ADB MARES Webinar

OTEC Viability as a Catalyst for Transformative Island Development

INSTITUTE OF OCEAN ENERGY SAGA UNIVERSITY JAPAN

Xenesys

with materials from Kumejima Town

OTEC: Ocean Thermal Energy Conversion

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Presentation Outline

- State of the Technology: What is OTEC?
- Overview of OTEC and Related Industries on Kumejima
- The "Kumejima Model" MW-scale Onshore OTEC and Industry
- OTEC Technology Readiness
- OTEC Implementation for MARES

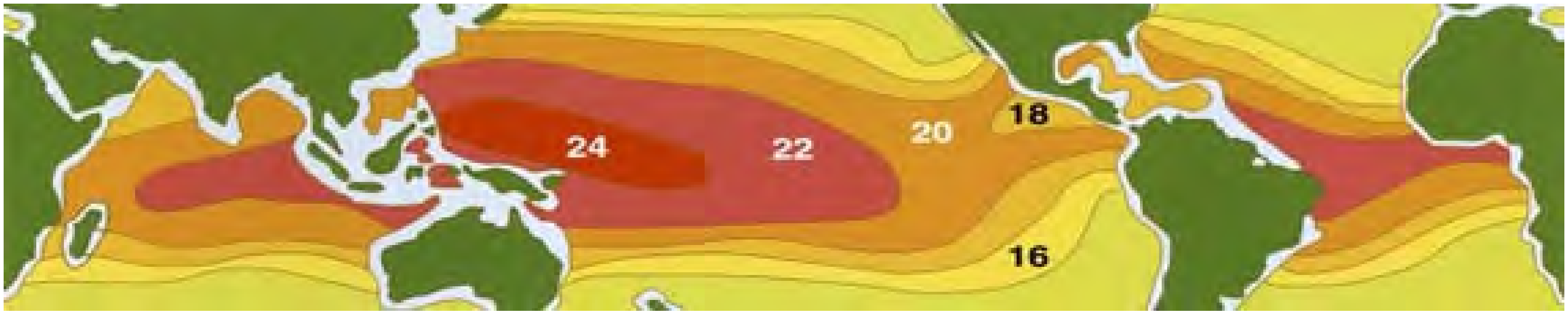


State of the Technology

What is OTEC?

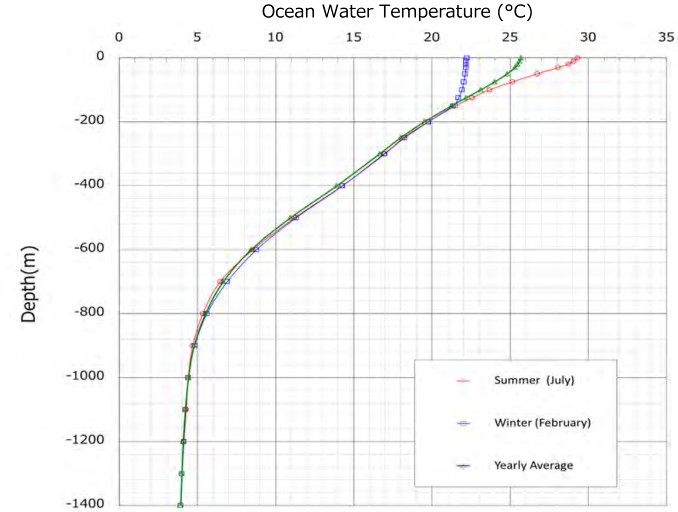
Image: Okinawa Prefecture Industrial Policy Division

Ocean Thermal Energy Conversion



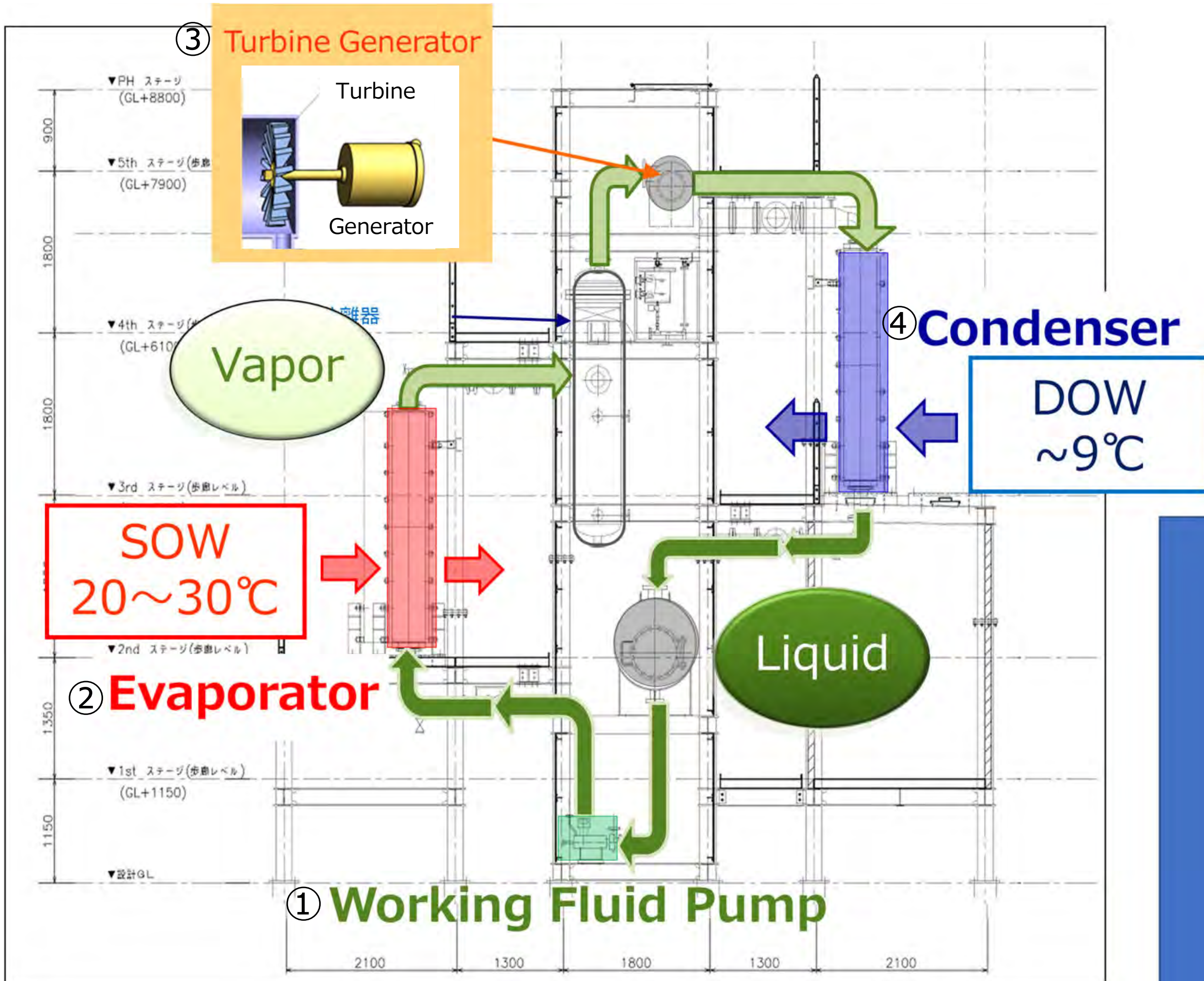
In the tropics and subtropics, there is a naturally occurring temperature difference between the surface ocean water (SOW) and deep ocean water (DOW).

OTEC is a power generation method using this temperature difference.



Temperature Profile for Kumejima, Japan

Renewable Energy from the Ocean: OTEC



OTEC is a simple Rankine Cycle with a low-boiling-point working fluid. Titanium Heat Exchangers extract heat from the ocean to vaporize the fluid which drives a turbine generator.

① The working fluid pump transfers a low-boiling-point liquid to a heat exchanger

② Warm Ocean Water in an evaporator the working fluid which vaporizes

③ Vapor expands in a turbine, which drives a generator, creating electricity.

④ A condenser cools the vapor back into a liquid for reuse. The cooling is achieved from DOW, which is naturally cold.

Okinawa OTEC Demonstration Facility

The Okinawa OTEC Demonstration is a **100kW** facility connected to the local grid and is one of only two fully operational OTEC facilities in the world.

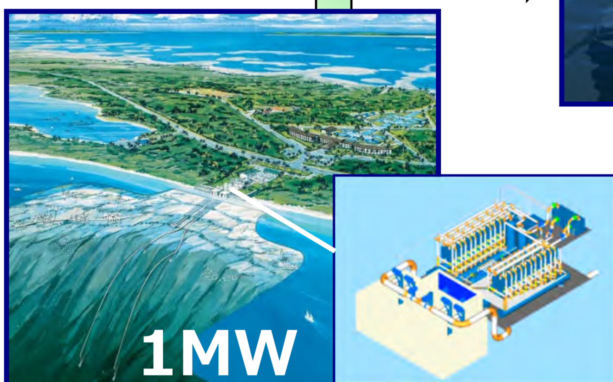
Established in **2013**, the facility can utilize DOW and SOW from the Okinawa Prefecture DOW Research Center to produce renewable energy.

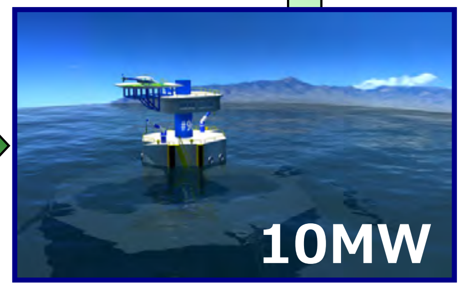
OTEC Roadmap from Japan

Current :
100kW Demonstration Test

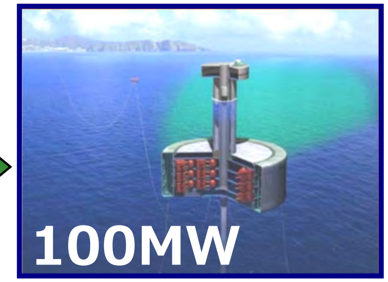
MW-Scale Demonstration
Detailed Planning Study Underway with National Funding

Offshore





Scaling



Expansion for large-scale demand in tropical/subtropical areas

Offshore Development

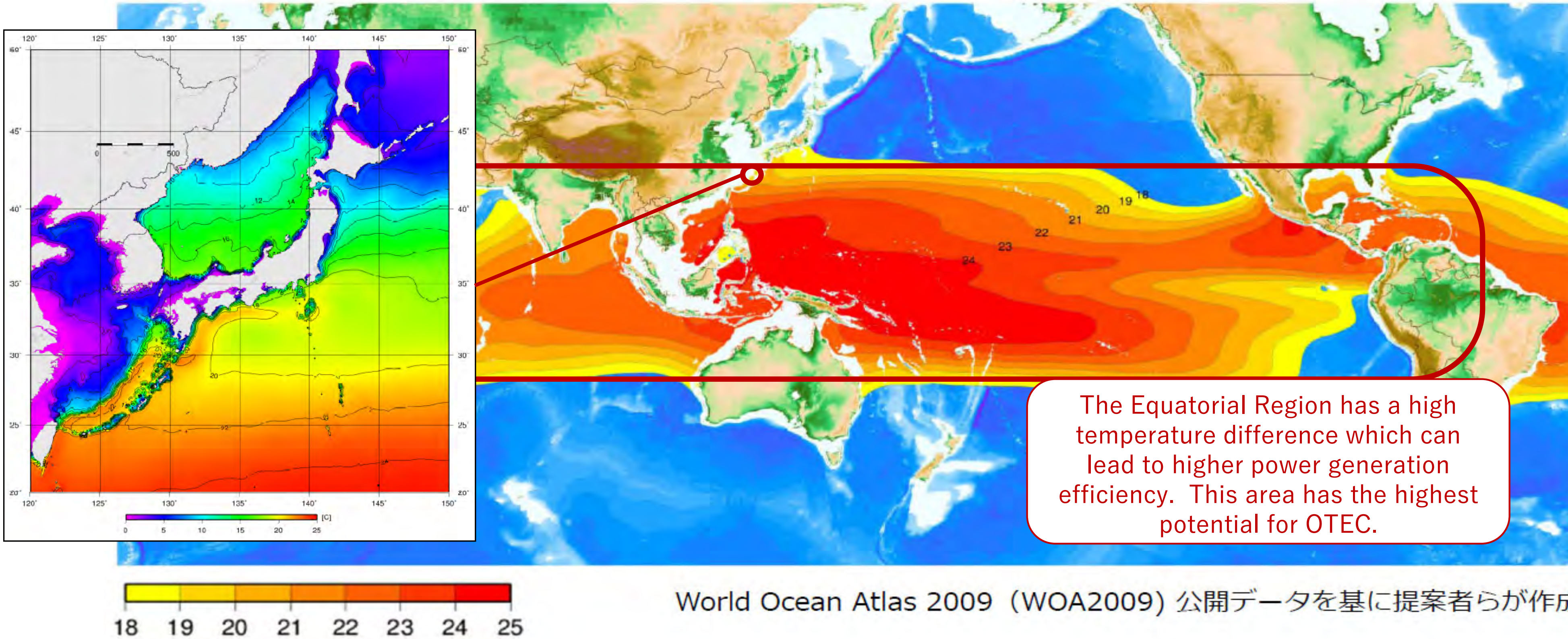
Develop for island and remote coastal areas (competitive power generation cost)

Parallel Development (Onshore)

Onshore

Increase economic efficiency through secondary use of ocean water in various industries such as air conditioning. Adapt the “Kumejima Model” for small islands and coastal areas.

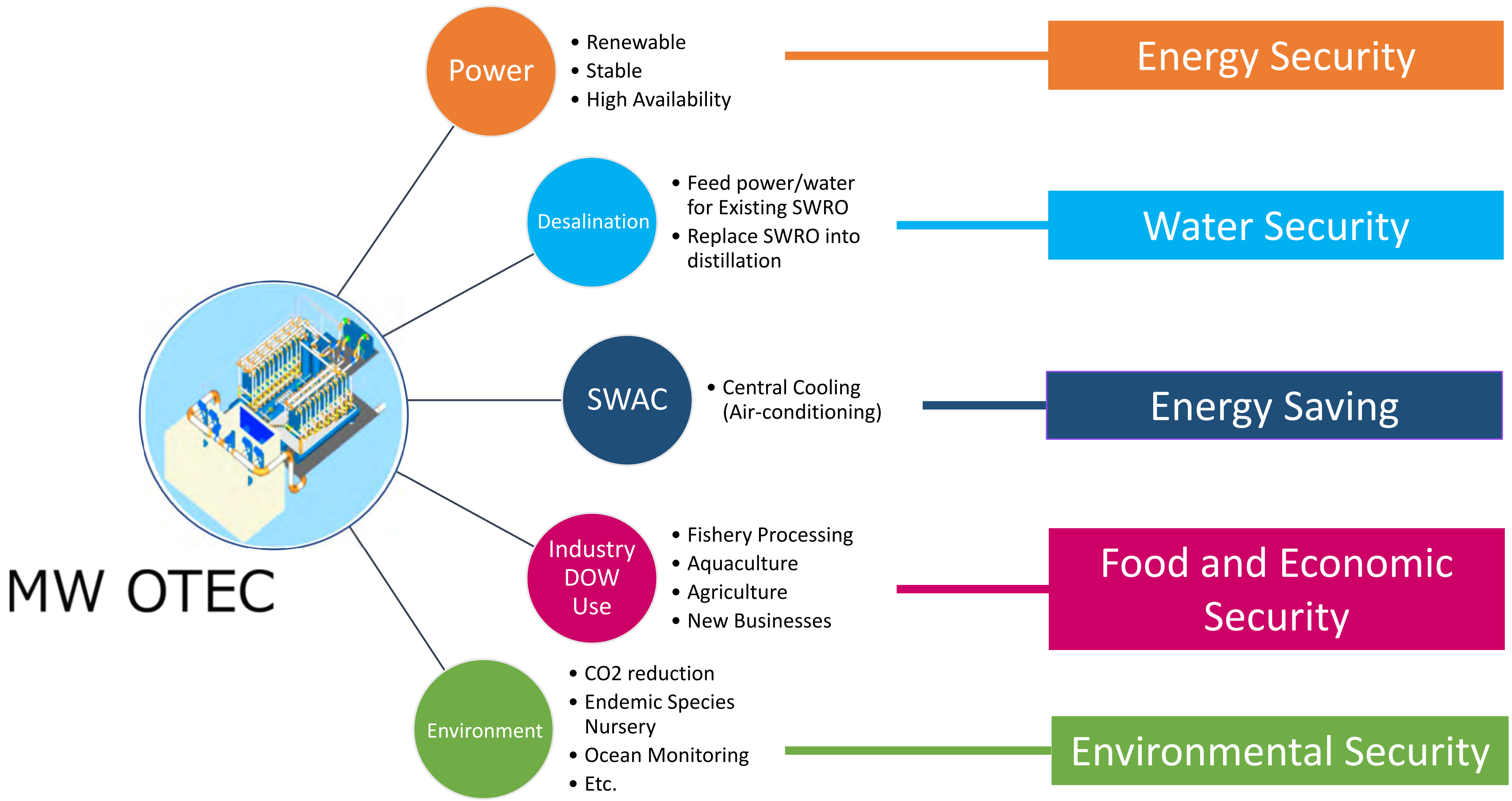
OTEC Potential



World Ocean Atlas 2009（WOA2009）公開データを基に提案者らが作成

While worldwide potential for OTEC is **vast**. In Okinawa, Japan’s southernmost prefecture, the potential is more than 2000MW, exceeding current demand.

Onshore OTEC Combined with DOW Industry: Local Resources for Global Challenges

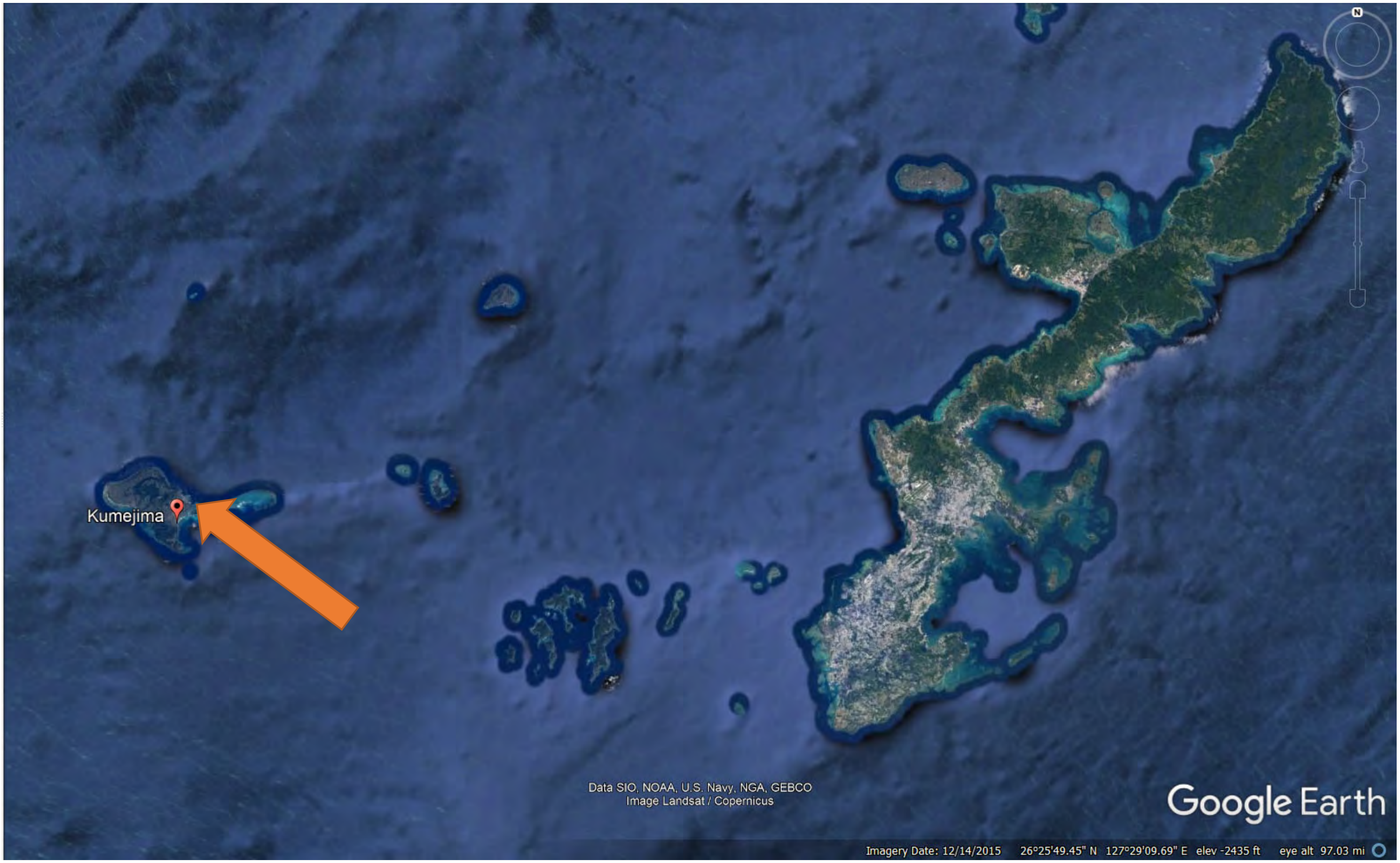


Overview of OTEC and Related Industries on Kumejima

(Current Activities)

Kumejima, Japan

Kumejima, Japan



Kumejima, Japan

〇**Yearly Average Power Demand:** ~5MW

〇Population（as of Jan. 2022）

Total： 7,574

Households： 3,979

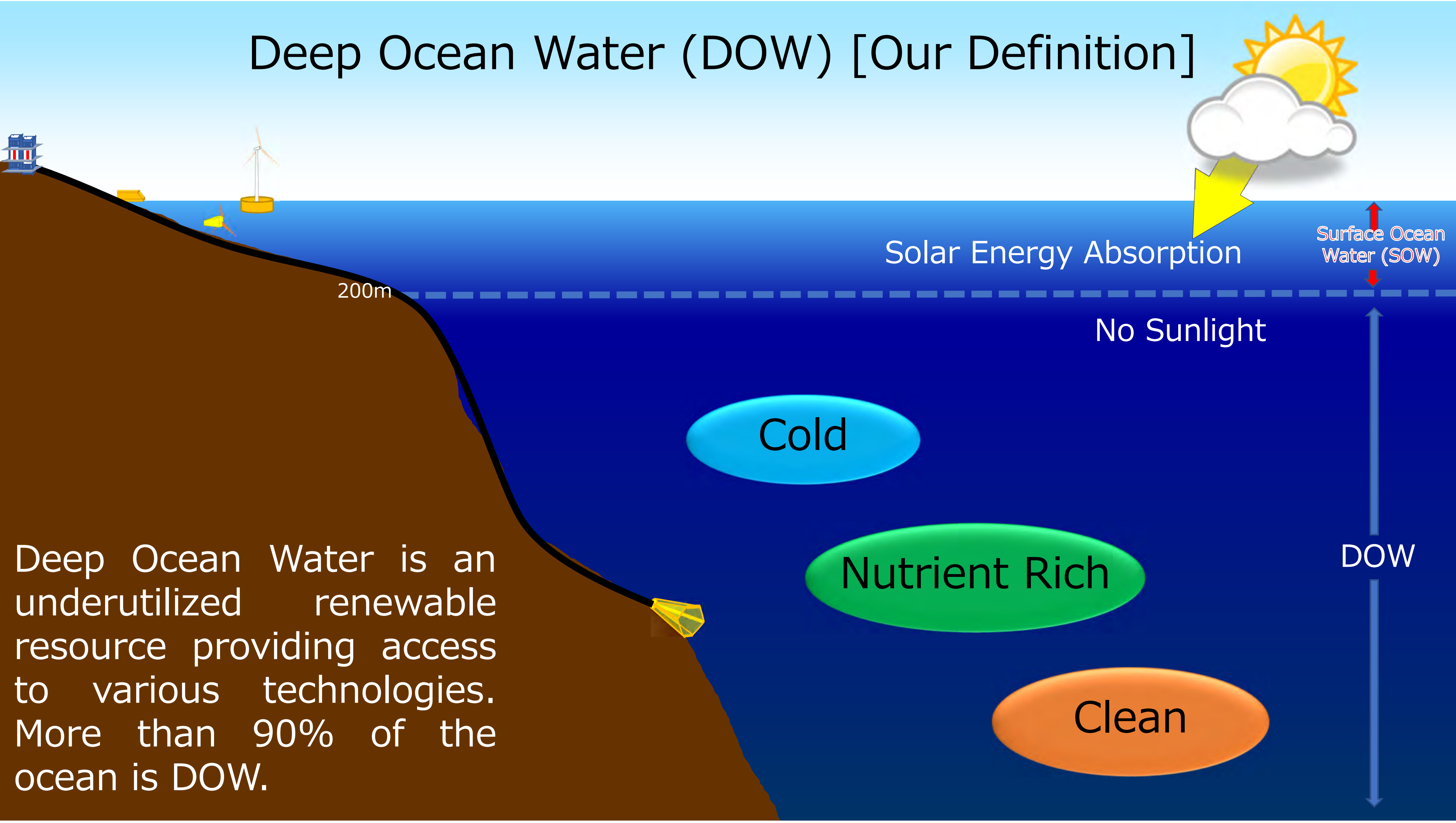
〇Area・Climate

- Area： 63.50㎢
- Circumference： ~48km
- Avg. Annual Temp.: 22.7℃
- Avg. Annual Humidity: 76%
- Avg. Annual Rainfall: 2,138mm

〇Main Industries

Deep Ocean Water Industries

Productive use includes fishery, agriculture, salt, water, cosmetics, etc.

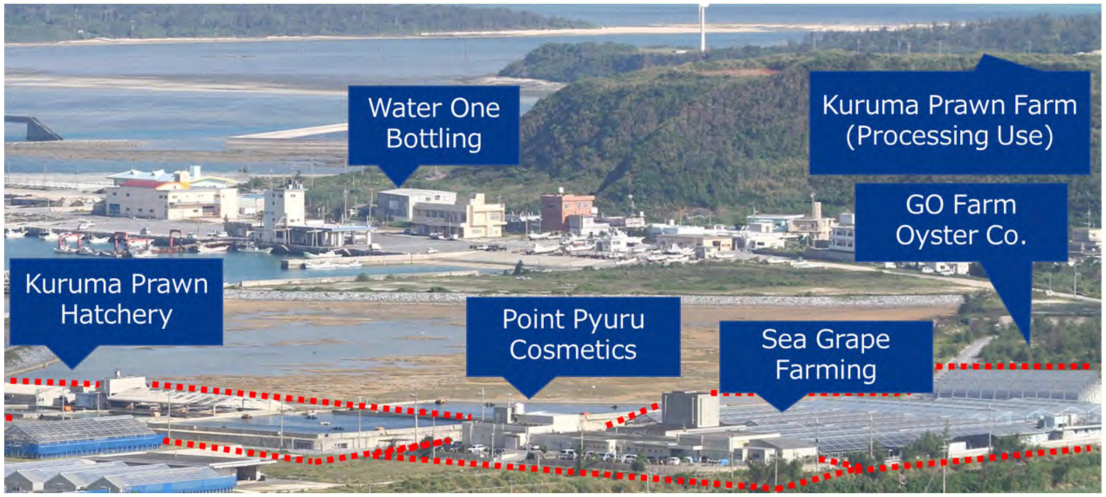

Deep Ocean Water (DOW) [Our Definition]
Solar Energy Absorption
Surface Ocean Water (SOW)
200m
No Sunlight
Cold
Nutrient Rich
Clean
DOW
Deep Ocean Water is an underutilized renewable resource providing access to various technologies. More than 90% of the ocean is DOW.

Deep Ocean Water Use in Japan

	1. Low Temperature	2. Nutrients	3. Fresh Water	4. Minerals/Salts	5. Metals	6. Dissolved Organic Matter	7. Microorganisms	8. Cleanliness	9. Consistency	10. Anti-Aging	11. Renewability
1. Fermented Foods				●				●		●	
2. Food and Drink				●				●		●	
3. Drinking Water			●	●				●			
4. Bittern and Salt				●				●		●	
5. Bathing Goods				●				●		●	
6. Cosmetics				●				●		●	
7. Medical Care				●		●	●			●	
8. Agriculture	●			●							●
9. Sea Plant Culture		●								●	●
10. Aquaculture	●							●		●	●
11. Fish Stocking	●							●		●	
12. Metals					●			●			●
13. Power Generation	●							●	●		●
14. Refrigeration	●							●	●		●
15. Cooling Water	●							●	●		●

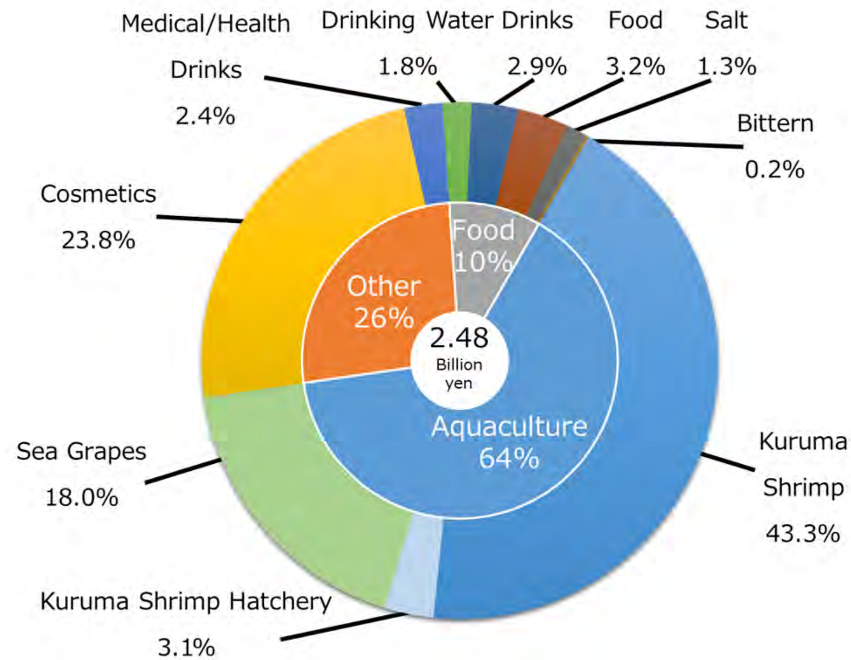
Source: Based on M. Takahashi, 10th Okinawa Hawaii Ocean Energy Workshop November 2019

DOW Industrial Use on Kumejima



Since 2010, Kumejima's access to DOW has allowed organic growth of local businesses. 18 companies and more than 300 jobs are related to DOW-use industries, which have a combined annual revenue of more than 24 million USD per year (recent feedback is that it has increased to $30mil), the largest single industry for the island (most land is subsidized sugar cane, with a revenue of about $10million / year).

Economic Impact on Kume Island



2.48 Billion yen is roughly equivalent to 24 Million US Dollars

Source: Kumejima Town, 2016 Survey

Aquaculture on Kumejima





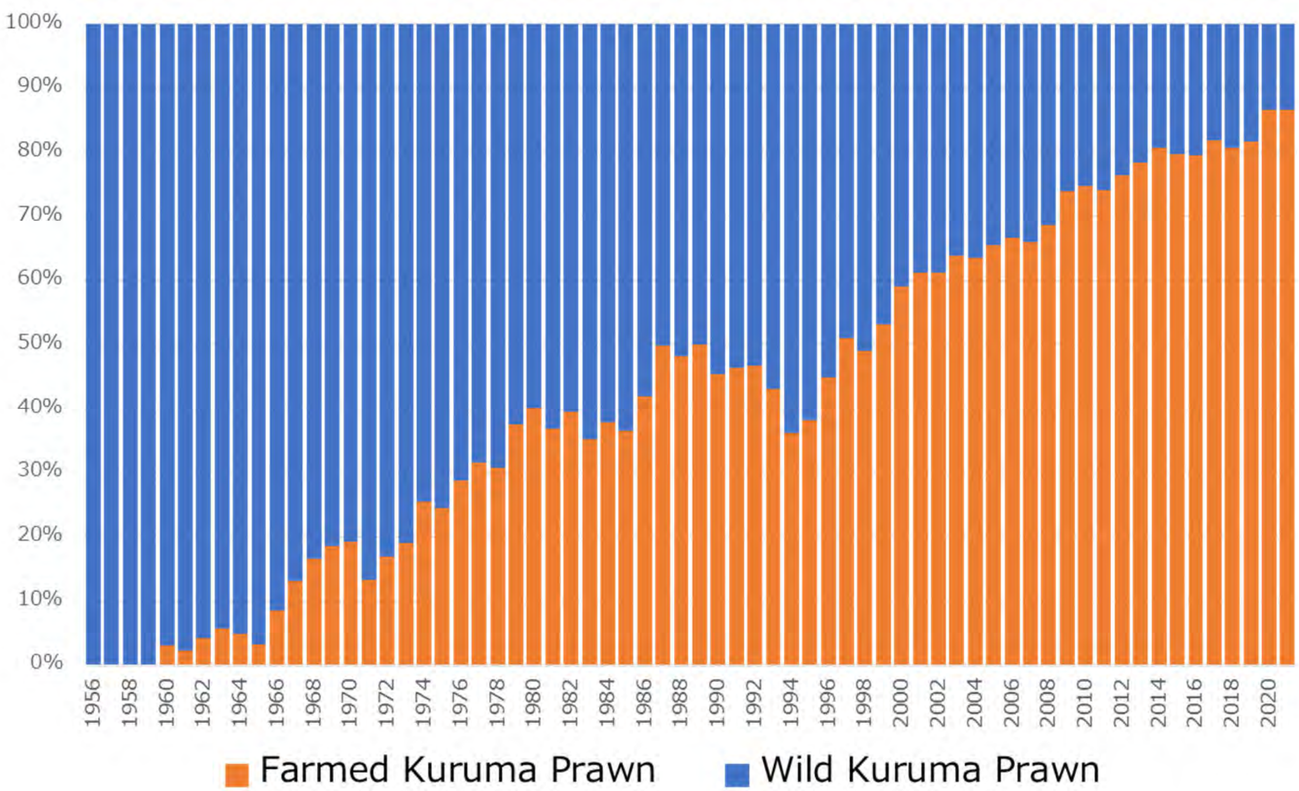

Kumejima has the highest market share in Japan for Kuruma Prawns and Sea Grapes (a type of sea plant).

The cleanliness, nutrients, and temperature controllability provided by DOW can provide farmers with lower operating costs, expanded or stable growing seasons, and reduced risk for their fishery.

In addition to existing commercial industries, research continues on new industrial uses that can utilize expanded intake capacity. Examples include oyster production, coral hatchery, trout-salmon, and a variety of sea plants.

For other locations, matching local demand to DOW enabling techniques can help transition fishery to sustainable growth.

DOW Aquaculture Trends



Proportion of Wild to Farmed Kuruma Prawn in Japan (1956-2021)

In Okinawa, aquaculture industries are the primary industry users of DOW. The consistent trend in Japan towards farmed prawns (vs. wild caught) reflects a global trend among many fisheries as they seek stability of supply, profitability (reduced die-off from virus free hatchery), and reduced risks associated with global warming. Sustainable aquaculture enabled by DOW can help secure local food supply, create jobs, and protect natural resources.

Source: Japan Ministry of Agriculture, Forestry, and Fisheries Fishery Statistics

Cosmetics from DOW

Utilizing DOW as a basic resource, the local company Point Pyuru produces a variety of cosmetics under its own brand and for OEM customers. The moisturizers, lotions, amenities, etc. are produced by combining extracts of local plants and other ingredients with DOW water as a base and DOW derived minerals.

The company continues to expand with new shops in Okinawa and expanding export market.

Coral Research and Nursery

Onshore coral research and nursery projects can help environmental activities, however temperature control in the tropics and subtropics can be a difficult challenge.

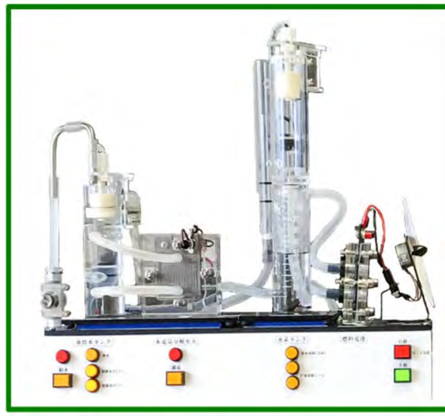
On Kumejima, the Fisheries Civil Engineering Construction Technology Center Institute uses surface water cooled in a heat exchanger with DOW when temperatures rise too high, significantly lowering operating costs while maintaining water quality.

Corals grown onshore are returned to the ocean to support reef health.

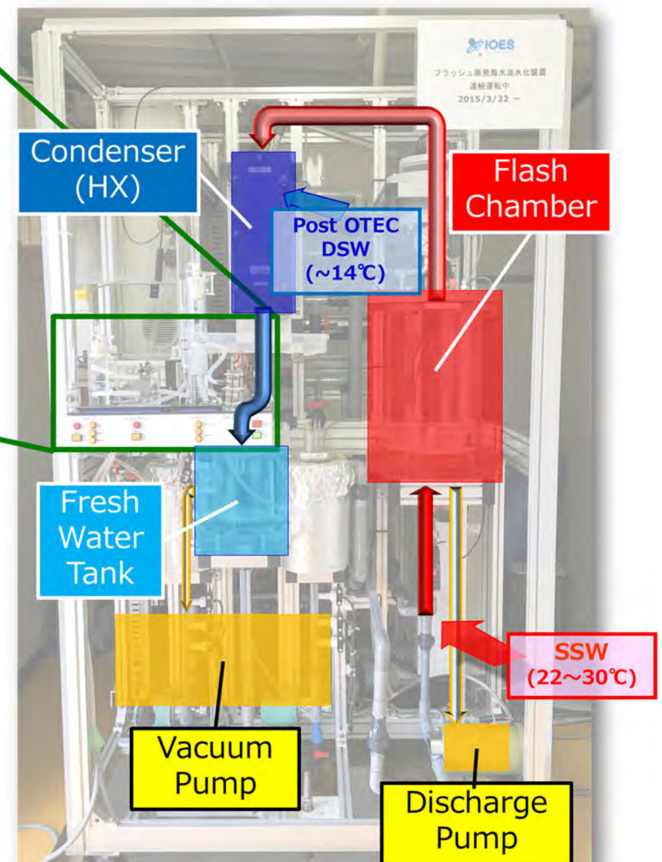
Flash Desalination and Hydrogen Production (Saga U.)

Small-scale practical demonstration connected
to Okinawa OTEC Facility on Kumejima
OTEC Electricity + Distilled Water = H_2

Satellite Research Opening Ceremony
(10/19/2014)



PEM Hydrogen Production
and Fuel Cell



Flash Desalination System Features

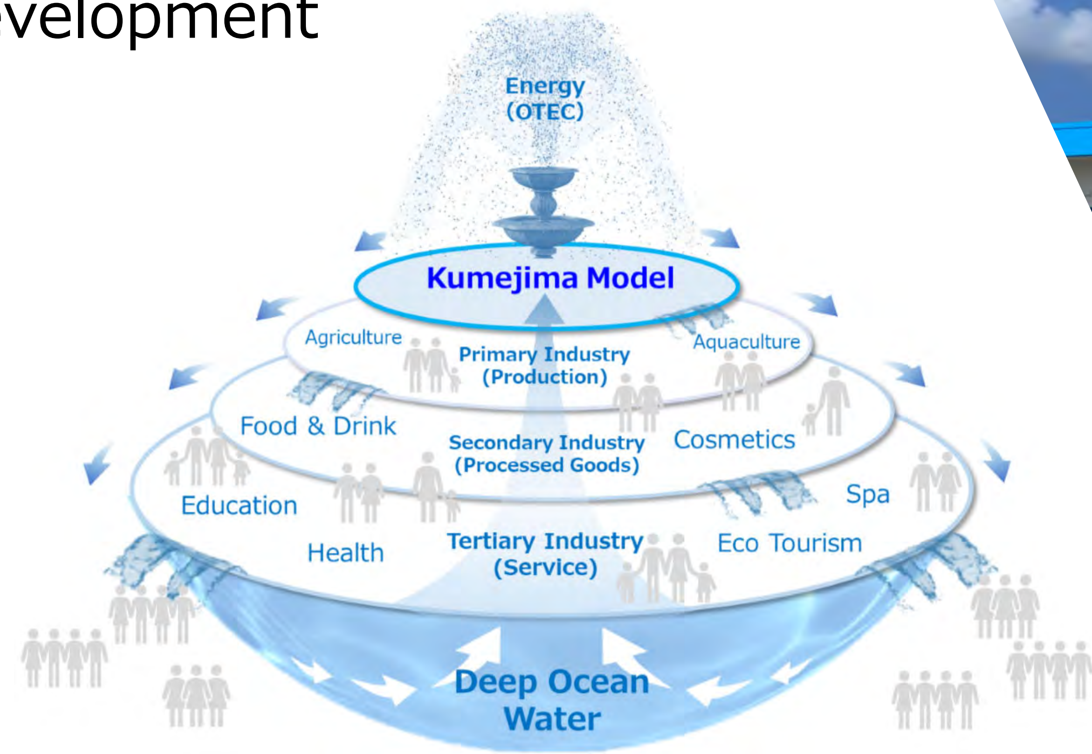
- Conventional Evaporation methods require energy to increase seawater temperature. OTED doesn't require seawater heating
- Use of high efficiency heat exchanger
  ⇒Desalinated water from small temperature difference

Continuing Development

Development of new techniques and products continue. Rohto Pharmaceutical has established a bioreactor within Kumejima Town's agriculture demonstration area to test production of algae such as spirulina which can be valuable as a superfood or through use of various extracts.

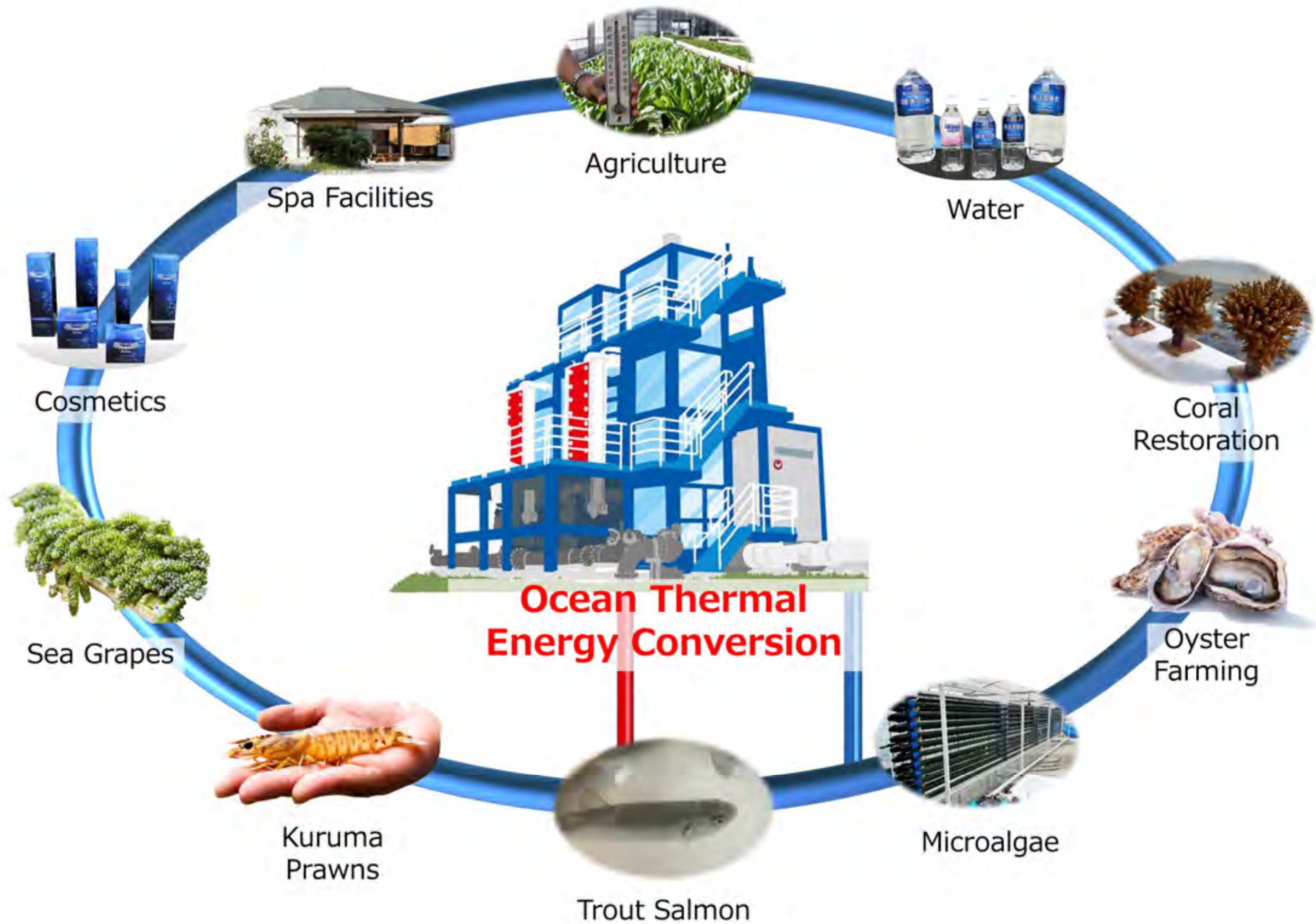
DOW may significantly improve cost efficiency through temperature control or nutrient support.

DOW as a Driver of Industrial Development



Rohto Pharmaceutical has begun use of DOW as a resource driving Primary to Tertiary industry development. Initial deployment includes phytoplankton farming as primary industry, beer and other food product made from DOW and phytoplankton extracts as secondary, and a café selling the products as tertiary.

DOW Industry and OTEC



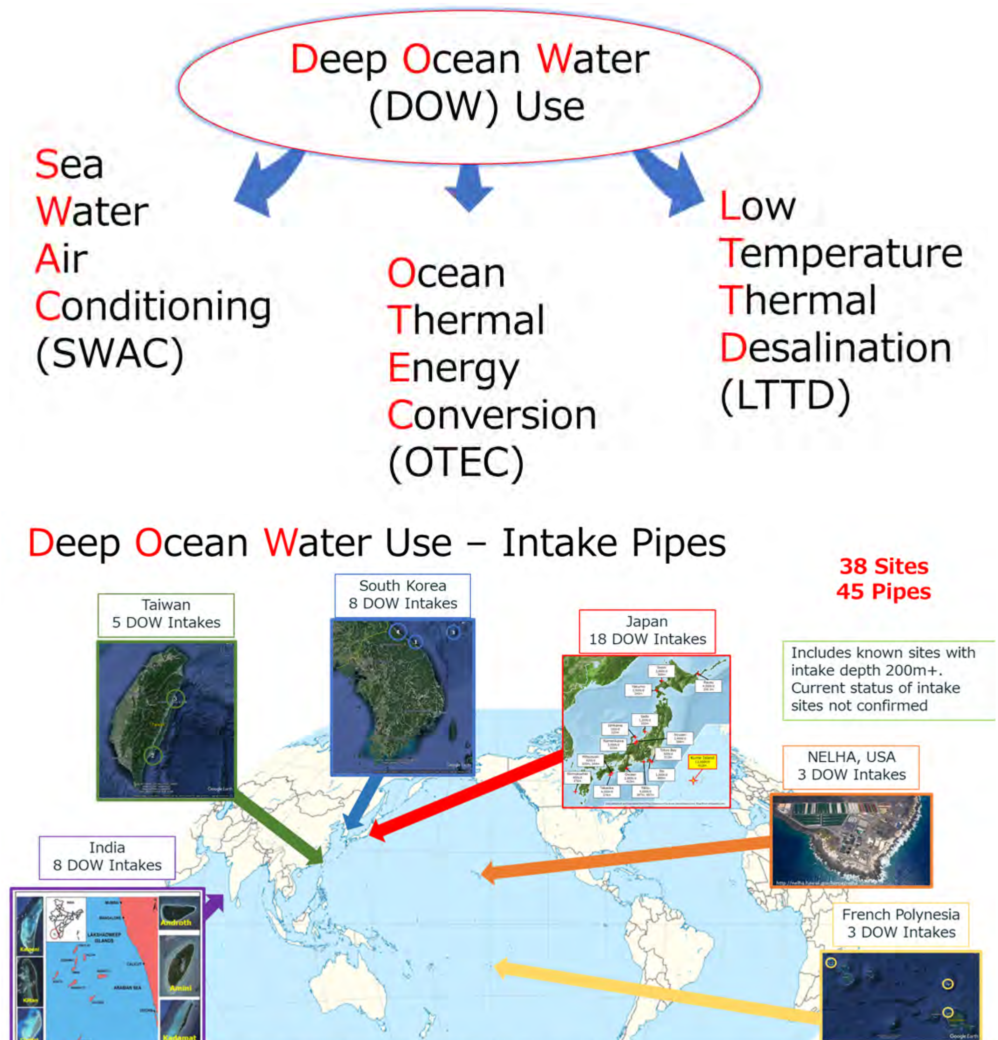
DOW provides a resource for Kumejima's largest industry sector.

Combined with OTEC, DOW provides additional benefits so each user has the resource they need to succeed.

Deep Water Industry Around the world

Deep Ocean Water use in industries began in the early 1980's in Hawaii, and over time has grown significantly, with more than 38 sites around the world.

Uses vary from SWAC, LTTD, agriculture, and research.

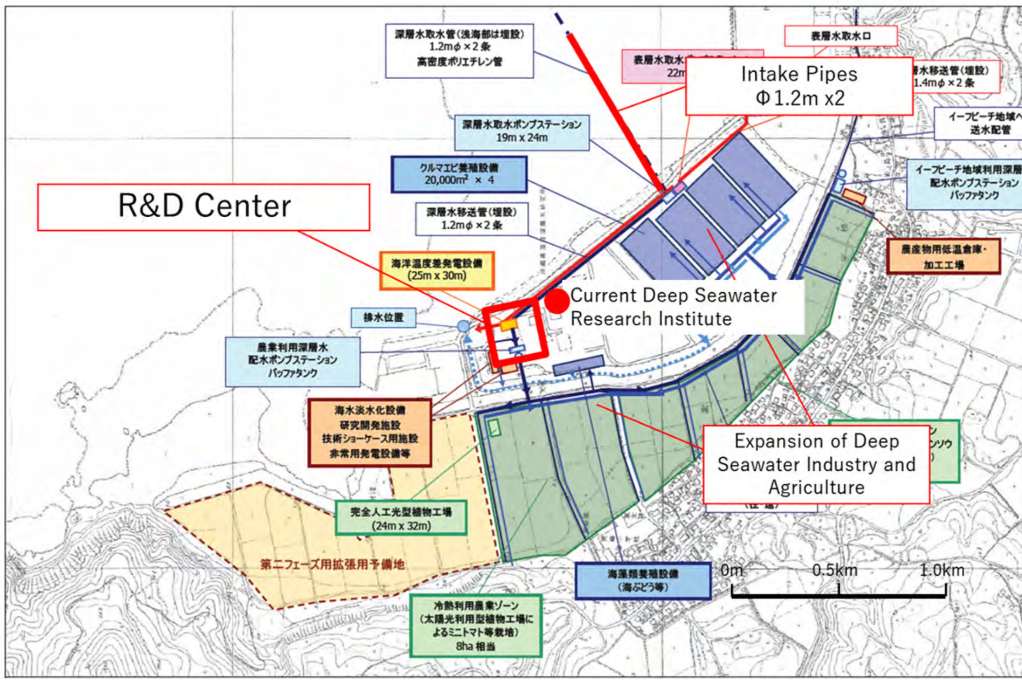


Basemap Source: https://commons.wikimedia.org/wiki/File:World_location_map_(W3_Western_Pacific).svg, South Korea Intake Information: dowas.net/paper/pdf/19-3/163.pdf

The "Kumejima Model" MW-scale Onshore OTEC and Industry

(Near-term Expansion Plan – Benefits and Cost)

A Plan to Expand: Industrial Demand for more DOW



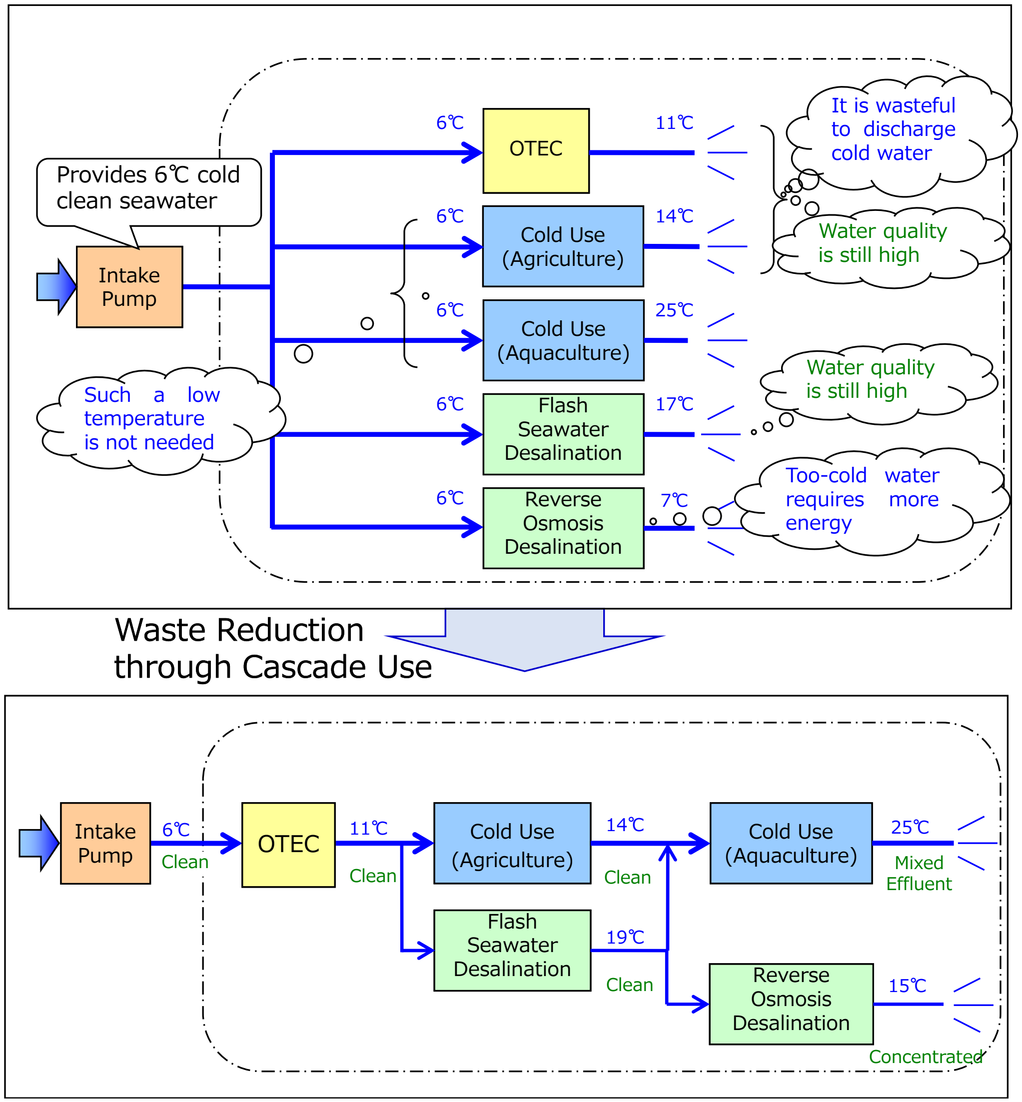
Since 2010, Kumejima Town has studied expanding DOW intake to meet local demand and future needs.

Expanded water intake increases resources, accelerates renewable energy introduction, and can help establish a system adaptable around the world.

OTEC and DOW Industries are the seeds of the “Kumejima Model”

Source: Kumejima Town, FY2010 Advanced DOW Use Feasibility Study

Sophistication through Cascade Use

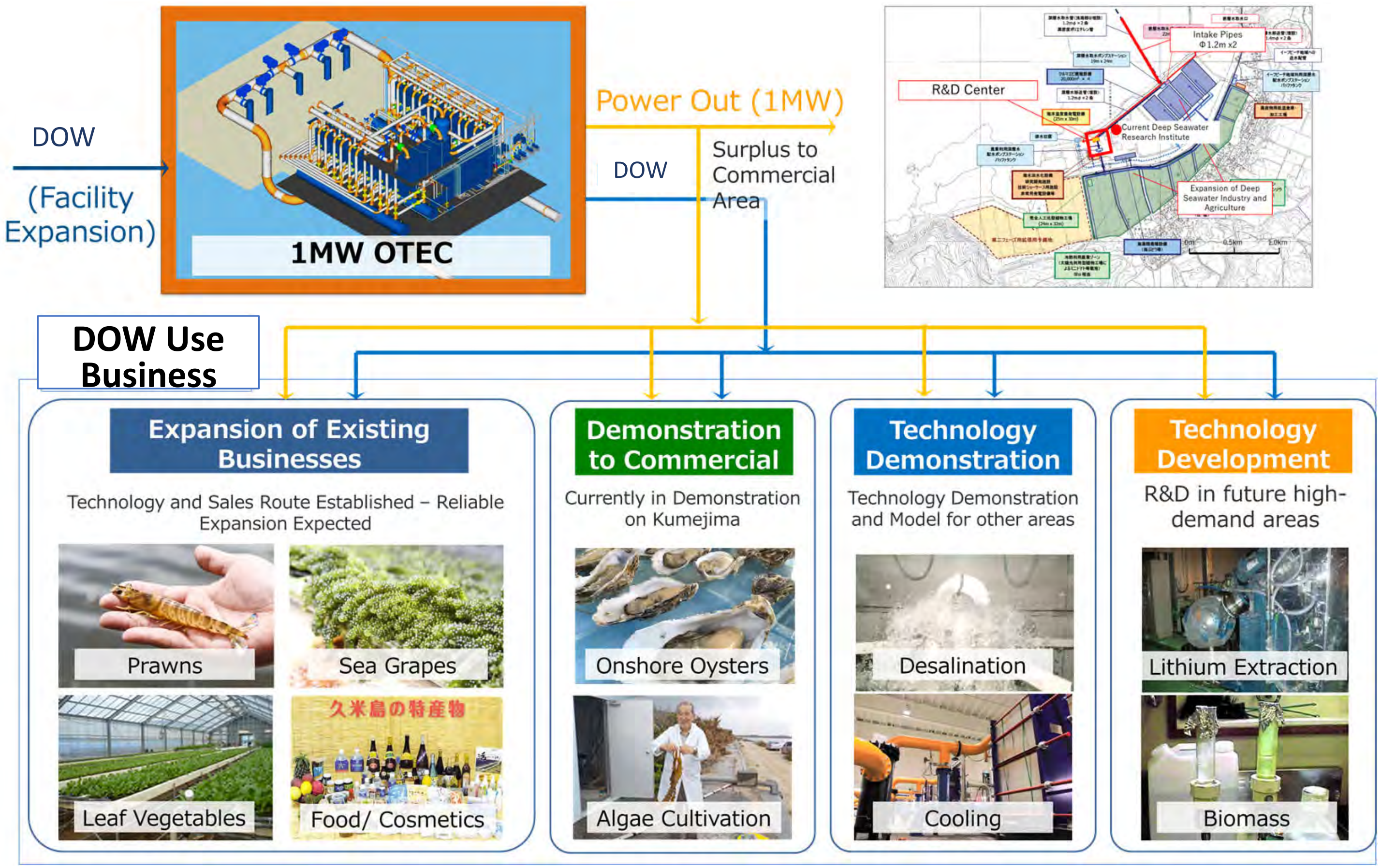


-Since the level and characteristics required by each technology is different, deep seawater can be more effectively utilized in "Cascade" allowing use of water in multiple stages and accounting for changes in the water's properties after each use. In the thermodynamic aspect, it is possible to reduce energy loss.

-The combination of use by different load facilities allows improved demand leveling through utilization of peak shifting. In addition, the ability to shift heat allows for flexibility in balancing the power supply, an important system feature.

Source: Adapted from Kumejima Town Feasibility Study. The full report can be downloaded in Japanese from the Kumejima Town Website

Implementing Onshore OTEC for Island Communities



Model Area Concept for Energy, Water, and Food Self-sufficiency

OTEC provides clean power production and reduced operation costs for DOW industry and technology development

Declaration by Kumejima Town: Towards 100% Clean Energy

久米島から世界へ

○…県庁を訪れ、島の振興施策を要望した大田治雄久米島町長。海洋深層水を用いた海洋温度差発電に触れ「将来的にはクリーンエネルギー100%の島を目指す」と夢を語った。「化石燃料を使わずに、太陽光や風力、海洋温度差発電で島の電力をまかないたい」と宣言する。島の海洋深層水取水設備を増強することで「電力を作り、さらにその水で養殖もする」と構想。「久米島で成功することで、世界にも発信できる事業になる」と、離島から世界を見据える。

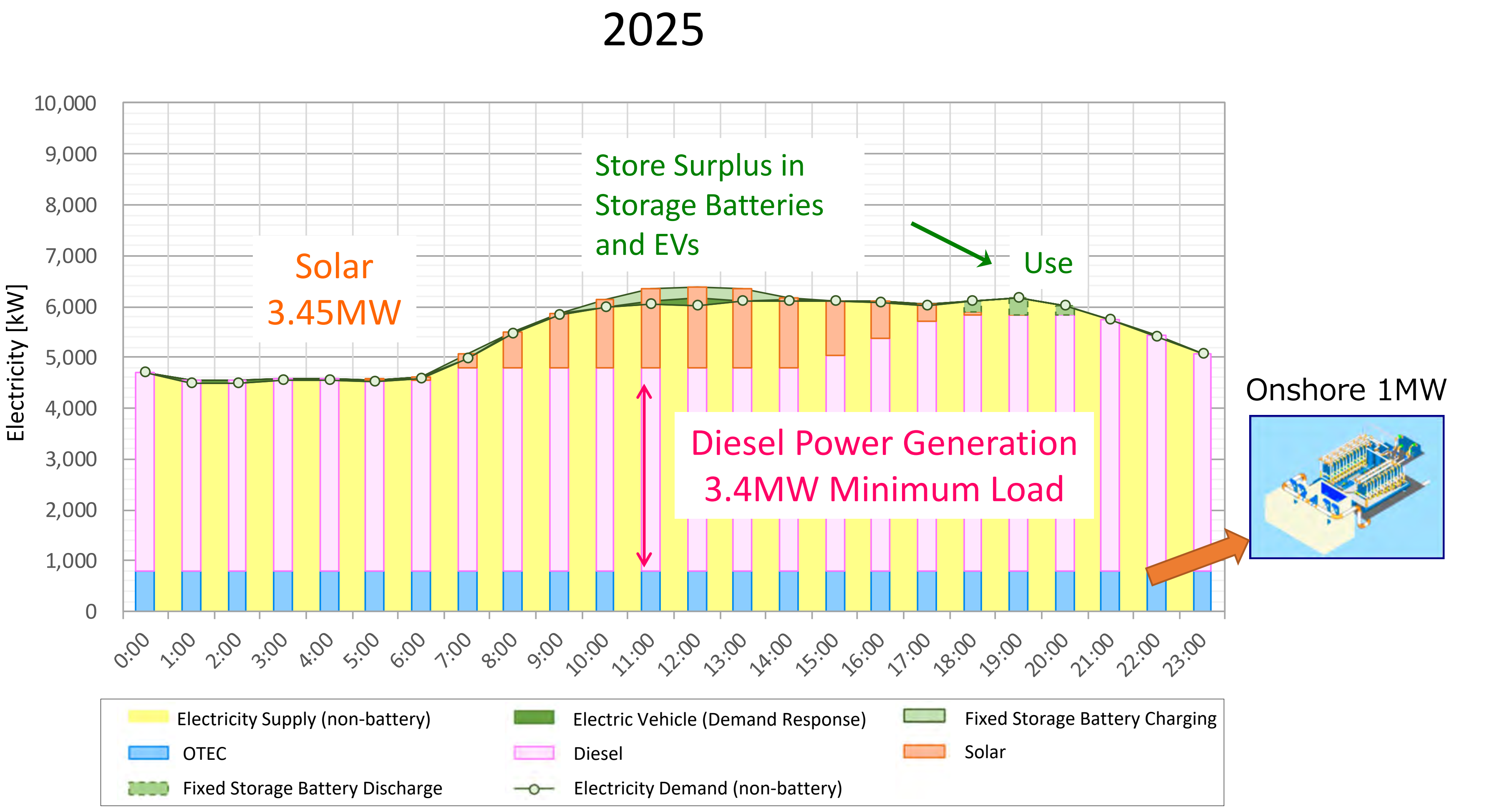
記者席

In 2018, Mayor Ota announced Kumejima's intention to work towards 100% clean energy

In FY2020, the Town released its new Energy Vision, with an eye to reaching 100% Renewable Energy

Source: Ryukyu Shimpo 2018/2/20

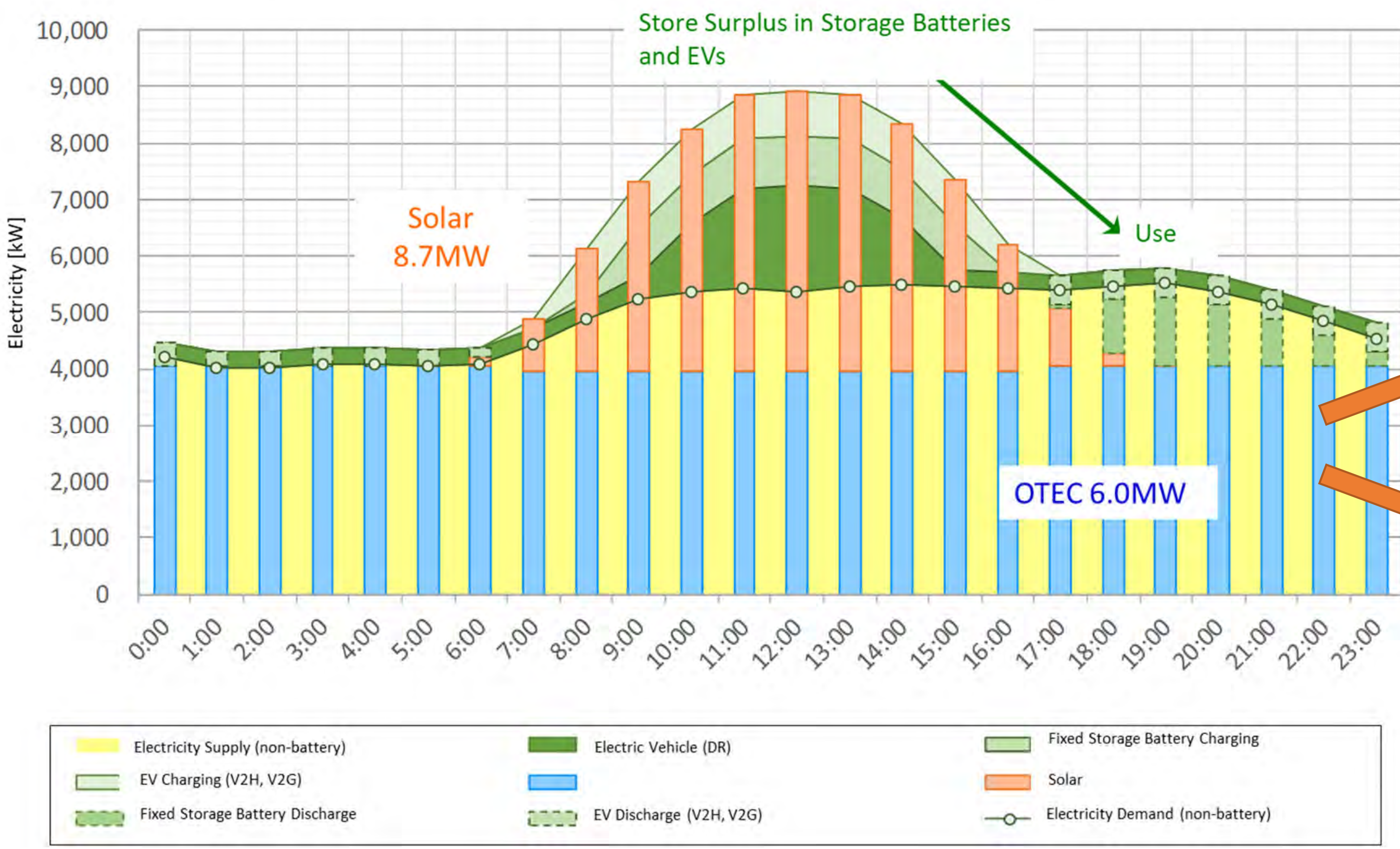
Going Carbon Neutral: Kumejima Town Energy Vision



Source: Kumejima Town Energy Vision, 2020

Going Carbon Neutral: Kumejima Town Energy Vision

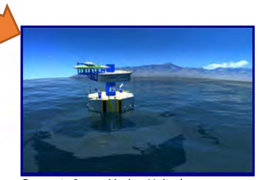
2035



Onshore 1MW

+

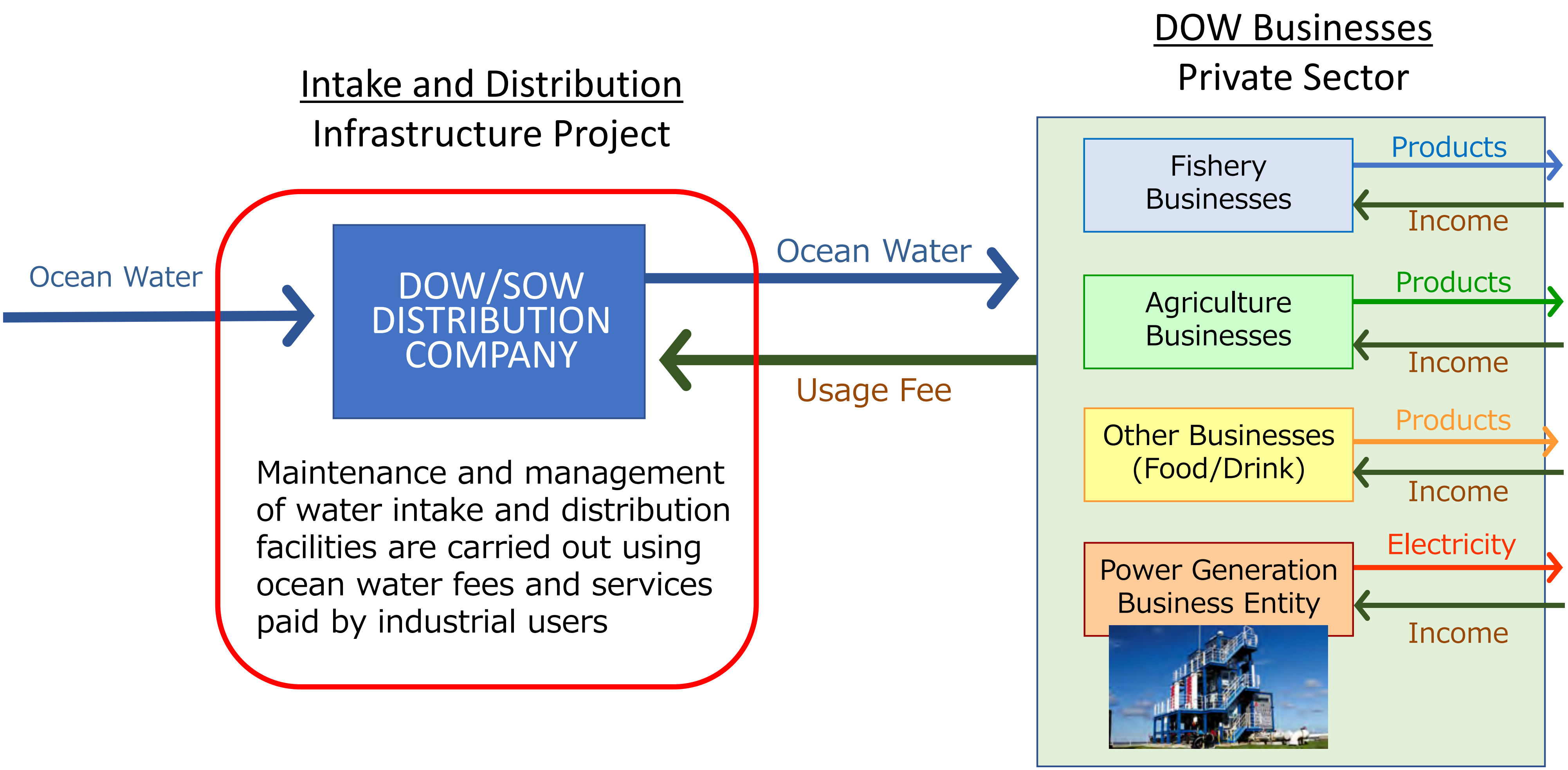
Offshore 5MW



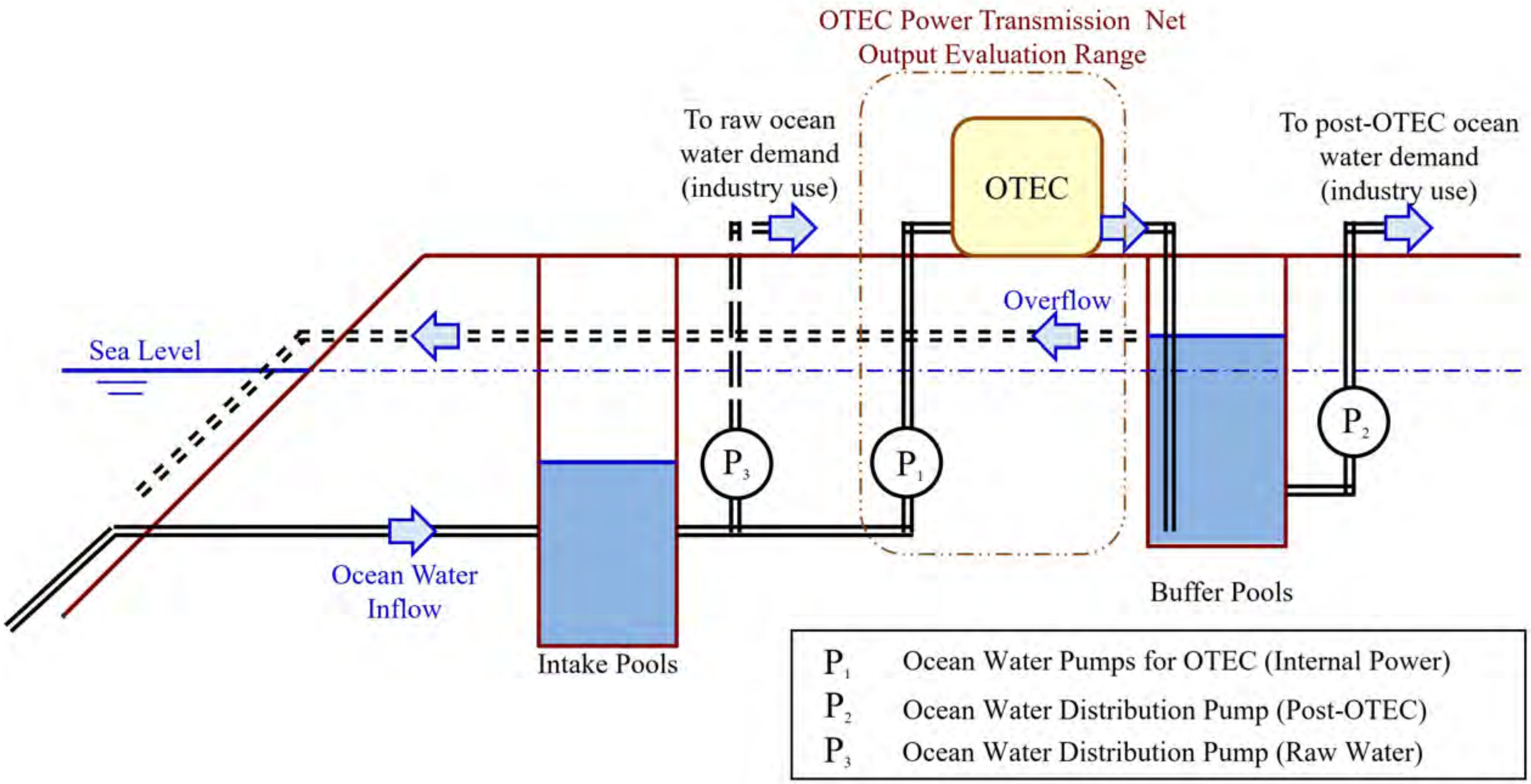
Concept: Japan Marine United

Source: Kumejima Town Energy Vision 2020

Implementing Onshore Ocean Water Intake



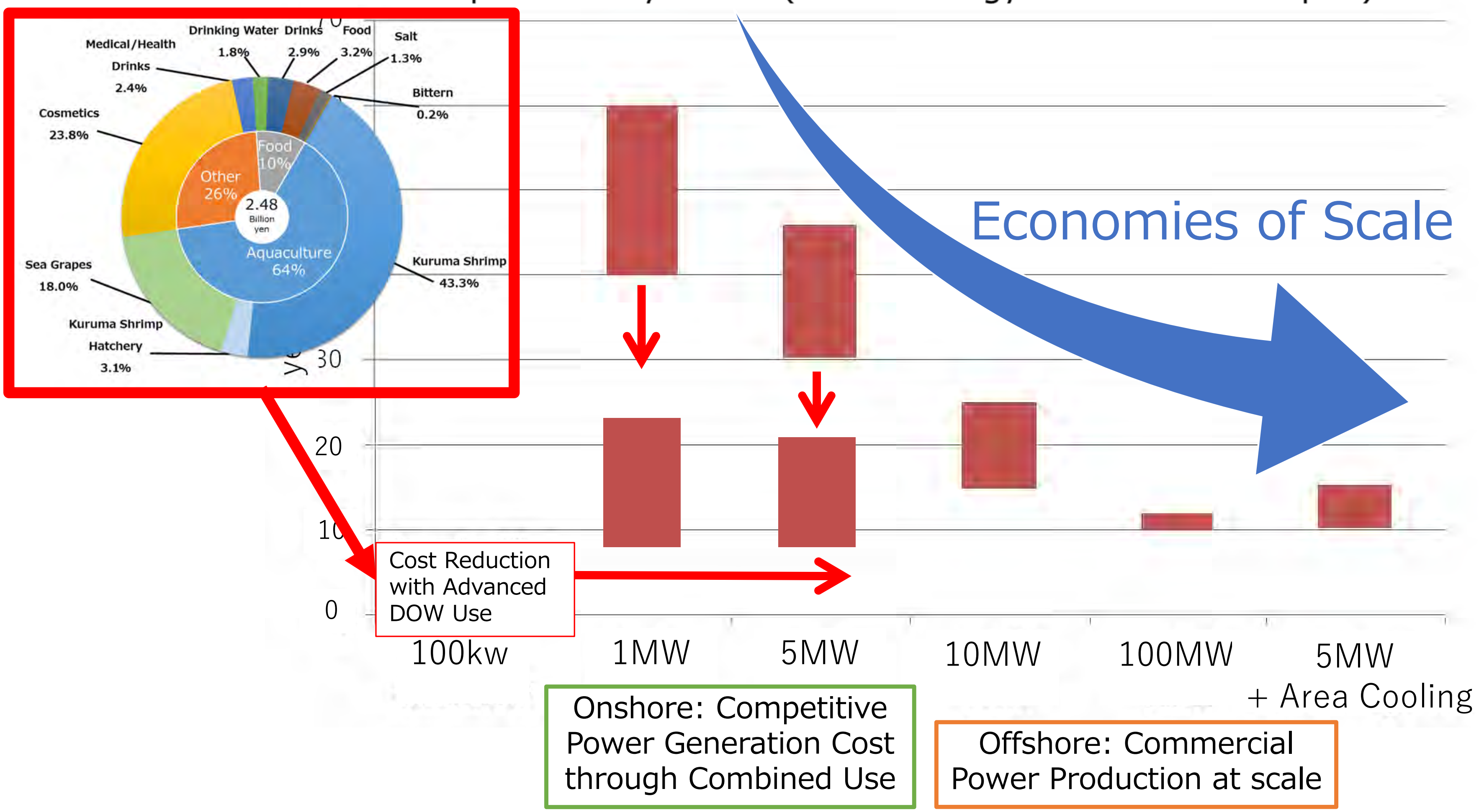
OTEC's Benefit to Industry



OTEC supplies varieties of water temperatures and clean energy for pumping and grid supply.

Costing OTEC: Strategy for Early Commercialization

(New Energy and Industrial Technology Development Organization)
Data provided by OEA-J (Ocean Energy Association of Japan)



1MW OTEC Power Generation Cost Estimates for Kumejima, Japan

1USD = 125JPY

	NEDO Estimate (updated after demonstration)	**Ocean Water Intake as Infrastructure**
Calculated Results		
Capital Cost	OTEC $24mil. + Intake Pipe $20mil. (50% of total cost)	OTEC $24mil.
O&M Costs	$156,000/year (Based on Okinawa OTEC Demonstration Results)	
Power Generation Cost (per kWh)		
Capital Cost Recovery	$.204/kWh	$.111/kWh
O&M	$.0336/kWh	
Power Generation Cost	$.238/kWh	**$.145**/kWh*

*Final costs are dependent on a variety of factors such as availability of subsidy and final ocean water intake distribution and management methodology.

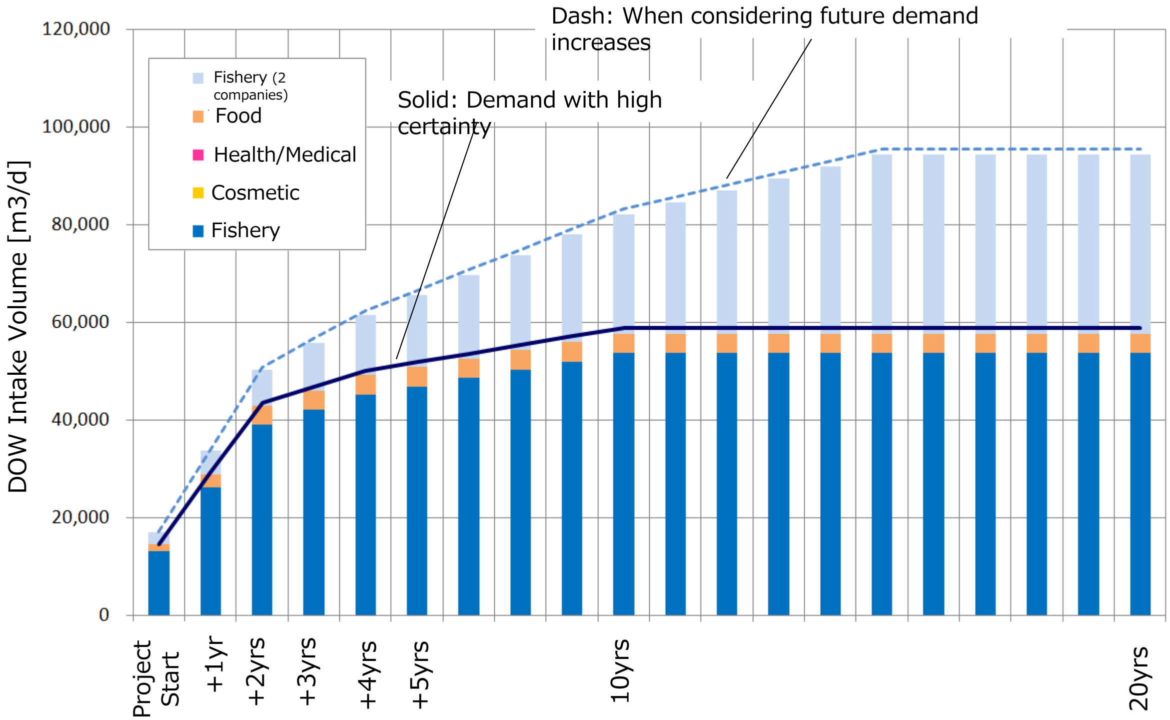
Reference Prices: FIT in Japan for Geothermal is $.32/kWh and offshore floating wind is $.228/kWh
Okinawa Electric Company's Commercial Rate is ~$.2/kWh

NEDO: New Energy and Industrial Technology Development Organization of Japan

**Costs do not reflect recent commodity price changes

Evaluating Demand and Economics of Expanded DOW Intake

In 2017, an economic survey was carried out to consider the costs and benefits from expanding ocean water intake on Kumejima, specifically focusing on the potential for large-scale water use in industries such as fishery.



DOW Demand Prospects (Annual Average)

OTEC's costs and benefits were excluded from the evaluation, as intake/distribution and OTEC will be developed in parallel under separate projects. The results of the study were positive with a benefit to cost ratio of **2.155**. Inclusion of OTEC is expected to increase the ratio through additional revenue from energy sales, etc.

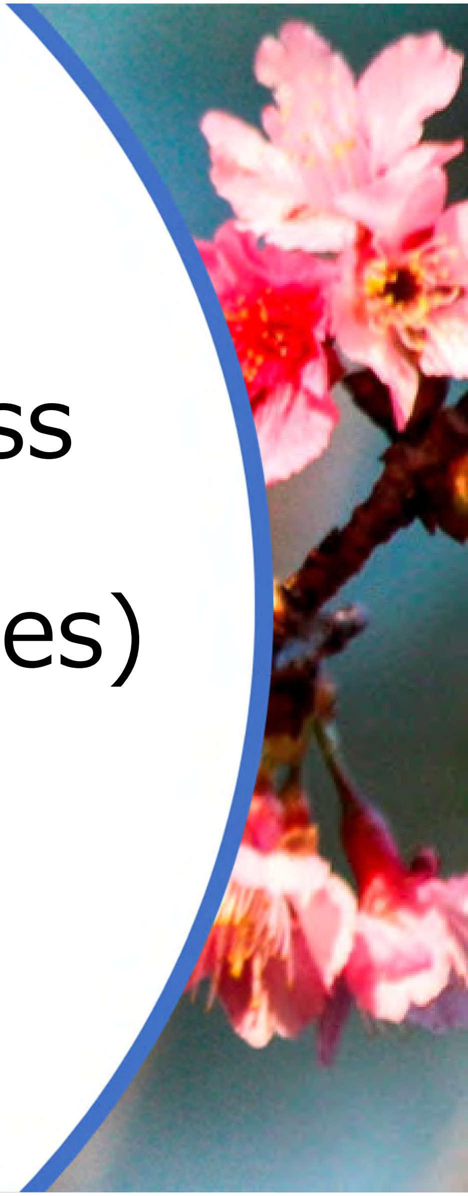
A detailed planning study is expected to be completed March 2023.

Source: Adapted excerpt from "Results of Survey on the Possibility of Regional Revitalization Using Deep Ocean Water" Okinawa General Bureau, 9th Okinawa Hawaii Ocean Energy and Economic Development Symposium and Workshop Materials, 2018 – Full Report in Japanese Available: http://www.ogb.go.jp/-/media/Files/OGB/Keisan/move/OSHIRASE/oshirase/201710/171010houkokusho.pdf

OTEC Technology Readiness

(Challenges and Opportunities)

- Ocean Water Intake
- Power Generation System
- Net Power, Grid Support
- Environment
- Social and Economics

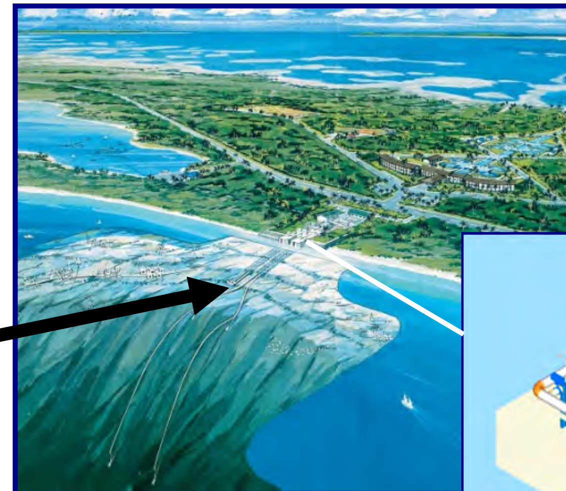


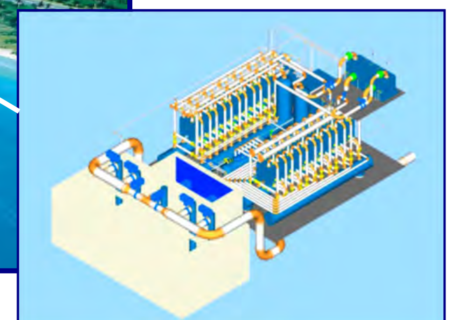
Is OTEC Viable?
Deep Ocean Water Intake

Onshore OTEC **requires** large intake pipes

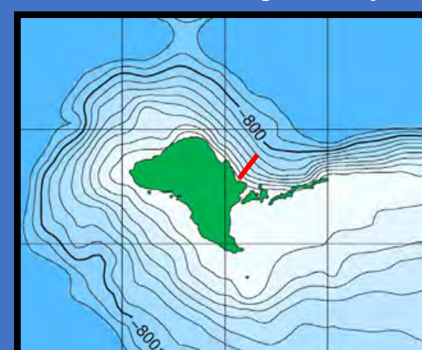
The largest DOW Intake in the world is NELHA's 1.4m intake in Hawaii

Larger HDPE pipes are used around the world in various industries, just not as deep





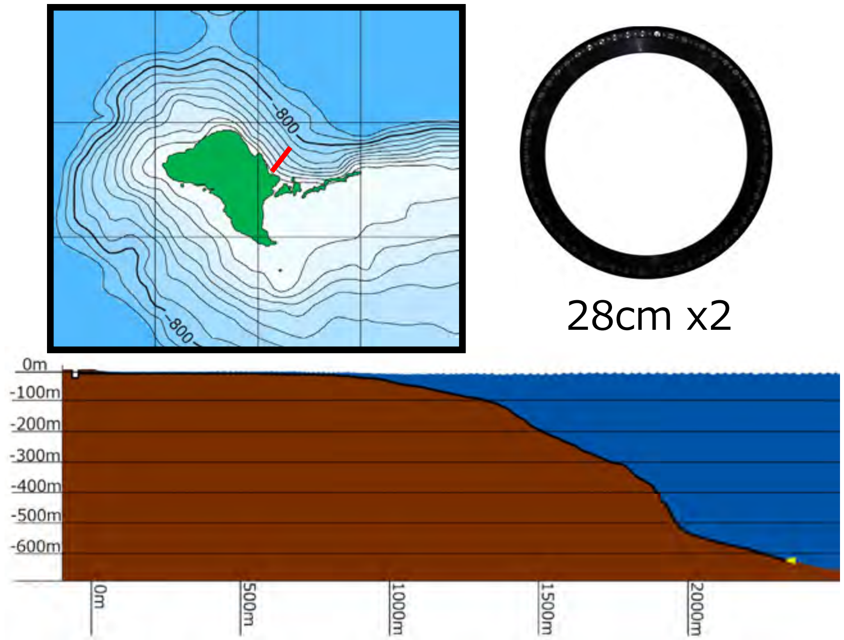
Kumejima (Current Intake)

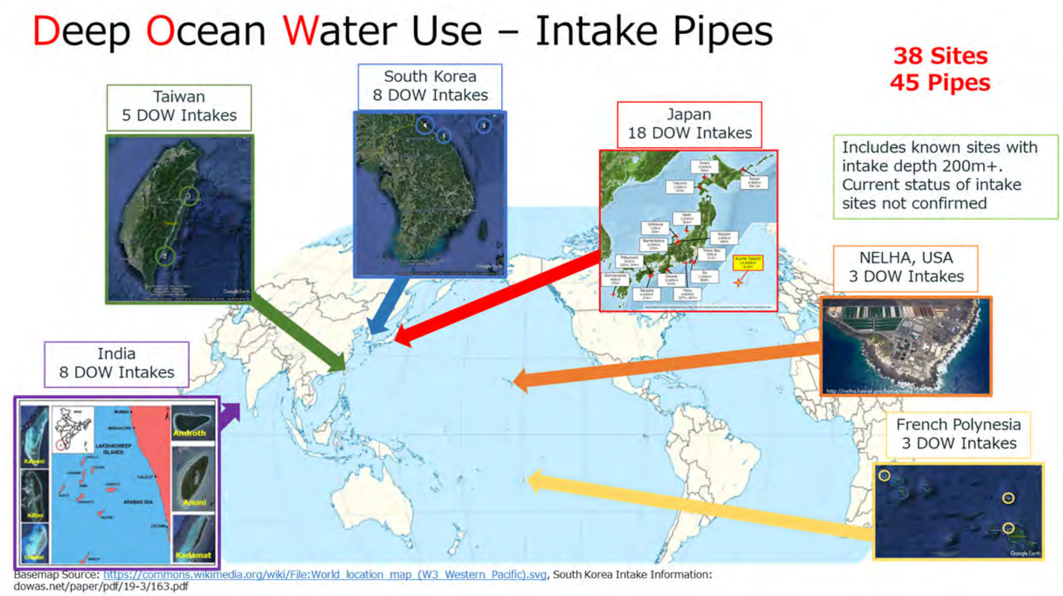


28cm x2

Deep Water Intake (onshore)

Kumejima (Current)





Onshore OTEC requires long intake pipes. Although initial cost is high, once installed they have very long operational lives and can contribute to various industry development.

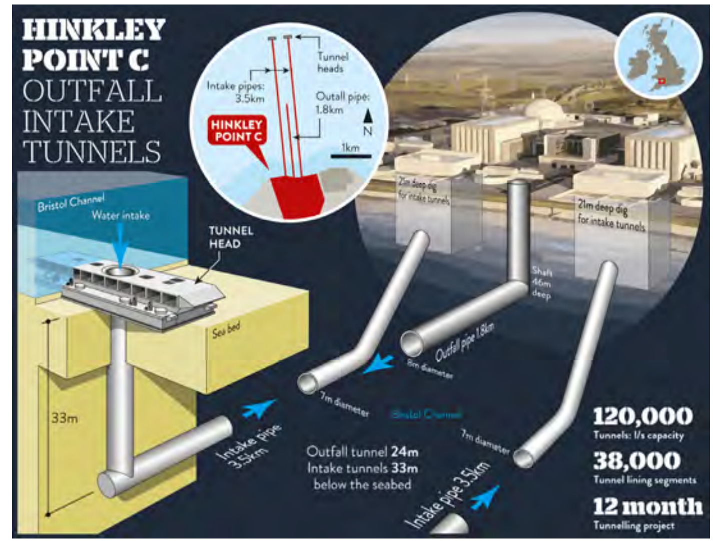
Benefits of DOW industries have supported increased installation of onshore DOW intake in recent years. Increased scale may supply capacity for OTEC.

Practical application and cost limits onshore scale to about 5MW.

Scaling Deep Water Intake (on/offshore)

Prototype Composite pipe for 10MW OTEC

HDPE Deployed in Shallow Waters for Power Generation

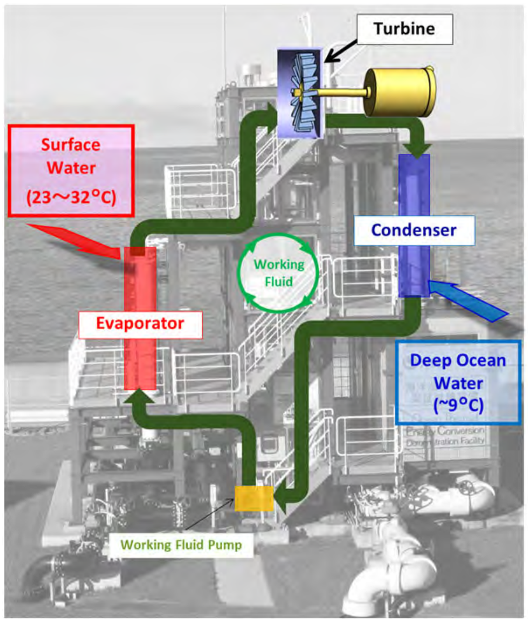


Nuclear power plants regularly use very large-scale intake. In this case, concrete lined tunnels.

Onshore OTEC requires intake larger than 1.4m diameter. 10MW OTEC requires a 4m diameter pipe or bundles of smaller pipes. A 100MW facility requires roughly a 10m inner diameter pipe. Large-diameter (~3m) HDPE pipes have been installed at desalination, oil and gas, and other facilities around the world and are commercially available. Hybrid intake pipes for OTEC have also been developed and tested. As a reference, the Hinkley Point nuclear power plant will use 7m concrete tunnels.

Source: Lockheed Martin under US DOE project: "SELECTION AND VALIDATION OF A MINIMUM-COST COLD WATER PIPE MATERIAL, CONFIGURATION, AND FABRICATION METHOD FOR OCEAN THERMAL ENERGY CONVERSION (OTEC) SYSTEMS" and middle: ATE Energy http://www.ateenergy.com.tw/Gallery.aspx and right: https://www.newcivilengineer.com/innovative-thinking/tunnels-delivering-hinkley-point-cs-cooling-system-16-12-2019/

Is OTEC Viable?
Power Generation System



Okinawa OTEC Demonstration
Closed Cycle (from 2013)

Institute of Ocean Energy Saga
University Lab (from 2003)

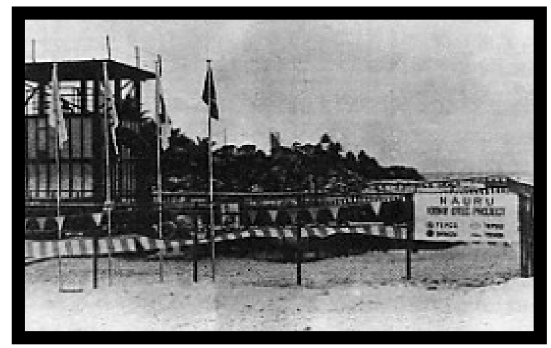
OTEC's power cycle is a type of binary power generation, simply, a steam power plant that uses a working fluid (refrigerant) in place of water. Such systems are already commercialized at larger temperature differences with a scale of several tens of MW around the world such as in geothermal.

OTEC in the 1970's~80's

From the original OTEC Concept in 1881…

Towards commercial power from a **small temperature difference**.

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）

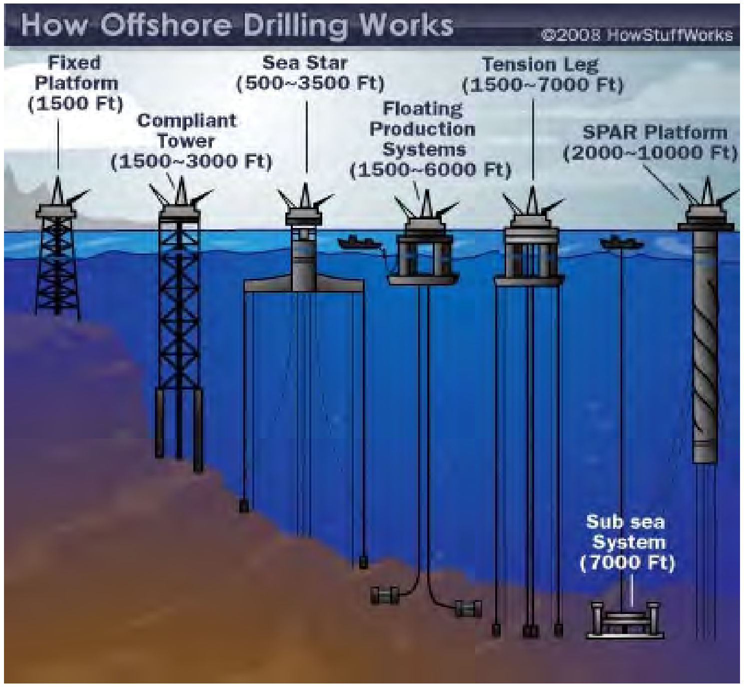
Evaluation in 1980s

~~OTEC is Technically Feasible but Not Economical~~

In the spotlight again due to ***technical improvement*** *and* **changes in social situations.**

Improvements in Technology benefitting OTEC

Technical developments in floating structure for offshore industries



（Reference： How Stuff Works Web Site）

Development of large capacity heat exchangers optimized for OTEC

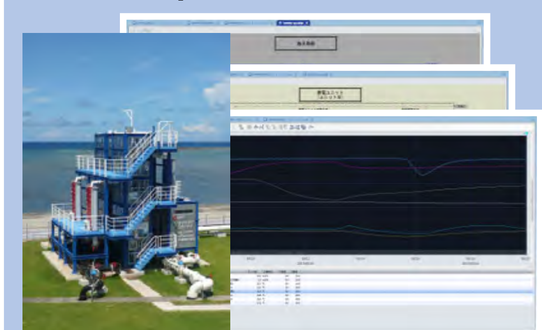
For commercial OTEC, the HX is a large component of overall cost.

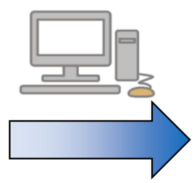
Performance Prediction from Demonstration Data

Main Differences between Kumejima Demonstration and Commercial Scale Plant
(Informing OTEC Scaling)

Item	OTEC Demonstration	Commercial	Remarks
DOW Intake Depth	612m (Temp. 8～9℃)	800～1000m (Temp. 4～6℃)	Affects Power Generation Efficiency and Self-Power Consumption
Intake Diameter	280㎜	1MW class ~1.5m diam. 10MW class ~3～4m diam.	Narrow pipes at same flow rate are disadvantageous in view of pressure drop
Device Performance	Special design due to small scale/ Off-design operation (existing research center priority use) on ocean water side	For 1MW and 10MW class, more commercial equipment is available for design point.	Difference in unit performance of equipment affects power generation output and self-power consumption

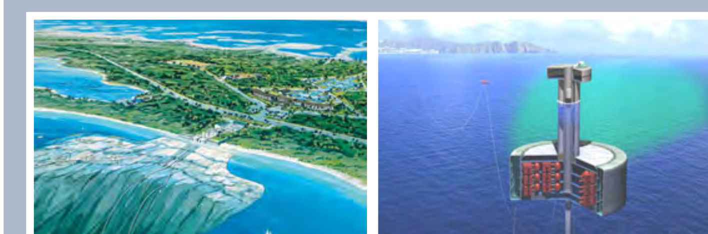
Various OTEC Facility Operational Data



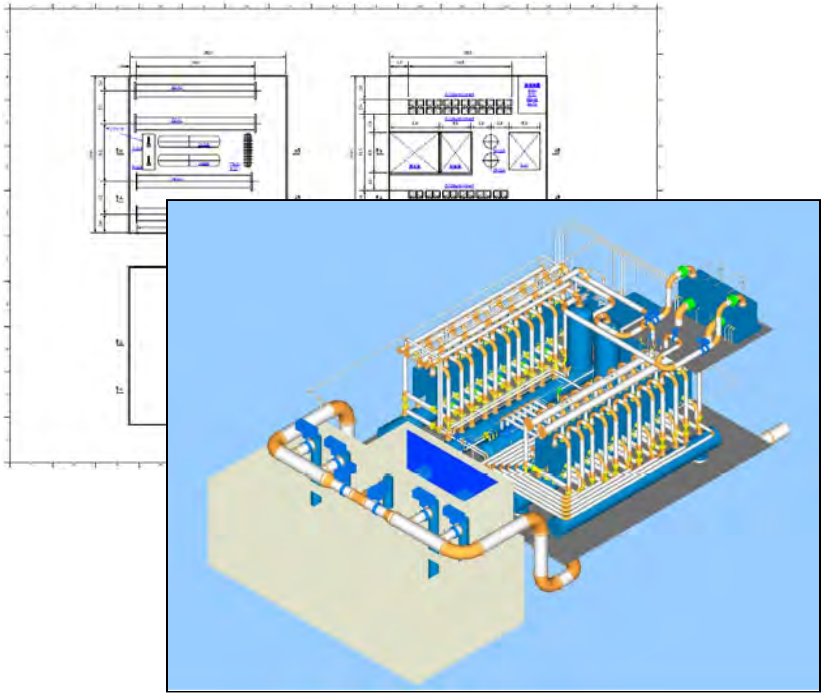


Performance Analysis Program

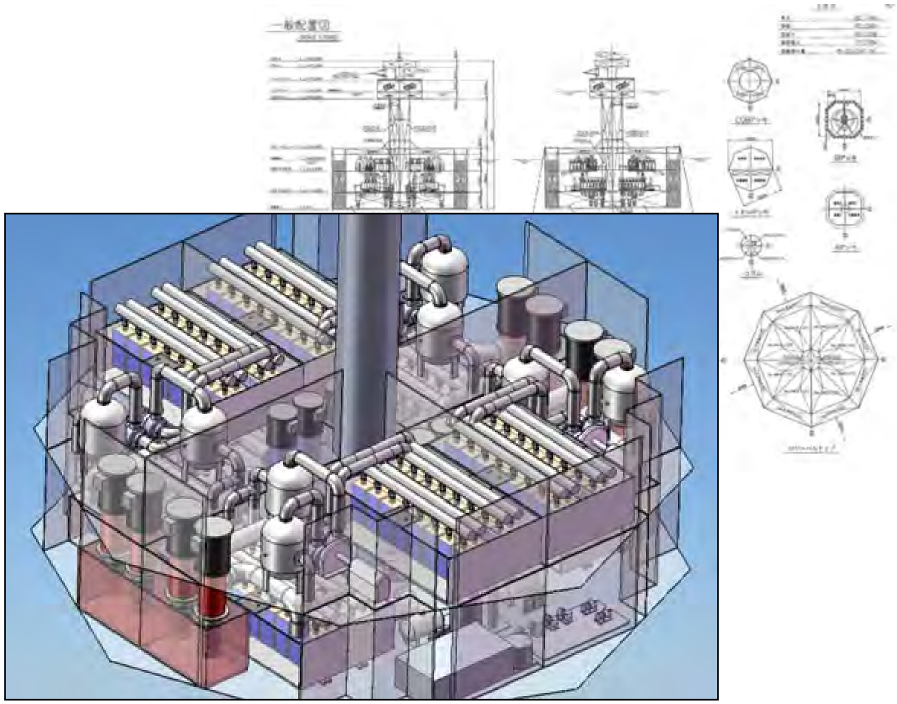
Commercial Scale Performance Prediction



OTEC Design



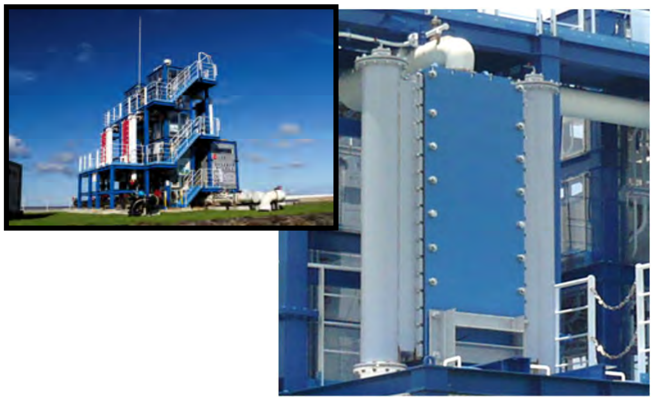
1MW Onshore-Type



10MW Floating Type

Binary Power generation systems are relatively simple, with few moving parts and no high temperature stress. Components are commercially available (more so at scales MW+). Preliminary design of 10MW floating plants have been completed in Japan.

OTEC Heat Exchangers Validated through Demonstration



Current Demonstration
Test Heat Exchangers

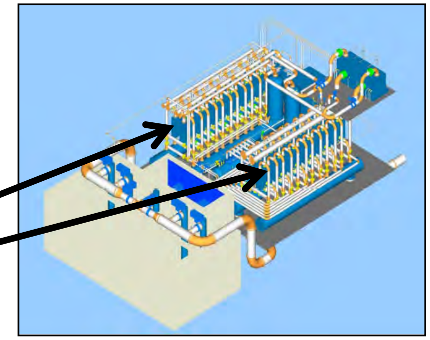
Plate Size：

W 0.7m x H 2.4m x
90 sheets ／unit

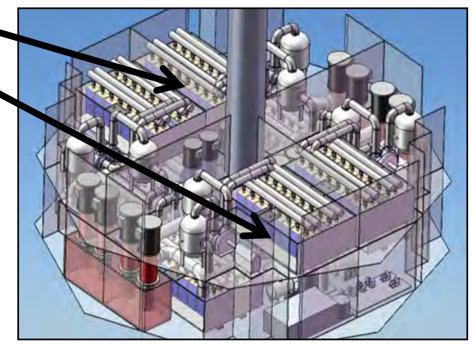
Commercial Heat Exchanger

Plate Size：

W 0.7m x H 2.4m x
240 sheets／unit



1MW Class Power
Generation Equipment



10MW+ Class Power
Generation Equipment

Multiple HX of the same size can be installed

As the plate size does not change, the same performance estimation formula can be used. Reliable scaling through increase in units.

Titanium heat transfer plates allows for long operational life

Is OTEC Viable?
Can OTEC Provide net Power?

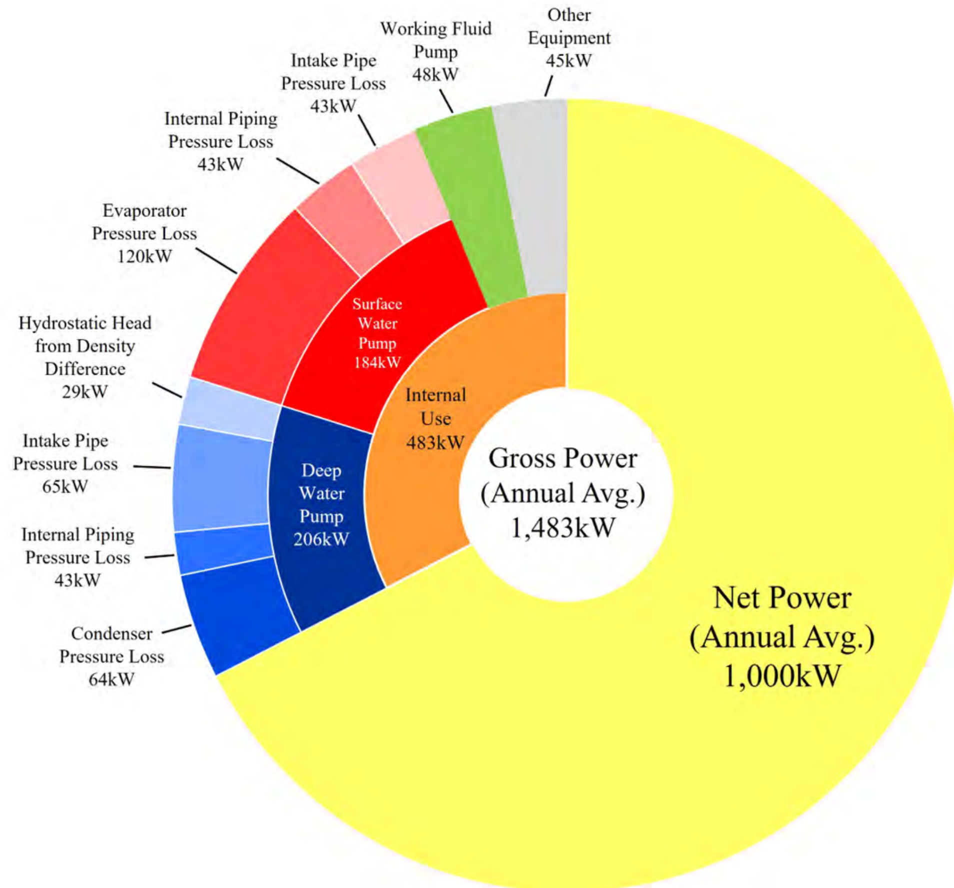
Net Power was demonstrated in 1979, but output was limited due to available technology.

Technical Improvements Effect on Net Power

Improvements in OTEC cycles and Heat Exchangers has shifted the net OTEC equation.

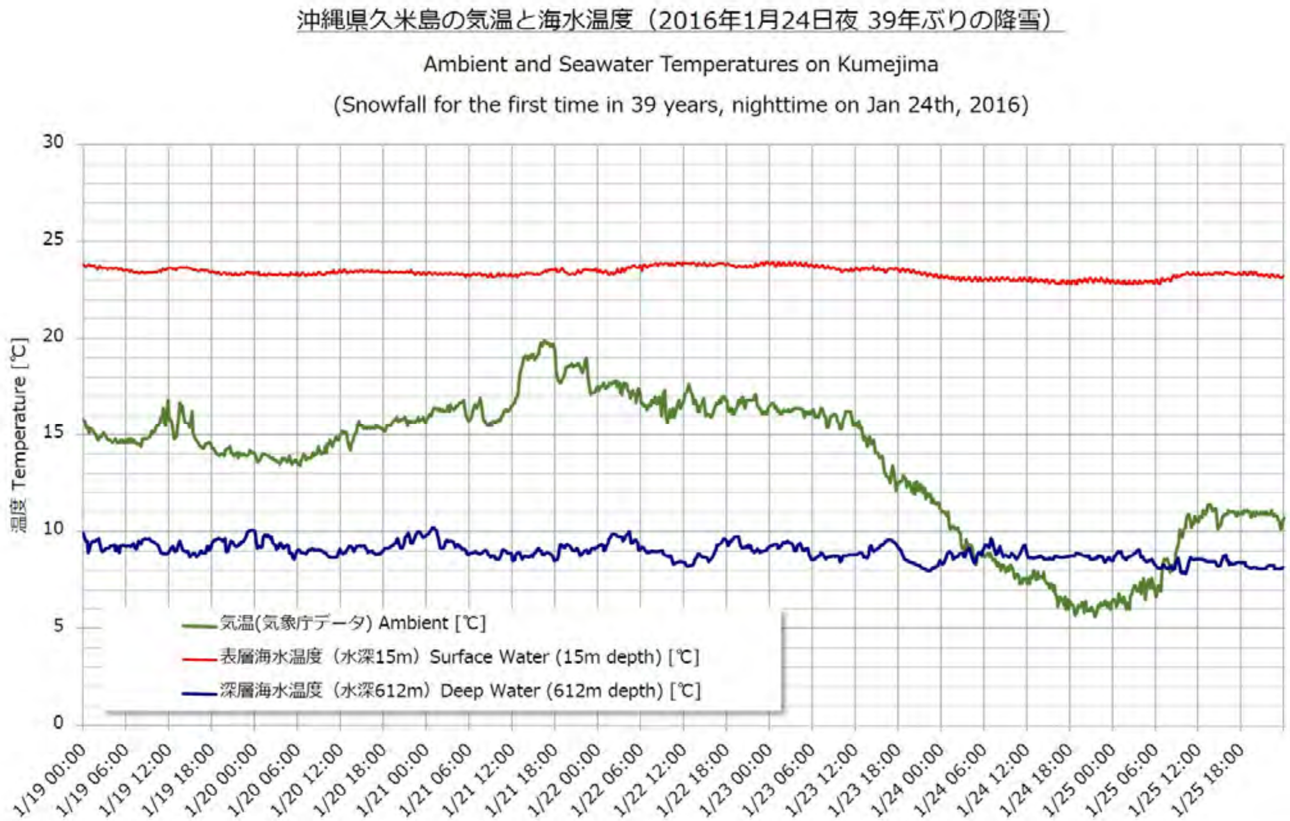
In early OTEC research, 70% of power produced was used internally. Now about 70% can be supplied to the grid.

~2x more baseload power for the grid



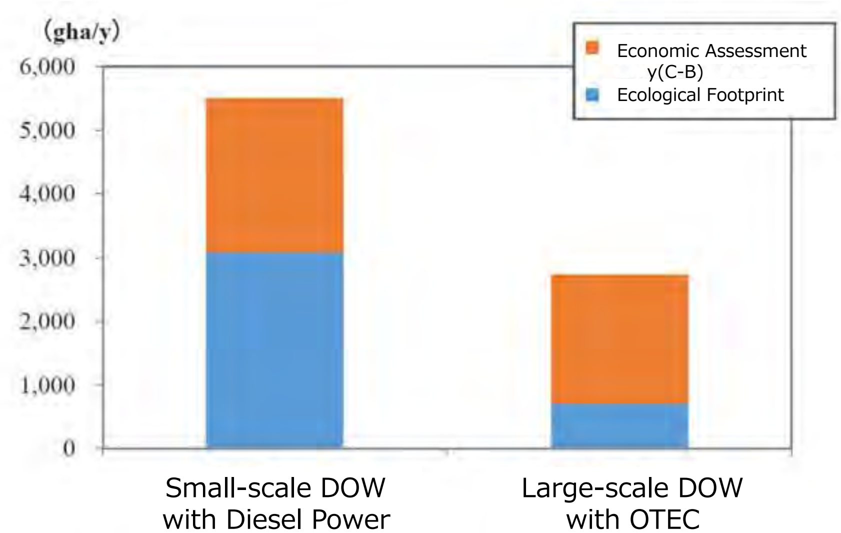
<u>Breakdown of Internal Power Consumption for 1MW OTEC on Kumejima</u>

High Capacity Factor and Stable Supply

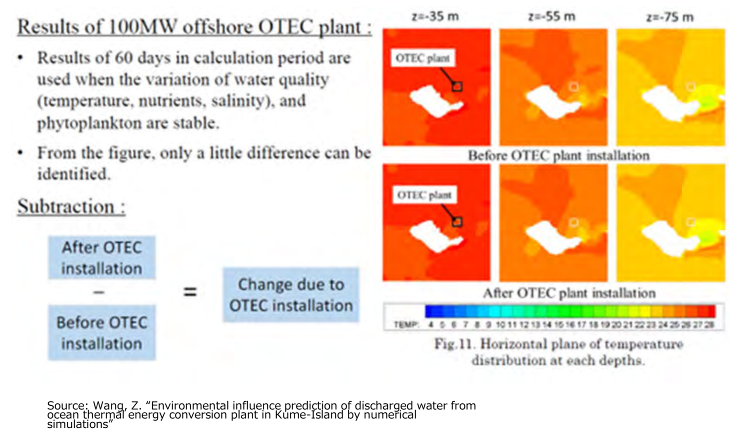


Ocean Water changes slowly compared to ambient temperatures, even during abnormal weather, as seen in the chart above. Combined with low fatigue, OTEC has a very **high capacity factor** (~90%) and stable output suitable for **baseload power**.

Is OTEC Viable?
OTEC and the Environment



Triple III Light evaluation of OTEC and DOW Industrial Use on Kumejima to gauge life cycle effect of OTEC vs. Fossil Fuels



Modeling of Impact from Post-OTEC Water in Kumejima Ocean Area

Source: Adapted from FY2018 Okinawa Prefecture "Demonstration Project of Power Generation Used for Advanced Deep Seawater Utilization" Report https://www.pref.okinawa.jp/site/shoko/seisaku/kiban/oceanrenewableenergy/otec/houkokusyo/h30houkokusyo.html

Environmental Consideration

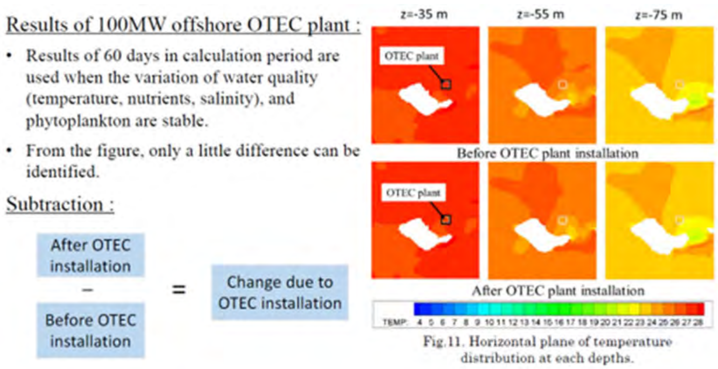
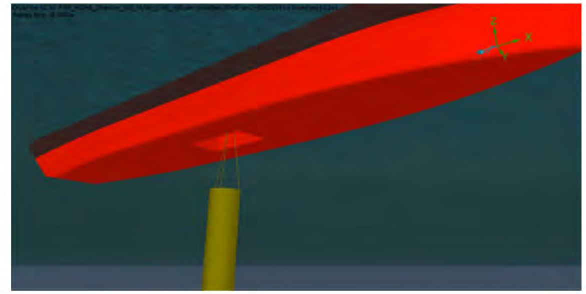
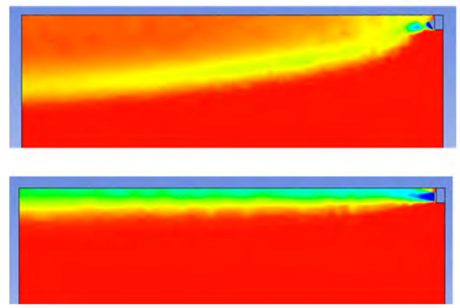


Fig.11. Horizontal plane of temperature distribution at each depths.

Source: Wang, Z. "Environmental influence prediction of discharged water from ocean thermal energy conversion plant in Kume-Island by numerical simulations"





Colour	Temperature (K)	Temperature (°C)
Red	297.00	25
Orange	296.40	24.6
Yellow	295.80	23.8
Green	294.45	22.45
Cyan	293.33	21.33
Dark Blue	292.00	20

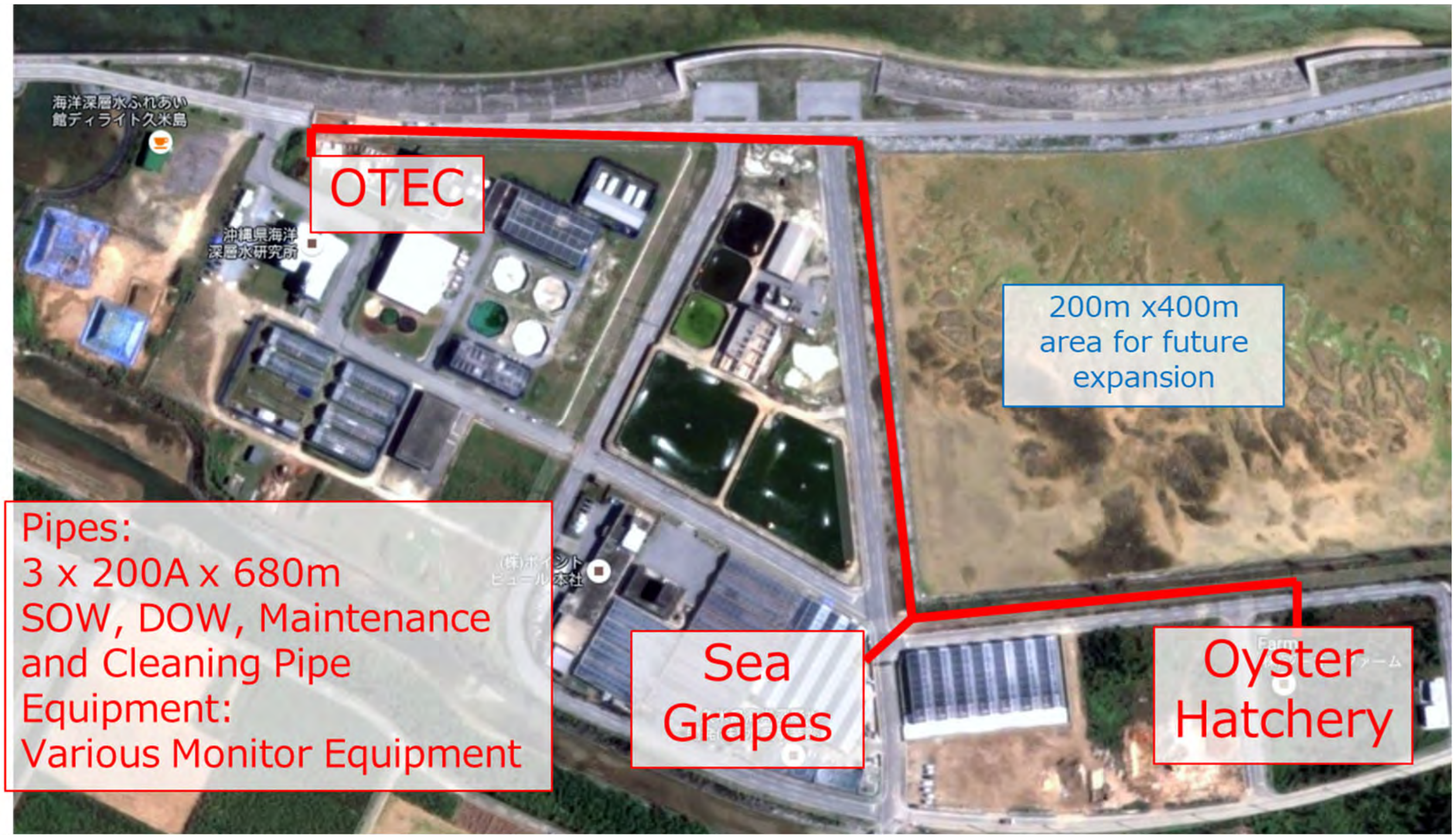
Source: Ocean Energy Systems Consulting

Multiple discharge strategies exist for onshore deployment depending on the location and use of deep ocean water. Generally, it is best practice to discharge deep ocean water past any coral communities.

For offshore OTEC, while various models have been performed, the final system configuration will affect its relationship with the surrounding environment. Environmental Impact Assessments may be required by any regulatory authority. Validation from at-sea testing has not yet been completed.

Demonstrating the "Kumejima Model" with Post-OTEC Pipelines

In 2016, new pipes were installed to transfer post-OTEC ocean water to local industries on Kumejima. This allows for evaluation of the merits and challenges associated with cascade use of OTEC and ocean water industries at a small-scale.



Provides Useful Understanding of Cascade Needs, Challenges, and knowhow.

Start of Establishing a Track Record of Successful Use

Is OTEC Viable?

Social and Economic Considerations

Comparative Study for Selection of Renewable Energy Introduction for Specific Tropic Islands

	Solar	Onshore Wind	Offshore Wind	Wave	Tide /Current	OTEC	Notes
Footprint/Power Generation	× (Large Land Use)	△	△	× (Large Ocean Area Use)	×	○	
Power Generation Cost ($/kWh)	◎	○	△	×	×	× (500 k W or less) ○ (1+ MW) ◎ (10MW+)	
Initial Cost ($/kW)	◎	◎	△	△	△	× Intake ○ Power Plant	
Running Cost ($/kW)	◎	○	○	○	△ (Difficult to Maintain)	◎	
Power Stability	×	×	×	×	○ (Predictable)	◎ (Stable 24hrs)	
No Need for Storage Batteries for Stability and Emergency	×	×	×	×	△ (Predictable)	◎ (Stable 24hrs)	
Capacity Factor	△ (~20%)	△ (~20%*)	△ (35%*)	○ (*)	× (*)	◎ (80-90%+)	*Survey Required. Currently Japanese Data

Note: The above is an initial analysis targeting specific islands and is not a final comprehensive evaluation

Comparative Study for Selection of Renewable Energy Introduction for Specific Tropic Islands Continued

	Solar	Onshore Wind	Offshore Wind	Wave	Tide /Current	OTEC	Notes
Necessity of Internal Power	◎	◎	◎	◎	◎	△ (internal power use of 20-40%)	Internal power for pumps, etc. required for power generation
Resilience to Weather (Typhoons, Earthquakes, etc)	〇	△	△	△	〇	◎ Onshore △ Offshore*	*Few Practical Installations/ However, in the "Takumi" project (floating body and intake pipe) there is a long term (5yr) track record.
Seawater Desalination	△	△	△	△	△	◎	For OTEC, continuous flash-type is possible if power provided from OTEC. Other RE can supply RO such as Demand Response.
Employment Creation	×	×	△ (Fisheries)	△ (Fisheries)	△ (Fisheries)	◎ (Combined Use)	In this case, Fisheries includes the installation of artificial reefs, artificial sea plant beds, cages, etc.
Industry Development	× (Power Only)	× (Power Only)	△ (Fisheries)	△ (Fisheries)	△ (Fisheries)	◎ (Combined Use)	In this case, Fisheries includes the installation of artificial reefs, artificial sea plant beds, cages, etc.
Hydrogen Production	△	△	△	△	△	◎	For OTEC, continuous flash-type is possible if power provided from OTEC. Other RE can supply RO such as Demand Response.
Compatibility with South Pacific Island Nations (typhoons, climate, etc.)	〇 (High Insolation)	△ (Typhoon, etc.)	△ (Typhoon, etc.)	△ (Typhoon, etc.)	△ (Typhoon, etc.)	◎ (Particularly High Potential, Typhoon Resistant)	

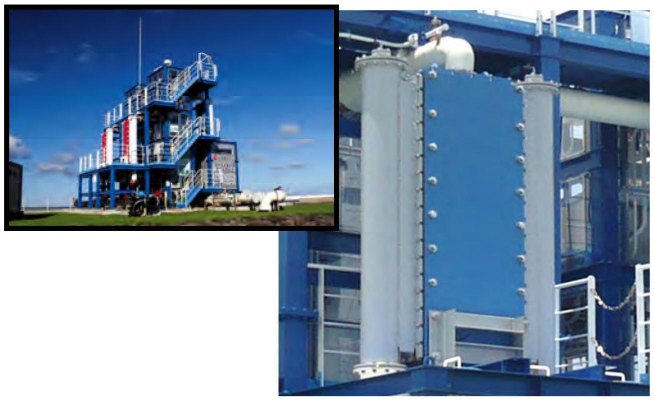
Note: The above is an initial analysis targeting specific islands and is not a final comprehensive evaluation

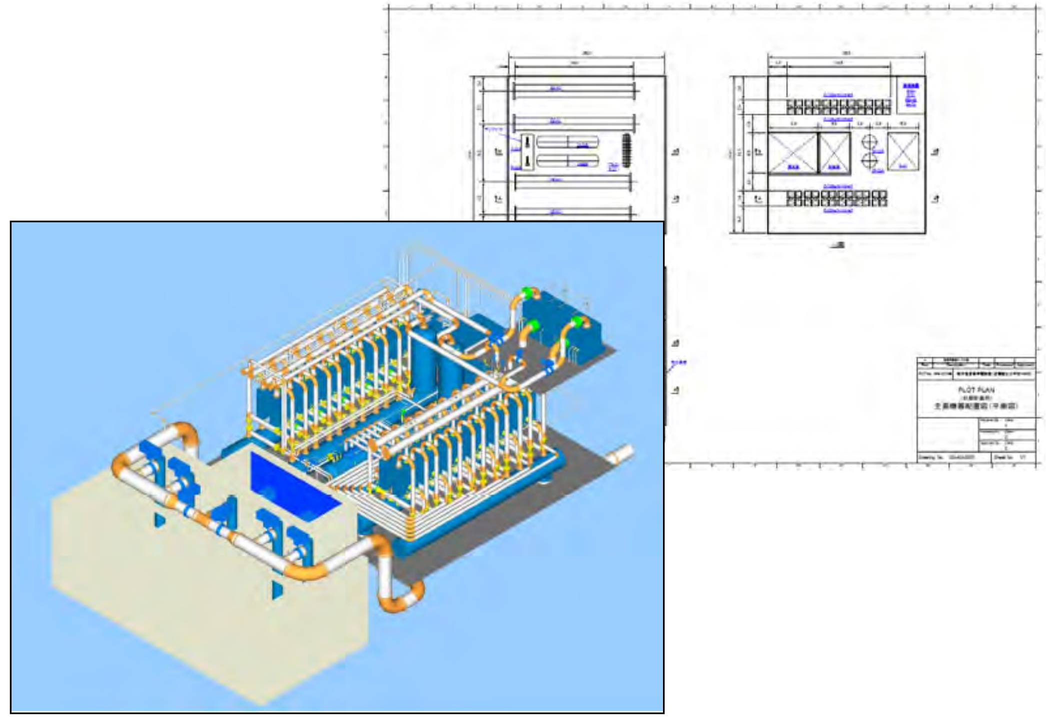
Tentative Evaluation of Introduction for Specific Islands in the Tropics

	Rating	Reasoning
Solar	○	There are advantages in terms of cost and operating costs, however, there are issues such as required area (land) use, intermittency, etc.
Onshore Wind	△	Issues with Low Potential, required area (land) use, intermittency, etc.
Offshore Wind	△	Issues with Low Potential, area (ocean) use, intermittency, etc.
Wave	×	A detailed survey is required for a final decision
Tide / Current	×	A detailed survey is required for a final decision
OTEC	◎	MW+ Onshore OTEC provides advantages in most categories

When aiming for 100% renewable energy, strategic combination of OTEC and Solar Power Generation is effective for SDGs Achievement in Tropics

Is OTEC Viable?





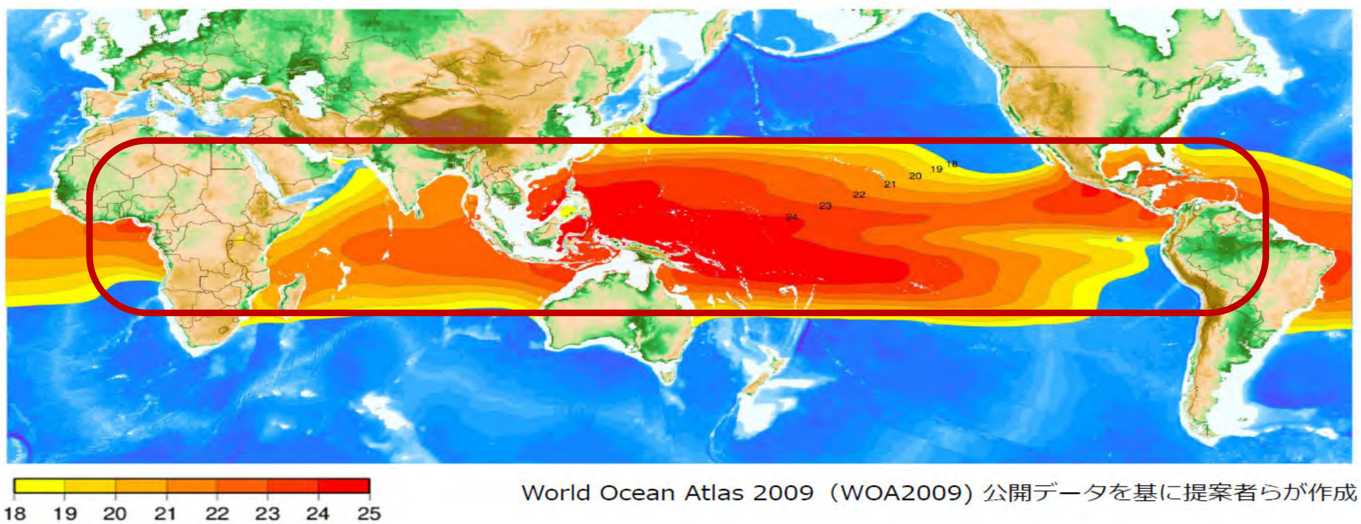
1MW Onshore-Type

- ✓ Ocean Water Intake
  - ✓ Power Generation System
    - ✓ Net Power, Grid Support, Potential
      - ✓ Environment
        - ✓ Social and Economics

In short? **YES**

Where OTEC Works

When viewed globally, the potential for OTEC makes it one of **the most promising renewable energy sources**. The potential is particularly very high near the equator. On the other hand, in developed countries such as Europe and the United States, potential is relatively low due to their high-latitude locations, so its attraction has been limited so far.



World Ocean Atlas 2009（WOA2009）公開データを基に提案者らが作成

There are **more than 90** developing countries and regions that have high potential to economically implement OTEC, but they need assistance to take advantage of it.

OTEC Implementation for MARES

(OTEC Aligned to MARES Goals)

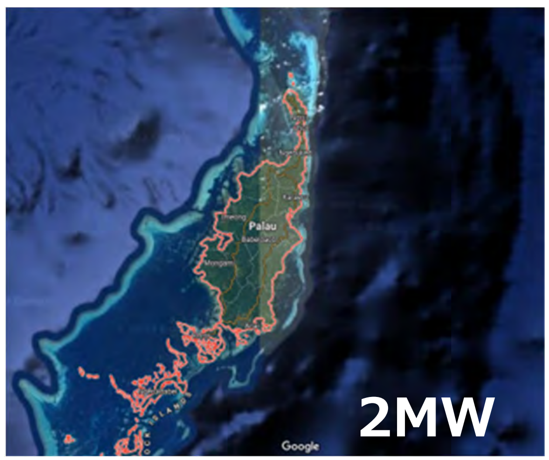
OTEC and MARES

Kumejima, Japan

MW Scale Demonstration
2024 Project Start Target

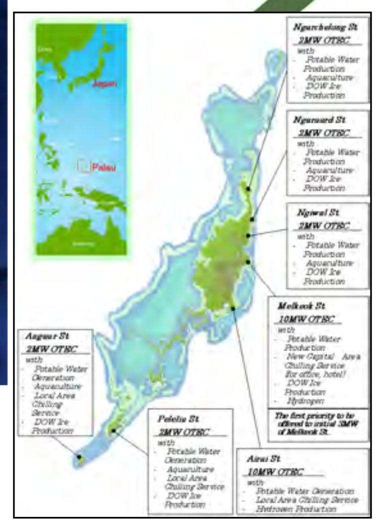
"Kumejima Model" adapted as catalyst for MARES

Palau



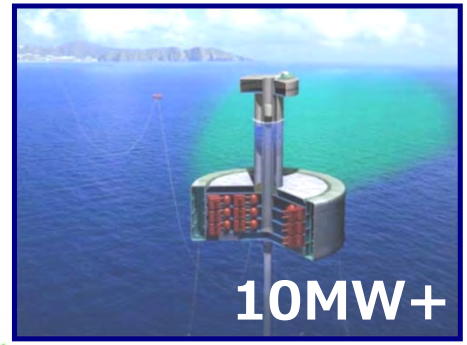
MW Scale Onshore

Potential OTEC sites in Palau



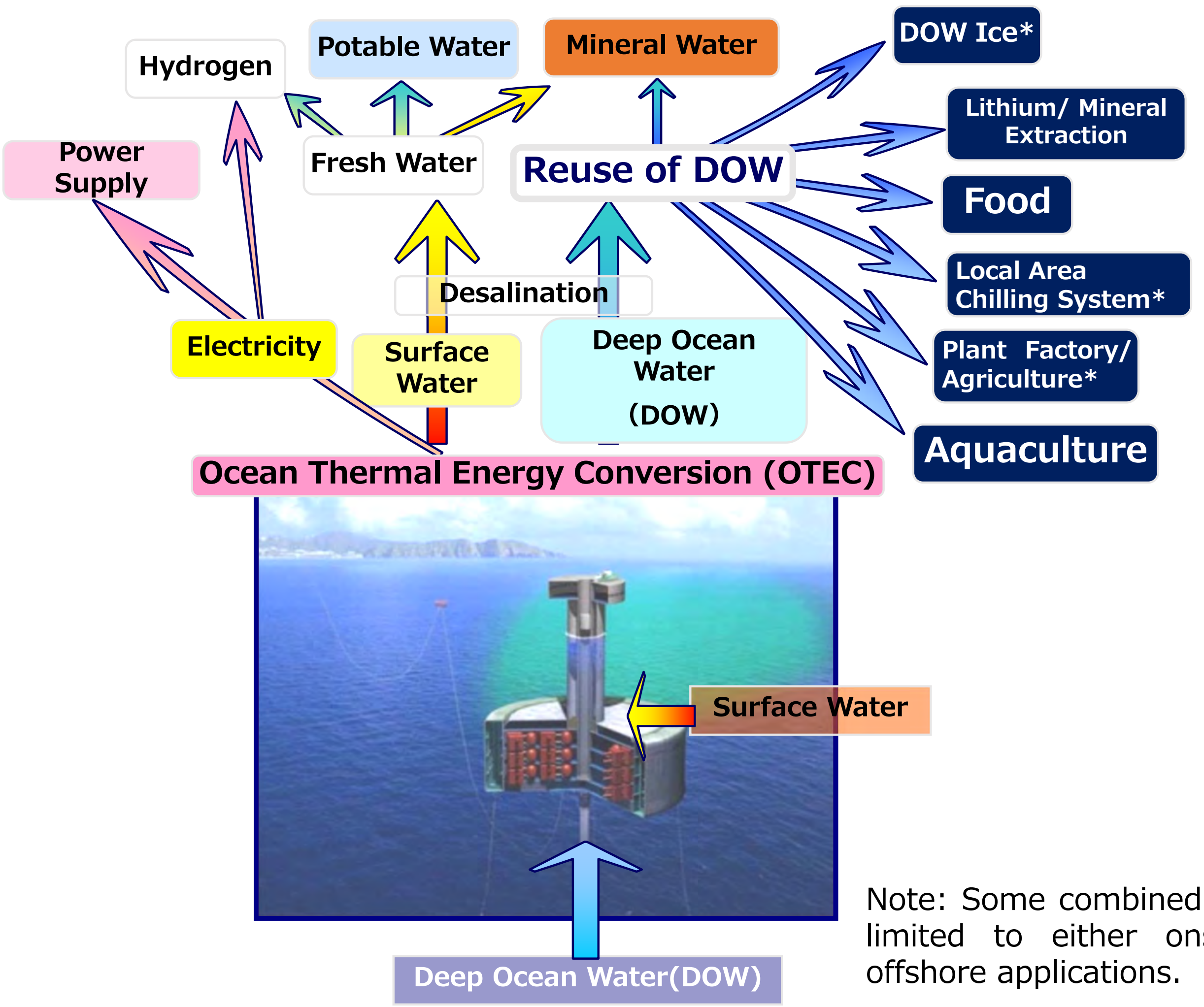
From 2002 World Water Forum

Scaling



10MW+ Scale
Meets the needs of larger capacity locations, repeatable product for wide development / reduced project development

OTEC and Power to X Opportunities



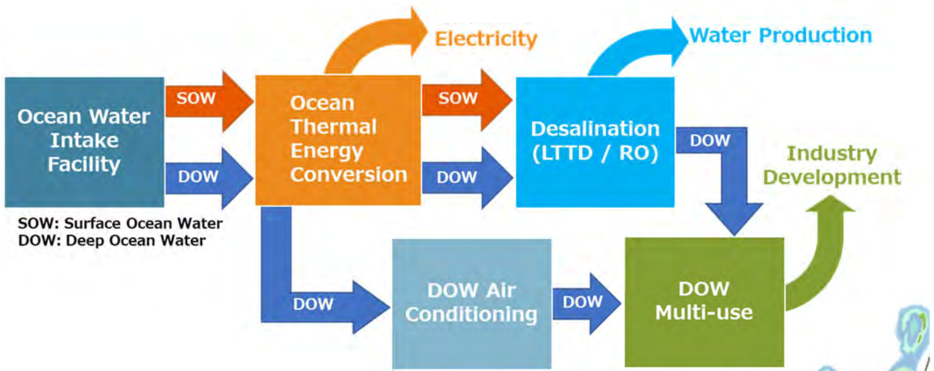
Desalination (100t/d by NIOT)

Lithium Recovery (Saga U.)

Hydrogen/Ammonia Production

Note: Some combined uses are limited to either onshore or offshore applications.

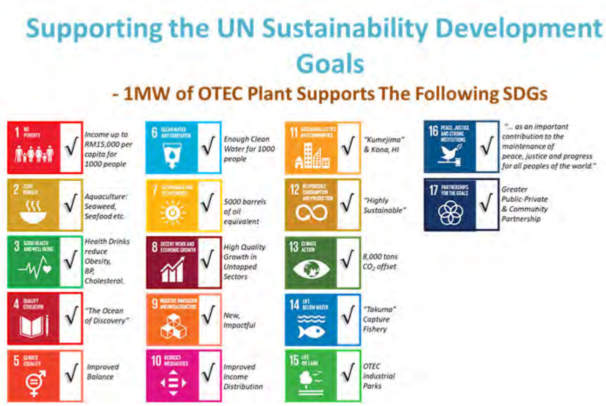
Adapting the "Kumejima Model" for Palau



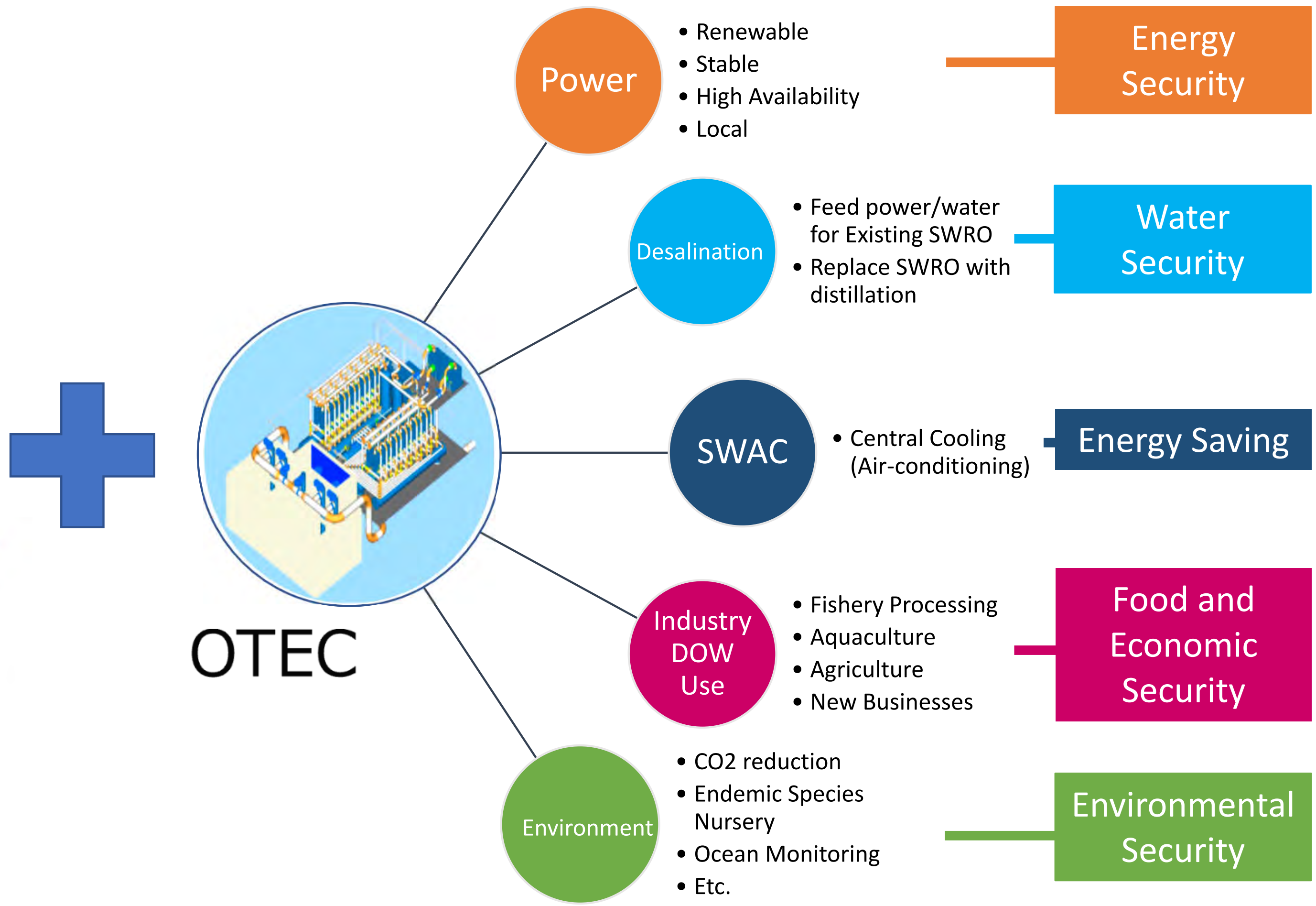
- Requires a system approach to local infrastructure that **enables** transition to sustainable energy, water, and food.
- Provides **clean baseload power** and catalyze decarbonization of related infrastructure while promoting economic development.
- **Addresses small community needs**, while also providing a steppingstone to large-scale commercial deployment via offshore OTEC.
- **Local Resource for local consumption** reduces risks while boosting health and wellness

A new Model for Island Development

MARES



Source: University Teknologi Malaysia



Thank You