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Novel Renewable Natural Resource of Deep Ocean Water (DOW) and Their Current and Future Practical Applications

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Abstract

Deep ocean water (DOW) contains a large stock of renewable natural resources, and is unique in having multiple essential resources such as energy, fertilizers, water, salts, metals and minerals. However, low concentrations of most resources, a high construction cost for the pumping system to obtain DOW and limited access to DOW pumping locations have discouraged actual attempts to obtain DOW. Recent developments in technology and practical applications of the DOW resources carried out in USA (Hawaii), Japan, Taiwan and South Korea have been included the followings: low temperature energy for generating electricity by ocean thermal energy conversion (OTEC), cooling electric power generators, air-conditioning, holding and handling fish and shell-fish, cold aquaculture and cold agriculture, inorganic nutrients for the culture of seaweed and phytoplankton, ocean fertilization, freshwater, salts, minerals, and metals, among others.

Key words: Renewable resource, deep ocean water, DOW, practical application, energy, freshwater, fertilizers, metals, minerals

1. Introduction

One of the urgent subjects which we are now confronting in the world is an increase or is a maintenance of the sustainability of our society while looking towards the future. The Natural Step (one international NGO) has proposed four system conditions in order to keep up the sustainability of society, and the first two are not to increase concentrations of substances extracted from the earth's crust, or to increase man-made products (http:// www. naturalstep. org/ the- sys tem-conditions, http://www.tnsij.org/index.html). Considering as how presently our society is supported by many natural resources obtained from the earth's crust, we have to replace those with renewable resources.

Deep ocean water (DOW) is one of the most promising and unique renewable resources for the future as it contains energy as well as various essential materials. A severe hurdle for DOW applications is DOW's low resource concentration. However, it is quite possible to make this low concentration useful in the future as microorganisms and plants are capable of absorbing materials efficiently even at extremely low concentrations, and our knowledge and technology for utilizing such low concentration of resources has now been improved to a high degree.

In the late 19 century, DOW resources attracted the attention of a French physicist, Dr. J. A. d'Arsonval, as energy for generating electricity by ocean thermal energy conversion (OTEC) (Takahashi 2000). During nearly 80 years of research in OTEC, we have come to recognize that DOW contains a great variety of resources in addition to its low temperature, and have investigated them further

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for practical applications (Kaiyo-shuppan 2000, Fujita and Takahashi 2006). DOW has been interested not only just energy but also other resources, and some of them have now been applied practically. The current status of DOW resource applications has been reviewed in this paper.

2. Origin and characteristics of DOW

DOW was defined as the seawater below the depth of ca. 200m in the ocean for the resource utilization of fisheries although actual depth is changeable depending upon geographical locations and the kind of target resource (Deep Ocean Water Conference for Fisheries 2001). For example, low temperature DOW can be obtained at shallower depths at higher latitudes, but at deeper depths in lower latitudes.

DOW is formed in nature in the following process. Firstly, the surface seawater is cooled at higher latitudes in winter, and then the cooled surface water sinks to deeper depths, dissolving rich oxygen and carbon dioxide due to the increased saturation level at low temperatures (Fig. 1).

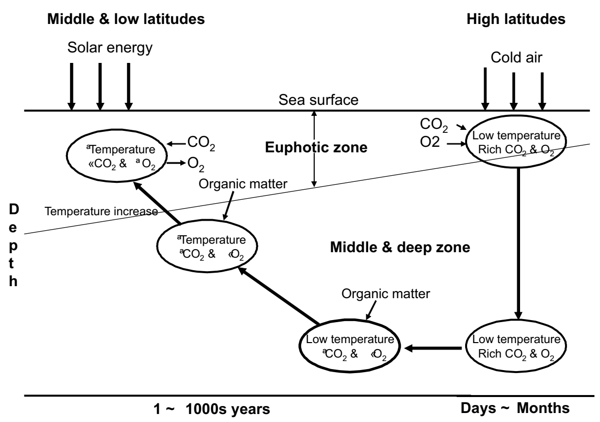

Fig. 1. Schematic diagram of DOW formation in the ocean.

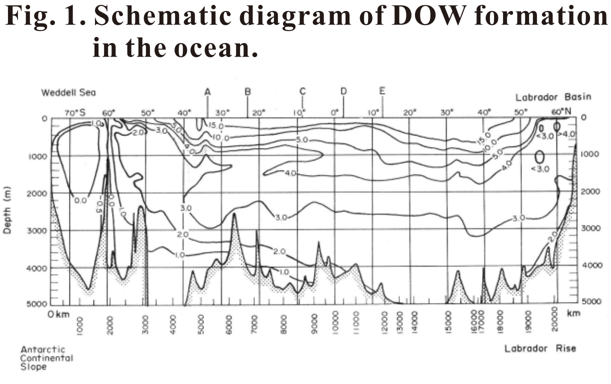

Fig. 2. Longitudinal temperature (℃) section in the Atlantic Ocean (Raymont 1980)

This sinking process of surface water takes from days to months for completion. The cold surface water sink to the deep and then moves toward lower latitudes, and comes up to the surface at mid or low-latitudes due to warming. The whole process from sinking to rising will take hundreds to thousands of years. Once the surface water sinks below 200 m where there is not enough solar radiation penetrating for photosynthesis, heterotrophic processes become predominant in DOW, which consume organic matter and oxygen, and produce carbon dioxide and inorganic nutrients. The newly sunk DOW contains rich oxygen and labile organic matter, but the old DOW contains less oxygen and almost no labile organic matter, and is rich in carbon dioxide and inorganic nutrients.

Carbon-14 dating of carbon dioxide in seawater at various depths indicates average years since the water sinks from the surface. Actual determinations of average years of seawater in the western Pacific Ocean showed over 2,000 years at about 2,000m in depth around 40°N, gradually becoming of young towards the south (Tsunogai 1981). The average year estimated by the carbon-14 dating gave <100 years for the DOW from 320m and 344m at the Kochi Deep Ocean Water Research Laboratory (Taniguchi et al. 2000), and 930 years for 600m and 2,030 years for 1,400m of the DOW collected off the Okinawan main island (Ooide 2002).

The first resource of DOW is its low temperature, ranging from -1.8°C to 15°C depending on depth and geographical location. Temperature is below 10°C at ca. 300m in temperate waters and in much deeper water at lower latitudes, and is 5°C or lower below 1,000m in the world's oceans (Fig. 2).

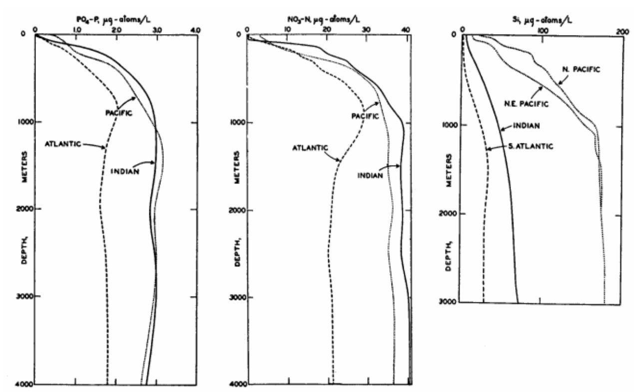

Fig. 3. Vertical distributions of inorganic nutrients in the world ocean (Sverdrup et al. 1942).

Such low temperatures are originally brought from higher latitudes to lower latitudes with DOW as mentioned above.

The second resource of DOW is inorganic nutrients, as shown in Fig. 3. Nutrients are increased in concentration with depth down to ca. 1,000m, reaching almost constant high concentrations. Old DOW contains more nutrients than young DOW, which can be seen in the Atlantic Ocean where the average nutrient concentrations are almost half of the concentration of the Pacific and Indian Oceans. Nutrient concentrations in DOW are still far lower than the level for agricultural fertilizers. However total amounts of nitrate and phosphate in DOW are estimated to be as large as 500×10^9 tons and 95×10^9 tons, respectively, which are about 5,000 and 2,500 times that of the respective fertilizers used for agriculture yearly in the world.

The third resource of DOW is freshwater. Of course salts have to be removed from seawater to obtain freshwater.

The fourth resource of DOW is salts, which are composed mostly of sodium chloride (77.9% in total weight of salts), magnesium chloride (9.6%), magnesium sulfate (6.1%), calcium sulfate (4.0%) and potassium chloride (2.1%).

The fifth resource of DOW is metals and minerals, most of which are in extremely low concentrations (Table 1).

Table 1. Average concentrations of elements in seawater (Nozaki 1996).

Element	Av. Conc. (ng/kg)	Element	Av. Conc. (ng/kg)	Element	Av. Conc. (ng/kg)	Element	Av. Conc. (ng/kg)
Cl	19,350,000,000	U	3,200	Re	7.8	Sn	0.5
Na	10,780,000,000	V	2,000	He	7.6	Ho	0.36
Mg	1,280,000,000	As	1,200	Ti	6.5	Lu	0.23
S	898,000,000	Ni	480	La	5.6	Be	0.21
Ca	412,000,000	Zn	350	Ge	5.5	Tm	0.2
K	399,000,000	Kr	310	Nb	<5	Eu	0.17
Br	67,000,000	Cs	306	Hf	3.4	Tb	0.17
C	27,000,000	Cr	212	Nd	3.3	Hg	0.14
N	8,720,000	Sb	200	Pb	2.7	Rh	0.08
Sr	7,800,000	Ne	160	Ta	<2.5	Te	0.07
B	4,500,000	Se	155	Ag	2.0	Pd	0.06
O	2,800,000	Cu	150	Co	1.2	Pt	0.05
Si	2,800,000	Cd	70	Ga	1.2	Bi	0.03
F	1,300,000	Xe	66	Er	1.2	Au	0.02
Ar	620,000	Fe	30	Yb	1.2	Th	0.02
Li	180,000	Al	30	Dy	1.1	In	0.01
Rb	120,000	Mn	20	Gd	0.9	Ru	<0.005
P	62,000	Y	17	Pr	0.7	Os	0.002
I	58,000	Zr	15	Ce	0.7	Ir	0.00013
Ba	15,000	Tl	13	Sc	0.7		
Mo	10,000	W	10	Sm	0.57		

In addition, there are several unique characteristics of DOW. The first is the cleanliness as shown in Table 2, which is created by isolation from active biological processes due to poor or no solar radiation and less physico-chemical actions compared with near the surface. The second is the temporal and spatial constancy of DOW characteristics. The third is a rapid regeneration time such as mostly <1,000 years.The above mentioned resources from #3 to #5 are not unique only for DOW but also to the surface seawater; however, the cleanliness of DOW is more advantageous for practical applications.Within the cleanliness of DOW, dissolved organic matter (DOM) will be described in more details as follows. DOM is classified into three fractions depending upon differences in turnover time (Ogawa and Tanoue 2003). The refractory fraction requires 1,000< years for turnover, and is about 40 μ mole/L on average throughout the water column. The second fraction is the semi-labile having a turnover time of months to years which is mostly distributed above the 1,000 m depth with 10-30 μ mole/L in concentration. The labile fraction with turnover time of <hours to days such as dissolved free amino acids, free sugars and labile protein is almost undetectably low concentrations in DOW.

Table 3 is a summary of the resources and characteristics of DOW. The others in the table indicate some possible resources which have not been recognized yet.

Table 2. Cleanliness of DOW (Takahashi and Ikeya 2002).

1. Poor biomass including no pathogenic and polluted
2. No labile organic matter
3. Poor suspended matter
4. No anthropogenic harmful chemicals such as POPs and so on
5. Naturally low levels of heavy metals
6. Naturally low levels of radioactive materials

Table 3. Summary of resources and characteristics currently recognized in DOW.

Resources	Surface seawater	DOW（*ca*.200m< depth）
Energy（low temperature）	×	○
Inorganic nutrients（fertilizers）	×	○
Freshwater	○	○
Minerals	○	○
Metals	○	○
Salts	○	○
Others	?	?
Characteristics		
Cleanliness	×	○
Constancy	×	○
Rapid regeneration time	○	○

Current major resources such as oil, natural gas, metal ores, coal and many other underground resources have commonly high resource concentrations to their great advantage, but are un-renewable, self limited, threatened with exhaustion and causing environmental problems, to their disadvantage. On the other hand, the resources of DOW are completely the opposite of the above mentioned resources, consisting of having low resource concentration but being renewable, abundant, many kinds of resources and posing fewer environmental problems.

3. Challenges of DOW resource utilization

There are four nations - U.S.A (Hawaii), Japan, Taiwan and South Korea - currently carrying out the research and technology developments of DOW resources in the world. Within these, the state of Hawaii established the Natural Energy Laboratory of Hawaii (NELH, now Natural Energy Laboratory of Hawaii Authority (NELHA)) in 1974 on Hawaii Island. The first land based pipe for pumping DOW was installed in 1981 in Hawaii, and a pipe with an interior of 1.40 m diameter was installed in 2001 which pumps up more than 150,000 tons of DOW per day from 915 m. The major purpose for DOW resource utilization in Hawaii has been for OTEC as well as other applications too.

There are 16 land based pumping stations of DOW in Japan, from Hokkaido to Okinawa, although their pumping capacity is small, varying from 200 to 13,000 tons per day (http://www.dowas.net/facilities/index.html). All these pumping facilities have serviced for various resource applications of DOW, particularly for producing many commercial goods.

In Taiwan, three private companies constructed their own land based DOW pumping facilities and necessary factories in 2006, and have run the business. On the other hand, two national institutes of DOW completed construction in 2011 and 2012 (Takahashi 2008, Lee et al. 2010, Huang et al. 2010, Takahashi et al. 2012). The Taiwanese government has recognized DOW as one of the promising renewable natural resources, and has strongly promoted its practical applications.

In South Korea, there are three land based DOW pumping stations (one for the Korea Ocean Research and Development Institute (KORDI) and two for private companies) and one for a private company and under construction on the north-east coast of South Korea in 2008 (Nakashima 2008).

4. Current resource utilization of DOW

Each DOW resource can be used independently. Multiple single resource utilizations can also be arranged in a series such as a cascade or multi-step utilization.

1) Single utilization of a given DOW resource

1)-1 Low temperature energy

(a)Ocean thermal energy conversion (OTEC)

The 1st challenge of the low temperature of DOW is for generating electricity by OTEC as mentioned above. In OTEC, warm surface water is evaporated to produce water vapor under low pressure (1-3 % of the atmospheric pressure), and the water vapor is then cooled to freshwater by cold DOW after turning the turbine for generating electricity as shown schematically in Fig. 4.

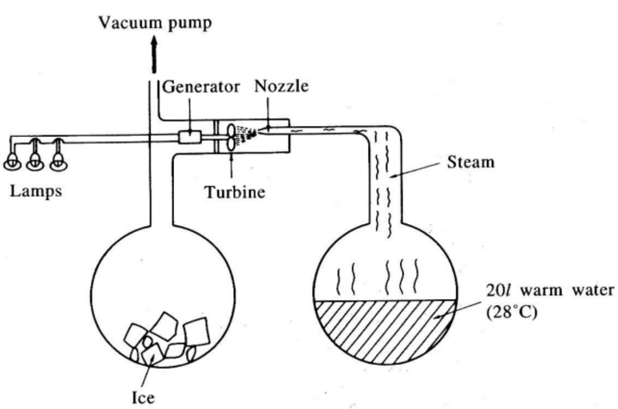

Fig. 4. Schematic diagram of ocean thermal energy conversion.

This is so the called open cycle, which produces freshwater as a by-product but the entire system becomes large in size (Fig. 5). The other system

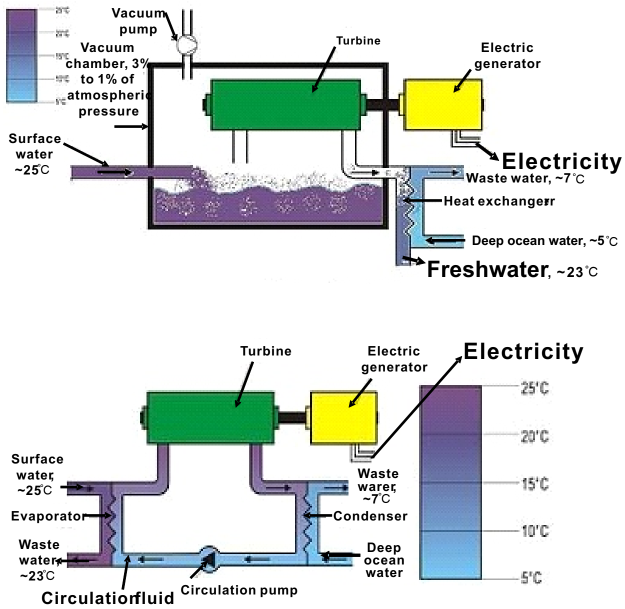

Fig. 5. Schematic diagrams of open cycle (above) and closed cycle (below) of OTEC systems.

is called the closed cycle (Fig. 5), in which a suitable circulation fluid such as ammonia is used for delivering energy, and an indirect freshwater production using the spray-flush system is also possible. The size of the closed cycle becomes small compared to the open cycle.

For the commercial operation of OTEC, a temperature difference of at least 20°C is required between the warm surface and the cold DOW. Then the low temperature water of below 10℃ is searched for OTEC operations in sub- and tropical oceans where warm surface water such as that at ~ 30°C is available.

Technology development of OTEC has been developed so as to increase the efficiency in generating electricity in the USA, Japan, Taiwan, France, South Korea (Kobayashi et al.). Increases in the efficiency of OTEC electricity generating system, in developing a more efficient heat exchanger for seawater, and in developing more economical way to pump up a large quantity of DOW are major hurdles for commercial OTEC operation. As a result, it is at stage of scaling up to the minimum commercial operation size of OTEC such as 5 mega watts (Ikegami 2011).

(b) Cooling electric generation power plants

Electric generation power plants have to be cooled using either air or water. In the water cooling, seawater or freshwater pumped up from near the surface is generally applied, and returns to the place where it is pumped after use with an increased temperature of ca. 7℃. Cooling water required for 1 million kW is about $40m^3.s^{-1}$ for the ordinary power plant and about $70m^3.s^{-1}$ for an atomic power plant (http://www.rist.or.jp/atomica/data/).

By changing the cooling water to DOW from the surface water, there are at least the following three advantages for power plant, which were evaluated by the five years research on applying a low temperature to cool an electric generation power plant as well as a variety of applications of DOW resources (http://www.nedo.go.jp/content/100096349.pdf).

The first is a large Δt due to the low temperature of DOW. Assuming the temperatures of DOW as 10℃, of surface water as 25℃, and of the waste water as 25+7℃ , Δt can be as large as 22℃ ((25+7) - 10 = 22). This indicates a great reduction of cooling water such as 7/22 of current requirement, which further proportionally reduces pumping energy as well as decreasing the size of the cooling system.

The second is an increase of generating efficiency of electricity due to the low temperature for cooling. An increase of 0.6 point for the existing plant and 1.2 point for new plants are expected.

The third is no bio-fouling in the entire cooling system over many decades and no suction of large organisms using DOW, which are serious problems associated with using the surface seawater.

There are several other advantages in the DOW applications such as application of the heated DOW for desalination and several other purposes, and fertilization of near shore environment by the nutrients contained in DOW.

The only disadvantage is the extra cost for constructing DOW pipe from subsurface deep depth compared to the near surface.

(C)Air-conditioning

The low temperature of DOW can be applied directly for air-conditioning. In conventional air-conditioning, an outside chiller cools the circulation fluid, and the cooled circulation fluid is then brought in the room for cooling the room air (Fig. 6, Takahashi 2011). In the DOW air-conditioning (SWAC, Seawater air-conditioning), low temperature of DOW directly cools the circulation fluid using heat exchanger (Fig. 6). Although conventional air-conditioning requires a large amount of energy for chilling, no energy is required for cooling in the DOW air-conditioning. The only energy required is for pumping up DOW and for the circulation of the fluid. Therefore, 60% to 90% of energy can be saved through the DOW air-conditioning compared to the ordinary air-conditioning.

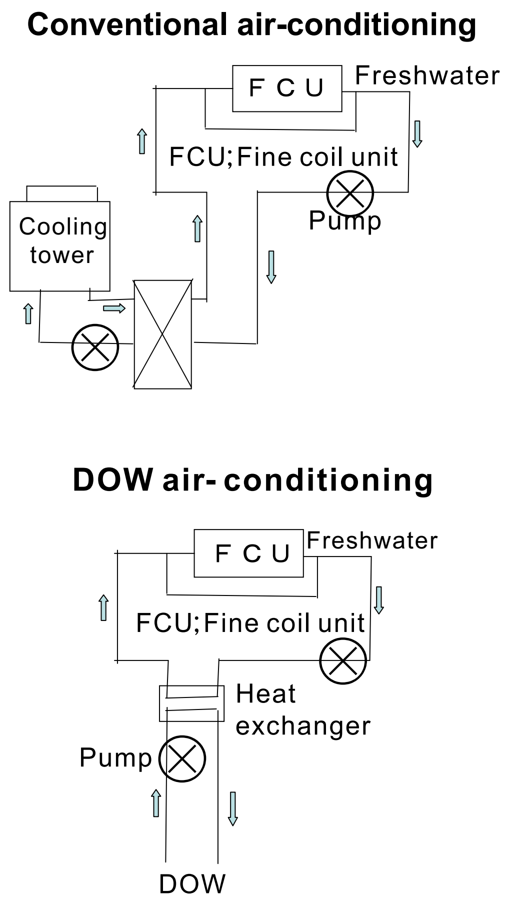

Fig. 6. Schematic diagrams of conventional and DOW air-conditionings.

In Taiwan's summer, about 40% of electricity generated is used for air-conditioning (Water Resource Agency, Taiwan 2005). Thus it will be quite a significant saving of energy if DOW can be widely applied for air-conditioning in a given society.

Low temperature lake water has been applied practically for air-conditioning in Cornell University since 2000 (Lake source cooling (LSC), http://energyandsustainability.fs.cornell.edu/) and for the city hall and several other large buildings in Toronto, Canada (http://en.wikipedia.org/wiki/Deep_water_source_cooling, http://www.economist.com/node/9065015). DOW air-conditioning was also applied for the main buildings in Kochi Deep Seawater Laboratory and in the Okinawa Deep Seawater Laboratory, both from 2000, as well as a NELHA laboratory building in Hawaii. The Taiwan Fertilizer Co. Ltd. is applying the DOW at 9 ℃ for cooling an office building with a savings of 77% in electricity energy in 2008. The Inter Continental Hotel in Bora Bora in French Polynesia has also been ooled by the SWAC system since 2006.

Although the LSC using freshwater can stop the pump for a prolonged time period and can apply an efficient aluminum heat exchanger, but the SWAC cannot stop the pump and requires a salt tolerant heat exchanger such as titan in order to avoid corrosion. Consequently, the SWAC is suitable in tropical climates where air-conditioning is required throughout the year.

(*d) Holding of fish and shellfish*

The cold temperature of DOW can be applied for holding cold water fish and shellfish species. Maine lobsters caught in the Atlantic North-East and Dungeness crab from the Pacific North-West of North America were transferred to Hawaii and kept alive in cold DOW for a prolonged time period for the markets in local and in Asian countries (http://konacoldlobsters.com/products.html). Cold water fish and shellfish caught locally and imported from Russia are also kept alive in cold DOW commercially in South Korea, because there are a large demand for fresh fish and shellfish in Korean society (Uh 2010). Snow crab (*Chionoecetes opilio*) is also kept in the cold DOW when they are caught in large numbers in Toyama. DOW has a great advantage in its cold and constant temperature for holding fish and shellfish as well as its cleanliness, although DOW might require bubbling air before application to saturate oxygen.

(*e) Cold aquaculture*

Cold DOW temperature can be applied for keeping adult animals of cold water species and for producing juveniles of those cold species (Fujita and Takahashi 2006). These species include coho salmon, Chinook salmon, Sockeye salmon, masu salmon, rainbow trout, bastard halibut, halibut, Japanese butterfish (H*yperoglyphe janonica*), alfonsino (*Beryx splendens*), Pacific cod, sailfin sandfish, Japanese pufferfish, abalone, ivory shell, Maine lobster, botan shrimp(*Pandalus nipponensis*), kuruma prawn (*Penaeus japonicus*), and sea urchin. Cleanliness of DOW is also advantageous for cold aquaculture as well as low temperatures. The cold temperature of DOW also makes it possible to culture cold water seaweeds such as kelp in sub-tropical and tropical conditions.Even though many species have been tested for cold aquaculture, only a limited numbers, including abalone, are run commercially due to the need to satisfy a positive cost-benefit.

(*f) Handling of fish and shellfish*

Food poisoning is a serious consequence of eating fish and shellfish particularly when these are raw. The Hygiene Council for Medicines and Foods in the Ministry of Public Welfare and Labor of Japan published the following guideline to prevent food poisoning on 18 May 2001 as follows; 1) keep fresh fish and shellfish below 10℃ all the time after catch, 2) use fish and shellfish as fresh as possible for processing, and use clean cold seawater, at least with the drinking water level or sterilized, or clean artificial seawater for processing, and 3) to keep the number of enteritis *Vibrio* cells less than 100 per gram of product.

Accordingly, the town of Rausu in Hokkaido constructed a clean and cold DOW supply system at the fishing port and the processing areas in 2007 (Takahashi and Yamashita 2005). About 4,500 m^3 of DOW of below 2.9℃ is pumped up from 350 m every day at Rausu and stored in 2,000 m^3 insulated reservoir tanks on pier. All fishing vessels load the DOW at pier before going out for fishing, and keep fish in DOW immediately after catch. The temperature of fish storage is kept below 10℃, adding clean ice if necessary. Processing fish at the pier is always under a cold clean condition controlled by the DOW.

(*g) Cold agriculture*

Many temperate and sub-arctic plants can be grown in tropical climate by chilling the roots

(Mitchell 1992). The basic theory of cold agriculture is that cold water passing through a PVC pipe system about 10 cm deep in soil chills the soil around the plant roots which makes it possible for some temperate plants to grow even in the tropical climate (Fig. 7). The Common Heritage Corporation

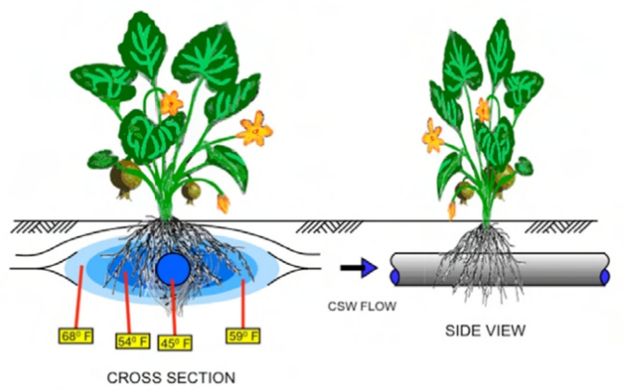

Fig. 7. Schematic diagram of cold agriculture (http://www.aloha.com/~craven/altaglla/html).

(CHC) conducted by Dr. John P. Craven at NELHA described the following three possible processes working in cold agriculture according to cultures of more than 100 temperate plants, including vegetables, fruits and flowers (http://www. aloha.com/~craven/altagllc.html). The first is chilling the roots of temperate plants under tropical climate. Since the leaves are not chilled, there is a large temperature difference between warm leaves and cold roots which can enhance the transport of fluids and nutrients to leaves, and result in enhancing growth. The second process is a supply of freshwater to the roots by condensation due to chilling in the soil. Water supplied by condensation supplies at least one-third of water required by the plant. The third process is a possible flow of nutrients in soil towards the roots by the condensed water flow.

Cold agriculture also has at least two additional advantages. One is that the growing period of a given plant can be controlled freely by controlling the root temperature. For example, grapes can be subjected into dormancy for a short time period by turning off the cold DOW supply to the root system after harvesting grapes every 120 days, and can then waken up by supplying DOW. Therefore, three crops can be obtained in one year. Another advantage is the capability of producing many sweet fruits due to the temperature difference between the roots and fruits (http://www.energinat.com/dow_cold.shtml).

1) -2 Inorganic nutrients

(a) Culture of seaweed and phytoplankton

DOW contains high concentrations of inorganic nutrients which are originally from decomposing organic matter, although most surface water contains trace concentrations of nutrients. Therefore, photosynthetic organisms such as seaweeds and phytoplankton can grow in DOW under light using those nutrients. As shown in Fig. 3, average concentrations of nitrate and phosphate in the Pacific Ocean are about 35 μM and 3.0 μM, respectively, at/below 1,000m, but lower than that at shallower depths. For example, DOW pumped up from 320m in Muroto, Kochi Prefecture, contains 12.1-26.0 μM of nitrate and 1.1-2.0 μM of phosphate. However nutrient concentrations in DOW are still low compared to the terrestrial agricultural field where chemical fertilizers of nitrogen and phosphorus are supplied, and the ground water in the vicinity of agricultural field often contains over the minimum permissible level of nitrate such as 10 mgN/l (ca. 700 μM).

Considering that 1 μM of nitrate approximately supports about 2 μg of chlorophyll *a*, a possible increase of chlorophyll a in the DOW of Muroto could be about 25-50 μg chlorophyll *a* per liter, and about 70 μg chlorophyll *a* per liter if the DOW from 1,000m in the Pacific Ocean is applied. Therefore, the maximum concentration of phytoplankton supported by DOW is not as high as a culture using high concentrations of nutrient such as more than 1,000 μg chlorophyll *a* per liter.

Seaweeds absorb nutrients from DOW supplied continuously as a flow through style rather than the batch style for phytoplankton, and then grow to a fairly large biomass without having nutrient limitations.

(b) Ocean fertilization

It is possible to fertilize the surface ocean by DOW if it is brought up and kept within the euphotic zone. However, it requires a fairly large quantity of DOW because the nutrient concentrations of DOW are not so high. OTEC and the cooling of electric generating power plants will probably be ideal operations to fertilize the ocean because a large quantity of DOW with increased temperature is discharged into the sea as a waste. Several estimations of fertilization effects by DOW were reviewed by Takahashi and Ikeya (2003).

1) -3 Freshwater

There are several ways to extract freshwater from DOW. Fig. 8 represents 2 approaches.

One is to use a reverse osmosis (RO) membrane filtration made of either cellulose or polyamide. Cellulose membrane stands for chlorine but is a little poor for separating organic matter; on the other hand, the polyamide membrane has the opposite characteristics. RO membrane removes more than 99.4% of salts, produces about 30% of freshwater and about 70% of concentrated seawater with a salinity of about 5%. DOW can be directly applied to the RO membrane filtration without any prefiltration, essential for the surface seawater, because of cleanliness, although it is ideal to raise the temperature of DOW to around 25℃ for increasing efficiency. DOW could save 20-40% for the space of the plant and 30-40% of the construction cost of DOW desalination compared to the desalination using surface seawater. Furthermore, running costs can be 76% compared to the surface water desalination.

The other is distillation under vacuum of 1-3% of the atmospheric pressure. In the open-system OTEC, freshwater will be produced automatically, and freshwater can also be produced by the closed-type OTEC applying the spray-flush system (Megesh 2010). The latter without OTEC has been operated in India.

Freshwater produced by the desalination mentioned above supplies a super clean product without contamination of any harmful materials and a good taste adjusted to the hardiness of water by the minerals extracted from clean DOW. The major hurdle for desalinating DOW for commercial operation is the construction cost for the DOW pumping system and the operating costs after that. However it could be solved in the near future due to current research on reducing the costs (http://www.kagakukogyonippo.com/headline/2011/06/03-2178.html), and a rapid increase of people's request for clean and tasty freshwater in the world.

Freshwater can also be obtained using the cold temperature of DOW by condensation where water in the atmosphere is extracted (See also "4.1)-1.(e) Cold agriculture")

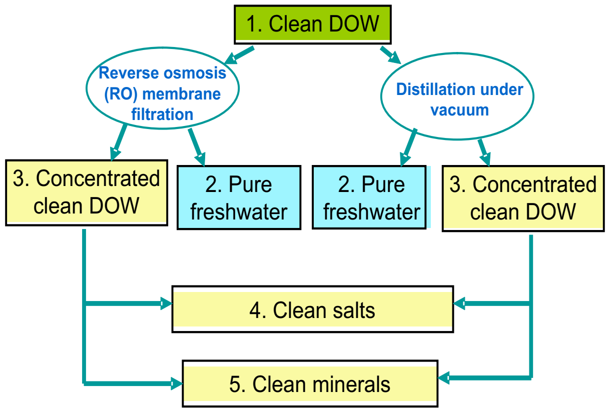

Fig. 8. Two processes for producing freshwater from DOW, and the resulted clean salts and clean minerals.

1) -4 Salts

Salts can be extracted from either DOW or concentrated DOW (Fig. 8). One of the obvious effects of DOW salts on foods and drinks is the reduction of the salty taste and minimizing bitter taste due to the combination effects of several different salts. This has been shown with the DOW salts, the DOW treated pickles, sweet jelly of beans, sweet stuffs and dried fish. Soybean curd made using DOW increased the sweet taste and smooth structure due to homogeneous gel formation. DOW increases the stability of noodles as well.

Since the composition and concentration of salts in DOW is not much different compared to the surface seawater, any seawater can probably be expected to have the same effects on salts as DOW. However, DOW is ideal for foods, drinks, and cosmetics because of its cleanliness compared to the surface seawater.

1) -5 Minerals

Seawater contains various minerals such as sodium, magnesium, calcium, potassium and so on, and the composition and concentration of minerals in seawater does not change much in space and time. However, DOW is advantageous for food, drinks, cosmetics and medical uses because of it cleanliness.

Minerals in DOW accelerate fermentation processes as well as making deep completion. Fragrance materials for Japanese sake, iso-amyl acetic acid, ethyl capron acid and ethyl capric acid, which determine the quality of sake, are all accelerated in production about by 30-70% by DOW (Fujita and Takahashi 2006). Each single addition of sodium, magnesium, calcium and potassium also stimulated some fermentation, but none of them reached the stimulation of DOW. A similar acceleration of fermentation was observed in beer, shoyu sauce, miso, bread, pickles and other foods and drinks, and is considered as resulting from a possible combination of effects of minerals in DOW.

The growth of human skin cells is also greatly stimulated by adding DOW into medium, which is also considered as possibly resulting from mineral effects in DOW (Ohta et al. 2002). DOW was used as a support for a medical treatment of atopic dermatitis (Nomura 1996). Accordingly, DOW is applied for thalassotherapy as well.

1) -6 Metals

Based upon the average concentration of each element in seawater shown in Table 1 and the total volume of seawater of 1.35x1018 m^3, the total quantity of each element contained in seawater was estimated (Table 4). Although most elements have a fairly low concentration in seawater, the total quantity of some elements, such as lithium, uranium, nickel and several others are higher than the land stock. Therefore, seawater could be a possible source for some metals if we develop on economical technology to extract them from seawater. DOW might be better than the surface seawater because of its cleanliness for extraction if large quantities of DOW are pumped up for OTEC, air-conditioning, ocean fertilization and other purposes.

Table 4. Total amount of elements in seawater estimated based upon the average concentration shown in Table 1 and the total volume of seawater (1.35 x 10^{18} m^3).

Element	Total (10^6 ton)	Element	Total (10^6 ton)	Element	Total (10^6 ton)	Element	Total (10^6 ton)
Cl	26,120,000,000	U	4,300	Re	11	Sn	0.7
Na	14,550,000,000	V	2,700	He	10	Ho	0.5
Mg	1,728,000,000	As	1,600	Ti	8.8	Lu	0.3
S	1,312,000,000	Ni	650	La	7.6	Be	0.3
Ca	556,000,000	Zn	470	Ge	2.4	Tm	0.3
K	538,000,000	Kr	420	Nb	<7	Eu	0.2
Br	90,000,000	Cs	413	Hf	4.6	Tb	0.2
C	36,000,000	Cr	271	Nd	4.4	Hg	0.2
N	11,700,000	Sb	270	Pb	3.6	Rh	0.1
Sr	10,500,000	Ne	216	Ta	<3	Te	0.1
B	6,100,000	Se	209	Ag	2.7	Pd	0.08
O	3,800,000	Cu	202	Co	1.6	Pt	0.07
Si	3,800,000	Cd	94	Ga	1.6	Bi	0.04
F	1,900,000	Xe	89	Er	1.6	Au	0.03
Ar	840,000	Fe	40	Yb	1.6	Th	0.02
Li	240,000	Al	40	Dy	1.5	In	0.01
Rb	160,000	Mn	27	Gd	1.2	Ru	<0.006
P	84,000	Y	22	Pr	0.9	Os	0.003
I	78,000	Zr	20	Ce	0.9	Ir	0.0002
Ba	20,000	Tl	17	Sc	0.9		
Mo	14,000	W	13	Sm	0.8		

Lithium and uranium have been selected to extract from seawater by chemical absorption (Yoshizuka and Kondoh 2011), in which no waste is produced. Although bio-remediation using bacteria can absorb mineral(s) at extremely low concentrations with much higher efficiency than the chemical absorption currently being investigated, feeding and collecting bacteria are major hurdles to be solved to apply bio-remediation for DOW.

1)-7 Others

There are several other resource(s) contained in DOW. Seawater contains about 40 μ M of refractory dissolved organic matter (DOM) throughout the water column. Refractory DOM separated from DOW has been recognized as controlling cholesterol by a test using mice. Bacteria containing some anti-cancer agent were also isolated from DOW. There are also other possible resource(s) from DOW which we have not found yet.

4.2. Multi-step utilization of DOW resources

Since DOW contains multiple resources and requires an expensive pumping system, it is better to use multiple resources in series once DOW is pumped up (Daniel 1992). Even a given single resource such as low temperature can be used with several steps requiring different temperature ranges in series.

Fig. 9 represents an example of multi-step

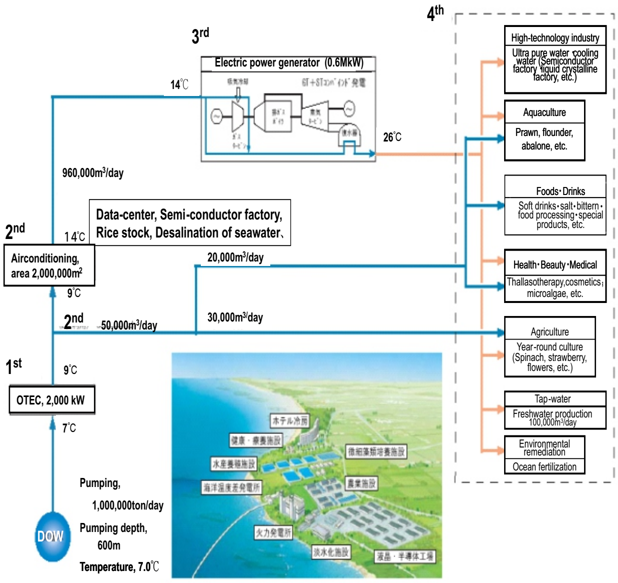

Fig. 9. An example of multi-step utilization of multiple resources contained in DOW.

utilizations of multiple resources contained in DOW which was proposed based on the five year research mentioned above (http://www.nedo.go.jp/content/100096349.pdf). In that research, one million tons of DOW of about 7°C per day is assumed to be firstly applied for the OTEC operation of 2,000 kW net-production (1st step application), and the 950,000 m^3 of DOW raised the temperature to 9°C is then applied for air-conditioning a 2 million m^2 as the second step application. The rest of 50,000m^3 per day of 9°C DOW is applied for cold agriculture (30,000m^3/day), and aquaculture, foods production and medical uses (20,000m^3/day) as the other second step applications. The heated DOW to 14°C of 950,000 m^3 is then applied for cooling a 0.6 million kW electric generating power plant as the third step application, which raises temperature to 26°C. The heated DOW can have various uses as the forth step application such as high technology industry, aquaculture, food industry, medical and health care, agriculture, tap water supply, and ocean fertilization. Based upon this scheme, there are many variations for actual practical applications of DOW resources in series.

Multi-step utilization can share the expensive cost of pumping DOW including the initial investment, and furthermore, it can minimize probable environmental perturbations due to resources remaining in the waste DOW or improve the quality of the surrounding ocean environment. Since DOW is low in temperature, many applications requiring higher temperatures can have benefits at the later steps with increased temperature.

5. Conclusion

There is no question that an increase of sustainability of our society is now the most essential subject in the world. One of our most urgent challenges is to change the non-renewable resources currently being used to renewable ones. DOW is a most promising renewable resource having a rapid renewable time such as a few to 1,000 years, and having a great variety of resources including energy and various materials. Many of DOW resources are fairly low in concentration, which have made it difficult for us to make actual applications. However, our knowledge and technology have now been developed for applying some DOW resources. It is necessary to make more efficient utilization of DOW resources, which will be an urgent subject.

Another hurdle for the application of DOW resources is the expensive construction costs of associated with obtaining DOW such as pumping facilities. This is because there has been no incentive of DOW until quite recently, and then there has been no challenge for improving the engineering connected with DOW. Therefore, technology development for obtaining DOW is another urgent subject.

DOW resources are renewable natural ones similar to solar radiation, and winds, wave power. Even all these natural renewable resources can not avoid possible environmental effects. We have to evaluate probable environmental impacts in order to minimize the effects. Several points related to the environment connected with using DOW resources have been reviewed by Takahashi (2011).

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