American Journal of Modern Energy
2022; 8(1): 1-5
http://www.sciencepublishinggroup.com/j/ajme
doi: 10.11648/j.ajme.20220801.11
ISSN: 2575-3908 (Print); ISSN: 2575-3797 (Online)

Okhotsk Sea Renewable Energy Options for Japan's Energy Import Diversification

Michael Berezkin, Oleg Sinyugin

Geographical Faculty, M. V. Lomonosov Moscow State University, Moscow, Russia

Email address:
sinyugin.oleg@yandex.ru (O. Sinyugin)

To cite this article:
Michael Berezkin, Oleg Sinyugin. Okhotsk Sea Renewable Energy Options for Japan's Energy Import Diversification. *American Journal of Modern Energy*. Vol. 8, No. 1, 2022, pp. 1-5. doi: 10.11648/j.ajme.20220801.11

Received: December 25, 2021; **Accepted**: January 20, 2022; **Published**: February 28, 2022

Abstract: In the end of 2010s decade Japan has declared a new policy direction to build a hydrogen energy based society. It should be a major component in full decarbonization strategy by 2050 in the framework of the Paris Greenhouse Agreement reached in 2015. Japan's economy is highly dependent on imports, especially in energy sector. Diversification of Japan's energy import represents a major problem, discussed in the article. In the same time significant renewable energy resources could be found just nearby at the Russia's part of the Sea of Okhotsk. The article views on the Sea of Okhotsk tidal energy potential, and background for the growth of hydrogen production and exports from Russian Far East using tidal energy. The authors consider both advantages and disadvantages of construction of Tugurskaya and Penzhinskaya tidal power plants on the Sea of Okhotsk coast. The work analyses the expected electricity production from Tugurskaya and Penzhinskaya tidal power plants, their possibilities to supply internal and neighboring East Asian market, and evaluates their opportunities to produce hydrogen through water electrolysis. The conclusion is that these tidal power plants can generate up to 4.2 million tons of hydrogen annually that would cover a significant part of the Japan's demand for hydrogen.

Keywords: Tidal Energy, Tidal Power Plants, Hydrogen, Hydrogen Economy, Renewable Energy Sources, Sea of Okhotsk, Japan's Energy Import

1. Introduction

Russian resources of tidal energy are concentrated mainly in several gulfs of Barents, White, and Okhotsk seas. The reserves of this energy are comparable with the river energy potential of the whole country's territory. The most of tidal resources are located in Sea of Okhotsk. So, their exploitable potential for Sea of Okhotsk is evaluated at 100 GW, for Barents Sea – 12 GW, and for White Sea – 8 GW.

The outstanding conditions of Sea of Okhotsk are caused by its unique natural conditions. The highest tides on the Earth (15.6-18 m) are observable on the Eastern coast of Canada. In Europe the highest tides take place on the Western coast of France. In Russia the highest tides are in Sea of Okhotsk' Penzhina Bay – up to 12.9, that are simultaneously are the highest ones for Pacific Ocean. The tides of Tugur Bay (Sea of Okhotsk' South-West) with 10.1 m are a little lower [9].

Constructions of even the simplest and light-powered tidal power plants (TPP) require an appropriate topography and sufficient tidal amplitude, but there are few places meeting these criteria. What about the abovementioned bays, they comply the all requirements for efficient building and exploitation of TPPs.

Different authors evaluate theoretical energy potential of the tide at 2500-4000 GW, that is comparable with the technical river potential (4000 GWh). Exploitation of tidal energy is designed now at 139 sites of the World Ocean with the expected production of 2037 TWh annually, or some 8% of the present world electricity consumption [6].

By now there have been built some two dozen TPPs of different capacities, particularly in France, Great Britain, Ireland, Norway, Canada, US, South Korea, and several micro-TPP in China.

The largest TPP in the world of 254 MW was built in 2011 in South Korea; the previous leader had been France with 240 MW plant in La Rance river.

At its time former USSR was among the first to build TPPs. In 1968 it built Kislogubskaya TPP on the Barents Sea coast in Murmansk region. The initial capacity was 0.4 MW, that was increased up to 1.7 MW being modernizes in 2000-ies.

In the recent years Russia has successfully tested the floating technology of building (for example the protection dyke in St. Petersburg) that accelerates works by 1.5-2 times and cuts costs by more than 30%.

The Russian technologies of water-proof and frost-resistant concretes are also important. They were proved by more than 40-year exploitation of Kislogubskaya TPP.

Russian Far East that is washed by Sea of Okhotsk is a knot transit region connecting Europe and Russia with South-East Asia, Japan and Australia. Despite the significant regional problems, the development of the Eastern regions is a priority in Russian policy [13].

The best way for development of this region is its economic conversion through major projects with both government expenditures and foreign investments as the sources of funding. Construction of the large-scaled TPPs for production of hydrogen through water electrolysis with its subsequent export can be the projects of this type.

Comparison of the designed TPPs and the existing Russian power plants energy potential shows that tidal plants even provided their full-scale work wouldn't complete all energy tasks.

Nevertheless, evaluation of already-present projects displays that only TPPs can solve essential energy and environmental problems of the remote and energy-deficit North European and Far Eastern regions of the country.

Use of tidal power enables to engage the principal energy's advantage, such as continuity of monthly mean potential in both a seasonal and a perennial period for maintenance of efficient and balanced co-working with power plants of different types, including hydrogen production [17].

2. Tugurskaya TPP

The choice of Tugur Bay for a TPP construction was based on the previous reconnaissance and hydrological observations that were made as early as 1980-ies. They enabled to define that natural conditions of the bay are advantageous for use of tidal energy.

The Bay's topography and geology are essentially ideal for these aims: it's a spacious bay with the narrowing in the center and the following widening. Resources of construction materials are substantially in the same place. The principal argument for a TPP specifically in Tugur Bay is that it is protected by the string of Shantarskyie islands from the Sea of Okhotsk' heavy ices.

The designed place for Tugurskaya TPP construction (figure 1) is Tugur Bay in the Sea of Okhotsk' South-West. The conditions of the Bay enable to build a TPP of 8-11 GW capacity and 30-40 TWh annual generation at the capacity factor 0.4 [7].

The project has also a significant export constituent. As this electricity production volume is overmuch for internal consumption, a considerable part of electricity can be either deliver directly to the East Asian neighboring countries: China, Korea, and Japan or used for hydrogen production. For example, 30-40 TWh enable to produce some 3.9 - 4.2 million tons of hydrogen per year at a cost price of about $2/kg hydrogen, that can be exported into East Asian markets.

Proximity of the potential consumers plays a key role: distance from the Bay is 600 km to Khabarovsk, 980 km to Yakutsk, 1100 km to Harbin, 1200 km to Sapporo, and 1900 km to Seoul.

By now there has been designed also a TPP of smaller capacity – 3.5 GW, with the annual production of 14 TWh [2].

3. Penzhinskaya TPP

In Penzhina Bay, where Kamchatka Peninsula connects with the mainland, the record tides take place. Water raises there by 9-13 meters on the area of 21,000 sguare km. The volume of inflowing water is 500 km^3 a day. For comparison, Volga the river pushes the same volume through its hydro dams in 2 years.

It is expected that capacity of a TPP with the dam in Penzhina Bay can amount as much as 100 GW. Now the largest hydropower plant (HPP) in the world Three Gorges in China has 22 GW, and the largest in Russia Sayano-Shushenskaya HPP has only 6.4 GW. By now there has been designed a project of Penzhinskaya TPP on the Sea of Okhotsk' coast, consisting of two parts: Northern Cross Section of 32.3 km wide and Southern Cross Section of 72 km wide.

The Northern Cross Section has a designed capacity of 21 GW, and the Southern one – of 87.4 GW (figure 1). If implemented, the Penzhinskaya TPP project will become the largest in the world. Dependently on the dam location annual electricity production will amount from 100 up to 400-500 TWh (the largest option means as much as almost a half of all electricity, produced in Russia now), that will enable to generate up to 10-12 million tons of hydrogen.

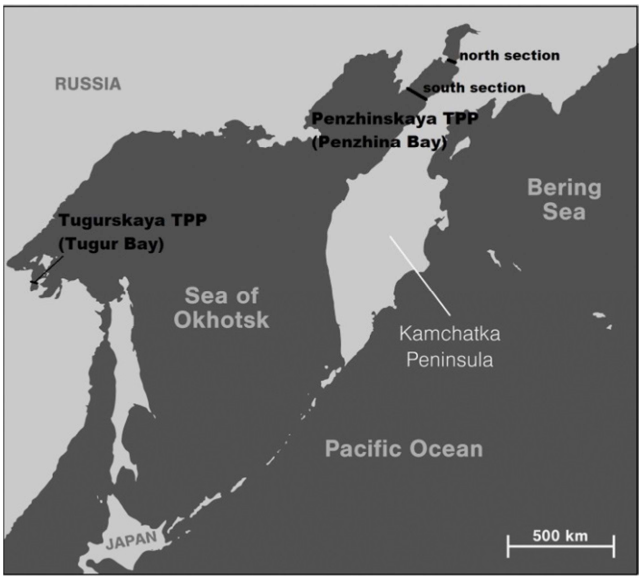

Figure 1. *Locations of Tugurskaya and Penzhinskaya TPPs.*

Besides their unique capacities, the key advantage of the Sea of Okhotsk' TPP projects is their environmental friendliness, including:

1) fuel-less electricity sources with zero emissions of greenhouse gases;
2) absence of radiation hazard;
3) a TPP dam almost doesn't obstruct plankton move; when passing a TPP dam only 5-10% of plankton dies, when at a HPP – 83-90%;
4) influence of emergency situations such as earthquakes, breakdowns, acts of military nature etc. doesn't jeopardize the adjacent inhabitants;
5) a TPP doesn't lower salinity of water, that is very important for the sea fauna.

At the same time, TPPs has also a significant minus, connected with high investment costs. Nevertheless, they have already matched with those for HPP and are within $1000 per kW, and their operation costs are the lowest.

It can be seen in the example of La Rance TPP in France, where operation costs were $0.023/kWh against $0.028/kWh for HPP, $0.043/kWh for fossil fuel plants, and $0.033/kWh for nuclear plants [6]. This difference in favor of TPPs will grow further.

Usually these projects have also two principal problems:

1) discontinuity of tidal energy;
2) transportation of energy to consumers that in the most cases requires high additional expenditures for building trunk lines;

A way to solve the first problem could be building of a pump-storage hydro plant (PSHP) that would balance electricity production. Topography of the area around Tugur Bay suits for construction of a PSHP with a sufficient vertical drop. This approach implies a TPP-PSHP tandem with capacity of 1.4 GW and production of 12.2 TWh per year. The same conditions are around Penzhina Bay.

A way to solve the other problem is cutting transportation costs through placement of a consumer at the same place. Hydrogen production through electrolysis that requires much electricity is that meets these criteria. Besides that the experience of liquefied natural gas transportation is applicable for analysis of possibilities for hydrogen sea transporting.

4. Hydrogen Economy Plans and Problems

In recent years, interest in the hydrogen economy has soared, and several countries have announced plans to multiply their hydrogen consumption. Hydrogen is viewed as an environmentally friendly carbon-free energy carrier, and development of hydrogen economy is viewed as a way to decarbonize and reduce resource consumption [1].

The possibilities of using hydrogen as an environmentally friendly energy carrier and for energy storage have been discussed with varying degrees of intensity since the 2000s. The rise in interest in this topic - both of experts and scientific community - is associated with the concept of a carbon-free economy put forward to date and the prospects for introducing a carbon tax. In accordance with this, the so-called green and blue hydrogens are considered the most popular, the production technologies of which imply zero greenhouse gas emissions into the atmosphere: electrolysis using energy from renewable sources in the first case, steam reforming of methane with CO_2 capture - in the second [11].

At the same time, hydrogen economy has a fundamental problem – unlike fossil fuel or the most of renewable sources, hydrogen is not a primary energy carrier. It can be only extracted from other chemical entities. Today's annual demand for hydrogen is evaluated as 116 million tons [16], including 74 million tons for pure hydrogen, and 42 million – hydrogen in mixture with other gases for heat and electricity production. Some 75% of hydrogen are produced through methane conversion, 23% - from coal, and only 2% - through water electrolysis.

Gas and coal conversion leads to growth of carbon dioxide emissions. Electrolysis of water could theoretically be considered as an "environmentally pure" way, but it requires a lot of electricity, most of it (some 65%) in the world is produced at coal and gas plants, so really it also would increase the carbon footprint. Besides that, production of 1 ton of hydrogen through electrolysis takes some 40-50 MWh of electricity while energy value of produced hydrogen is less – some 36 MWh [10].

So, wide use of hydrogen and cardinal growth of its production matches an almost impassable environmental and technological handicap [3].

The only way to develop environmentally friendly hydrogen economy is its connection to renewable energy. It includes production of hydrogen: 1) through water electrolysis; 2) with use of electricity, generated on renewable (hydro-, wind, solar, tidal, geothermal etc.) plants.

In its turn, renewable industry that matches instability of electricity production requires hydrogen as an effective energy accumulator. So, the best situation for hydrogen production is presence of large and relatively cheap renewable sources of energy.

In Russia there are regions that could make space for hydrogen production and exports to East Asia and West Europe, where the large-scale plans to increase hydrogen consumption face deficit of green energy facilities [8].

In August 2021 Russian Government accepted Conception of Hydrogen Energy Development in Russia [4]. Inter alia it notices the following competitive advantages of Russia in connection with hydrogen production, including: 1) strong energy potential together with a large volume of under-loaded capacities; 2) large experience in hydrogen production and strong scientific-and-engineering background; 3) vantage geographic location (closeness to the principle export markets) of the territories that have higher renewable energy potential.

5. Japan's Energy Import

Japan at the end of 2017 accepted the Hydrogen Strategy up to 2050. According to the strategy Japan purposes not only produce but also import hydrogen. Before the Fukushima disaster in 2011 Japan had had almost continuous trade balance surplus, but thereafter sharp growth of fuel imports almost every year lead the trade balance of Japan into a negative zone.

93% of Japan's primary energy needs are covered by imports [14]. Of the 15 billion m^3 (1.35 million tons) annually consumed by industry in Japan, almost 70% is accounted for by oil refining, and the rest - by the production of ammonia and petrochemicals.

LNG, coal and oil currently account for 89% of Japan's primary energy supply. It is expected that by 2030 the share of fossil fuels will decrease to 56%, and in the long term, the transition from coal to natural gas will be carried out, and by 2030 the share of renewable energy sources in electricity production will be 22-24%.

Japan's Hydrogen Strategy since 2017 has focused on reducing the cost of producing and purchasing hydrogen with the goal of achieving an 80% cost reduction by about 2050, making hydrogen fuel competitive with natural gas. The current price of USD 0.90/m^3 ($10/kg) is expected to be reduced to $0.17/$m^3$ ($1.9/kg) in the long term. Japanese market for hydrogen equipment and infrastructure could reach approximately $10 in 2030 and $75 billion in 2050 [15].

In the Far East of the Russian Federation, a large-scale resource of tidal energy of the Tugur Bay with a capacity of 8 - 11 GW is allocated, which corresponds to the production of 3.9 - 4.2 million tons of hydrogen per year at a cost price of about USD 2/kg hydrogen. The Tugur project can become an important component in the diversification of Japanese energy imports. With the successful implementation of this project, it is possible to use a larger-scale tidal energy resource of the Sea of Okhotsk - the Penzhinsky Bay with a capacity of 21 - 87 GW (potential hydrogen production 8 - 33 million tons of hydrogen per year).

In this case Russia due to implementation of the TPP projects in Sea of Okhotsk could cover a considerable part of perspective Japan's hydrogen demand.

6. Conclusion

To avoid a "carbon footprint" development of hydrogen economy requires a cardinal growth of renewable plant capacities. In its turn, renewable industry that faces instability of energy inflow requires hydrogen as an efficient energy accumulator. The best situation foe hydrogen production is the presence of relatively cheap and strong renewable energy sources [5].

The Government of Russian Federation in October 2020 approved the Action Plan ("road map") for the development of hydrogen energy up to 2024 [12]. The purpose of the implementation of this plan is to increase production and to expand the areas of application of hydrogen as an environmentally friendly energy source, as well as the country's achievement of leading positions in the world in its export. The task of developing hydrogen energy is also set in the Energy Strategy of the Russian Federation for the period up to 2035. According to this document, the export of hydrogen from our country should reach 2 mln t per year [13].

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This quantity of 'green' hydrogen could meet the East Asia demand in a long term. Besides that, it's possible to transport hydrogen by sea, that is the cheapest transportation way.

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