Current Situation and Considerations on LNG cold energy utilization

Authors:

Mr. Toshiyuki HIBINO
Assistant Manager Technical Solutions Sect., Energy Production Dept., Tokyo Gas Co., Ltd.

Mr. Norio HATANAKA
Manager of LNG Terminal BU, Business Strategy Team, Planning Dept., LNG Terminal & Power Generation Business Unit, Osaka Gas Co., Ltd.

On behalf of **GIIGNL Technical Study Group**

Date of publication: March 2018

1. Introduction

1.1 Background

Today, taking measures to solve energy security and global environmental issues has become a worldwide concern. The consumption of fossil fuels is increasing rapidly at the global level, and it is anticipated to increase further in the future with energy demand from rising countries. The reduction of carbon dioxide emissions becomes the urgent problem that we should address on a global scale.
In this context, the demand for natural gas, whose environmental impact is less important than the impact from fossil resources such as oil or coal, is rising rapidly. As the production sources of natural gas are not limited to a specific area, natural gas is also considered to have superiority in terms of energy security in comparison with other fossil fuels.
By 2020, world LNG demand is likely to near 350 million tons, up from around 260 million tons in 2016. Particularly, it is anticipated that Asia will pull world demand expansion. Demand growth in India and China is expected to continue and the traditional export countries such as Malaysia and Indonesia are going to turn into importing countries. In Europe, LNG usage should progress due to supply security concerns. It is expected that imports of the Middle East, Central and South America will also increase in the future.
As mentioned above, imports of LNG are expected to increase gradually. In the process of regasification at LNG import terminals, a significant quantity of cold energy is available, though the majority of current LNG import terminals do not make use of it and simply dissipate it into the environment (air or sea). If LNG cryogenic energy could be utilized effectively, it would greatly contribute to the reduction of the global environmental load of natural gas. When LNG is vaporized and returned to natural gas at a normal temperature, vaporization heat is eliminated from the surroundings and LNG cryogenic energy uses this phenomenon. The LNG cryogenic energy came into practical use in manufacturing of liquid oxygen, liquid nitrogen, liquefaction carbon, dry ice, cryogenic power generation, cold storage & warehousing.
In a situation where LNG demand and energy cost are expected to increase in the future, the business of using LNG cryogenic energy could play a big role that cannot be ignored. In the near future this business is expected to become widespread.

1.2 Study objectives

In this Study, LNG cold energy utilization of the technology was put to practical use all over the world and the application examples were widely investigated. In addition the current situation of energy savings utilizing LNG cold energy was arranged in this study.

Moreover, towards the expansion of LNG cold energy utilization, information about the consideration on the installing equipment and the operation are summarized. The purpose of this study is to provide information that can be used as a reference, when considering the implementation of LNG cold energy utilization equipment in the future.

1-3 Scope of the study

① WG Members:
Tokyo Gas、Osaka Gas, Elengy, Enagas, Kogas.

② Schedule:

Table1. Study schedule

Fiscal Year	15	2016				2017			
	10	1	4	7	10	1	4	7	10
58th TSG@Tokyo -Selection of New Study	▼								
59th TSG@Brugge -Member, -Schedule			▼						
-Study (information collection)									
60th TSG@Quintero -Study progress reports -Schedule					▼				
Study - Document drafting									
-Study Draft Report					Draft▼				
61thTSG@Singapore -Study Final Report						Final▼			

③ Process to Goal:
・Tokyo Gas and Osaka Gas become the coordinator of this study and proceed.
・With reference to the materials summarizing Japanese LNG cold energy utilization business, each member shares it and conducts survey and analysis of each area.
・Progress report of this Study at the 60th TSG.
・Draft of the report sent to TSG members on January 2017. Brush up of Study contents, incorporating each TSG member's opinion.
・Final report of this Study at the 61th TSG.

④ Expected achievements:
・Application Examples of LNG cold energy utilization
・Trends of LNG cryogenic energy utilization business
・Energy Savings
・Considerations on installing equipment

1.4 Structure of this report

1. Introduction
2. Study Results
   2-1. Types of LNG Cold energy utilization system
   2-2. Manufacture of liquid oxygen and nitrogen by air separation
   2-3. Manufacture of liquefied carbon dioxide and dry ice
   2-4. LNG cryogenic energy Processing of rubber, plastic, etc
   2-5. LNG-BOG Re-liquefaction
   2-6. Refrigerated warehouses
3. Application Examples（Design and analysis）
   3-1.Cryogenic Power Generation
      ① Huelva LNG terminal（Spain）
   3-2.Air separation
      ① Fos Tonkin terminal and Air Liquide plant（France）
      ② Air Separation Plant at Cold Air Products Co, Ltd.（Japan）
      ③ Kogas Pyeongtaek Terminal to Solunar（Korea）
   3-3.liquefied carbon dioxide and dry ice
      ① Kinki Ekitan（Japan）
      ② Tokyo Tansan（Japan）
   3-4. LNG cryogenic energy Processing of rubber, plastic
      ① Osaka Gas Liquid（Japan）
   3-5.LNG-BOG Re-liquefaction･LNG-BOG Recovery optimization
      ① Tokyo Gas Ohgishima（Japan）
      ② Cartagena LNG Terminal (Spain)
   3-6.Refrigerated warehouses
      ① Japan Super Freeze（Japan）
4. Trends of LNG cryogenic energy utilization business
   4-1.Japan
   4-2.Europe
5. Energy Saving
6. Consideration to install equipment
7. Conclusion

2. Study Results

2-1.Types of LNG Cold energy utilization system

Liquefaction accounts for about 30% of LNG costs. When gas of normal pressure and temperature is liquefied at the rate of about 840 kJ /kg, the released cryogenic energy is left in the LNG and when ORV is used this energy is mostly discharged into the sea water.

Recovery of cold heat energy and its effective utilization would not only saves expenditures for regasification but also have an energy-conserving effect.（Refer to Figure.1）

The enthalpy varies with the vaporization pressure. Under a pressure of 1 MPa, enthalpy amounts to 920 kJ/kg till reaching 25 °C. The latent heat subtotal comes to 500 kJ/kg. Under a pressure of 7 MPa, the enthalpy amounts to 750 kJ/kg. As this indicates, a rise in pressure leads to a decline in the latent heat portion and reduction of the usable heat amount.

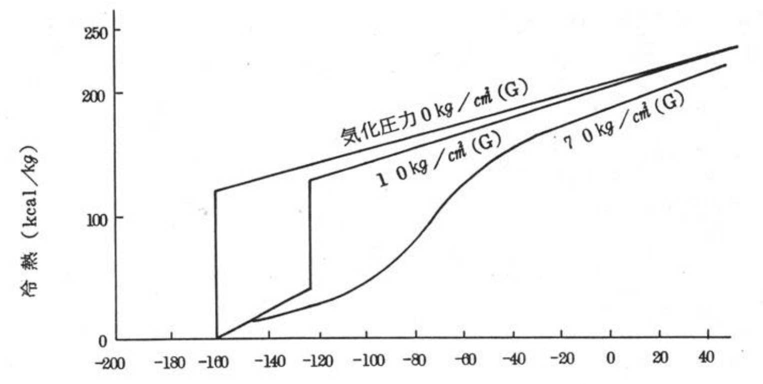

Figure 1. LNG enthalpy curve

Mentioned below are examples of fields in which LNG cryogenic energy is used:

(1)Cryogenic Power Generation
(2)Manufacture of liquid oxygen and nitrogen by air separation
(3)Manufacture of liquefied carbon dioxide and dry ice
(4)LNG cryogenic crushing. Processing of rubber, plastic, etc.
(5)LNG-BOG Re-liquefaction・LNG-BOG Recondenser
(6)Refrigerated warehouses
(7)Use in chemical industries for ethylene separation, xylene, etc.

※Regarding cryogenic Power Generation, the relevant technology is mature, and there are many examples of installing around the world. Therefore, introduction in this section is skipped.

2-2. Manufacture of liquefied oxygen and liquefied nitrogen by air separation

Oxygen, Nitrogen and Argon have a range of applications in various industries and are used by many industrial customers. While air can be separated even in a gaseous state to produce such industrial gases, since liquefaction is essential in view of efficient storage and transportation after production, most of the industrial production processes of these gases involve air separation through chilling, liquefaction, distillation and separation. In the early stage of industrial air separation, broadly speaking two methods of liquefaction air separation are employed: separation using electrical energy alone, and separation using mainly cryogenic energy from LNG, etc., as well as a smaller amount of electrical energy.

<Ways of Using Cryogenic Energy from LNG for Air Separation>
Conventional liquefaction air separation plants provide coldness via the plant's coldness creation cycle, with nitrogen providing a thermodynamic function as an intermediate fluid. More specifically, the nitrogen obtained through the separator is pressurized by the circulation nitrogen compressor; cooled down in the refrigerator using Freon, and also in the expansion turbine; and adiabatically expanded in the throttle valve. The nitrogen liquefied by this process is supplied to the distillation separator to provide cryogenic energy for the separation process. (Refer to Figure2)

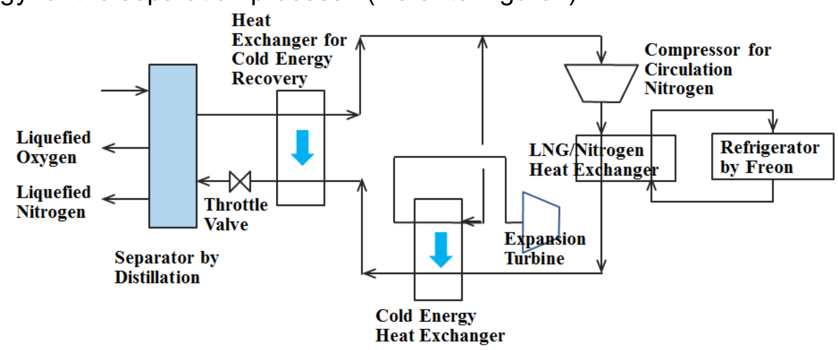

Figure 2. Conventional Coldness Creation Cycle

Meanwhile, the following energy conservation measures are implemented at the air separation plant using LNG cryogenic energy:

<Use of Cryogenic Energy from LNG to Create Coldness>
If cryogenic energy from LNG is used to create coldness as mentioned earlier, the Freon refrigerator and expansion turbine do not need to be installed. At the same time, the quantity of circulation nitrogen and electric power consumed by the nitrogen circulation compressor will decrease, since most of the coldness for the process is obtained from the cryogenic energy from the LNG. (Refer to Fig3)

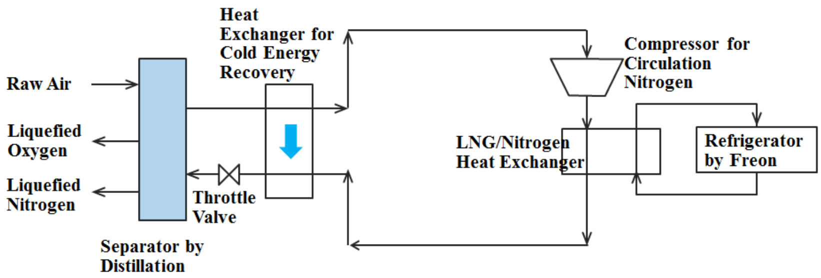

Figure 3. Coldness Creation Cycle Utilizing LNG Cryogenic Energy

<Use of Cryogenic Energy from LNG to Compress Nitrogen at Low Temperature>
In general, most of the electric power consumed at the air separation plant is used to compress the raw air and the circulation nitrogen. While, conventionally, the raw air compressor pressurizes the introduced gas and the heat produced is cooled down by water, the method using LNG can reduce electricity consumption since the gas to be introduced into the compressor can be cooled in advance by the coldness of the LNG. (Refer to Figure4)
The nitrogen introduced into the nitrogen circulation compressor is cooled down in the refrigerator using Freon as a fluid medium, the appropriate type of which is selected to be applied to the nitrogen at the inlet of the compressor at a low temperature within the range of -100 ˚C to -140˚C. By adopting such a cooling and compression system, the consumption of not only electrical power but also cooling water are significantly reduced. We should point out that we select nitrogen as the intermediate fluid for heat exchange with LNG due to its inertness and ease of containment in vessels, from the viewpoint of safety as a basic principle of utilizing the cryogenic energy of LNG, since LNG is flammable. The pressure of the circulation nitrogen in the heat exchanger with the LNG is considered to be higher than the pressure of the LNG at a given time.

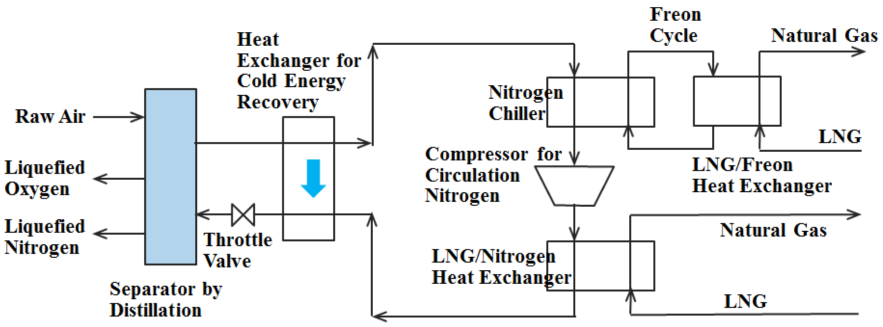

Figure 4. Coldness Creation Cycle Utilizing LNG Cryogenic Energy (Compression after Chilling)

2-3. Manufacture of liquefied carbon dioxide and dry ice

Liquefied carbon dioxide is produced by liquefying carbon dioxide gas at high pressure. In industrial fields, carbon dioxide, the source of liquefied carbon dioxide, is generally recovered from a petroleum refinery plant or an ammonia production plant as a by-product, while in a laboratory, it is produced by adding hydrochloric dioxide to limestone or heating sodium hydrogen carbonate.
The amount of carbon dioxide produced in Japan is about 760,000 tons per year. Its applications have expanded to welding, drink carbonation, use as a cooling medium, steel manufacturing, and so on. In the past, liquefied carbon dioxide was mainly produced by pressurizing carbon dioxide and chilling it in a refrigerator powered by electricity.

The production of liquefied carbon dioxide and dry ice is conducted through the procedures shown in the diagram in Figure 5.

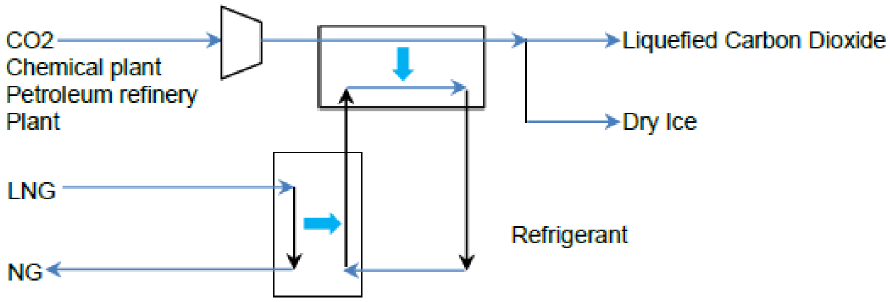

Figure 5. Production Flow of Liquefied Carbon Dioxide and Dry Ice

① The feedstock CO_2 is received from an adjacent chemical plant or petroleum refinery plant.
② The CO_2 is compressed by the compressor. After CO_2 being dried and deodorized, CO_2 is liquefied by the coldness of LNG.
③ The liquefied carbon dioxide is stored and shipped depending on demand.
④ For dry ice production, the liquefied carbon dioxide is solidified into blocks; blocks are then packed into a flexible container bag to be shipped.

2-4. LNG cryogenic energy Processing of rubber, plastic, etc.

Resins with low melting points, materials with high elasticity, and oil- or water-rich materials are not easily crushed into powder at normal temperature.
Recently, there has been a trend of increasing demand for foods containing water to be crushed into powder, and for drugs and painting materials to be crushed into fine powder.
Generally speaking, cryogenic crushing is conducted by freezing the water in the target material to embrittle it to allow crushing into powder, by cooling it down in a refrigerator or by the coldness of liquid nitrogen, liquid carbon dioxide or dry ice. Of these media, liquid nitrogen has very useful properties that allow it to be applied to a wide range of materials to be crushed: inertness which prevents oxidation, ease of embrittlement at the extremely low temperature of -196℃, and high capability of preventing degradation from the heat generated during crushing.

2-5. LNG-BOG Re-liquefaction

Entering heat into LNG generates boil-off gas (BOG). Use of BOG as feedstock for city gas requires to increase the BOG pressure to a higher level than the send-out pressure of city gas. As the send-out pressure rises, the electric power of the compressor required for the step-up also rises. Thereby the cost of pressurizing BOG would become extremely high.
Effective cost reductions would be achieved by adopting a BOG re-liquefaction sequence applying the cold energy from LNG. The re-liquefaction sequence is as follows: first BOG is pressurized to medium pressure, then is re-liquefied with the cold energy from LNG, then the re-liquefied LNG is pressurized to the sending out pressure in the liquid state, and after adjusting its calorific value, is vaporized.
In this process, most of the pressure increase is performed in the liquid state, and the thermal energy of seawater transferred to the liquid by the vaporizer is used to increase pressure. Energy required to increase pressure in the liquid state, is considerably less than that of the gaseous state, and this leads to cost down significantly.

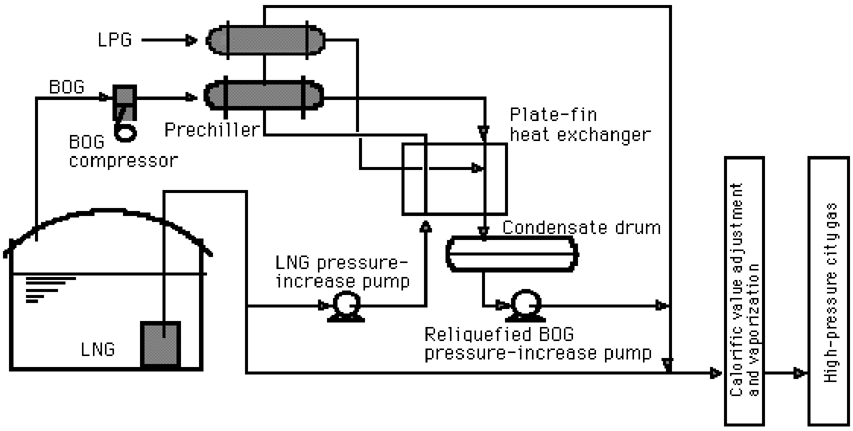

Figure 6. Diagram of BOG reliquefaction facilities and process

2.6. Refrigerated warehouses

The key to manufacturing high quality frozen foods lies in rapid freezing that is to freeze instantly single microcrystals that contain much in foods. The instant freezing leaves the cell membranes unbroken, so even after thawing the food is kept as fresh as it was before freezing.

Refrigerated warehouses using LNG cryogenic energy gives the following benefits compared to the conventional mechanical type.

1) Whereas the conventional type require a large freezer, condenser, cold water tower, and other equipment, the refrigerated warehouses using LNG cryogenic energy consist basically only of an LNG/Freon heat exchanger, Freon liquid drum, and Freon liquid pump. They consequently offer simpler electrical wiring and instrumentation as well as a lower construction cost.
2) They do not require several freezers and so allow more effective use of space.
3) They consume only about one-third of the power the mechanical type do.
4) By not using a compressor they become free of noise and vibration problems.
5) They make it easy to obtain ultralow temperatures in the range of minus 50 ~100 °C merely by controlling the LNG flow, and this enables a swift recovery of temperatures inside the warehouse.
6) They can facilitate maintenance by not using mechanical equipment such as compressors that breakdowns occur.

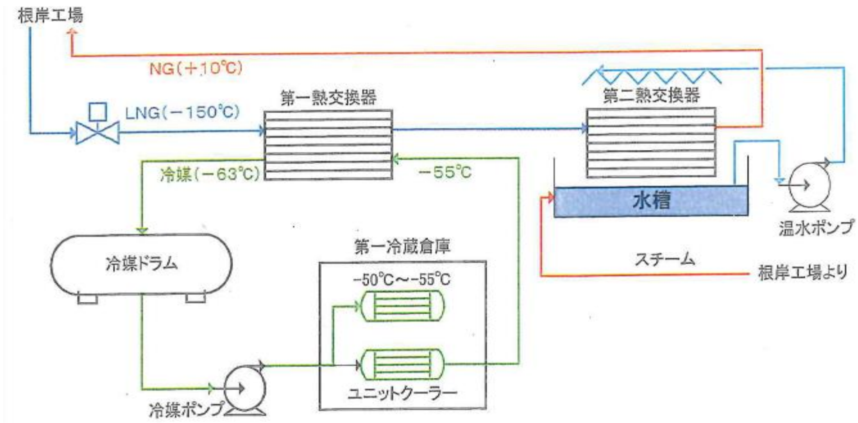

Figure 7. Diagram of Refrigerated warehouses and process

3. Application Examples（Design and analysis）

3-1.Cryogenic Power Generation

①Huelva LNG Terminal（Organic Rankine thermodynamic Cycle）

In Enagás Terminals, the process to regasify Liquid Natural Gas (LNG) is based on the use of seawater vaporizers. The LNG becomes into gas and the seawater is cooled and returned to the sea. Seawater is available in large quantities at low cost as compared to other sources of heat. However there is a loss of potential chilling energy contained in the LNG which is only inverted in cooling seawater. As an example, in a regasification plant with an average emission of 300,000 m3(n)/h, a seawater flow of 70 million m^3 a year is necessary in the process. Taking into account seawater temperature decreases 5-6ºC it represents an annual energy of around 500 GWh.

One of the applications for using the cold from liquid natural gas is power generation. In view of the fact that it is technically possible to recover part of this lost energy, in 2010, Enagás carried out a project at Huelva Terminal based on the application of an Organic Rankine thermodynamic Cycle (ORC). Working principle of Huelva's Rankine cycle is illustrated by Figure 8.

<Process overview>

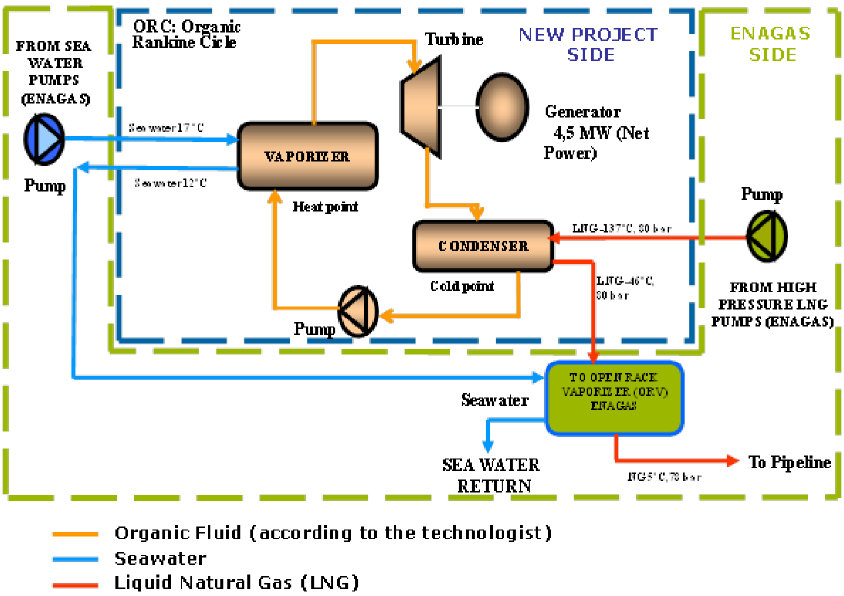

Figure 8. Diagram of Huelva's Rankine cycle

Huelva's Rankine cycle uses LNG as a cold thermal source and seawater as a hot thermal source. An organic fluid is used as working fluid in a closed circuit. Two turbines have been implemented: one for low pressure (LP) and another for high pressure (HP), both designed to produce a total of 4.5 MW. Rankine cycle is foreseen to run all the year (except maintenance periods). The on-site generated electricity is sold to the Spanish electrical grid.

Parameters	Values		Units
Huelva LNG Terminal			
Nominal Capacity	11.8		Bcm/y
Availability	(90%) 7,890		h/y
Sea water inlet temperature	17		ºC
Regasification pressure	77	88	bar
LNG flow rate	265	128	t/h
Sea water flow rate	8,000	4,300	t/h
Organic Rankine Cycle			
Generated gross power	4.9	2.0	MW
Generated net power	4.6	1.8	MW
Generated net energy	36.2	14.2	Mwh/y

<Description of the components>

- HP and LP turbines (three-stage turbines): They are specially designed to operate with vapor from an organic fluid.
- Vaporizer: Horizontal shell-and-tube exchanger. The seawater flows inside the tubes (single pass design) while the organic working fluid goes through the shell side.

•HP and LP condensers: The LNG flows into both condensers on the tube side and the working fluid comes in on the shell side.
•Circulation pumps: centrifugal electrical pumps for cryogenic applications. They have a mechanical seal with the lubrication and refrigeration being provided by the working fluid itself.

Figure 9. Picture of Huelva's Rankine cycle

3-2.Air separation

①Synergy between Fos Tonkin terminal and Air Liquid plant(France)

The LNG receiving terminal of Fos Tonkin is located on the Mediterranean coast at the heart of an Harbor industrial zone, Fos sur Mer - Marseilles. The terminal is the oldest of the three terminals, operated by Elengy.

Figure 10. Aerial view of Fos Tonkin terminal and Air Liquide plant

Figure 11. Aerial view of Air Liquide Plant

At the engineering stage Fos Tonkin terminal and the neighboring company Air Liquide plant developed synergies to maximize energy efficiency. Both facilities started up simultaneously in 1972. Since this year the synergy has been running at the satisfaction of both partners.The two plants have to be designed to run separately. This means that back up facilities have to be installed on the air separation plant.

<Presentation of the synergy>
Cold energy coming from the LNG of the receiving terminal is partly recovered by Air Liquide through its liquefaction process of Nitrogen. The heat exchange is performed through heat exchanger installed on the terminal where a continuous flow of LNG at high Pressure (# 70 Bar) colds a flow of Gaseous Nitrogen coming from Air Liquid plant.

The principle of the synergy is shown on the figure 12.

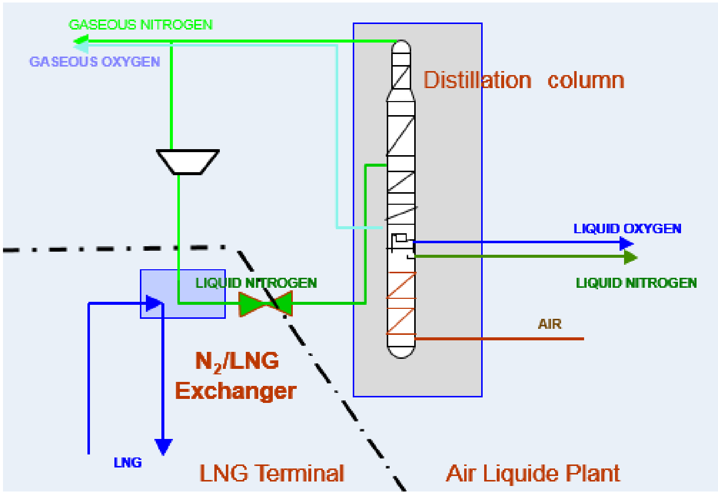

Figure 12. The synergy between Air Liquide plant and LNG terminal

After its cooling the nitrogen is sent to the distillation column of Air Liquide which is meant to separate the 02/N2 from the air.

<Major specifications of the Heat exchanger>

	LNG	Nitrogen
Operating pressure mini/nominal/max	45 / 72 / 82 barg	33 / 36 / 55 barg
Operating temperature mini/nominal/maxi	-160°C/-160°C/20°C	-110 °C/8°C/ 20°C (Inflow)
Flow-rate mini/ nominal /maxi	100 / 585 / 900 m3 LNG/h	84 000 / 113 000 Nm3/h
Nominal operating temperature		-150 °C (Outflow)

<Type of heat exchanger>
The heat exchanger, which is installed at Fos Tonkin terminal, is a plate exchanger. It is composed of many thin, slightly separated plates that have very large surface areas and small fluid flow passages for heat transfer. The plates and the headers are in INOX steel.

Figure 13. Picture of N2/ LNG heat exchanger at Fos Tonkin terminal

②Air Separation Plant at Cold Air Products Co, Ltd.（Japan）

Cold Air Products Co., Ltd. has adopted the flow system shown in Figure 14. for liquefied gas production at its plant. The raw air is sent to the air filter, compressed by the raw air compressor, deprived of carbon monoxide and hydrogen, and washed and cooled down in the water shower tower. From the tower, the air is sent to the two switching molecular sieve (=MS) towers, where absorption and revitalization processes are alternately carried out to eliminate carbon dioxide and moisture from the air. Following these processes, the air is sent to the main heat exchanger to be cooled down by the cold exhaust nitrogen and the circulated nitrogen.

The exhaust nitrogen warmed up at the heater is sent to the MS absorber vessel on the recovery turn to eliminate carbon dioxide and moisture, and is dissipated into the atmosphere. The raw air, cooled down almost to a liquid state, is supplied to the high pressure distillation column (the lower part of the tower) to cause the nitrogen, which has a low boiling point, to move to the top of the high pressure column while increasing in purity, while the oxygen-rich liquefied air falls to the bottom of the high pressure column.

The liquefied air is flushed into the low pressure distillation column (the upper part of the tower), causing the liquefied oxygen to fall to the bottom of the column. The nitrogen in the high pressure column is cooled down by the coldness of the oxygen at the bottom of the low pressure column and extracted as liquefied nitrogen, the end product.

The nitrogen flowing out of the top of the low pressure column (the exhaust nitrogen) is led to the main heat exchanger as explained earlier.

Argon, whose boiling point differs slightly from that of oxygen, is separated as raw argon and purified by a catalytic reaction with the hydrogen in the purifier vessel, where the water is removed at the same time.

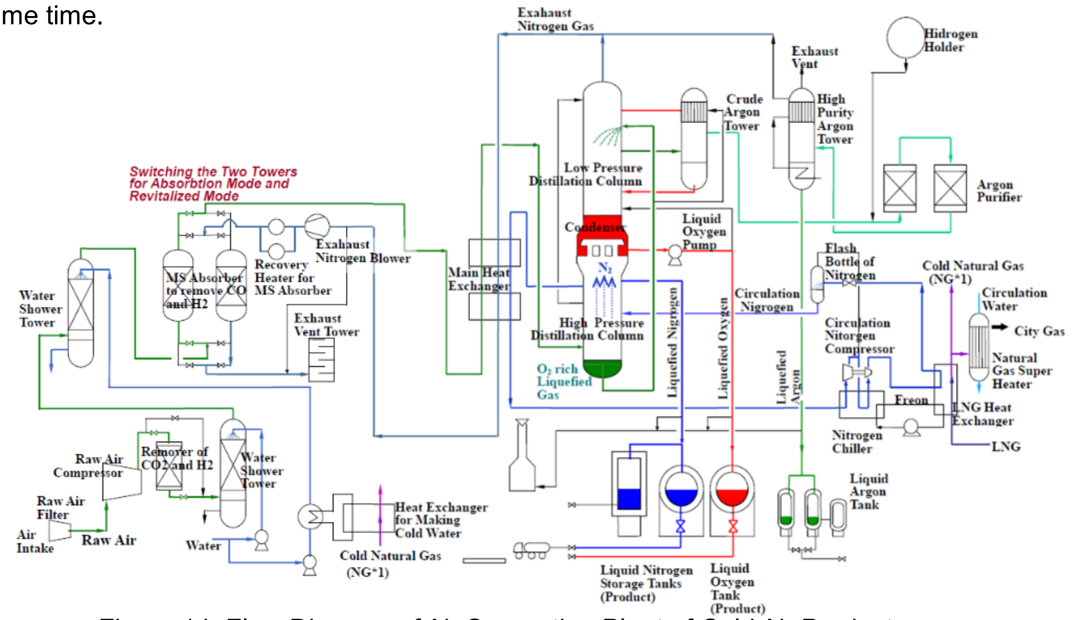

Figure 14. Flow Diagram of Air Separation Plant of Cold Air Products

The pressurized circulation nitrogen cooled down by the coldness of the LNG is adiabatically expanded into the liquefied nitrogen and supplied to the high pressure distillation column. The nitrogen at the top of the high pressure distillation column is supplied to the main heat exchanger to cool down the raw air, and is circulated after being induced into the circulation nitrogen compressor. In order to reduce electrical power consumption, the nitrogen to be induced into the nitrogen circulation compressor is cooled down in advance at the heat exchanger using the refrigerant Freon.

Meanwhile, the LNG providing coldness to the circulation nitrogen heated up at the heat exchanger is in turn heated up at the heat exchanger (the natural gas super heater) into normal-temperature natural gas by the circulation water heated up by the heat produced through the compression of the raw air.

The production capacity of this plant is as follows:

・Liquefied Oxygen (Purity 99.8% or more) 7,500 m^3_N/h

・Liquefied Nitrogen (Purity 99.9995% or more) 7,500 m^3_N/h

・Liquefied Argon (Purity 99.9995% or more) 200 m^3_N/h

The specifications of the major equipment are shown in Table 1:

Table 3. Specifications of Major Equipment in Air Separation Plant

Name of Equipment		Specifications
Raw Air Compressor		Multistage Centrifugal Compressor with Cooling at Each Stage Capacity 45,500 m^3_N/h, 4,000 kW
Circulation Nitrogen Compressor		Multistage Centrifugal Compressor with Intermediate Cooling Capacity 42,400 m^3_N/h, 3,500kW
Storage Tank	Liquefied Oxygen	Insulated Pressurized Tank with Double Shells (Filled with Perlite in Between) Capacity 2,000 m^3
	Liquefied Nitrogen	Insulated Pressurized Tank with Double Shells (Filled with Perlite in Between) Capacity 2,000 m^3 x 1, 1,500 m^3 x 1
	Liquefied Argon	Insulated Low Pressure Tank with Double Shells (Filled with Perlite in between in Vacuum) Capacity 40 m^3 x 2, 25 m^3 x 1
Power Receiving Station		Type of Gas Insulated Switchgear (GIS) Filled with SF_6 77 kV, 13 MVA
Hydrogen Tank		Capacity 250 m^3 x 1, 950 kPaG
Shipping Equipment		Tunnel Type Portal Frame with Filling Nozzles Oxygen x 5, Nitrogen x 7, Argon x 1

<Air Separation Plant and Operation Control Terminal>

An overall view of the air separation plant of Cold Air Products Co., Ltd. and the state of its operation control terminals are shown in Figure.15.

Since the operation control of the plant is highly automatized, only two consoles are needed.

Figure15. Air Separation Plant of Cold Air Product and Control Terminal

③Kogas Pyeongtaek Terminal to Solunar（Korea）

- type of application: air separation
- location: At KOGAS Pyeongtaek Terminal to Solunar (http://www.solunar.co.kr/)
- major specifications input LNG volume flow (about 3,500 tons/year)
- purpose and merit of the application:

Air separation (N2 & O2) by using LNG Temperature
Pyeongtaek terminal receives occurred BOG from Solunar

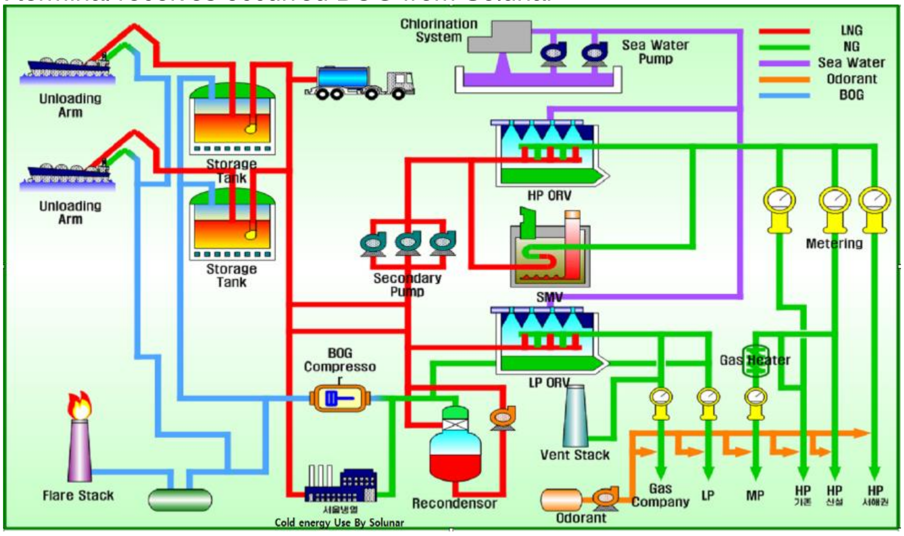

Figure 16. Diagram of Kogas Pyeongtaek Terminal and Solunar

3-3.liquefied carbon dioxide and dry ice

①Kinki Ekitan（Japan）

The production of liquefied carbon dioxide and dry ice is conducted through the procedures shown in the diagram Figure17.

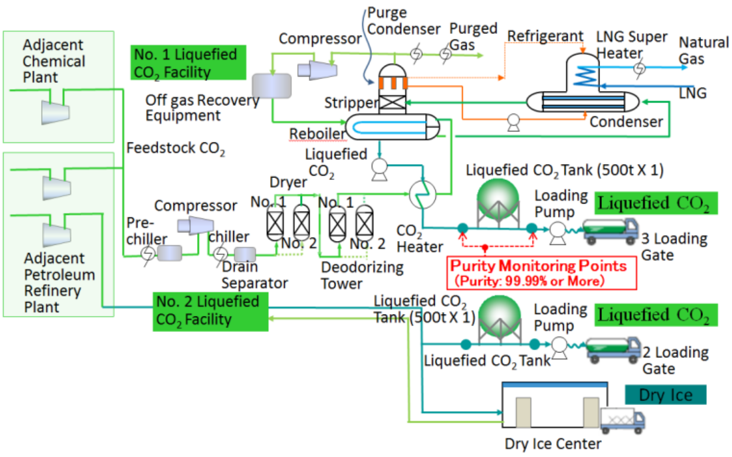

Figure 17. Production Flow of Liquefied Carbon Dioxide and Dry Ice

① The feedstock CO_2 is received from an adjacent chemical plant or petroleum refinery plant at 35°C and 0.035 MPaG.
② A high standard of purity is set for CO_2, considering its usage in the food industry, for example. The CO_2 is pre-chilled and the drain it contains is removed.
③ The CO_2 is compressed to a state of 170 °C and 0.84 MPaG by the compressor.
④ The pre-cooled CO_2 is dried and deodorized.
⑤ The CO_2 is liquefied by the coldness of LNG to a temperature of -46°C.
⑥ The liquefied carbon dioxide is stored and shipped depending on demand. At this stage, it is -23°C and 2.0 MPaG.
⑦ For dry ice production, the liquefied carbon dioxide is solidified into 25-kilogram blocks; sets of 36 blocks are then packed into a flexible container bag to be shipped in a state of -79°C.

The production capacities of the liquefied carbon dioxide and dry ice are shown in Table 4.

Table 4. Production Capacity of Liquefied Carbon Dioxide and Dry Ice

Name		Specifications
Production Facility of Liquefied Carbon Dioxide	Production Capacity	250 t/day
	Liquefied Carbon Dioxide Storage Tank	500 t x 2
	Purity Standard of Liquefied Carbon Dioxide	99.99% or more
Production Facility of Dry Ice	Dry Ice Press (Production Capacity)	26 t/day x 2
	Storage Warehouse for Dry Ice	Rack Type 81 t

Figure 18. Production Facility of Liquefied Carbon Dioxide and Dry Ice

②Tokyo Tansan（Japan）

Tokyo Tansan co.,Ltd was established in April 1982 for the purpose of manufacturing liquefied carbon dioxide and dry ice utilizing cold heat of LNG.

The company has effectively used carbon dioxide generated as a by-product of the oil refining process as a weight loss, and has continued pursuing energy saving and resource saving while contributing to environmental conservation by utilizing the LNG cold energy.

In 2000, the company switched the refrigerant (fluorocarbon) used in the liquefied carbon dioxide production process from R-13B1 (CFC) to R-23 (HFC), realizing a manufacturing process with less environmental burden.

Table 5. Production Capacity of Liquefied Carbon Dioxide and Dry Ice

Name		Specifications
Production Facility of Liquefied Carbon Dioxide	Production Capacity	86t/day
	Liquefied Carbon Dioxide Storage Tank	500 t x 2
	Purity Standard of Liquefied Carbon Dioxide	99.99% or more
Production Facility of Dry Ice	Dry Ice Press (Production Capacity)	24 t/day x 3
	Storage Warehouse for Dry Ice	Rack Type 72 t

Figure 19. Production Facility of Liquefied Carbon Dioxide and Dry Ice

3-4. LNG cryogenic energy Processing of rubber, plastic

①Osaka Gas Liquid Company, Ltd.（Japan）

<Features of Cryogenic Crushing Using Liquid Nitrogen>

If liquid nitrogen is easily obtainable, cryogenic crushing using liquid nitrogen is a very useful method. An example of the flow diagram for cryogenic crushing using liquid nitrogen is shown in Figure 20.

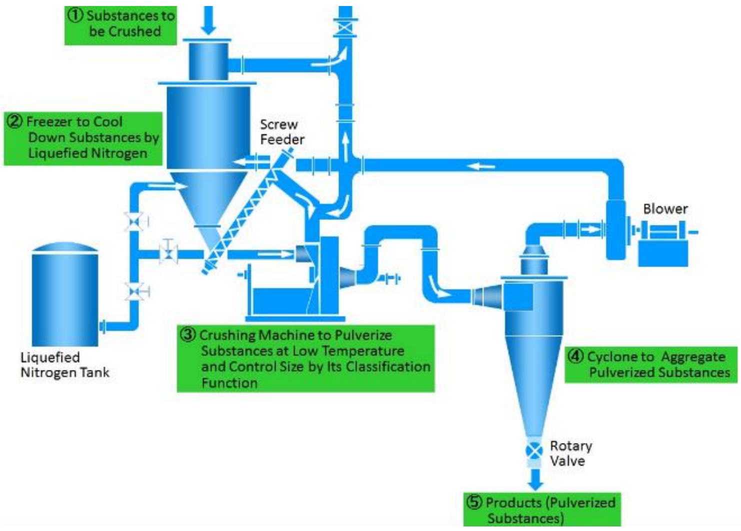

Figure 20. Diagram of Cryogenic Crushing Using Liquid Nitrogen

The features of the cryogenic crushing machine using liquid nitrogen are as follows:

① It reduces property changes and degradation by heat at the time of crushing, and can minimize the oxidation of materials through the use of inactive nitrogen gas.

② By micronizing the crushed powder, it enhances the speed of dissolution of the powder in water.

③ By crushing the materials at the extremely low temperature of -196℃, it produces fine powder with high fluidity without any “beard-like” projection, which is one of the features of ductile fractures that usually result from crushing at normal temperatures or temperatures outside the extremely low temperature range.

<Control of Particle Size>

While fine powder can be obtained by crushing using liquid nitrogen, the required size of the powder particles to be produced is usually specified by the customer.

Usually, a mechanical mesh screen with a specific mesh size corresponding to the requirement of the customer is used, although sometimes a centrifugal separator with a flow of gas is used.

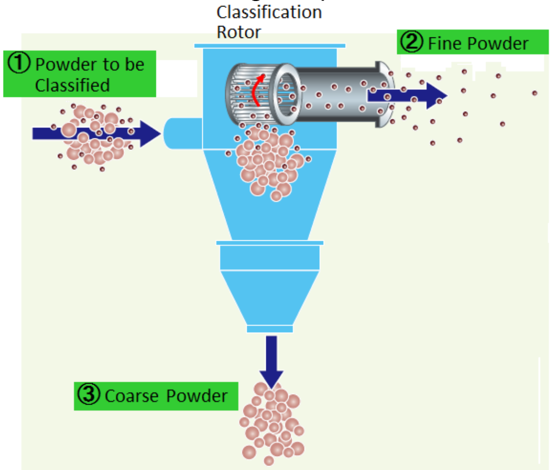

Figure 21. Conceptual Diagram of Centrifugal Classifier

Through technological development, the grain size has been made finer and the distribution range of the grain size has become narrower, as shown in Figure 22.

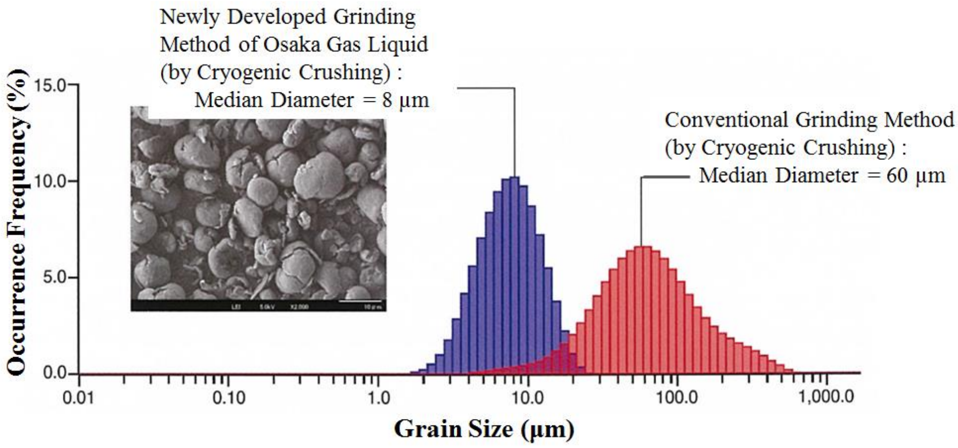

Figure 22. Technological Development and Grain Size

3-5.LNG-BOG Re-liquefaction･LNG-BOG Recovery optimization

①Tokyo gas Ohgishima（Japan）

Tokyo Gas Ohgishima terminal has started operations in 1998. This terminal has BOG treatment equipment for sending out BOG together with gas vaporizing LNG as city gas.

Regarding BOG treatment equipment, we have the following two methods:

・To be sent by boosting by the compressor to a pressure of city gas

・Re-liquefaction system to be mixed in the carburetor the previous stage using the LNG cold heat

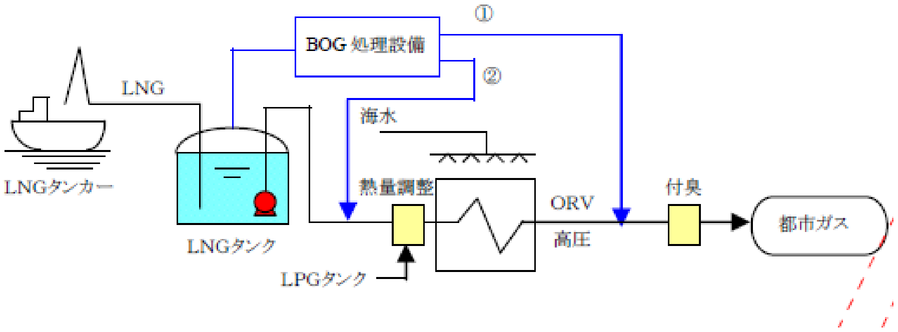

Figure 23. Process flow of Ohgishima terminal

Following, we introduce the LNG-BOG re-liquefaction system using the LNG cold energy, adopted in Ohgishima terminal.
The main process is as follows.

①Pressurization of the BOG generated to the re-liquefaction level (0.5MPa) using a compressor

②Cooling and re-liquefaction of the BOG after pressure increase by means of LNG cold energy using a pre-chilling heat exchanger and plate-fin type heat exchanger

③Increase in the pressure of the re-liquefied BOG to the LNG send-out pressure using a pressurization pump

④Transportation of the re-liquefied BOG together with LNG used for cooling to the vaporizer after adjustment of its calorific value

⑤Warming and vaporization of the mixture of re-liquefied BOG and the LNG transported to the vaporizer, and after that, sent to high-pressure city gas line.

Ohgishima LNG terminal has been operating in a combination of the method of the BOG boosting by the compressor to a pressure of city gas and the BOG re-liquefaction system.

<Equipment specifications>
The process flow of the BOG re-liquefaction equipment installed in Ohgishima shown in Figure 24.
Boosted BOG is cooled by the pre-cooling heat exchanger and sent to the condenser. BOG guided in the condenser is primarily cooled for LNG branched from LNG line, and is re-liquefied. Condenser have adopted the plate fin type heat exchanger which has good performance, compact and inexpensive.

Re-liquefied BOG is stored in the condensate drum, it is sent to the LNG main line using the condensate pump. On the other hand, cooling LNG coming together with LNG main line, through the ORV, is sent out as a city gas.

The pressure in the condenser becomes constant by re-liquefaction conditions of the flow rate and temperature of the BOG and cooling LNG, and BOG re-liquefaction continues stably. As the supply amount becomes large, cooling LNG can reduce the outlet pressure of the compressor and operating power cost.

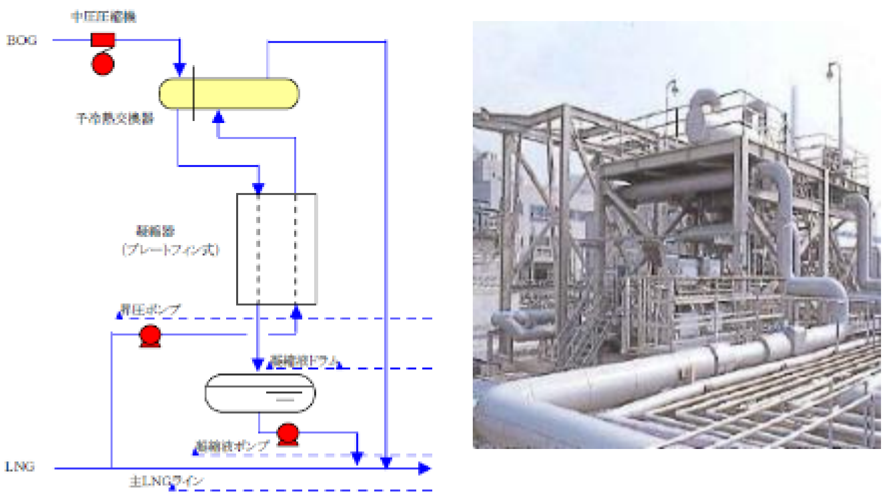

Figure24. LNG-BOG re-liquefaction system of Ohgishima terminal

②Cartagena LNG terminal（Spain）

<Boil off gas recovery optimization using LNG cryogenic energy>

BOG generated at Cartagena LNG terminal under normal operating conditions is recovered in the recondenser. Within this equipment, BOG and available LNG in circulation are mixed, resulting in the condensation of the BOG. BOG management implies high operating costs, as BOG needs to be compressed from in-tank pressure to the optimal pressure of this process (6 to 10 barg).

When the terminal operates below the minimum send-out rate, full recovery of BOG generated at the tanks and pipes is not possible through the process described above. In the last few years, several actions have been taken in order to manage these scenarios. The main important ones include sending BOG to local network, BOG precooling by means of a sea water heat exchanger, heating up parts of the plant or improving plant insulation.

High pressure (HP) compressors where installed at the terminal, allowing BOG compression to network pressure. HP BOG compression prevents BOG burning at the flare, as it allows full recovery of BOG independently of the send-out rate, even at zero send-out conditions.

In order to optimize BOG management, reducing operating costs of both LP and HP compressors, a BOG/sea water heat exchanger was installed in 2015. Temperature of the BOG flow sent to the recondenser depends on the operating conditions of the terminal. The sea water heat exchanger allows BOG pre-cooling between LP compressors and recondenser reducing BOG temperature in 50ºC. The BOG recovery rate is this way increased by almost 15%, reducing OPEX of HP and LP compressors at low send-out rates and under normal operating conditions.

This initiative is considered as a first step towards full utilization of LNG cryogenic energy. An LNG heat exchanger will be installed at the terminal, cooling BOG to sub-zero temperatures with the aim of reducing further operating costs.

Further cooling of BOG to cryogenic temperatures allows significant OPEX reduction during both low send out periods, when BOG recovery rate is increased, and under normal operating conditions, as it enables a reduction of the optimal pressure of the BOG recovery process.

A technical-economic analysis of different configurations for LNG cryogenic utilization has been carried out concluding that given the current utilization rate of the terminal, the connection in series of an LNG heat exchanger to the sea water one is the most cost efficient solution. HP LNG from secondary pumps can be partially conducted to the heat exchanger, cooling BOG up to -70 ºC.

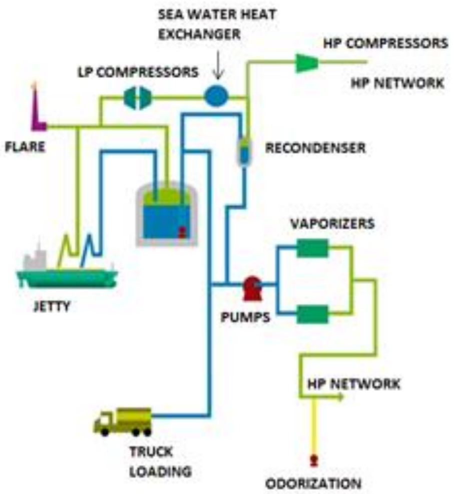

Figure 25. Process Diagram

Figure 26. BOG/sea water heat exchanger

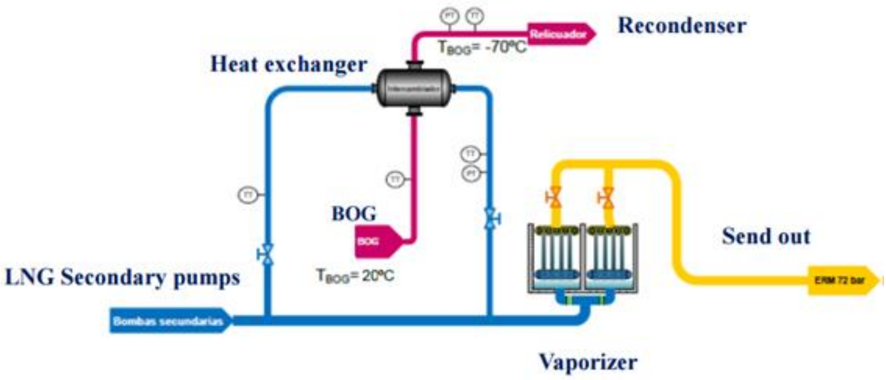

Figure 27. BOG/LNG Heat exchanger

Table 6. Main sea water heat exchanger specifications:

Plate & Shell Heat Exchanger	
Capacity	944 kW
Flow rate BOG (Shell side)	30 000 kg/h
Sea water flow rate (plate side)	150 m^3/h
Heat transfer area	77.5 m^2
K-value	641 W/m^2K

Table 7. Main BOG/LNG heat exchanger specifications:

Plate & Shell Heat Exchanger	
Capacity	1500 kW
Flow rate BOG (Shell side)	18 000 kg/h
LNG flow rate (plate side)	92 m^3/h

3-6.Refrigerated warehouses

①Japan Super Freeze (Japan)

Japan Super Freeze is a warehouse company that runs the world's first LNG-type cryogenic refrigeration business. Its head office is located in Yokohama City, Kanagawa Prefecture. Japan Super Freeze is an related subsidiary company of Tokyo Gas and started operations in 1974. LNG is supplied from the neighboring Tokyo Gas Negishi terminal and a cryogenic warehouse utilizing cold heat generated when LNG vaporizes is installed.

The warehouse inside temperature is managed in the range of -40 to -60 ° C, and higher grade marine products such as tuna, fish eggs and shrimp are preserved. Under Japan's warehouse Industry Law, warehouses which inside temperature is below -40 ° C are called super freeze warehouses.

The company owns the largest domestic super freeze warehouse, which is equivalent to 10% of the domestic super freeze warehouse capacity (corresponding to 50% in the metropolitan area).

Figure 28. Negishi terminal and Japanese super freeze in freezer warehouse
(From Japan super freeze HP)

Table 8. Process of refrigeration system

LNG	① Receiving LNG from Tokyo Gas Negishi terminal by the pipeline.（reaching temperature -150℃） ② In the first heat exchanger, LNG cool refrigerant Freon by heat exchange. ③ The LNG flows into the second heat exchanger and exchanges heat with hot water and becomes natural gas. ④ The vaporized NG is returned to Negishi terminal, and it is used as city gas after calorie adjustment and odor process.
Refri gera nt	① The refrigerant cooled in the first heat exchanger is temporarily stored in a drum and sent to a refrigerated warehouse by a pump. ② In the refrigerator, the refrigerant exchanges heat with the warehouse air in the unit cooler. By circulating the cooled air, the temperature in the warehouse is kept at cryogenic temperature. ③ The refrigerant returns from the refrigerator to the first heat exchanger again.（liquid circulation cycle）

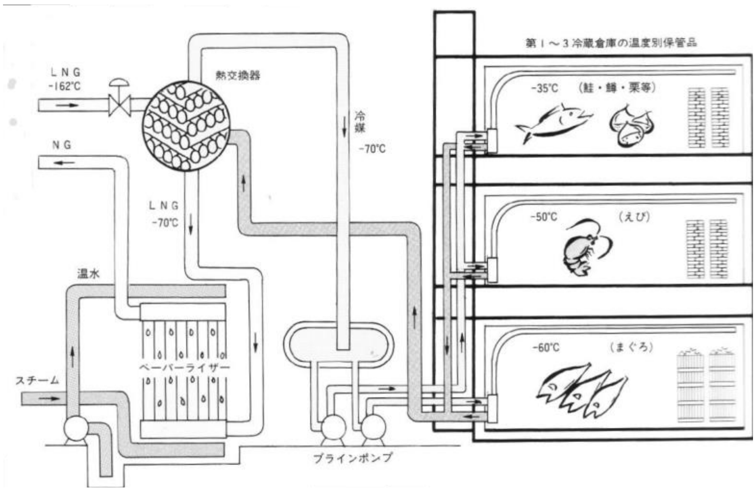

Figure 29. Process diagram of refrigeration system

＜Operation and Maintenance＞

・Based on High Pressure Gas Safety Act freezing safe rules of Japan, certificate holders are placed.

・Employees monitor the facilities and the processes of refrigeration systems and warehouses 24 hours a day. They repair refrigeration equipment in cooperation with a maintenance company in the Neighborhood.

・ Maintenance of pumps and valves is carried out periodically without stopping the operation of refrigeration systems and warehouses.

・LNG refrigeration systems have not experienced major troubles so far without large-scale maintenance. They don't have heavy machinery such as compressors, and the plumbing corrosion doesn’t occur because corrosive low Freon is adopted as refrigerant.

4. Trends of LNG cryogenic energy utilization business

4.1 Japan

In Japan, most of the LNG terminals receiving more than 3 million tons of LNG yearly carry out some sort of LNG cold energy utilization such as cryogenic power generation, air separation, boil-off gas re-liquefaction, liquefied carbon dioxide dry ice manufacturing, liquefied hydrogen, refrigerated warehouses, air conditioning, refrigeration alternatives. On the other hand, in the satellite terminal where handling amount of LNG per year is as low as between several thousand tons to several ten thousand tons, LNG cryogenic energy is abandoned by ambient air vaporizers, but recently gas turbine intake cooling by the circulating water -the heat source- has been carried out at the terminals where LNG is used as the industrial fuel.
Air separation equipment can cool the circulating nitrogen gas to near -150℃ and can recover the cold energy at the high efficiency of about 8%. Therefore, it is possible to reduce the power consumption required for air separation liquefaction of 1.2 ~1.3kWh / product Nm3 to around 0.5kWh. For this reason, air separation equipment were installed together with the introduction of LNG, but its utilization has remained only about 5% of the LNG introduced, due to the restrictions on continuous 24 hours operation and sale of product nitrogen, oxygen. However, in response to the increase of the hydrogen demand, a new movement of attaching liquid hydrogen production to air separation equipment started its operation.
The BOG, generated from LNG tank, re-liquefaction system which is adopted widely in overseas LNG receiving terminal, has also been adopted in the Japanese city gas companies for the reduction of the step-up power.
On the other hand, currently when manufacturing liquefied carbon dioxide, dry ice and at refrigerated warehouse Freon is used as intermediate medium, and particularly in the refrigerated warehouse of liquid circulation system there lies a problem of switching to CFC alternatives. In addition, the amount of LNG usage of refrigerated warehouse is as low as several tons per hour level, so high equipment cost of vaporization system is becoming an obstacle to the introduction promotion.
Cryogenic energy power generation that can respond to LNG load fluctuations, is gathering attention in the tendency toward energy-saving and is installed successively by the city gas companies and electric power companies. Currently, the amount of LNG usage per year is about 10 million ton.
Cryogenic power generation is carried out in three ways. One is Rankine cycle system using cold energy of LNG directly through refrigerant of hydrocarbon base and fluorocarbon base, another is a direct expansion system recovering the pressure energy in the turbine after raising pressure by pump vaporizing LNG to room temperature, and the third is a combination of these two systems.
Since recently, cryogenic power generation by the Rankine cycle system is no longer built due to the issue of dealing with the Freon refrigerant.
When low temperature power generation by the Rankine cycle system is constructed, restriction on the use of Freon refrigerant is a problem.
Effective utilization of valuable LNG cold energy is an important issue for Japan. In areas already established such as cryogenic power generation, air liquefaction separation, etc., it is important to steadily expand LNG heat utilization facilities based on the business potential.
In recent years, there have been cases where LNG cold energy was used in a cascade process by combining cold energy utilization facilities with different operating temperature ranges, such as freezing refrigerated warehouse, food processing factory, plant factory, etc. as a local production for local consumption type energy system.
A new case of cold energy utilization in the future is the field of environmental conservation and resource recycling.
We can contribute to conservation of the global environment and effective utilization of natural resources if we can recover and reuse useful metal resources from waste such as home appliances crushed using LNG cryogenic energy.
Further as a new field, it is expected to be applied to the technical field of superconductivity (electric

power storage, transportation system, etc.) utilizing cryogenic energy of liquefied nitrogen produced using LNG cryogenic energy.

4-2 Europe

(1)Spain

Enagás strongly believes that the use of the energy inherent in cold LNG is a resource that must be harnessed. Therefore a New Company has been developed by Enagás (early march 2017) named “e4efficiency Ltd”, which is engaged with the advantages of that huge wasted energy.
A powerful and well-structured market study has been doing just that (near LNG Terminals) since March by e4efficiency Ltd: large Cold-Consuming Companies, as preservation and frozen food warehouses, dry-ice factories, the air separation industry such as oxygen and nitrogen production, sea water purification, hemoglobin conservation, data centers, etc...
In addition to this promising market study, and at the same time, e4efficiency is analyzing and evaluating the most interesting technical and profitable solutions.

(2)France

Among the four LNG receiving terminals installed in France, three of them have developed synergies with neighboring sites. Two with power plants and one with an air separation plant.

There are currently no new projects of LNG terminals in France and no projects of additional synergies regarding the existing terminals.

Studies carried out in the past on the matter of the synergies showed that two factors are required for the development of synergies, especially with existing LNG terminals :

- A proximity between the sites
- A high electricity price

The synergies require the construction of significant infrastructure (heat exchangers, pipework, pipelines…) to transport and exchange the cold energy. As soon as the distance of the two sites exceeds hundreds of meters the investment costs become very high. These costs are even higher than part of the civil works and tie-in points take place in sites which are sensitive in terms of safety.
Furthermore in Europe a Directive so-called SEVESO requires a stringent control of the urbanization in the vicinity of Industrial establishments like LNG receiving terminals.
The regulation aims at having a land-use compatible with the risks resulting from the activity of the sites. These requirements tend to keep a certain distance between sites and can hamper the development of synergies.

The last point and not the least is the electricity price. The synergies are usually intended to reduce the cost of electricity consumption. The lower is the cost of electricity in a country the more difficult is the development a cost effective solution, except if incentives are at stake.

5. Energy Savings

5-1. Cryogenic Power Generation（Huelva）

Using Rankine Cycle to power generation brings the added value of recovering cryogenic energy that is currently coming into the sea without being used at all.
This is an important increase in the energy efficiency of the regasification terminal as well as providing environmental benefits since it substitutes an energy obtained from fossil fuel consumption in conventional power stations.

5-2.Air separation

①Air Liquide plant（France）

・Important electricity saving for the Air separation company as the traditional liquefaction process of Nitrogen is a very high energy-consumer

・Lower need of warmth for the LNG regasification process

②Cold Air Products（Japan）

・It is generally agreed that the way to use the cryogenic energy of LNG can cut the consumption of the electrical energy by half compared with the way without using the cryogenic energy of LNG.

・From an environmental aspect, the air separation plant of Cold Air Products Co.,Ltd. utilizing LNG cryogenic energy can reduce CO_2 emissions by 55% compared with conventional plants powered exclusively by electricity.

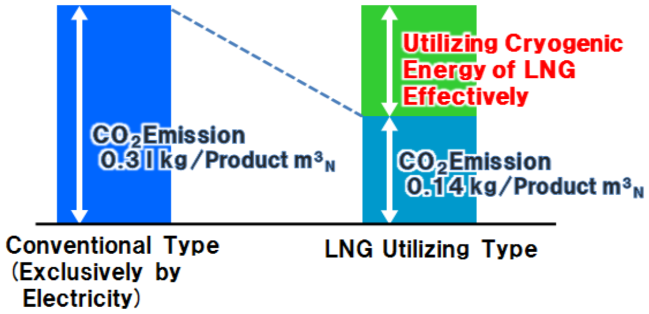

Figure 30. Reduction Effect of CO_2 Emissions by Utilizing LNG Cryogenic Energy

5-3.liquefied carbon dioxide and dry ice

①Kinki Carbon Company (Japan)

Kinki Carbon Company, Ltd. has enabled to reduce its electricity consumption in producing carbon dioxide by about half, since it can produce it at a lower pressure and temperature than by its previous method and liquefy it by using the coldness of LNG.

②Tokyo Tansan (Japan)

- Utilizing cold energy possessed by LNG at Tokyo Gas Negishi Terminal, electricity consumption is reduced by half.
- The motor propels the power of the compressor by controlling the rotation speed.
- All the gas vaporized by dry ice is recovered and reused as raw material gas.
- We adopt a flexible container system for storing and transporting dry ice, we are striving to reduce sublimation loss and to streamline transportation.
- In order to secure power stability, city gas cogeneration is introduced and exhaust heat is effectively used in the manufacturing process.

5-4.LNG-BOG Re-liquefaction・LNG-BOG Recovery optimization

①Ohgishima terminal (Japan)

From the beginning of operations, Ohgishima terminal has been operating the BOG re-liquefaction unit. This method is very economical. Because the range of the pressure risen by the compressor is small, and heat exchange can be performed without reducing the pressure of the cooling LNG.
Effective use of cold energy in the LNG terminal is very important from the point of view of reducing energy saving and carbon dioxide emissions. Therefore, although LNG cold energy should be used as much as possible, the amount utilized should be planned considering the minimum limitation of LNG vaporization amount at the LNG terminal.
Since it is possible to boost liquefied BOG by BOG re-liquefaction equipment, with this method power cost reduction of about 40% could be achieved comparing with sending out by directly boosting the BOG

② Cartagena LNG terminal（Spain）

Using a process simulation model, the reduction of OPEX has been estimated, resulting in a reduction of approximately 7.7 GWhe/year. Estimated CAPEX for the installation of a BOG/LNG heat exchanger are 0.5 M€, taking into account the cost of the equipment, associated pipes and instrumentation and required installation work. Corresponding estimated savings allow a payback time of around 3 years.

5-5.Refrigerated warehouses（Japan Super Freeze）

In the case of-60°C,the standard refrigerating temperature of tuna, the electricity consumption required to operate the LNG type cryogenic refrigerated warehouse becomes about 1/3 in comparison with machine type.
※The lower the refrigeration temperature, the more energy-saving and economics are improved in the case of LNG type.
In the case of LNG type, compressor is not needed. Therefore the power energy of the compressor is unnecessary.

In the case of mechanical type, gas refrigerant is compressed by a compressor and cooled with a condenser to make a liquid with high pressure. After that the pressure is lowered with an expansion valve and air is cooled with vaporization heat by evaporating at vaporizer. The energy of the compressor is not proportional to the refrigeration temperature, and the lower the refrigeration temperature is, the more it is required.

6. Considerations to install equipment

6-1.Air separation

In order to obtain high cost efficiency for the construction of the new air separation plant, the following requirements should be met in addition to the recovery of the investment.

①By utilizing the cryogenic energy of the LNG, the operating costs should be kept to a minimum level by the reduction in electricity consumption in the air separation plant. As a result, the products should enjoy good price competitiveness.

②By locating the LNG send-out facility close to the air separation plant, the cryogenic energy of the LNG should be able to be efficiently utilized at the air separation plant.

③The products of the air separation plant should enable to sell at a reasonable good price for a period long enough for us to recover the initial investment in a short span of time so as to make the investment decision.

For example, there should be good prospects to sell the products at a reasonable good price for a span of long period by having a long term take-or-pay clause included in the contract with the customer, or by having the markets sell the products at a reasonable and stable price for a long time. In order to realize this, the good conditions of the plant location should be prepared. At the same time, the operation rate of the plant should be maintained at a high level enough to realize sufficient profitability.

④The production ratio of the oxygen and nitrogen should be appropriate for the demand so as to increase the economic efficiency of the plant.

⑤In certain regions like Europe, the air separation process may be sensitive to the natural gas send-out flow-rate which depends on the pace of the cargoes unloaded into the LNG receiving terminal.

6-2.liquefied carbon dioxide and dry ice

The following requirements should be met in the new carbon dioxide production plant in order to achieve high profitability in addition to the good investment recovery mechanism.

①By utilizing LNG, the electricity consumption of the carbon dioxide production plant should be kept to a low level. As a result, the products should enjoy good cost competitiveness.

②The LNG send-out facility and the liquefied carbon dioxide plant should be located close enough to utilize the LNG's cryogenic energy for the liquefied carbon dioxide production plant.

③The liquefied carbon dioxide and the dry ice should be sold at a good price for a long period enough for us to recover the initial investment. For example, there should be good prospects by having a long term take-or-pay clause included in the contract with the customer, or by having the markets sell the products at a reasonable and stable price for a long time.

In order to realize this, the good conditions of the plant location should be prepared.

④The purity of the carbon dioxide should be maintained at a high level to cope with the intended usage stated by the customers.

6-3.LNG-BOG Re-liquefaction・LNG-BOG Recovery optimization

The following requirements should be met in the new LNG-BOG re-liquefaction system in order to achieve high profitability in addition to the good investment recovery mechanism.

①The operational cost of the BOG re-liquefaction system is lower compared to the gas send-out system that boosts BOG with a compressor. In particular, the higher the delivery gas pressure, the greater the energy saving effect.

On the other hand, the system of BOG re-liquefaction equipment is complicated and initial investment may become expensive.

In order to achieve investment recovery in a short span of time so as to decide the investment decision, it is necessary to minimize operating costs.

②To consider the minimum send-out amount of LNG terminal. In order to realize investment recovery in a short span of time, it is desired to maintain the LNG-BOG reliquefaction facility at a high operating rate.

As a method for reducing the minimum send-out, the amount of LNG necessary for BOG reliquefaction may be minimized, and it is necessary to adopt a high efficiency heat exchanger and design system .LNG - BOG generation occurs in large quantities when unloading LNG from an LNG carrier to the terminal storage tanks.
For LNG terminals with a low LNG unloading frequency, even if the terminal has facilities to re-liquefy all LNG-BOG, investment profitability may not match due to declining equipment availability.
Therefore, it is thought that it is desirable to operate in a combination of the method of the BOG boosting by compressor to a pressure of city gas and the BOG re-liquefaction system.
③To consider the following contents in the design of BOG re-liquefaction equipment.
By returning the re-liquefied BOG to the LNG storage tank, the effect of suppressing LNG concentration in the tank can be expected. On the other hand, that increases the heat input to LNG storage tank, and the amount of steady BOG generation in the LNG tank may increase.
④To consider the introduction of equipment to remove nitrogen as necessary. Immediately after unloading LNG from the carrier to the terminal storage tank, the nitrogen concentration in the BOG increases and the nitrogen concentration may rise to about 20%.
When the nitrogen concentration in BOG is high, the following problems may occur:
・The methane recovery rate in the LNG-BOG reliquefaction equipment may decrease.
・The adjustment cost for keeping send-out gas calorific value within regulated range may increase, since the re-liquefied BOG calorific value decreases.
・Nitrogen oxide at the time of combustion must be increasing in the case that the nitrogen concentration in send-out gas is high.

<Boil off gas recovery optimization using LNG cryogenic energy>
① The estimation of the number of days under low send out rates is critical for the cost-benefit analysis. During these periods, cooling BOG to sub-zero temperatures allows the increase of the BOG recovery rate in the recondenser with an important reduction of compression costs.
②Loading and unloading imply a large amount of BOG to be recovered at the terminal. BOG cooling allows important electricity savings on its recovery during these operations.
③Electricity price is another crucial parameter when evaluating the cost effectiveness of the project. Potential variations may be studied to determine its impact on final cost efficiency.
④The analysis carried out to determine the optimal temperature of the BOG showed that a decrease on the temperature of the BOG stream always implies a decrease on compression needs. However, the limit of the cooling temperature is to be set to avoid the generation of condensates in the heat exchanger. Temperatures of -70ºC guarantee that no condensate is generated under all scenarios in Cartagena Terminal.
⑤BOG could be cooled further than -70ºC connecting up to three BOG/LNG heat exchangers in series. In this case, LNG would be evaporated, avoiding the vaporization process using sea water. However, condensates could be generated in the BOG stream and moreover investment cost would increase significantly. Cost efficiency thus would be reduced.
⑥Minimum requirements of LNG cold energy are to be determined, especially if several projects related to cold energy utilization coexist in one terminal. The needs for each one are to be evaluated in order to establish the viability or to prioritize when needed.

6-4. Cryogenic Crushing

The following requirements should be met in the new cryogenic crushing plant in order to achieve high profitability in addition to the good investment recovery mechanism.
①The LNG send-out facility and the cryogenic crushing plant should be located close enough to utilize the LNG’s cryogenic energy for the cryogenic crushing plant.
②There should be good prospects to set an appropriate price for the cryogenic crushing to produce high added value over the long term to recover the initial investment.
③The crushed particles should not be deteriorated by contamination or oxidation in the process of passing through the crushing facility, so as to prevent the reduction of added value by the cryogenic crushing.
④The particle size distribution of the substance as a result of the cryogenic crushing should be sufficient to fulfill the requirements of the customers.

6-5.Refrigerated warehouses

①The freezing warehouse is located adjacent to the LNG terminal.

②A situation where the freezing warehouse business can be carried out in a place relatively close to a tuna fishing port or a demand place.
Japan Super Freeze is located in the metropolitan area of the tuna demand area, and it is also located on the transport route between the fishing port of Yaizu and the metropolitan area.

Figure 31. Location of Japan Super Freeze

③The value of goods refrigeration is high.
Economic efficiency greatly affects the value of refrigerated products.
In areas where fatty fish such as tuna is considered to be valuable, big income is obtained by frozen tuna. There is a correlation between the quality preservation time of fishery products and the freezing temperature, and it is necessary to store below -50 ° C in order to keep fish with high fat content for a long time.
④Compared with mechanical type, it is superior in terms of economy.
When comparing mechanical type and LNG type, initial investment of mechanical type is more inexpensive, but operational costs including compressor electric consumption are significant. Therefore, under conditions such as low refrigeration temperature and high power price, the LNG type is superior in terms of economic efficiency.

7. Conclusion

In this study, we have extensively studied the technology of LNG cold energy utilization, and organized examples of application of LNG cold energy utilization and energy savings.
We also interviewed business operators on matters to be considered when introducing LNG cold energy utilization facilities, and described the contents to expand the LNG cold energy utilization business.
As a response to global environmental problems, efficient use of energy is an important issue. Since the demand for LNG in the world is expected to increase in the future, we hope that LNG cold energy utilization will spread widely.
We hope that this study will be useful when introducing LNG cold energy utilization equipment. Finally, we would like to express our gratitude to everyone who contributed to this study.