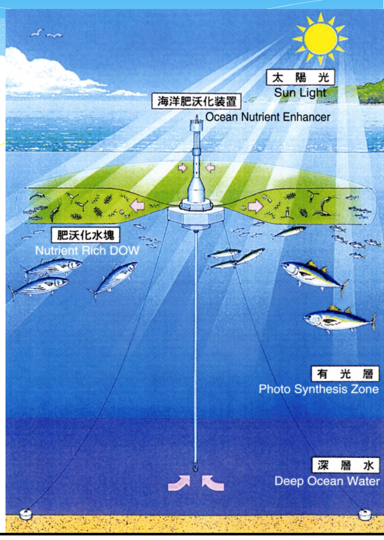


Fish Resources in Japan

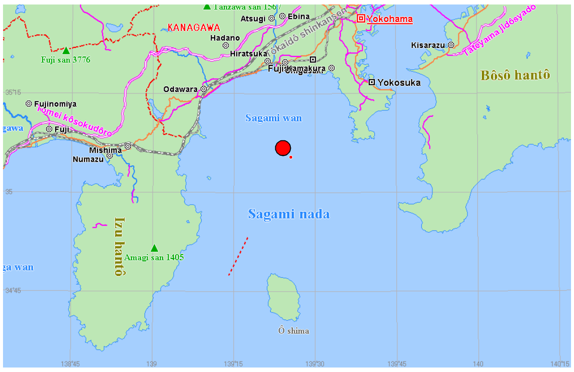


TAKUMI
Increase Fish Resources

Recycling Nutrient-Rich Deep Ocean Water to the surface



Location of Takumi



100,000 t/d

TAKUMI in Operation at Sagami Bay

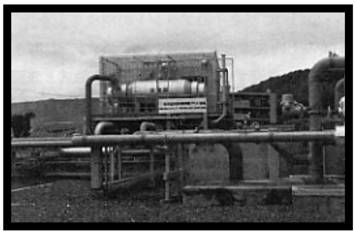
(by Prof. Ouchi, The University of Tokyo)

OTEC in '70s~'80s

From the Suggestion of OTEC Concept in 1881…

The first closed cycle Mini-OTEC plant to produce net power (15 kilowatts) at Keahole Point, Hawaii, in 1979

Nauru OTEC Project
（1982～84）



Tokunoshima Project
（1982～84）

Evaluation in 1980s

OTEC is Technically Feasible
but Not Economical

In the spotlight again due to Development in the marine industry

History of OTEC research in Japan

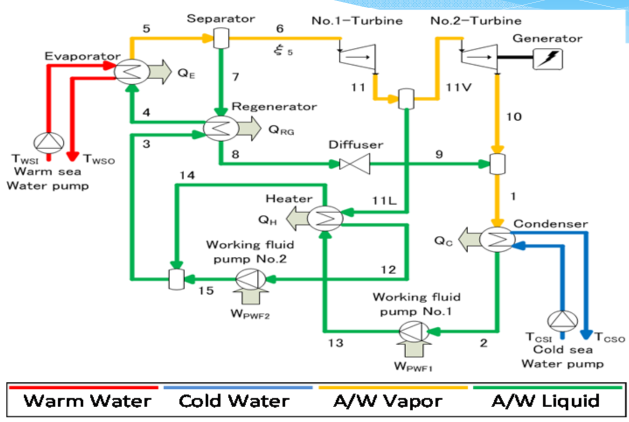
1970	New energy research committee of Japan expressed interest in OTEC for power generation
1973	Saga University, Japan commenced research study on OTEC technology
1974	OTEC was researched as part of Sunshine project plan, Japan
1977	Saga University has been able to generate 1kW of power using OTEC system
1980	Saga University performed experiments off Shimane in Japan Sea
1981	Tokyo Electric Power Co., succeeded in generating 120kW of power at the republic of Nauru in the south pacific
1982	Kyushu Electric Power Co. succeeded in generating 50kW of power at Tokunoshima, off Kagoshima, Japan
1985	Saga University completed 75kW experimental OTEC plant
1988	Establishment of OTEC association in Japan
1989	Japanese Agency of Science and Technology began studies on utilization of deep ocean water (DOW) off Toyama in Japan Sea after success in generating 3kW power
1994	Saga University constructed a plant of new power cycle
1995	Saga University started testing the new 4.5kW cycle (Kalina cycle, Uehara cycle)
1997	Signing of collaboration memorandum with National Institute of Ocean Technology (NIOT), India, on OTEC study
2003	Saga University Completed 30kW multipurpose OTEC Plant at Imari, Saga Pref.
2009	Saga University has been able to generate a net power of 20.5 kW using Ammonia/water working fluid, representing about 70% of the total generated power

Institute of Ocean Energy, Saga University

OTEC research at Saga University

General view of 30kW OTEC system (Saga University)

Power Cycle at IOES



Schematic of ammonia/water power cycle developed and constructed at IOES

30kW OTEC turbine using Ammonia/Water mixture

Experimental research

Achievement of 20.5 kW net Power at IOES

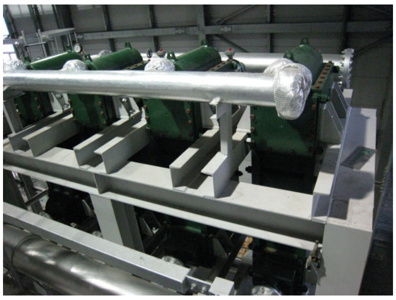
Experimental conditions

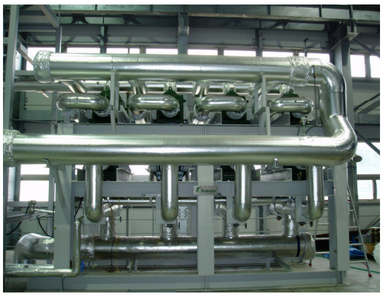
Parameter	Value
Warm source inlet temperature [^oC]	30
Warm source volumetric flow rate [m^3/h]	350~450
Cold source inlet temperature [^oC]	9
Cold source volumetric flow rate [m^3/h]	350~450
Heat transfer area of evaporator per unit [m^2]	136.2
Heat transfer area of condenser per unit [m^2]	91.1
Number of heat exchanger units [-]	2,3,4
Evaporator inlet mass flow rate [t/h]	6~12
Evaporator inlet mass fraction y_4[NH_3 kg/kg]	0.95

Specification of the heat exchangers

Heat exchanger		Evaporator	Condenser
Total heat transfer area	m^2	136.3	91.2
Plate dimensions	mm	1813×709	1213×709
Plate tickness	mm	0.6	0.6
Number of Plates	-	100	100
Material	-	titanium	titanium

Specification of the Plate-type evaporator and condenser





Side and top views of the 4-unite heat exchangers

Evaluation equations

$$\eta_{net} = W_{net} / W_{tur}$$

$$W_{net} = W_{tur} - \left(Wp_{ws} + Wp_{cs} + Wp_{wf}\right)$$

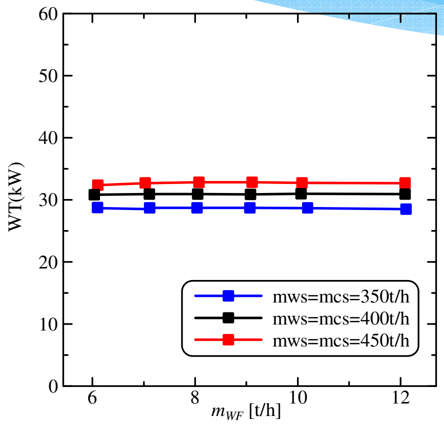
$$\eta_{\max} = W_{net,Exp} / W_{\max}$$

$$W_{\max} = (T_{WSI}^{\frac{1}{2}} - T_{CSI}^{\frac{1}{2}})^2 / (Cws^{-1} + Ccs^{-1})^*$$

$$Cws = m_{ws} Cp_{ws} \qquad Ccs = m_{cs} Cp_{cs}$$

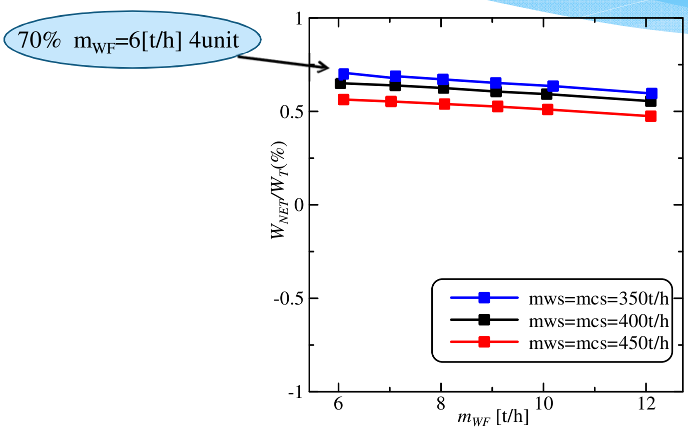
* Ikegami Y., Bejan A., “On the Thermodynamic Optimization of Plants with Heat Transfer and Fluid Flow Irreversibilities”, Trans. ASME. J. Sol. Energy Eng., Vol.120, No.2, 1998, pp.139-144

Results



Variation of Turbine power with working fluid flow rate [4 units of HE are used]

Net power ratio

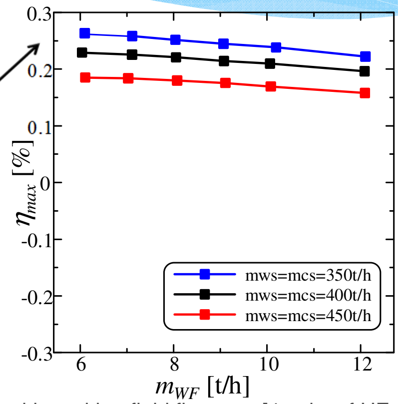


Variation of net power ratio with working fluid flow rate [4 units of HE are used]

Maximum net power efficiency (Experimental results)

$$W_{max} = (T_{WSI}^{\frac{1}{2}} - T_{CSI}^{\frac{1}{2}})^2 / (Cws^{-1} + Ccs^{-1})^*$$

26% m_{WF}=6[t/h] 4unit



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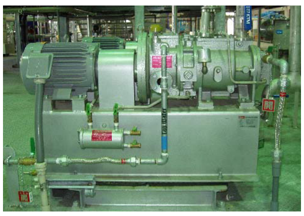
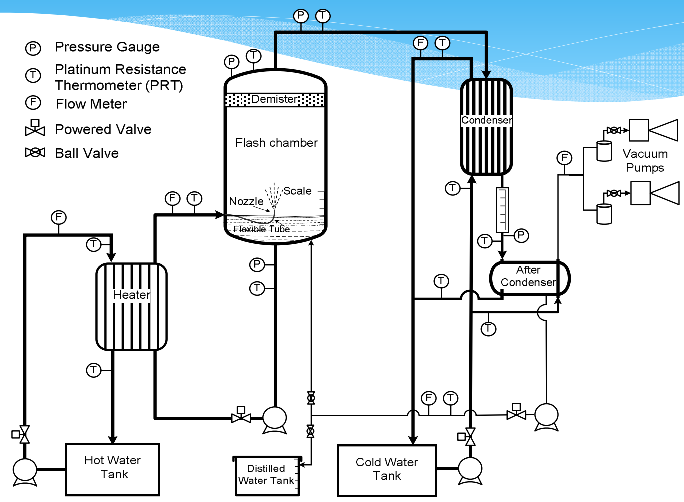
Desalination Plant at IOES

Flash evaporation chamber

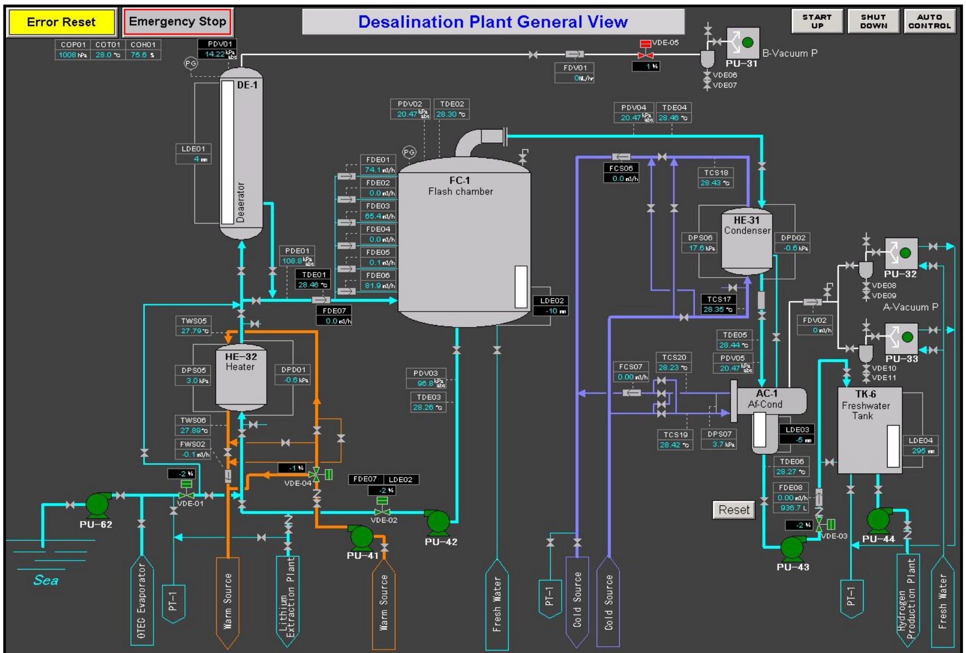


Vacuum pump

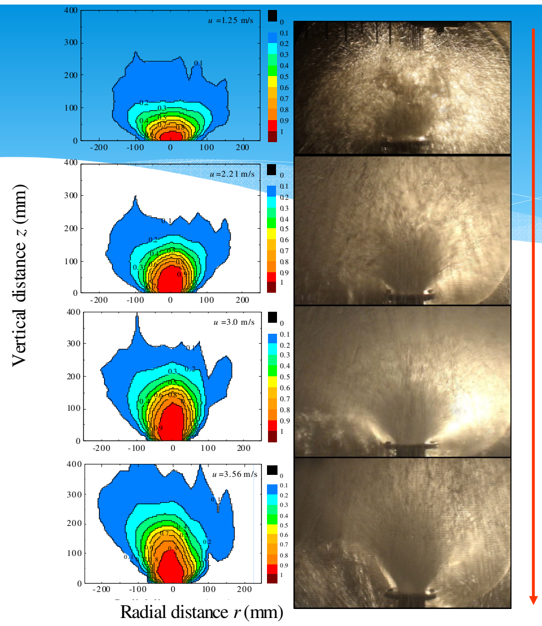
Low Temperature Thermal Desalination (LTTD)



Schematic of the experimental apparatus



Control interface of the experimental setup



Photographs of the jet and the corresponding isothermal diagrams at various flow velocities (d = 81.3mm, T_o =35°C, DTs= 4 °C)

Roadmap for OTEC (NEDO)

Vision, challenges and actions

- World top in experimental studies
- There has been more interest in many countries and R&D restarted.

Goals

- Accelerating R&D for commercialization, keeping the world top rank in technology, and developing competitive equipment and domestic companies
- Promoting installation in the country and developing new industries from the view point of necessity of developing industries in Japan, realizing a low carbon society, and securing energy.

- Promoting R&D on MW-class plants through verification tests and improving reliability
- Establishing core technologies
- Improving business feasibility and reducing generation costs

Challenges for realizing vision and actions to be taken

Technological development targets

	2015	2020	2030
Enlightening Japanese enterprises and reinforcing international competitiveness	Verification tests on a 1-MW plant	· Starting operation of a plant for commercial use · Promoting installation in Japan	· Increasing plant output · Increasing global market share
Plant size	Up to 1 MW	Up to 10 MW	Up to 50 MW
Generation costs	About 40 - 60 yen/kWh	About 15 - 25 yen/kWh	About 8 - 13 yen/kWh

Detail of technological development

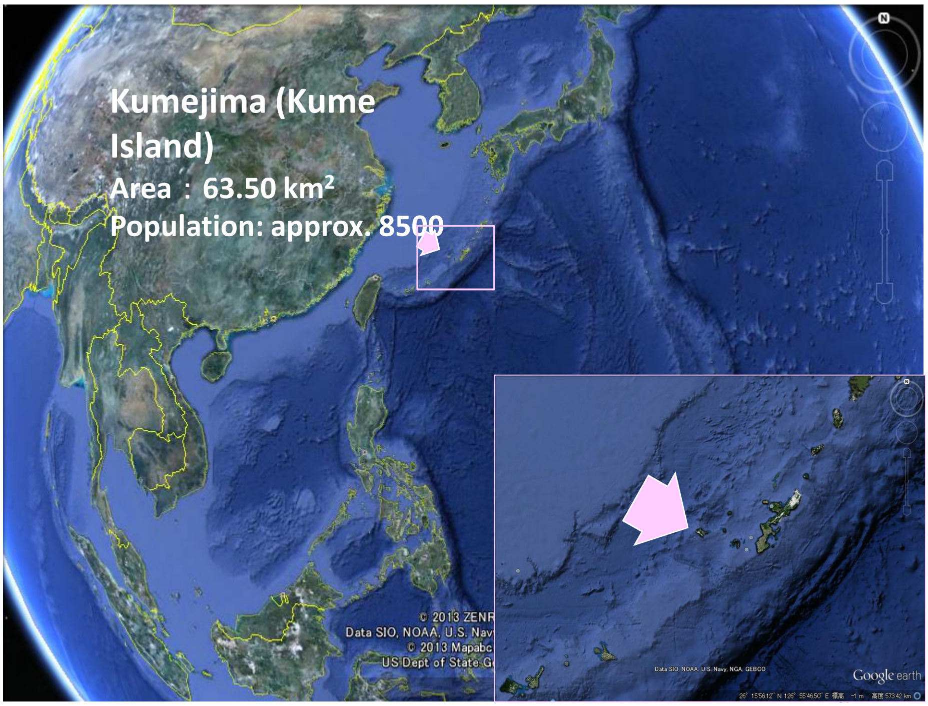
Technological challenge		Solution & component technology
Establishment of core technologies	Initial cost reduction	· Development of low cost · Low cost construction technologies
	Improvement of generation efficiency	· Improvement of cycle thermal efficiency · Highly efficient working fluid · Development of highly efficient new cycles
Establishment of plant operation technologies	Maintenance and prevention of failure of plants	· Monitoring system · Marine environment prediction system · Remote control system
	Application to marine environment	· Prevention of attaching marine creatures
	Environmental impact evaluation	· Collecting basic data through verification tests · Prediction of influence through simulations
Improvement of business feasibility	Effective utilization of hot discharged water	· Utilization of discharged water from manufacturing and power plants
	Complex use of deep seawater	· Seawater desalination technology, creation of fisheries with deep seawater, cold energy utilization (for air conditioning etc.), hydrogen production, collection of lithium, etc.

OTEC Roadmap (July 2010)

New Energy and industrial technology Development Organization (NEDO)

Aspect/Year	2015	2020	2030
Technology	-Demonstration Tests	-Domestic implementation -Start commercialization	-Wide implementation in the international markets
Scale (MW)	∼1	∼10	∼50
Cost (JPY/kWh)	40~60	15~25	8~13

NEW STAGE (ReSTART) of OTEC plant connected to the electricity grid for the first time in 15 years



Okinawa Prefectural Deep Sea Water Research Center and Business Park

DSW Pump-up Capacity: 13,000 ton/day, the Largest Capacity in Japan.

OTEC project motivations

Background

- Okinawa is open to the influence of external factors such as international energy situation, because it depends on fossil fuel for about **99.8%** of its energy.
- Reduction of the discharge of CO_2 is an urgent issue.

Necessity

A rise in the self-sufficiency rate of energy and diversification of energy sources are necessary. These are the reasons why Okinawa is implementing on OTEC demonstration project toward large-size and commercializing OTEC.

Project outline

- Budget: 500 million yen
- Place: Deep Sea Water Research Center（Kumejima-cho）
- Contents:
  - ・Set up demonstration plant and measure various data
  - ・Demonstrate technology for output stability.
  - ・Examine more advanced multiple usage of deep & surface sea wate
- Term: 2012～2014
  - ・2012 Set up demonstration plant
  - ・2013～2014 Demonstration

Unit Image

Project Scheme

PROJECT OWNER

Okinawa Pref.

ADVISER

Saga Univ.

Cooperation

Contract

Cooperation

J/V
(IHI Plant Construction, Xenesys, Yokogawa Electric)

<u>Schedule</u>

FY2012 (-March 2013): Construction of Demonstration Facility

FY2013-14 (April 2013 -March 2015): Continuous Operation and Experimentation

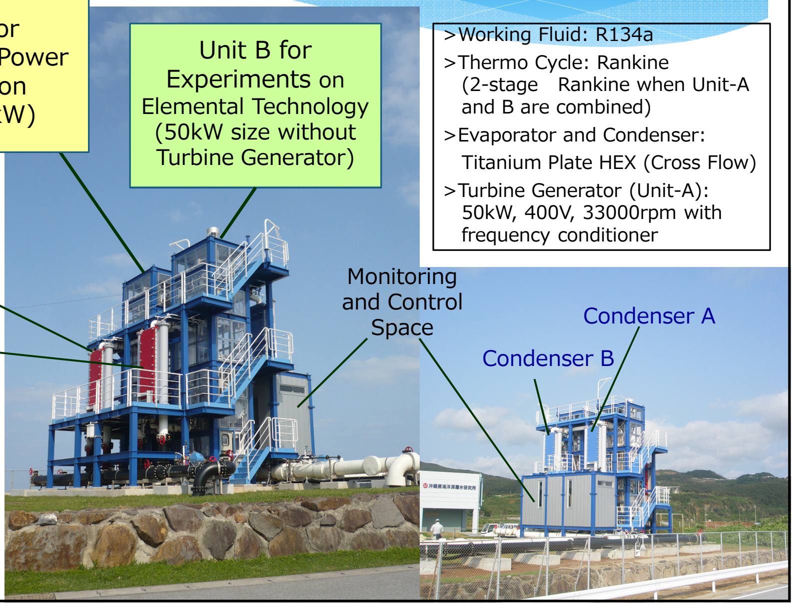
OTEC Demonstration Facility in Kumejima (Okinawa)

Power Generation Unit

Unit A for Continuous Power Generation (max.50kW)

Unit B for Experiments on Elemental Technology (50kW size without Turbine Generator)

- >Working Fluid: R134a
- >Thermo Cycle: Rankine (2-stage Rankine when Unit-A and B are combined)
- >Evaporator and Condenser: Titanium Plate HEX (Cross Flow)
- >Turbine Generator (Unit-A): 50kW, 400V, 33000rpm with frequency conditioner



Milestones

Jan. 2013	Feb. 2013	Mar. 2013	Apr. 2013	May. 2013	Jun. 2013

28 Jan.
Construction Started at Site

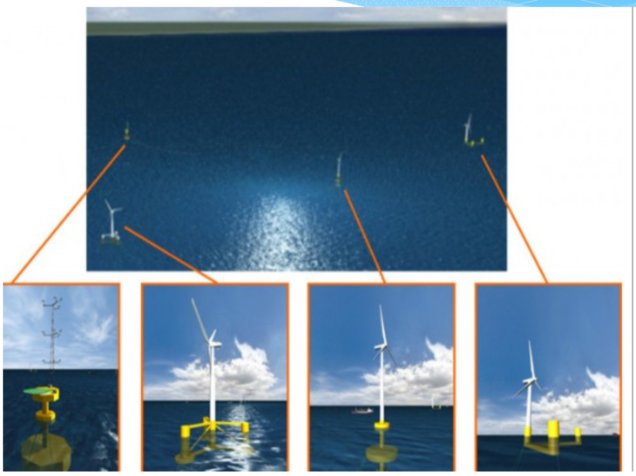
30 Mar. / 1st Power Generation Test Succeeded

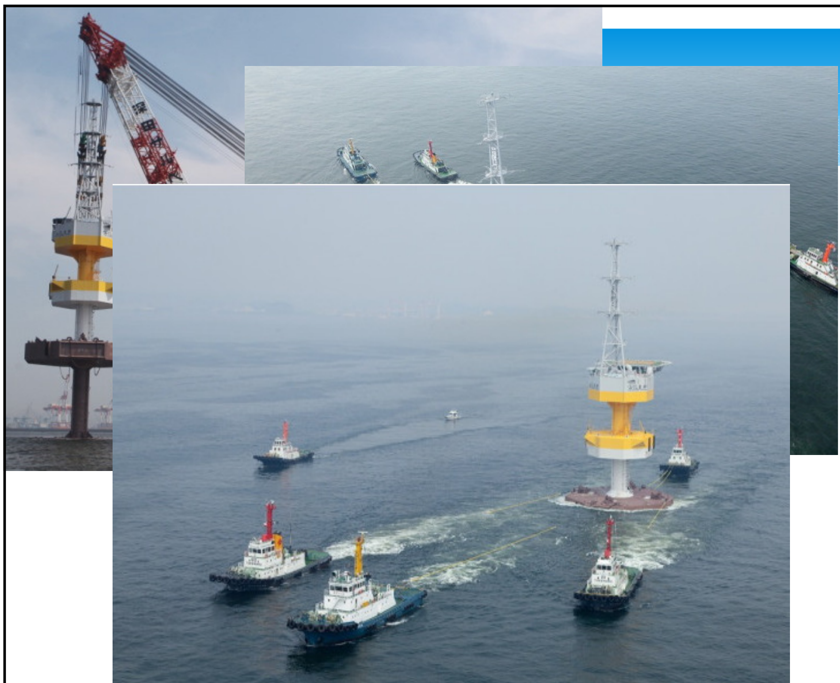
Surface Water:	23.5 ºC, 330t/h
Deep Water:	9.3 ºC, 250t/h
Power Output:	3.1kW (for Test)

15 Apr.
Official Operation

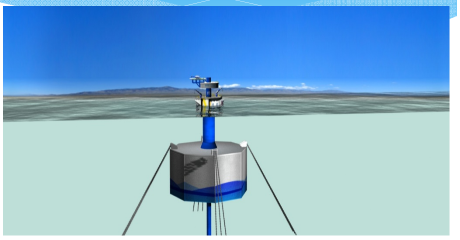
16 Jun.
Opening Ceremony

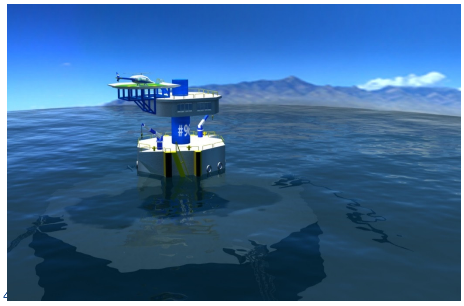
Fukushima Wind Farm Project





Nippon Kaiji Kyokai (known as ClassNK) has issued its first Approval-in-Principle (AIP) for Totally Submerged OTEC floating power plant model of JMU(Japan Marine United Corp.)





September 2nd ,2013

Summary

Besides the technological developments, secondary applications of OTEC plant play a major role on the economics of OTE utilization, of particular significance is Seawater Desalination and/or Air Conditioning in places where these applications are needed

End..
Thank You

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