Improvement study for the critical component of 1MW OTEC plant

2017. 11. 4

Hyeon-Ju KIM, Seung-Taek LIM, Jung-Hyun MOON and Ho-Saeng LEE

Seawater Utilization Plant Research Center(SUPRC)

Korea Research Institute of Ships and Ocean Engineering (KRISO)

Korea Institute of Ocean Science and Technology (KIOST)

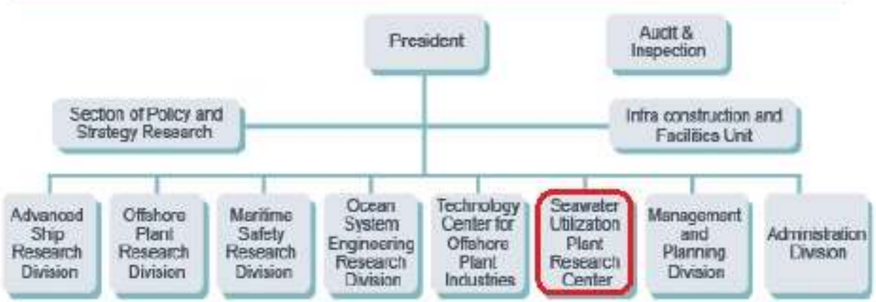
Main function and mission of SUPRC

KRISO — Korea Research Institute of Ships&Ocean Engineering

KRISO, a leader of marine transport and ocean development

The government funded research institution that focuses on Ocean Engineering area, including environmentally friendly advanced ship, offshore plant, ocean energy, maritime safety and ocean system

KRISO Organization



Seawater Utilization Plant Research Center — SUPRC

Seawater Utilization Plant Research Center(SUPRC)

Utilizing seawater resources, SUPRC develops essential seawater utilization plant technologies for sustainable production and use of food, energy and water in the climate change era.

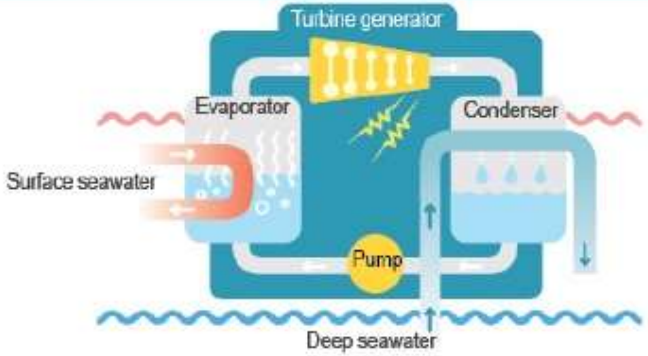
Main responsibilities

Main research areas of SUPRC

SUPRC main research areas

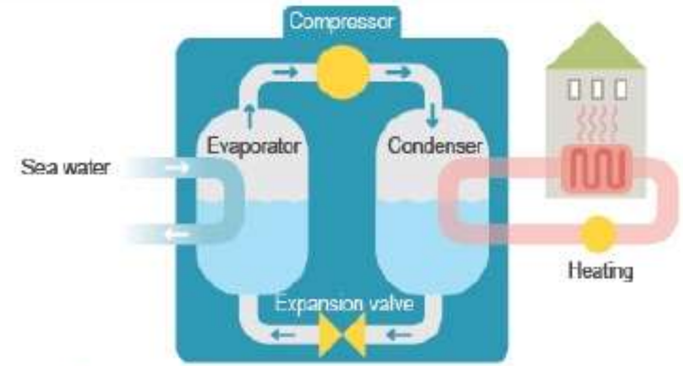
SUPRC

OTEC (Ocean Thermal Energy Conversion) system



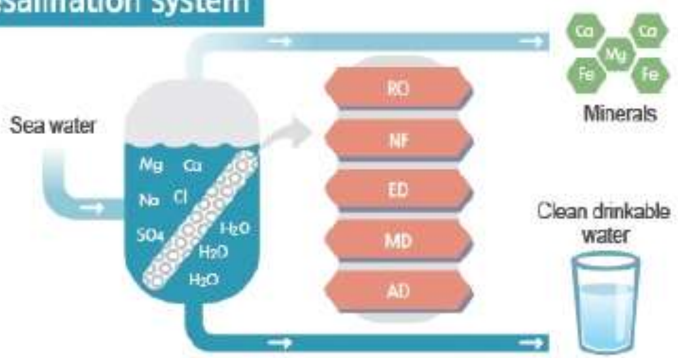
- In OTEC, working fluid (R32, etc.) evaporates as it gains heat energy from warm surface seawater, and condenses as it loses heat to cold deep seawater.
- Resulting flow of the working fluid rotates the turbine and generates electricity. *Closed-cycle, Open-cycle, Hybrid-cycle can be applied for electricity and water

SWAC (Seawater Air Conditioning) system



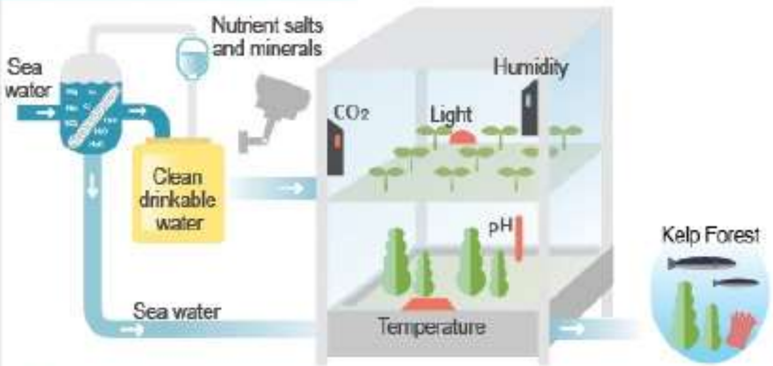
- SWAC utilizes coldness and heat of seawater as heat sources for heat pump for cooling, heating, freezing, and hot water supply.
- Heat pump can switch to cooling if three way valve is used from heating.

Desalination system



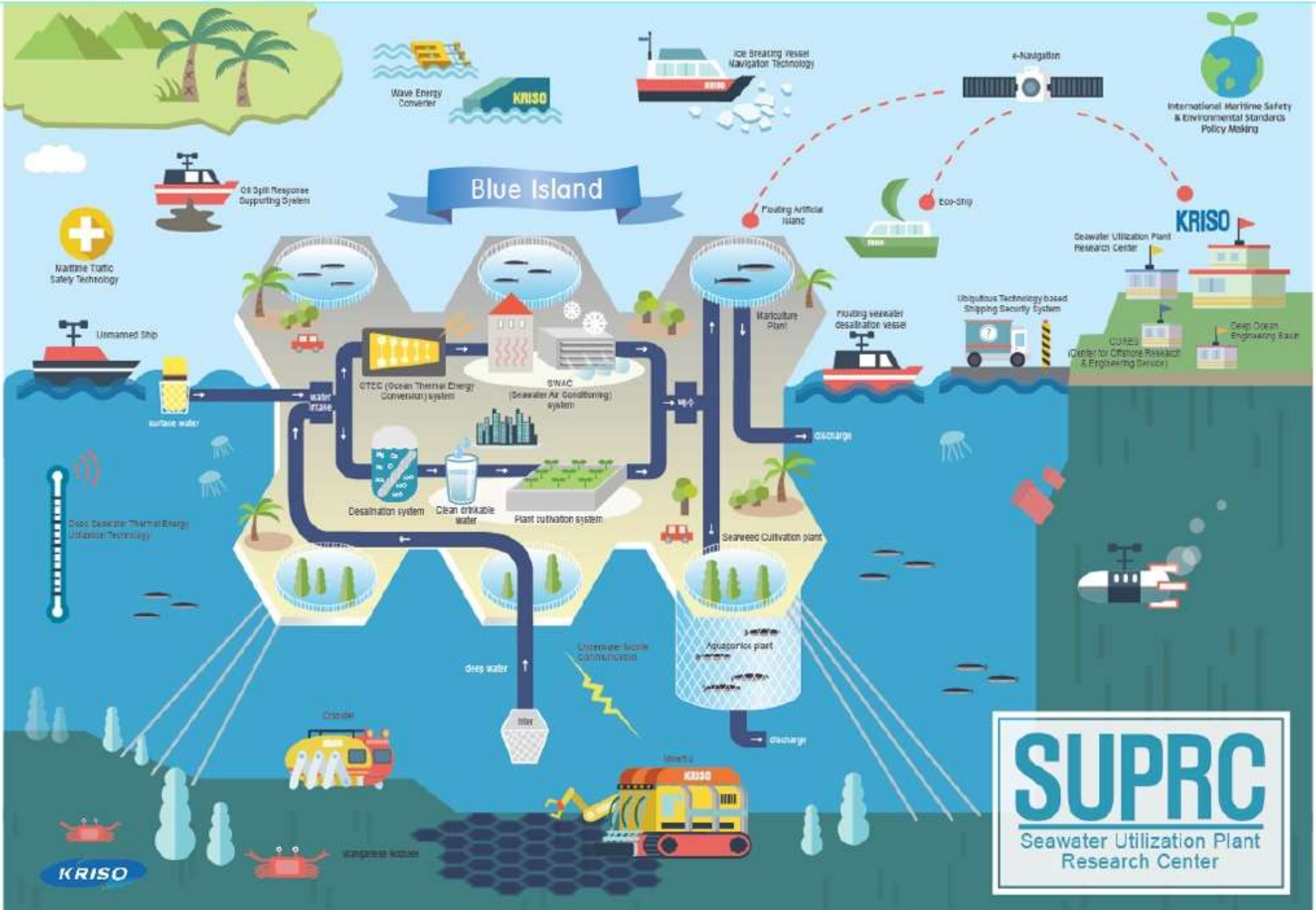
- Membrane desalination technologies turn deep seawater into clean drinkable water.
- Evaporative concentration and electrodialysis technologies extract minerals and produce concentrated deep seawater.
- Membrane technologies: RO(Reverse Osmosis), NF(Nanofiltration), ED(Electrodialysis)
- Extraction technologies: MVR(Mechanical Vapor Recompression), VMD(Vacuum Membrane Distillation), AD(Adsorption Desalination)

Plant cultivation system



- Nutrient salts and minerals from deep seawater are utilized as main components of nutrient solution and seawater-based heat pump controls temperature for optimal growth of marine plants such as seaweeds, microalgae, and land plants such as fruits and vegetables.
- Floating or movable seawater utilization plant cultivation plant (Seawater Farming Plant)

Activity areas of SUPRC in KRISO



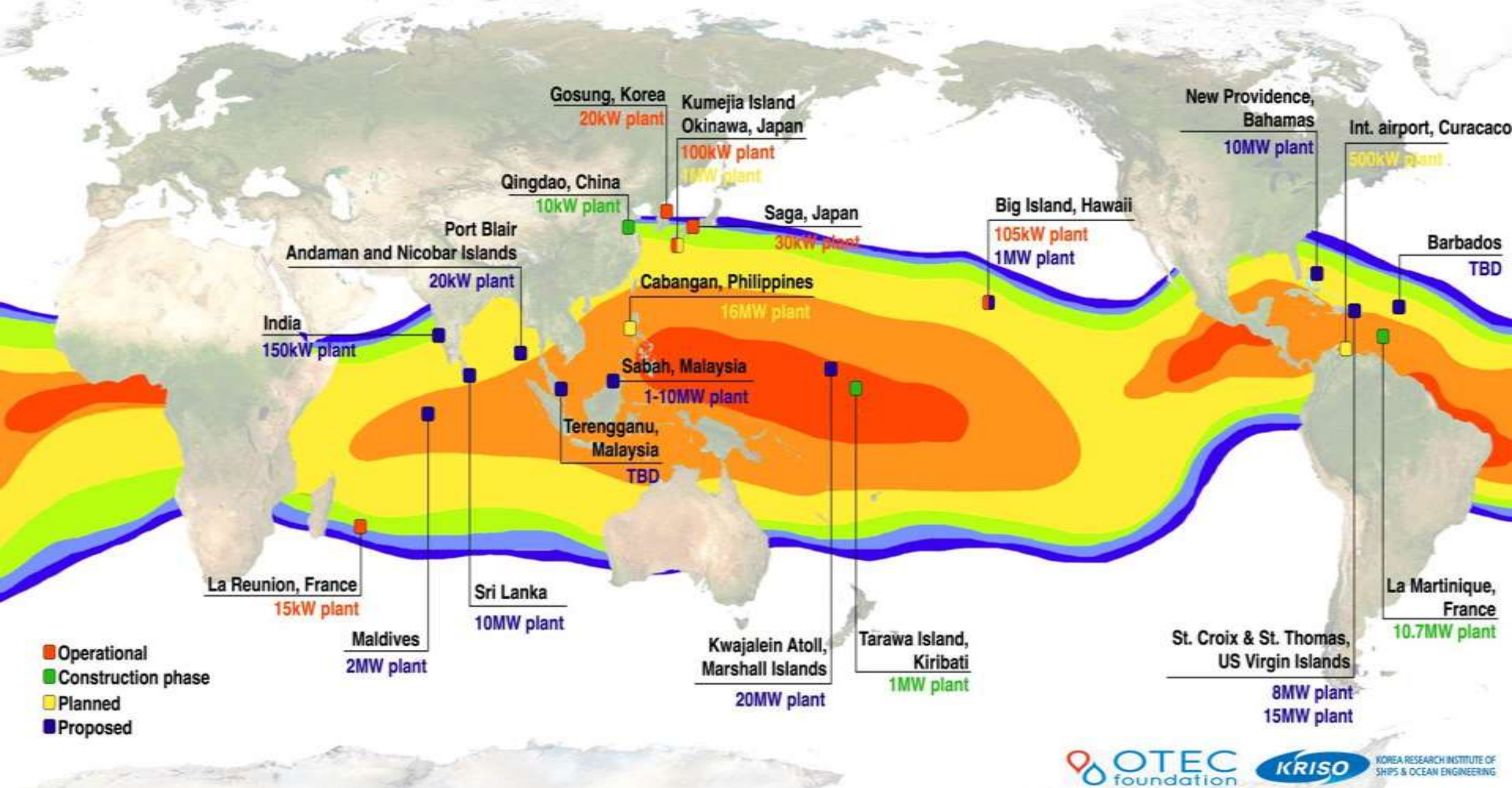
Global OTEC R&D and Demonstration Projects

https://sung7.typeform.com/to/ImOfIN

Status of OTEC survey

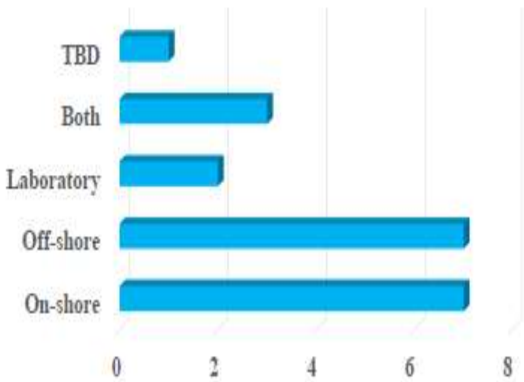
Take 2 minutes to share your OTEC project with us and receive our breif report on 'The status of OTEC around the globe'

Yes, let's start!

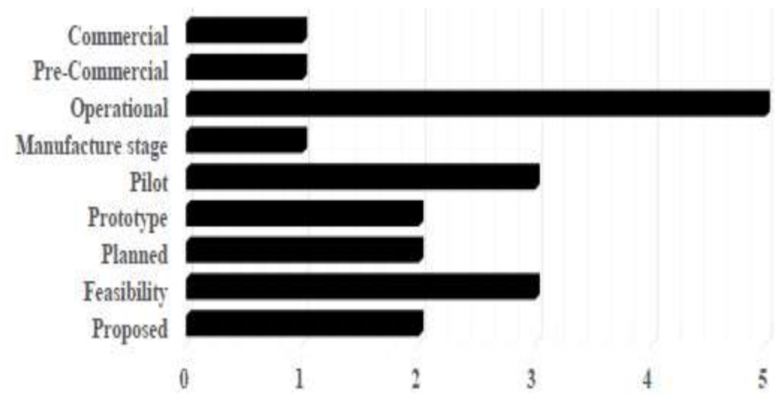


Global OTEC R&D and Demonstration Projects

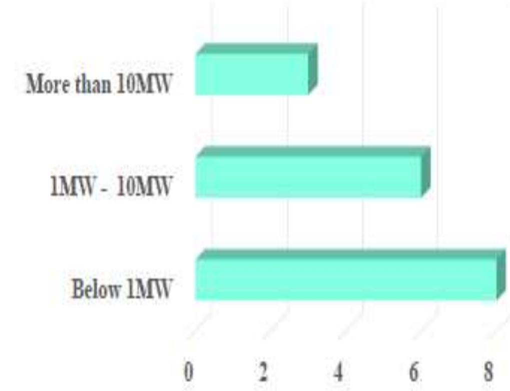
Plant Type



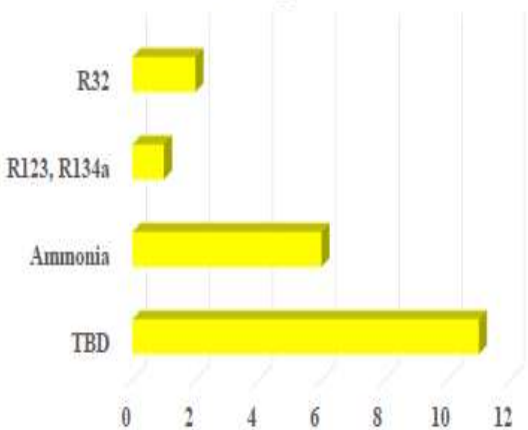
Project Stage



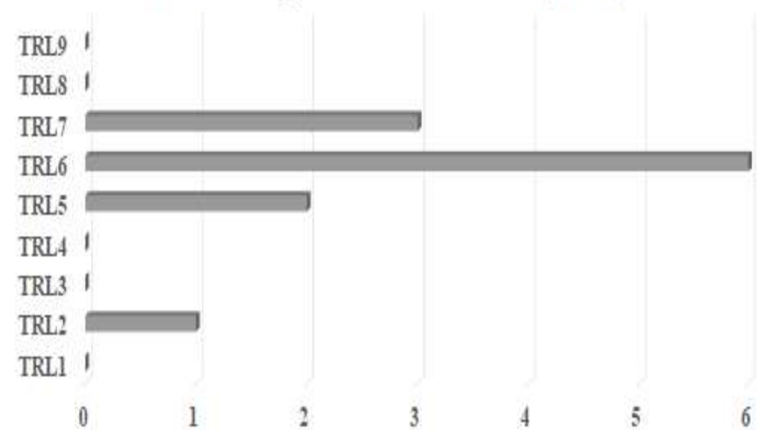
Generation Capacity



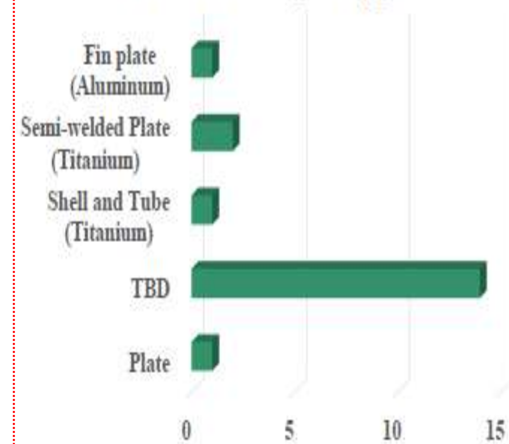
Working Fluid



Technology Readiness Level (TRL)



Heat Exchanger Type



Economical evaluation needs through demonstration for OTEC commercialization

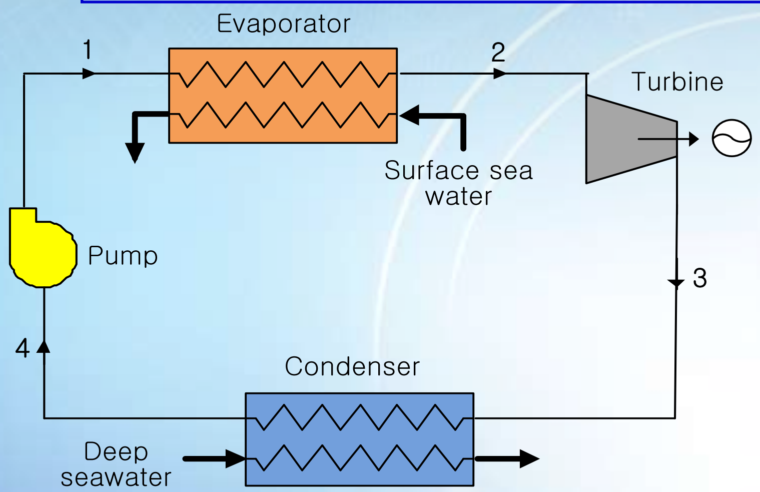
Summary data averaged for each stage of deployment, and each technology type

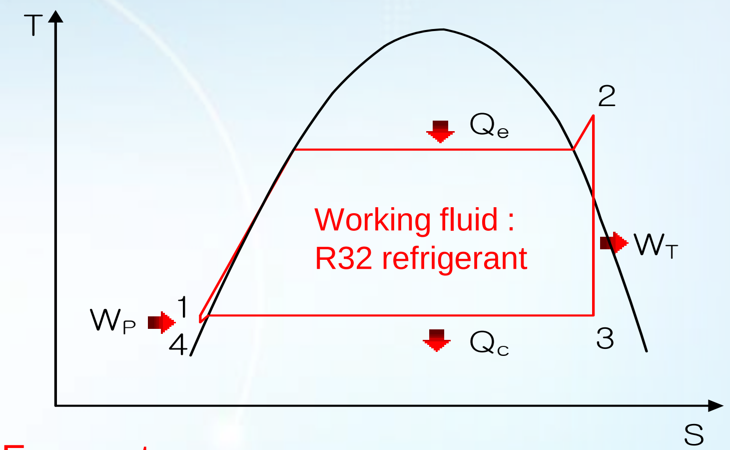
Deployment Stage	Variable	Wave		Tidal		OTEC	
		Min	Max[1]	Min	Max	Min	Max
First array / First Project[2]	Project Capacity (MW)	1	3 [3]	0.3	10	0.1	5
	CAPEX ($/kW)	4000	18100	5100	14600	25000	45000
	OPEX ($/kW per year)	140	1500	160	1160	800	1440
Second array/ Second Project	Project Capacity (MW)	1	10	0.5	28	10	20
	CAPEX ($/kW)	3600	15300	4300	8700	15000	30000
	OPEX ($/kW per year)	100	500	150	530	480	950
	Availability (%)	85%	98%	85%	98%	95%	95%
	Capacity Factor (%)	30%	35%	35%	42%	97%	97%
	LCOE ($/MWh)	210	670	210	470	350	650
First Commercial-scale Project	Project Capacity (MW)	2	75	3	90	100	100
	CAPEX ($/kW)	2700	9100	3300	5600	7000	13000
	OPEX ($/kW per year)	70	380	90	400	340	620
	Availability (%)	95%	98%	92%	98%	95%	95%
	Capacity Factor (%)	35%	40%	35%	40%	97%	97%
	LCOE ($/MWh)	120	470	130	280	150	280

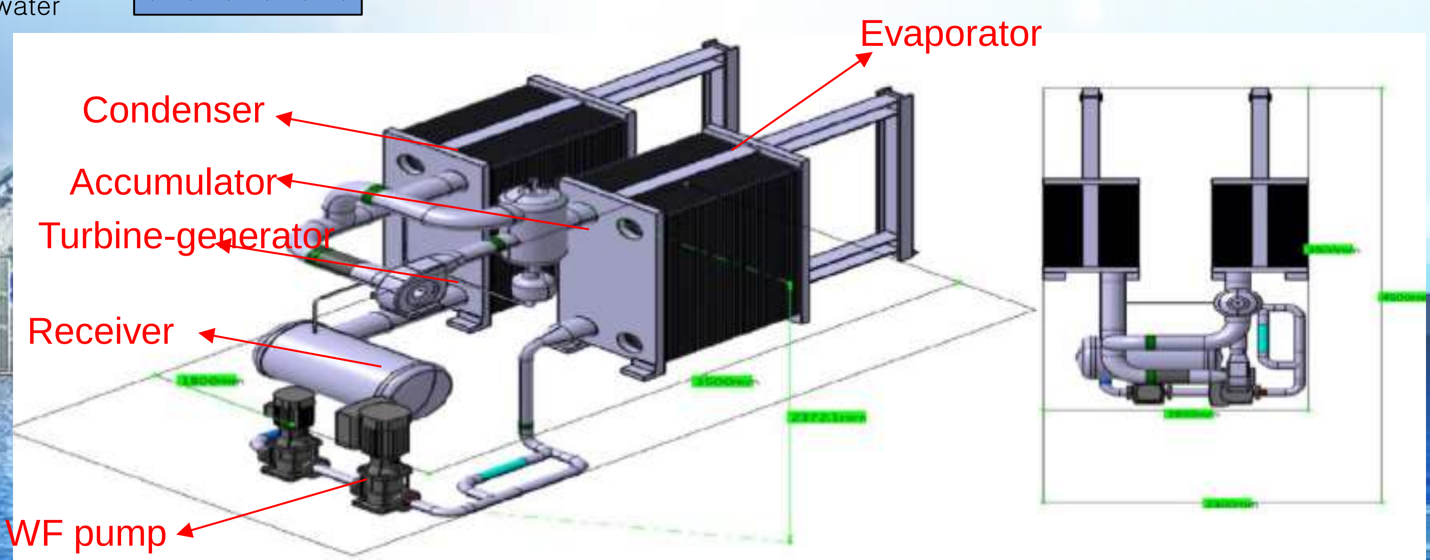
IRENA(2015)

Design of 1MW OTEC plant by Korean OTEC team

- **Electric power can be generated by rotating a turbine using gaseous flow of evaporated working fluid. Warm surface(29ºC) and cold deep(5ºC) seawaters are used for heat source and sink, respectively.**





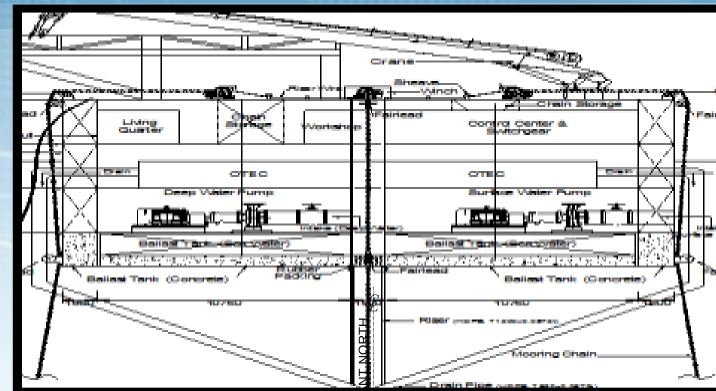


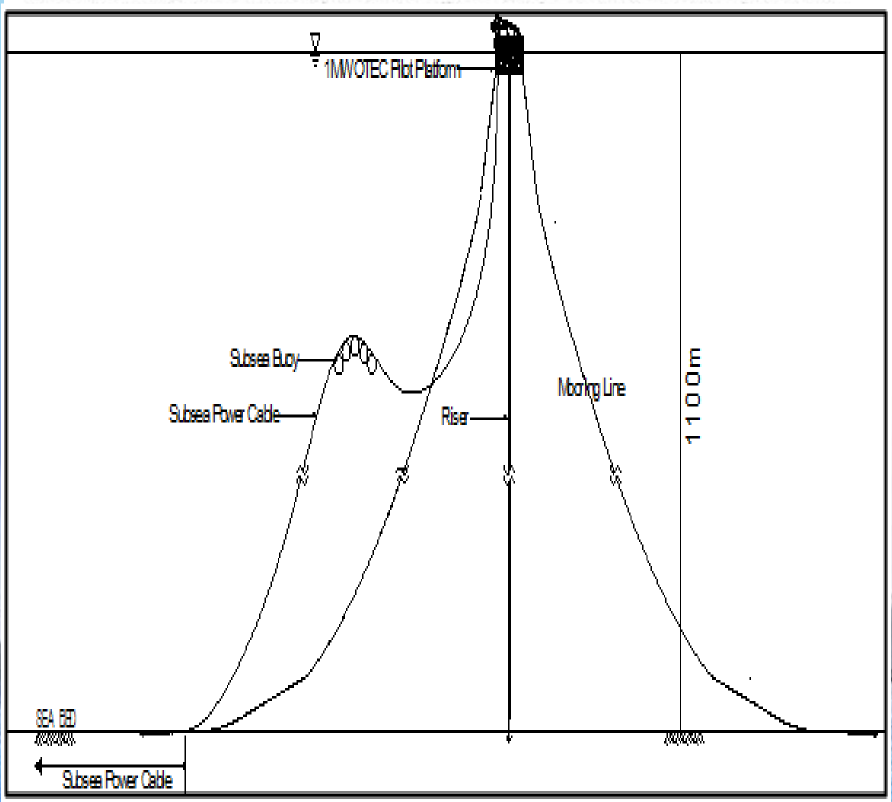
Design of offshore 1 MW OTEC plant

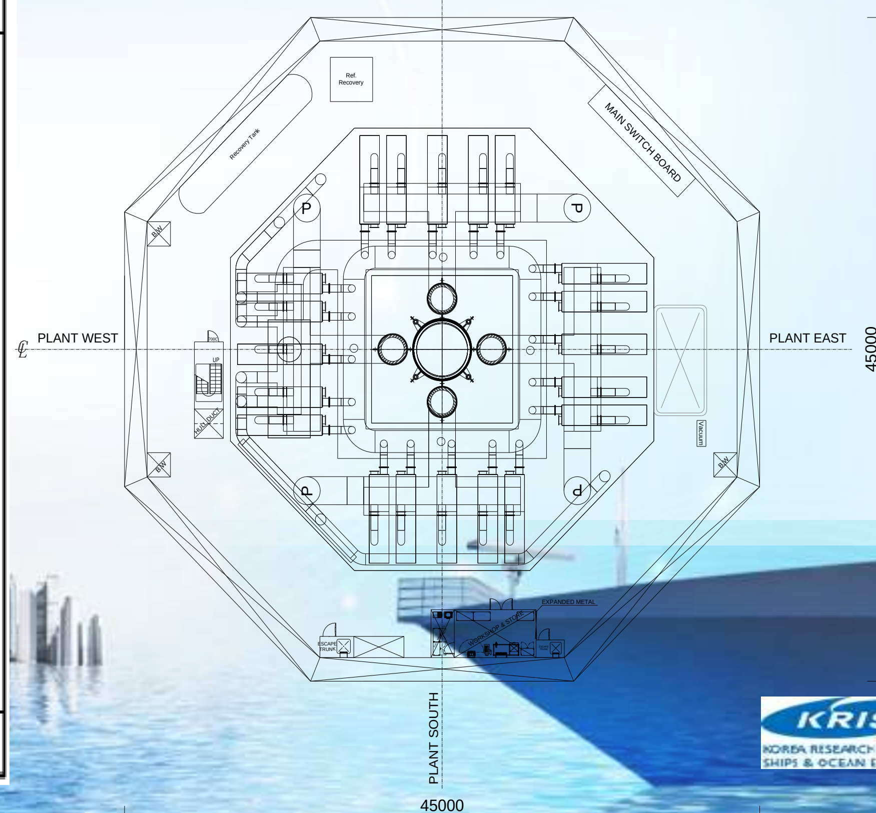
Korea develops ocean thermal energy converter for Pacific island

Written by Kevin Tester

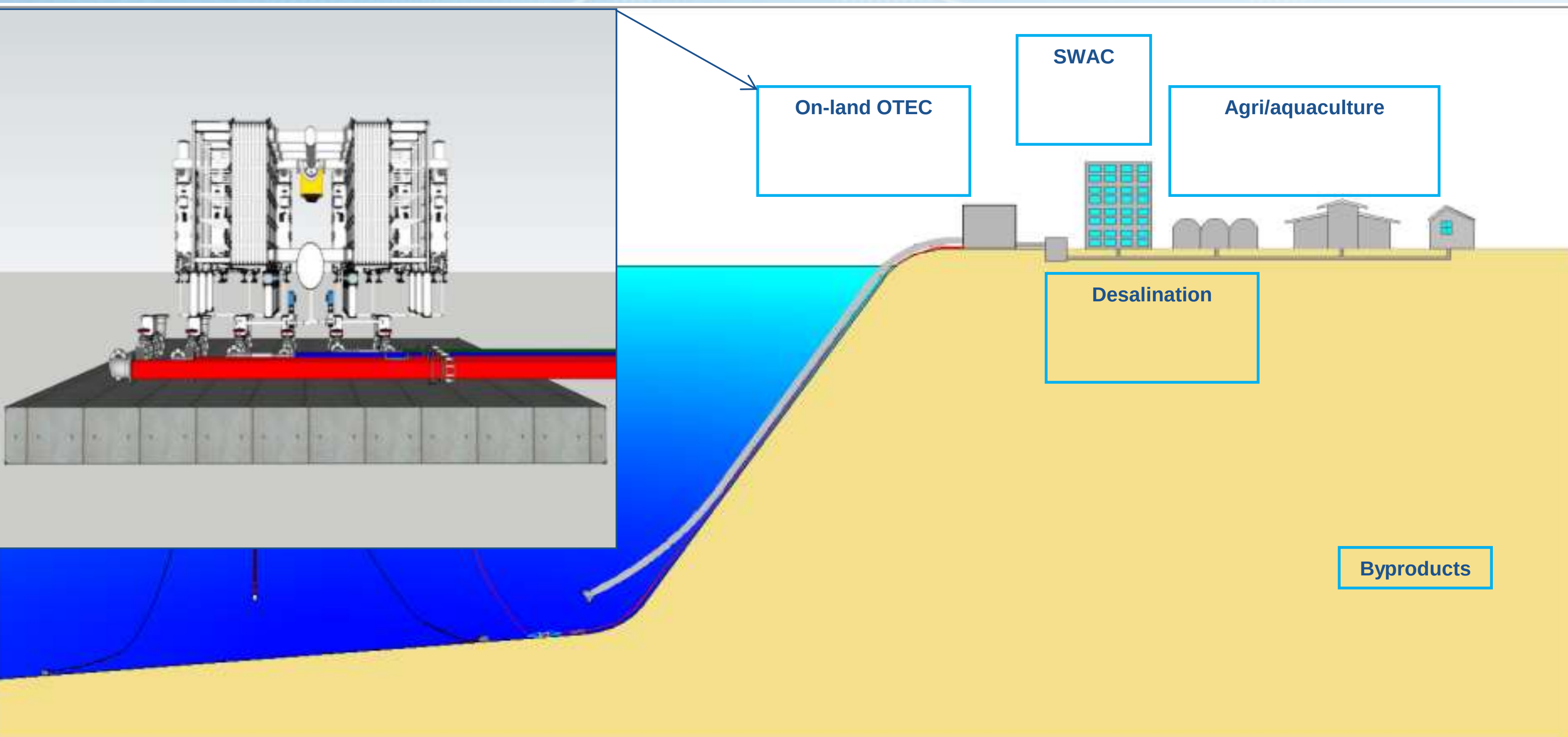
Classification society Bureau Veritas has issued an approval in principle for an Ocean Thermal Energy Converter (OTEC). The approval applies to a 1MW plant developed by the Korea Research Institute of Ships and Ocean





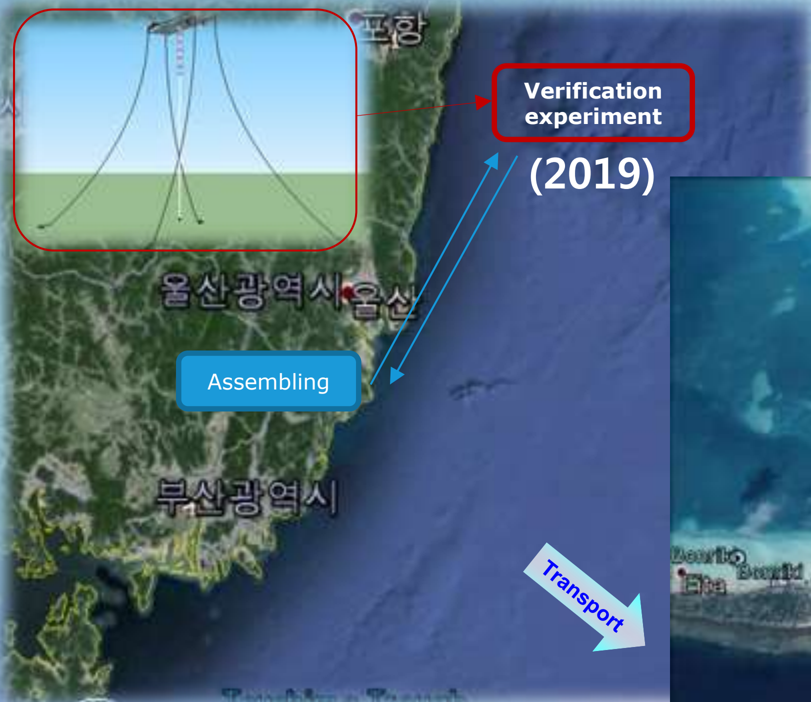


Design of on-land 1MW OTEC plant



Demonstration plan of 1MW OTEC plant for performance test and grid-supply operation

Int. OTEC symposium
Busan(2019) or Tarawa(2020)



Design approval of 1/10MW OTEC plant on offshore platform will be tried in 2020

For multi-purpose use of discharged seawater for FEW application

LCOE of 1MW OTEC demonstration plant by the Korean OTEC team in 2015

Summary data averaged for each stage of deployment, and each technology type

Deployment Stage	Variable	Wave Min	Wave Max[1]	Tidal Min	Tidal Max	OTEC Min	OTEC Max
First array / First Project[2]	Project Capacity (MW)	1	3 [3]	0.3	10	0.1	5
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	LCOE ($/MWh)	120	470	130	280	150	280

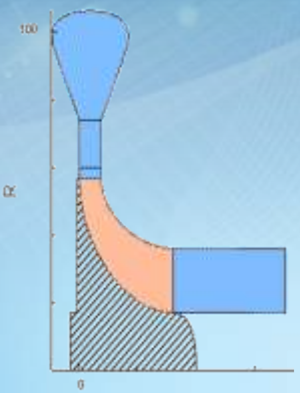
IRENA(2015)

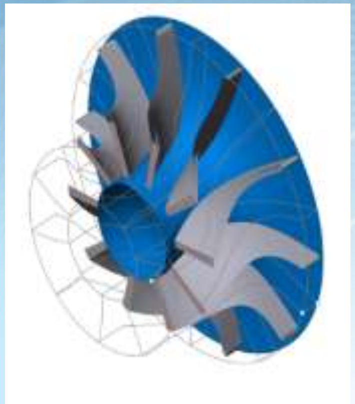
KRISO(2015)

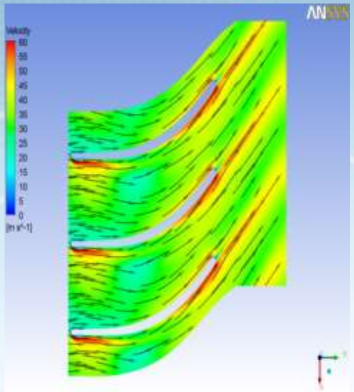
Capital Cost	Operation Cost CC 4%	Operation Cost CC 5%
2015 Design $19M	$0.366 /kWh	$0.395 /kWh
Assumption	- Lifetime : 20 years - Discount rate : 5.5% - Transportation is charged for only OTEC plant *Construction equipment is available on site	
Uncertainty	- Maintenance cost for TG and HEX is not clear	

Improvement of Turbine generator

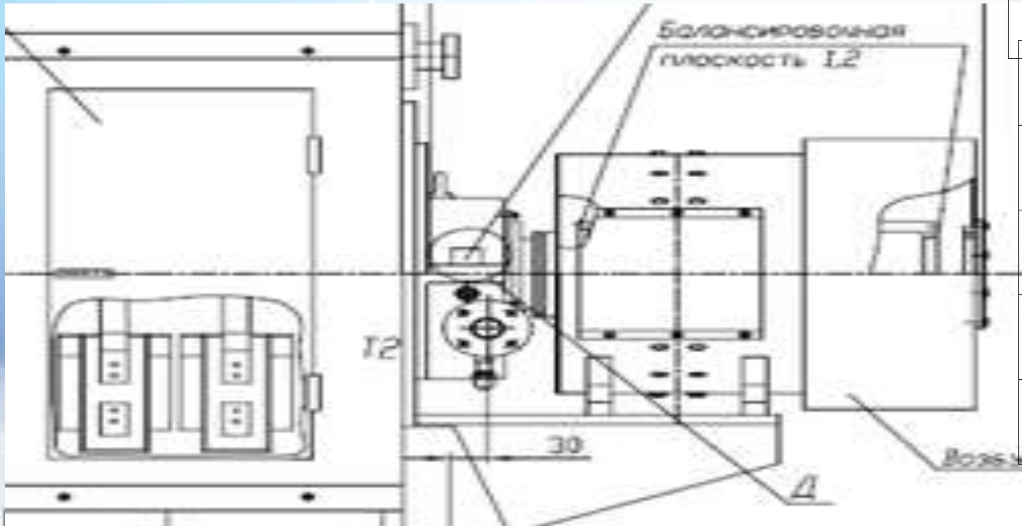
< Original Design, 2015 >





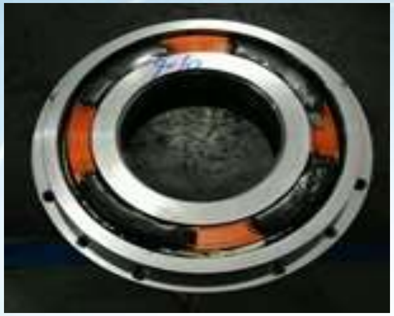


Turbine	Unit	Value
Stator Inlet Radius	mm	465
Stator Outlet Radius	mm	355
Stator Number	ea	20
Rotor Inlet Radius	mm	330
Rotor Outlet Shroud Radius	mm	200
Rotor Outlet Hub Radius	mm	73
Rotor Number	ea	14
Generation Power	kW	1
Efficiency	%	93.1
Phase		3
Frequency	Hz	50
Mechanical Speed	RPM	3,000

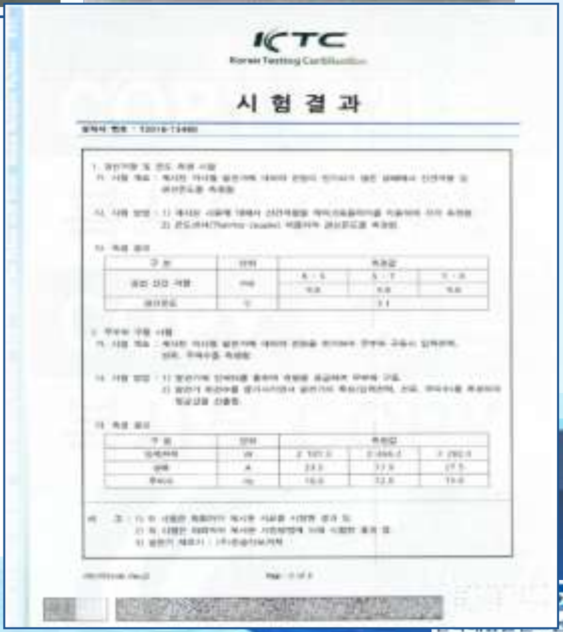


[Radial inflow : Mechanical bearing and sealing]

Improvement of turbine generator for less repair and maintenance

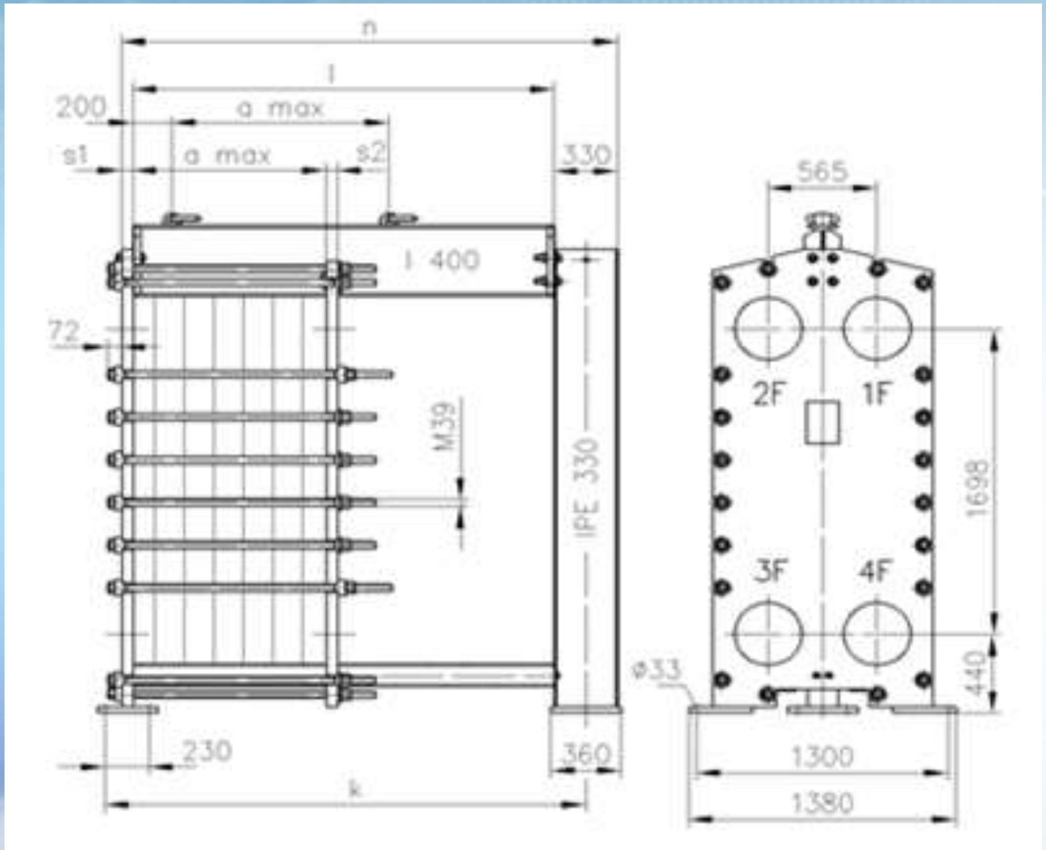
Radial Bearing	Thrust Bearing	Sensor	Sensor Amp
			

- **Performance test of 1.2MW PMS generator**
  - Method : KS C IEX 60034-2-1:2008
  - Output : 275V/600rpm (=> 1,140V/3,000rpm)
  - Total estimated loss : 32.5kW
  - Efficiency of generator : about <u>98%?</u>



Improvement of HEX, Condenser

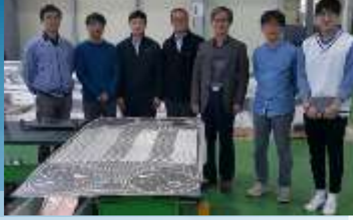
< Original Design, 2015 >



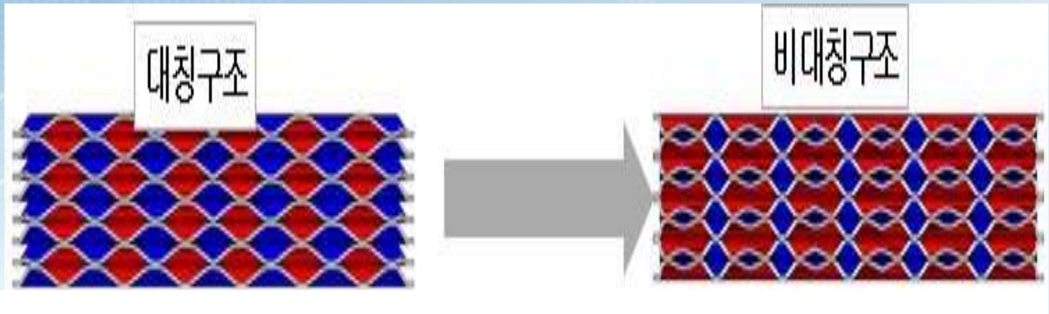
[Semi-welded Symmetric plate HEX]

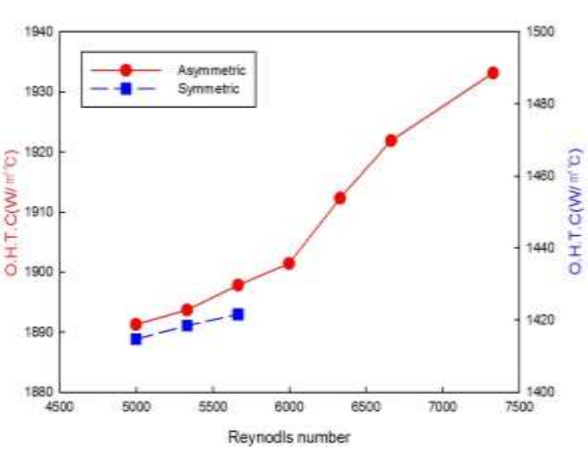
Counts(ea)	6
Port Size	350A
Overall Size(mm) L x W x H	3960x1135x2776
Empty Weight(kg)	7,191

Improvement of HEX, Condenser for higher efficiency & less cost

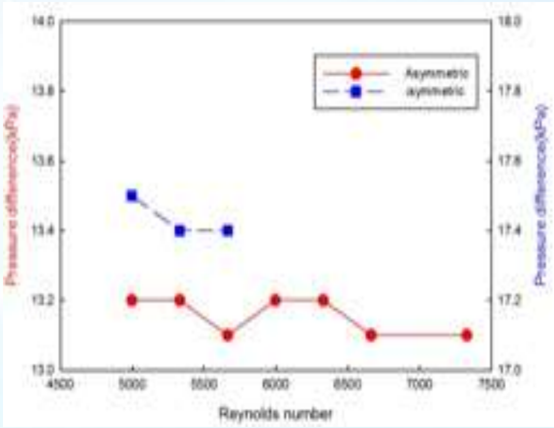


Index	Evaporator	Condenser
Model	B16Hx12/ B26Hx16	B16Hx28/ B26Hx36
Temp.(℃)	29(Source)	5(Sink)
Flow rate (kg/min)	25	23
Ref. rate (kg/min)	0.8 - 1.75	0.75 - 1.1





[Heat transfer coef.]



[Pressure loss of condenser]

- Overall heat transfer coef. of asymmetric plate is 5% higher than symmetric plate
- Volume size of asymmetric plate HEX is 11% smaller than symmetric pale HEX
- Production cost of condenser could be reduced to at least 11~20%

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Possible LCOE of 1MW OTEC demo plant by improving key components of 1MW system

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IEA-OES (2015.5)

KRISO(2017)

Capital Cost	Operation Cost CC 4%	Operation Cost CC 5%
2015 Design $19M	$0.37 /kWh	$0.39 /kWh
Reduction CC of HEX		Less TG maintenance
'17~18 HEX Reduction $18M	$0.35 /kWh	$0.37/ kWh

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Join to online survey for OTEC projects and to publish 'OTEC' book in 2018

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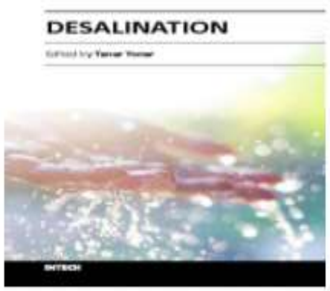

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