Liquefied natural gas (LNG) and DC electric power transfer system by cryogenic pipe of superconducting DC power transmission (SCDC)

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Abstract. We propose a hybrid energy transmission pipeline that combines the liquefied natural gas (LNG) cryogenic pipelines and superconducting direct current (DC) electrical power transmission cable system (SCDC). The system design is based on experimental data from the SCDC Ishikari project in Japan and related laboratory experiments. The particular structure of the hybrid cryogenic pipe connects the thermal radiation shield of the pipe that contains the DC high temperature superconducting (HTS) electrical cable to the LNG pipe and significantly reduces the heat leak into the SCDC pipe. Because the specific heat of LNG is higher than that of liquid nitrogen and the LNG transfer rate is quite high, the thermal loss of the SCDC cable becomes only 1/100 that of present-day conventional copper cables, far below the factor 1/10 reduction achievable by a stand-alone SCDC transmission lines. The LNG temperature rises by less than 2 K over a 100 km transport distance, which is negligible in actual use. LNG also saves significantly on pumping power compared to a natural gas pipeline. To liquefy the LNG at cryogenic temperature from natural gas at ambient temperature requires a large refrigerator that consumes enormous power. The gas pipeline, however, needs a compressor to produce high-pressure gas, which also consumes a massive amount of power. Due to these considerations, the proposed hybrid system is a viable design for the long-distance joint transportation of LNG and electricity.

1. Introduction
This century's energy trend is going to use electricity much more [1] for many reasons. For example, the trains initially used coal as the fuel, but it is electricity entirely now. Home and office increase in spending electric power for many purposes from the past few decades, and their consumption of electricity will be increasing. The electric vehicle (EV) is a trend of the automobile, and the fuel is changing from gasoline to electricity. These are demand sides, but the supply sides are also going to generate electricity. Renewable energy (RE) is a significant trend now, and it is one of the primary energy sources now. The RE cannot produce the oils and coals and only generate electricity. Therefore, both the supply and demand sides are going to electricity, and this trend will reduce CO₂ emission significantly. Thus, the electric transmission is an essential energy transfer system in this century.
Simultaneously, the share of natural gas (NG) has been increasing in the world energy market in the past few decades because it is one of the clean energies, and its CO$_2$ emission is lower than the coal and oil power systems. Moreover, the shale gas and oil technology are improved, and their reserves are more significant than those of conventional reserves. It is critical to change the world trade and economy after 2010. Thus, NG can keep considerable parts of the energy market in the early phase of this century. At the same time, the liquid natural gas (LNG) also used in many countries, EU countries, China, Japan, Korea, and the USA because of the transportation issue. This is also an energy trend in this century.

The superconducting power transmissions were developed in the past 20 years [2-5] in the world, and the performance of the superconducting DC power transmission (SCDC) is improved significantly [6-8]. The engineering merits of the SCDC are listed as follows

- Low loss because of no electric resistance and low heat leak to the cryogenic system;
- Environmentally friendly because the SCDC cables are small system and set underground;
- Low voltage, large current, and high current density system because the resistance of the wire is zero, and as a result, it is a smaller energy transfer system than the existing power grid.

SCDC can connect the power station to the distribution substation directly because its voltage is not high. Since the maximum voltage of the present grid is AC 500 kV in Japan [9] and to AC 1000 kV in China, we need to use the ultra-high voltage substation, high voltage substation in the electric network to reduce the loss of the electric transmission. The costs of the ultra-high substation and high voltage substations are not cheap, and they need a wide area to build. On the other hand, the design voltage of the SCDC is ±25 kV [8, 10], and therefore the power stations can be connected to the distribution substations directly. But the transmission power is 500 MW in the standard design, and the same as the present high voltage direct current power transmission (HVDC). Therefore, we can omit the ultra-high voltage substations, the primary and the secondary substations from the existing grid. We will build SCDC underground usually, and therefore it is a safety system for bad weather and lightning. Reference [10] is the report of the feasibility study for the technology and the economy, and to estimate the capital cost and their related technological and economic subjects to install the SCDC, and the construction cost of the SCDC is only 1.5 times higher than the existing grid in Japan [9]. The cost will be lower in the future because of the advances in technology. This is the fundamental reason why the SCDC will be cheaper than the present transmission line, and we can expect the merits of low cost and high safety.

Heat leak of the cryogenic pipe from the ambient temperatures is a major loss of the SCDC, and its reduction is the critical technological issue to keep low temperatures. If the heat leak is high, the refrigerator's electric power consumption is high, and the merits of the SCDC will be lost. Its power consumption will higher than the Ohmic loss of the copper cables. Therefore, this subject was a fundamental problem of R&D [2, 6, 11, 12] in the past 20 years. The target value of the heat leak of the cryogenic pipe was set 1.0 W/m for round trip circulation in the 1990s, but it was not a secure target value until the 2010s. Besides, we should pay attention to the hydraulic loss of the cryogen circulation, too. Because of these problems, we did not use the corrugated pipe and bellows pipe entirely to reduce the heat leak and the hydraulic loss from the early stage of the research [2, 13].

Fortunately, the experimental data reached the target value in 2017 [7], and this was done during the Ishikari project [6]. We continued the basic research of the heat transfer of the cryogenic pipe after the experiment in Ishikari and found several ideas to reduce the heat leak lower than 1.0 W/m in the laboratory. This proposal depends on these experimental data, new ideas, and analysis [14]. These experimental data and analysis are the basis of a long SCDC and the proposal of the paper. Eventually, the design study of an ultra-long SCDC showed that the cooling station's distance exceeds 100 km [8, 10]. The improvement of the thermal insulation of the cryogenic pipe depends on the radiation shield [6] and the surface process of the cryogenic pipe [15] mainly, and it also depends on a unique design and procedure of the cryogenic pipe structure, the knowhow to use the multi-layer insulation (MLI), and the support of the GFRP inside the cryogenic pipe. These are quite different from other superconducting cable experiments [3-5, 16].
In the paper, we propose the transmission system of electricity and the LNG in the same cryogenic pipeline. We apply the low heat leak technology not only to the SCDC but also to the transfer line of the LNG. Since the temperatures of the superconducting cable and the LNG are as low as the boiling temperature of methane at 0.1 MPa, we have several merits to combine two systems of the SCDC and the LNG pipeline technologically. One of the benefits is to be able to reduce the heat leak to the cable pipe. It improves the efficiency of electric power transmission. Our estimation indicates the loss of the SCDC will be ~1/100 of the present AC grid. When we apply the low heat leak technology of the cryogenic pipe to the LNG transmission line, the LNG transfer power will be the lowest. Its power is lower than the transfer power of the natural gas because the liquid transfer power is lower than gas transfer power usually.

Similar proposals to combine the LNG transfer pipe and the superconducting power transmission were published [17-20], but they did not discuss with the heat leak of the cryogenic pipe, the pressure drop of the pipe for the circulation of the cryogen and finally the length of the transmission line. But our proposal includes these estimations, depending on the experimental data in Ishikari and the analysis. Since the gas component of the LNG is methane (CH₄) mainly, our calculation uses the parameters of CH₄, instead of the LNG.

We mention the proposal, the superconducting cable system, and the LNG pipeline in section two. We discuss the fluid thermodynamic estimation of the superconducting cable and LNG transfer system in section three and the evaluation of the natural gas transfer rate and its electric power consumption in section four, and finally, we describe the conclusion in the last section.

2. Proposal of hybrid transmission line and its design parameters

Table 1 lists the parameters of the hybrid pipeline of the proposal and the experiment in Ishikari project. Figure 1 shows the cross-section of the hybrid pipeline, one of the design proposals. There are three inner pipes, and two of them include the superconducting (SC) cables inside, and the last one is the LNG pipe. They are separated from each other thermally because LNG temperature and two SC cables are different. The LNG pipe is connected with the radiation shield [6] thermally.

|                         | Outer size, mm | Inner size, mm | Ishikari project, outer size, mm |
|-------------------------|----------------|----------------|----------------------------------|
| LNG pipe                | 267.4 (250A)   | 260.6          | -                                |
| Cable pipe              | 89.1 (80A)     | 84.9           | 76.3 (65A)                       |
| Outer pipe              | 457.2 (450A)   | 448.2          | 318.5 (300A)                     |
| Radiation shield        | 375            | 373            | 216 (equiv. 200A)                |
| Cable                   | 43.5           | -              | 40                               |

The radiation shield is critical to reducing the heat leak to the cable pipes from the outer pipe. The outer pipe is the vacuum chamber for the inner pipes, and the vacuum degree should be lower than the order of 10⁻³ Pa to keep thermal insulation. Its temperature is ~300 K usually. Besides, the multi-layer insulation (MLI) is to wind three inner pipes and the radiation shield. It is quite useful to reduce the heat leak, and the MLI and its winding method are the key technologies to establish the system. The cable pipes are also covered by the MLI to reduce the heat flux from the LNG pipe. But since the temperature difference between the LNG and the cable pipes is ~40 K, the number of MLI layers is 5 to 6. The inside surface of the outer pipe is coated by zinc to reduce the emissivity of radiation power. It is beneficial, and the standard technique [15]. The vacuum pumps set along the pipeline, and the distance between the pump stations is ~10 km from the experimental data of the Ishikari project [21]. One of the residual gases in the vacuum is hydrogen because the iron pipe emits the hydrogen from the bulk. Therefore, we need the hydrogen pumping system.
The LNG temperature is lower than 110 K. The refrigerator's output temperature for the cable pipe is as low as 70 K, and the liquid nitrogen (LN2) is the cryogen for the SC power cables. The pipes material of the LNG and the cable pipe is stainless steel (SS). We connect the bellows pipes to the inner pipes to absorb the thermal shrinkage of the internal pipes. This structure is one of the standard designs of the previous studies [2, 12, 13]. If we use a larger LNG pipe, we can transfer the LNG much more. The heat leaks of the inner pipes are significant heat load for the refrigeration system. There are two physical processes of the heat leak. One is the radiation process, and the MLI is a superior technology to suppress the heat leak. Another is the thermal conduction of the support legs. Therefore, we should choose the low thermal conductivity material for the support leg carefully.

Two SC cables are set inside the cable pipes (see figure 1). Figure 2 shows the cross-section of the cable and is one of the designs of the cable. The structure is one of the co-axial cables, but it is not a usual co-axial cable because the current of the inner HTS layer is two times higher than that of the outer HTS layer. We will use the cable for the bipolar metallic return circuit, and three cables are usually necessary. In order to make a simple cryogenic pipe, we use two proposed cables for the same electric circuit. The outer HTS layers of two cables are connected in parallel and to the ground on the one side. The inner HTS layer is connected to the positive and negative high voltage from the power converter, and insulated from the ground. The significant difference between the copper cable is the voltage. Since we use the SC cable, we do not need to use high voltage. This is an essential character of the SC power cable because we can use a low or medium voltage system for the transmission line in the grid.

Figure 1. Cross-section of hybrid energy transmission line.  
Figure 2. Cross-section of SC cable.

The insulation voltage of the cable is 25 kV. Since the inductance of two HTS cables circuits is not low as a usual co-axial cable, the new cable can suppress the short circuit current. It is crucial to design the transmission line, including the power converters, the circuit breakers for safety instruments, and their cost.

The critical current of the inner layer is 14.6 kA. The material of the insulator is polypropylene laminated paper (PPLP) or the craft paper. Since the critical current of the outer layer is higher than 7.4 kA, the outer layer's current is almost half of the inner layer's. Therefore, we should connect two
outer layers of the cables in parallel, and the current capacity of two outer layers is the same as the inner layer (see figure 3). The diameter of the cable is ~43.5 mm.

Figure 3. Back-to-back electric transmission circuit of two SC cables.

Figure 3 shows the electric circuit of the SC cables and the power converters. The AC/DC and DC/AC power converters are connected with both ends of the cables, and they are connected to the AC grids. This DC circuit system is named the bipolar metallic (or superconducting) return circuit and called "Back-to-back (B-to-B)" and used all over the world, especially in the high voltage DC power transmission line (HVDC) and the ultra-high voltage DC power transmission line (UHVDC). The voltages of the HVDC are 200 kV to 1100 kV for the normal conductors (copper and aluminum), but the proposed voltage is ±25 kV. Because the cable resistance is zero, it is not necessary to use a high voltage system to reduce the loss. The outer layers of two HTS cables connect in parallel and to the ground on one side. Since the rated current of the SCDC is 10 kA, we can transfer the electric power of 500 MW. Therefore, the size of the substation will be smaller than the usual HVDC's. It is one of the essential merits of the proposal for the electric power transmission because we can omit high voltage substations from the grid [10].

Figure 4. Temperature dependence of the critical current for Bi-2223 and RE-123 HTS tapes.

Since the radiation shield is used to reduce the heat leak to the cable pipe, we can save the refrigerator's freezing capacity for the SC cable. The electric power consumption of the refrigerator is the major loss of the SCDC, and its power consumption of the proposed system will be 1/10 of the standard design of the SCDC [7, 10]. As the loss of the usual SCDC [7, 10] is 1/10 of the typical AC power grid cable loss, the loss of the proposed SCDC will be 1/100 of the cable loss in the present AC
grid finally. This is the fundamental merit of the proposal. We will set the cryogenic pipe underground, and two pipes surround the SC cable; one is the inner pipe, and the second is the outer pipe, connected to the ground electrically. Therefore, the SC cable is free from the lightning strike from the sky directly. It can also be a safety system against the serious weathers and the earthquake because of the underground setting. Finally, it is a safer system than the HVDC using the overhead headlines.

The critical current of the HTS is defined at the current of the electric field = 1.0 µV/cm, and it depends on the temperature. We have two candidates to use the HTS tapes. One is Bi-2223, and the other is Y(RE)-123 HTS tape. Figure 4 shows the temperature dependence of the critical current for these two HTS tapes [22]. This is normalized at 77 K. Therefore, the critical current is high at low temperatures. The temperature profile depends on the heat leak and pressure drop of the cable pipe, and it is discussed in the next section.

Finally, Table 2 shows a summary of the parameters of the electric power transmission line. The rated current of the transmission line is 10 kA, and the critical current of the SC cable is larger than 14.5 kA at 77 K. If the temperature is 70 K, the critical current is ~21.5 kA if we use the Bi2223 HTS tapes. The electric converter's circuit is bipolar metallic return, and the DC transmission line is connected to the AC grids at both ends. The rated voltage is ±25 kV; therefore, the transmission power is 500 MW. It is the typical transmission power of the HVDC.

| Table 2. Summary of the electric power transmission line. |
|-----------------------------------------------|
| Value | Comment |
| Rated current, kA | 10 |
| Rated voltage, kV | ±25 |
| Transmission power, MW | 500 |
| Critical current, kA | >14.5 | Critical current at 77 K |
| Configuration | Metallic return |

3. Fluid thermodynamic estimation of the superconducting cable and LNG transfer system

The refrigerator and the circulation pump are necessary to use in the cryogenic system. The temperature of the SC cable should be controlled from 70 K to 77 K, and LN2 is circulating in two cable pipes. The electric power consumptions of the refrigerator and the pump are the major losses of the SCDC, and we should minimize the heat leak to the cable pipe. The pump power is smaller than that of the refrigerator, and we can neglect it usually for the short distance pipeline. The LN2 temperature is 70 K at the inlet of the cable pipe, and the temperature profile along the pipeline is estimated by the heat leak to the cable pipe and the flow rate of the LN2 substantially. The radiation shield is connected to the LNG pipe thermally, and its temperature is ~110 K. A similar structure of the radiation shield was applied in the Ishikari project [6], and the heat leak of the radiation shield is estimated from the experimental data of the Ishikari project and the related experiment and its analysis in the laboratory. Table 3 shows the size and heat leaks of the pipes and the radiation shield. Since the radiation shield is covered the LNG pipe entirely and the temperature of the radiation shield is the same as the LNG pipe, the heat leak of the LNG pipe is zero here.

| Table 3. Size and heat leaks of the pipes and the radiation shield. |
|-----------------------------------------------|
| Inner diameter, mm | Outer diameter, mm | Heat leak, W/m |
| LNG pipe | 260.6 | 267.4 | - |
| Cable pipe | 84.9 | 89.1 | 0.05 |
| Radiation shield | 373 | 375 | 0.90 |
| Cable | 39 | - |
Table 4 shows the calculated thermo-hydrodynamic parameters of the hybrid pipeline. The length of the pipeline and the LN2 flow rate are input parameters, and the heat leaks of the cable pipe and LNG pipe are estimated to be 0.05 W/m and 0.9 W/m, respectively, from the experimental data of the Ishikari project and the related experiments and analysis. The inlet pressure of the LN2 is 1 MPa, and it is available to use the present circulation pump. Therefore, if we use a higher inner pressure pipe for the LNG transfer, we can extend the pipeline distance. The component gases of the LNG and NG are methane (CH\(_4\)) and ethane (C\(_2\)H\(_6\)), and the ratio of the gases depend on the production area of the gas field. We assumed that the LNG is methane 100%. The boiling temperature of methane is 112 K at the pressure of 0.1 MPa, and therefore we assume that the temperature of the LNG is lower than 110 K at the inlet of the pipeline.

| Table 4. Thermo-hydrodynamic parameters of the proposed hybrid pipelines. |
|-------------------|-------------------|-------------------|
| Option 1          | Option 2          |
| Length, km        | 50                | 100               |
| LN2 flow rate, L/min | 40                | 40                |
| LNG flow rate, kg/s | 96.2              | 67.2              |
| Pressure drop (cable pipe), MPa | 0.43             | 0.86              |
| Pressure drop (LNG pipe), MPa | 0.80             | 0.80              |
| Temperature difference (cable pipe), K | 2.2              | 4.4              |
| Temperature difference (LNG pipe), K | 1.0              | 1.9              |
| Heat leak (cable pipe), W/m | 0.05             | 0.05              |
| Heat leak (LNG pipe), W/m | 0.90             | 0.90              |

Figure 5 shows the schematic structure of the hybrid pipeline. The directions of the LN2 flows are opposite in two cable pipes for the circulation. The refrigerators are necessary to cool the LN2 located at each end of the cable. Two cooling stations have the refrigerator, the circulation pump, the control and the monitor system, and the terminal cryostat at the end of the cable, individually. The cooling capacity of the refrigerator is 5 kW for each, and the LN2 temperature from the refrigerator is 70 K. The standard design of the refrigerator power is 50 kW of the cooling capacity for the 100 km SCDC [8], but the cooling capacity is 5 kW at 70 K in the proposed system. It is 1/10 of the usual design of the SCDC because of the radiation shield. Therefore, the loss of the SCDC is 1/10 of the standard
design [7, 9, 10]. If we use the temperature of LN2 up to 77 K for the cable pipe, we can extend the length of the pipeline to 150 km. Furthermore, since the cost of performance (COP) of the refrigerator for LNG is higher than the COP for LN2, we can save the electric power consumption. This merit is fundamental to combine the LNG pipeline in the same cryogenic pipe system, shown in figure 1.

If we use a larger pipe and pump system to transfer the LNG, the flow rate can be higher. Table 5 shows the calculation results for the pipe size, the flow rate, the pump power, and the other parameters. We set the pipeline at the flat area for the calculation and used the thermodynamic parameters of CH\textsubscript{4} from NIST calculation [23]. Here, we assumed that the efficiency of the pump is 100% and the CH\textsubscript{4} fluid is incompressible. The flow rate per pump power is almost constant for the different sizes of the pipe.

Table 5. LNG (CH\textsubscript{4}) flow rate and the other parameters of transmission pipeline for larger pipe.

| Pipe size, mm | Flow rate, ton/hr | Pump power, MW | Outlet pres., MPa | Outlet temp., K | Flow rate / Pump power, ton/MJ | Pump power / Distance, W/m |
|---------------|-------------------|----------------|-------------------|----------------|-------------------------------|---------------------------|
| 260           | 63.6              | 0.030          | 0.28              | 112.0          | 0.586                         | 0.30                      |
| 348           | 137.7             | 0.069          | 0.28              | 111.2          | 0.589                         | 0.65                      |
| 448           | 268.9             | 0.127          | 0.28              | 110.8          | 0.589                         | 1.27                      |

The pressure is 1.0 MPa at the inlet, and the outlet pressure is 0.28 MPa as the calculation constraint. The inlet temperature of the LNG is 110 K, and we calculate the temperature rise for the 100 km pipeline, and show the temperatures at the outlet for the different size of the pipe. The temperature rise depends on the heat leak and the pump power, and we use the experimental data of the heat leak in the Ishikari project and the related experiment and its analysis in the laboratory. The pump power is one of the heat loads for the cryogenic system, and we include the heat load to estimate the temperature rise of the LNG.

4. Estimation of natural gas transfer rate and its electric power consumption

The gas pipeline for NG is a universal energy transfer system in the world. We should compare the LNG pipeline to the NG transfer pipeline system to evaluate the proposed hybrid pipeline. Reference [24] gives the formula for NG's flow rate. NIST calculation [23] gives the enthalpy of CH\textsubscript{4}. Finally, we can calculate the flow rate and pump power, and table 6 shows the calculation results. The temperature of methane is 288 K through the pipeline. We assumed that the inlet pressure is 7.0 MPa, the outlet pressure is 5.0 MPa, and the pump efficiency is 100%. The distance between the inlet and the outlet is 100 km as the calculation constraint. We calculated the compression power from 0.1 MPa to 7.0 MPa, and the temperatures are the same as 288 K, and we assumed the compressor efficiency is also 100%.

Table 6. Flow rate of the NG, the pump power and the other parameters.

| Pipe size, mm | Flow rate, ton/hr | Pump power, MW | Flow rate / Pump power, ton/MJ | Compression power, ton/MJ |
|---------------|-------------------|----------------|-------------------------------|-------------------------|
| 400           | 107.60            | 0.95           | 0.0314                        | 2.26                    |
| 500           | 188.00            | 1.79           | 0.0293                        | 3.94                    |
| 600           | 296.59            | 3.01           | 0.0274                        | 6.22                    |
| 1000          | 1063.59           | 13.55          | 0.0218                        | 22.30                   |

The flow rate is increased with the increase of pipe diameter and the pump power. However, the energy transfer efficiencies (= the flow rate per pump power) are 0.02 to 0.03 ton/MJ for all pipes, and these values are almost 21 times smaller than that of LNG (see table 6, 0.586 ton/MJ), and this is the typical difference between the liquid and the gas for the transfer efficiency. Therefore, we can save the pump power if we transfer the LNG.
5. Discussions and conclusion
We compared the conventional energy transfer system and the proposed system. The conventional system is composed of the NG pipeline and the overhead line illustrated in figure 6. Since the DC transmission system has higher efficiency than the AC system for long transmission, the high-voltage DC systems are used all over the world. However, the electric loss of the HVDC is 10 to 100 times larger than that of the proposed SCDC. Moreover, the HVDC substations are necessary at both ends of the wires, and its substation is extensive and needs a wide area. The voltage of the SCDC is ~25 kV, and it is lower voltage to produce the corona discharge in the air, and it is essential to keep high safety and low cost. Furthermore, it is easy to connect the RE because the RE voltage is lower than the conventional grid voltage usually, and it is also convenient to use the DC for the RE. However, its transmission power is at the same level as the HVDC.

Figure 6. Conventional energy transmission lines, composed of the overhead line (HVDC) and the high-pressured NG pipeline, and the proposed system, composed of LNG pipeline and superconducting DC power transmission (SCDC).

A high-pressured NG transfer system is used worldwide as the primary energy transfer system, and many pump stations are necessary for a long transmission, and the distance per each pump station is ~100 km. On the other hand, the proposal is composed of the LNG transfer system. It may be suitable for short-distance to long-distance transmission.

As mentioned in the introduction, the NG is the primary energy source now and will be a major energy source until 2050. However, many countries, such as EU countries, China, Japan, and Korea, import LNG from the Middle Eastern countries, the North Africa countries, Indonesia, Brunei, Russia, and the USA, and use the LNG tankers for transportation. Therefore, if we can transfer the LNG by the cryogenic pipe like the proposed system, it is suitable because tankers cannot move inland.

Table 7 shows the methane flow rate instead of the LNG, and they are the same as 268.9 ton/h, and figure 6 indicates their thermodynamic parameters and conditions. The compression power for the NG is calculated from 0.1 MPa to 7.0 MPa at 288 K. We need the liquefier to make LNG, and its refrigeration power is estimated from 288 K to 110 K at 0.1 MPa. The compressor and the refrigerator efficiencies are assumed to be 100%, but we should consider the Carnot efficiency of the refrigeration process. The transfer power is almost proportional to the distance of the pipeline, and they are estimated in the previous sections for the 100 km transmission line. Because we need high power to make LNG from the NG, the LNG transfer system needs higher power than the NG transfer system.

However, if the transmission distance extends to 2000 km, we need the NG compressor stations and the pipeline. The transfer pump increases the pressure from 5 MPa to 7 MPa for each 100 km. We
need to use the cooling stations for the LNG for each 100 km, and it is composed of the refrigerator and the circulation pump. We also assume that the efficiencies of these compressors, refrigerators, and circulation pumps are 100%. The total consumption power of the LNG system is lower than the NG system. We should consider the efficiencies of those components, but we believe it is starting to analyze the LNG system, and it will be a better energy transfer system.

### Table 7. Comparison between the NG and the LNG transfer systems.

| Distance | 100 km | 2000 km |
|----------|--------|---------|
|          | Flow rate, ton/hr | Compression refrigeration, MW | Transfer, MW | Sum, MW | Compression refrigeration, MW | Transfer, MW | Sum, MW |
| LNG      | 268.9  | 66.72   | 0.127   | 66.85 | 10.71 | 77.43 |
| NG       | 5.63   | 2.74    | 8.37    | 5.63  | 83.99 | 89.62 |

Furthermore, since the LNG import countries do not need to liquefy the NG, the transfer energy of the LNG is always smaller than that of the NG. In addition, when we can transfer the LNG to the metropolitan area, we can use the cold of the LNG for modern life, and it is useful especially in the hot summer season, the tropical and subtropical zone on the earth because we spend huge amount of electricity to cool the food storage, air conditioning, and the other applications.

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