THE ACCOMPLISHMENT OF 100% UTILISATION OF LNG COLD ENERGY

－Challenges in Osaka Gas Senboku LNG Receiving Terminals－

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Keywords: LNG cold energy utilisation, energy saving, LNG receiving terminal

1. ABSTRACT

Osaka Gas has been making efforts towards advancements in the utilisation of LNG cold energy, which will contribute tremendously to energy saving and environmental preservation. In Senboku LNG Receiving Terminals 1 and 2, which account for approximately 70% of Osaka Gas' city gas requirement, we have installed facilities capable of utilizing cold energy in almost all types of plants, including those for cryogenic power generation, air liquefaction and separation, carbon dioxide liquefaction, dry-ice manufacture, and BOG re-liquefaction with a cold energy storage system.

Terminal 1 in particular, located in an industrial complex, has promoted the use of LNG cold energy. In Terminal 1, in January 2011, we started supplying LNG cold to a neighboring factory's ethylene plant, enabling considerable saving of energy and reduction in CO_2 emissions along with some improvements in operations in Terminal 1. As a result, we were able to accomplish 100% (volume-based) utilisation of LNG cold in Terminal 1. This means that we no longer have to use seawater to produce city gas in Terminal 1.

Thanks to the electric power reduction achieved through this use of LNG cold energy, CO_2 reduction over a year in Terminal 1 has reached approximately 113,000 tons. This paper provides further details.

2. INTRODUCTION

2.1. LNG cold energy

Increasing attention has been given to the utilisation of cryogenic energy from LNG (LNG cold energy) as an effective means of achieving greater energy conservation and reducing CO_2 emissions. In the background to this trend is a rising demand for LNG on a global level amid concerns over addressing the issue of climate change and achieving efficient energy utilisation [Figure 1].

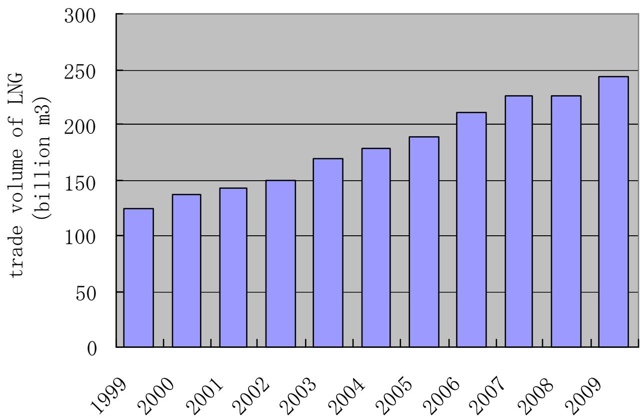

Figure 1. Trend in global trade volume of LNG from 1999 through 2009 [1]

LNG cold energy has two elements in its utilisation: "temperature energy" and "expansion energy." The former is derived from the temperature difference between LNG and the atmosphere, the latter from the expansion process of LNG when it expands 600 times in volume upon evaporation. Without effective facilities for its recovery and utilisation, LNG cold energy is lost into the sea when LNG is evaporated in LNG receiving terminals.

The maximum potential work generated by these energies, so-called "exergy", is calculated by the following formulae:

Temperature energy: $E=H-H_0-T_0(S-S_0)$ Expansion energy: $E=R'T_0 \ln (P/P_0)$

(H: enthalpy, T: temperature, S: entropy, R': gas constant, P: pressure; the subscript "0" indicates the ambient condition)

In LNG receiving terminals, LNG exists under a variety of conditions, and the ratio between the temperature and expansion energies depends on its temperature, pressure and composition [Table 1]. Under the same composition and temperature, the greater the expansion energy of he LNG, the lower its temperature energy becomes.

Table 1. LNG's cold energies under different conditions

Temperature [deg.C]	Pressure [MPaG]	Temperature Energy [kWh/t]	Expansion Energy [kWh/t]
-160	0	240	0
-160	4.4	110	130
-160	8.0	90	150

Today, Japan, which imports over 60 million tons of LNG per year (that is, approximately 35% of total global imports [Figure 2]), is the world's biggest importer of LNG. If we could convert about 15% of the cold energy of LNG annually imported into electricity, the amount produced would be equal to the power consumed by about 400,000 houses for one year [2].

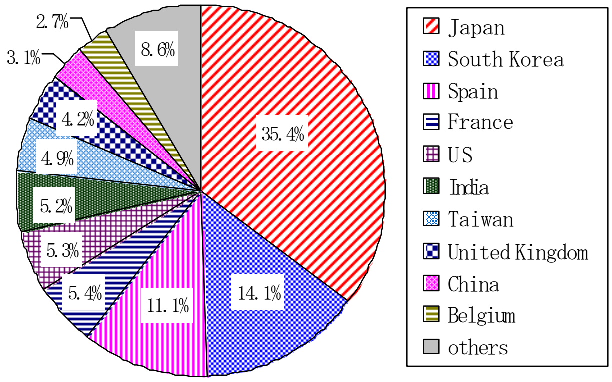

Figure 2.Percentage of global import volume of LNG by country in 2009 [1]

2.2. Features of Osaka Gas's LNG Terminals

2.2.1. Introduction to Osaka Gas

Osaka Gas is one of several city gas companies in Japan, and started to import LNG in 1972. Today in 2012, Osaka Gas has long-term contracts with seven countries, namely Brunei, Indonesia, Malaysia, Australia, Qatar, Oman and Russia; in 2010, it imported about 7 million tons of LNG from those countries and others. Osaka Gas will newly start to import LNG from Papua New Guinea in 2013 through long-term contracts.

Osaka Gas has three LNG terminals, namely the Senboku LNG Terminals (Terminal 1 and Terminal 2) and the Himeji LNG Terminal. Osaka Gas supplies city gas, produced in these three terminals, to about 7 million customers in the six prefectures of the Kansai Region [Figure 3].

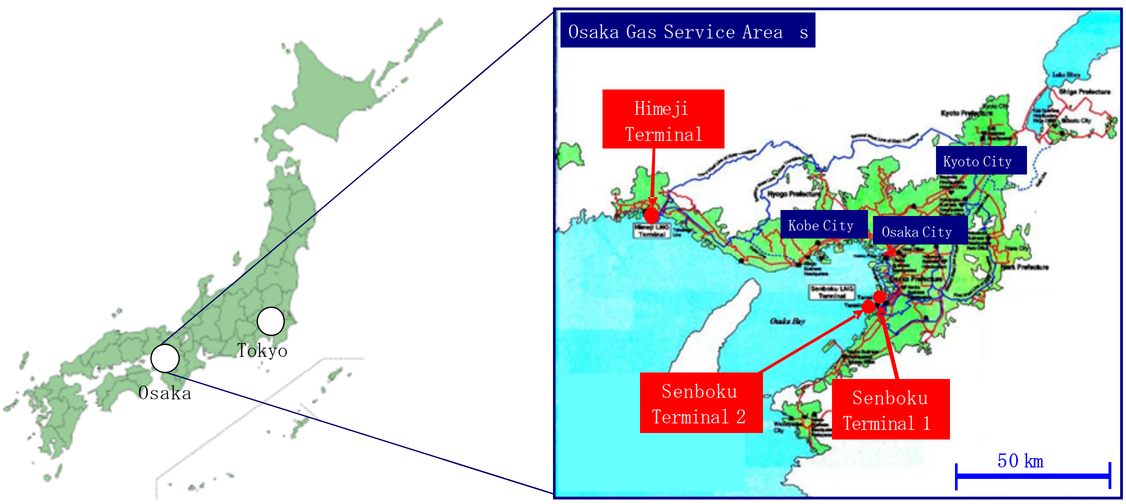

Figure 3.Osaka Gas service areas

2.2.2. Utilisation of LNG cold energy in Osaka Gas

At the Senboku LNG Terminals (Terminal 1 and Terminal 2) and the Himeji LNG Terminal of Osaka Gas, we make good use of LNG cold energy in many types of facilities, including plants for processes such as air liquefaction and separation [Figure 4], carbon dioxide liquefaction [Figure 5], cryogenic power generation, and BOG re-liquefaction with a cold energy storage system [Table. 2]. For example, the air liquefaction and separation plant that uses LNG cold energy has reduced electric power consumption by 50% compared to other plants that do not use LNG cold energy.

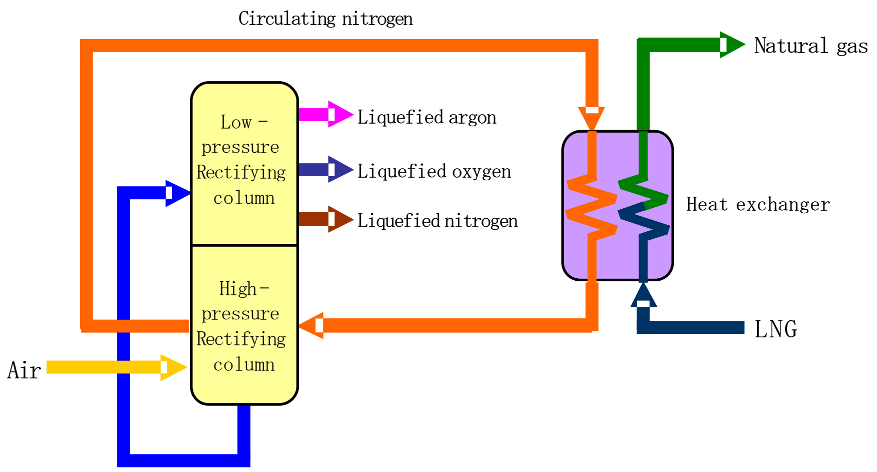

Figure 4. Flowchart of the air liquefaction and separation facility using LNG cold energy

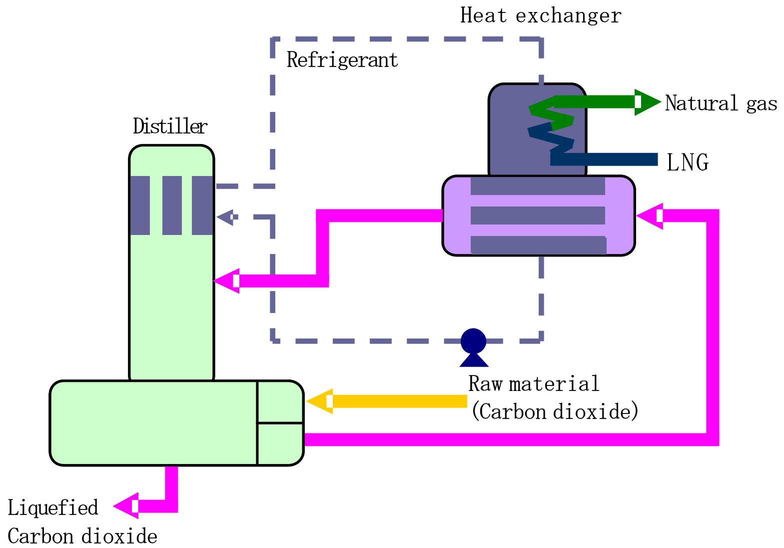

Figure 5. Flowchart of the carbon dioxide liquefaction facility using LNG cold energy

Table 2.Facilities using LNG cold energy in each LNG terminal of Osaka Gas

Senboku Terminal 1			
The facility using LNG cold	Start of operation	Installation site	The LNG cold utilization rate*
Air-condition with LNG cold	1978	in the terminal	approximately 100 %
Carbon dioxide liquefaction	1980, 2004	in the terminal	
Warm water chilling	1987	in the terminal	
Brain chilling	1987	in the terminal	
Expansion turbine	1989	in the terminal	
Air liquefaction and separation	1993	in the terminal	
Ethylene plant	2011	in a neighboring factory	

Senboku Terminal 2			
The facility using LNG cold	Start of operation	Installation site	the LNG cold utilization rate*
Cryogenic power generation	1979, 1982	in the terminal	approximately 50 %
Air liquefaction and separation	1983	in the terminal	
BOG re-liquefaction with cold energy storage system	1997	in the terminal	

Himeji Terminal			
The facility using LNG cold	Start of operation	Installation site	the LNG cold utilization rate*
Cryogenic power generation	1987	in the terminal	approximately 50 %
Expansion turbine	2000	in the terminal	
Intake air cooler	2004	in the terminal	

*This is the ratio of the volume of LNG vaporized at facilities using LNG cold to total volume of vaporized LNG in each terminal.

In Terminal 1 (Senboku LNG Terminal 1) in particular, we have achieved the effective use of LNG cold energy, connecting the plants with those of neighboring factories, taking advantage of the terminal's location in an industrial complex [Figure 6]. The following chapters provide further detail about the efforts pursued in Terminal 1.

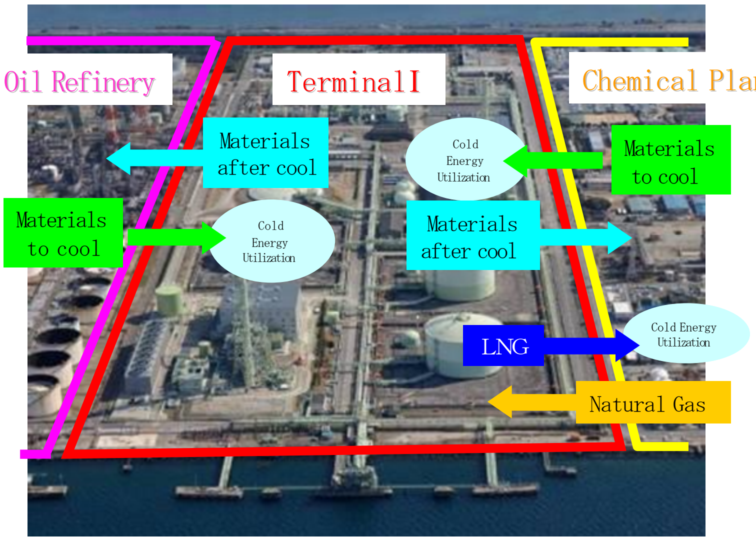

Figure 6.LNG cold energy utilisation in Terminal 1 located in an industrial complex

3. BACKGROUND

3.1. Previous efforts towards advanced utilisation of LNG cold energy in Terminal 1

3.1.1. General remarks

In Terminal 1, we have pro-actively installed a high-efficiency air liquefaction and separation plant, carbon dioxide liquefaction plants, and other plants using LNG cold energy, and supplied LNG cold energy to neighboring factories. As a result, Terminal 1 has achieved the highest rate of LNG cold energy utilisation in the world. Figure 7 shows the outline of the LNG cold energy in Terminal 1. Next, we introduce one of the special efforts toward the advanced utilisation of LNG cold energy in Terminal 1.

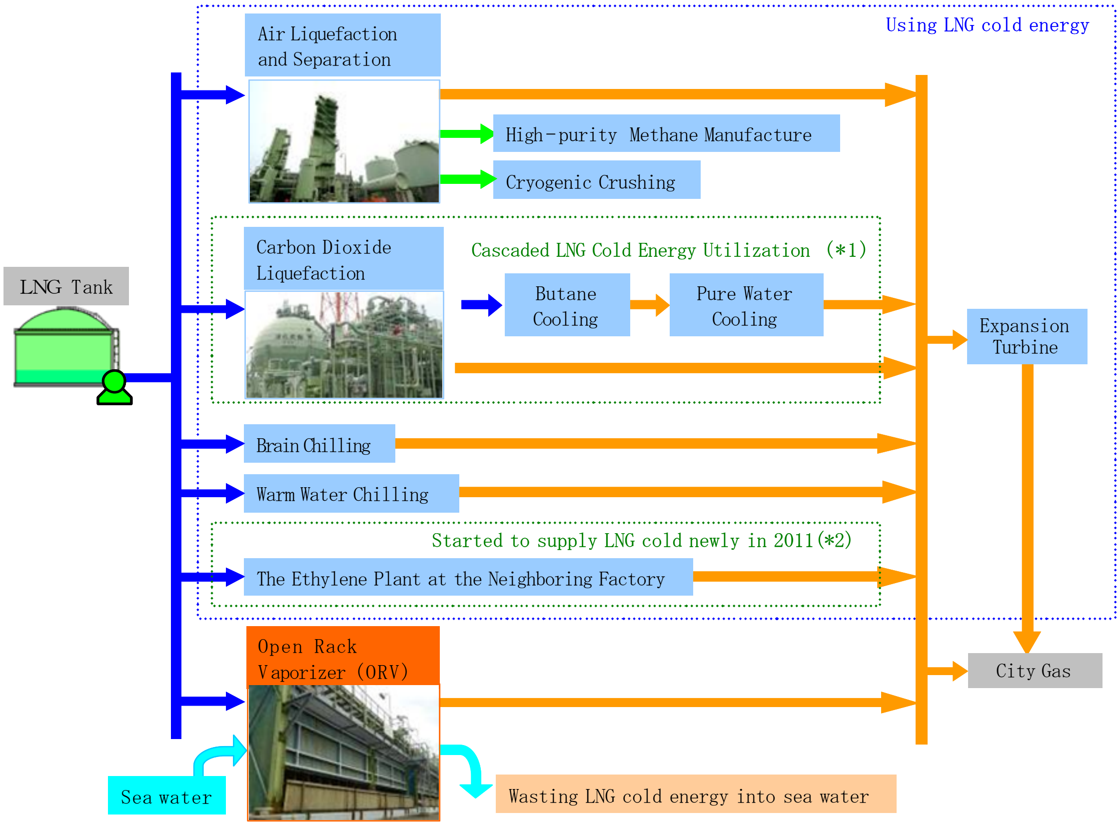

Figure 7.Outline of the utilisation of LNG cold energy in Terminal 1

3.1.2. Special effort -Use of LNG cold energy over a wide temperature range-

Terminal 1 is a member of the Research Association of Refinery Integration for Group-Operation. Since 2003, as an effort by the Research Association of Refinery Integration for Group-Operation, Terminal I in concert with its neighboring factories has conducted research and development on the optimum process for using LNG cold energy, as shown in Figure 8 [4].

In this research and development activity, LNG cold energy is used for four purposes: (1) To separate olefins produced as byproduct at a neighboring oil refinery plant; (2) To liquefy carbon dioxide produced as byproduct at a neighboring hydrogen manufacturing plant; (3) To cool room-temperature butane refined at a neighboring petrochemical plant; and (4) To cool pure water used in inlet air coolers installed in gas turbine power generation plants. While these plants conventionally used refrigerators or the like, the use of LNG cold energy enables substantial reduction in their power requirements. Moreover, efficient use of LNG cold energy over a wide temperature range, which is achieved by installing heat exchangers in series for exchanging heat between LNG and the aforementioned plants at four stages between low temperature (-160 C) and room temperature (10 C), improves the quality of LNG cold energy use and enables an approximately 23% reduction in cold energy amount, as compared with the case when supplying LNG cold energy separately to individual plants.

Since 2006, general research has been conducted on carbon dioxide liquefaction, cooling room-temperature butane and cooling pure water. In this research, LNG cold energy is used over a wide temperature range. It is expected that carbon dioxide emissions will be reduced by approximately 65,000 tons per year. Of this reduction, approximately 3,000 tons per year is expected to be due to LNG cold energy use.

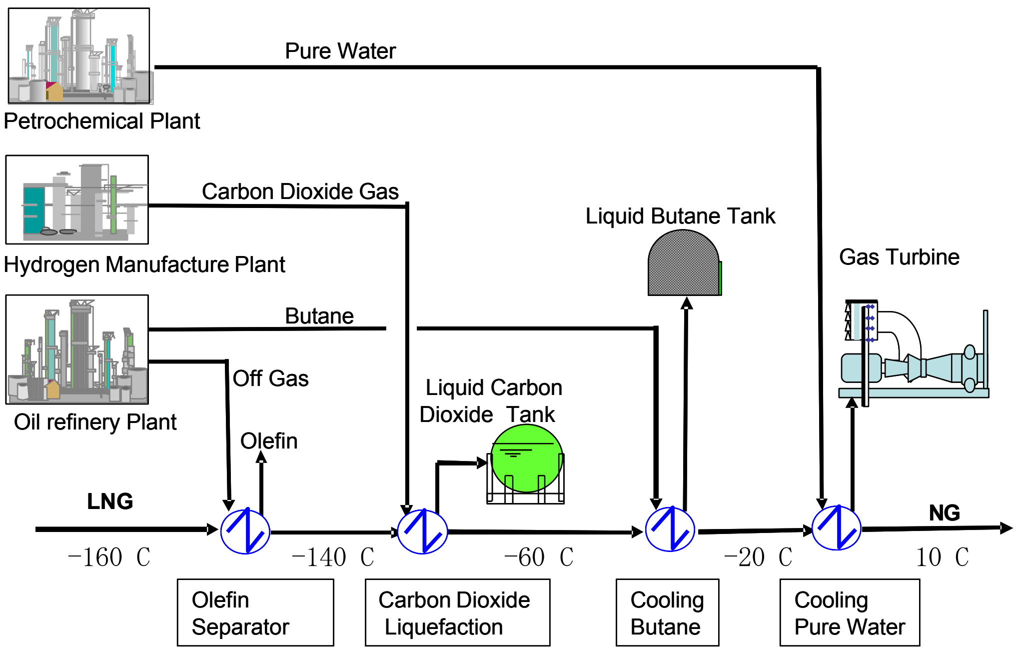

Figure 8. Process flow of research and development

3.2. Challenges for 100% utilisation of LNG cold energy

In Terminal 1, we had previously installed many types of facilities utilizing LNG cold, and as a result, Terminal 1 had already achieved the highest rate of LNG cold energy utilisation in the world. However, the rate of cold energy utilisation thus achieved in Terminal 1 was not 100%, but approximately 80%. When the city gas demand was high, we had to use LNG vaporizer, which wastes LNG cold energy by dissipating it into seawater. This was because in most of these facilities, such as air liquefaction and separation, it was difficult to change cold energy load despite seasonal and hourly fluctuation of Osaka Gas's gas supply. So, previously in Terminal 1, the challenge in accomplishing a 100% utilisation rate was to curb the use of LNG vaporizer by developing a new process utilizing LNG cold, whose load could be changed. Figure 9 shows the image of the previous structure of LNG cold energy utilisation in Terminal 1. Figure 10 shows the actual contemporary data on the LNG flow rates at the facilities vaporizing LNG.

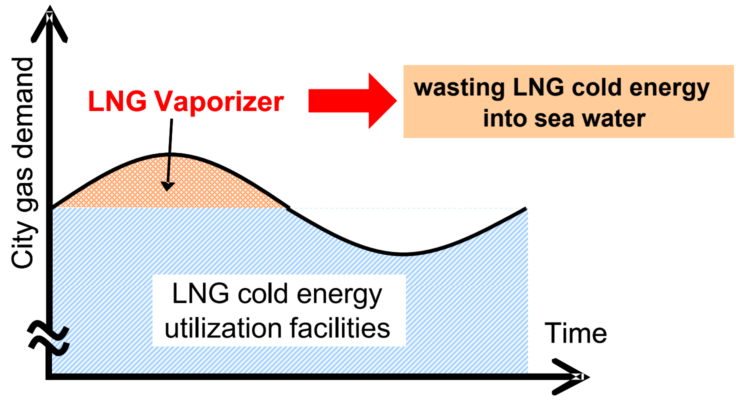

Figure 9. Image of previous structure of LNG cold utilisation

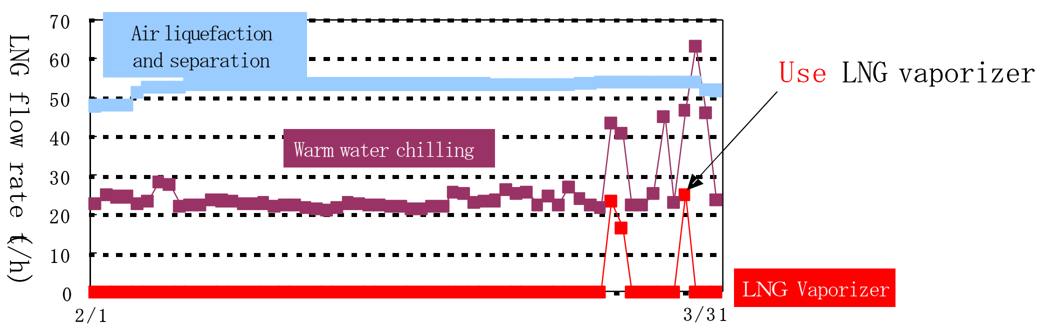

Figure 10.Actual data of previous situation（February 1 to March 31, 2010）

4. EFFORTS TOWARD 100% COLD ENERGY UTILISATION IN TERMINAL 1

In order to solve the problem, we increased the amount of LNG handled first in 2006. Then, we increased LNG cold supply to neighboring factories in 2011. This chapter provides further details about these efforts.

4.1. Increasing amount of LNG handled

The LNG unloading facility of Terminal 1 was designed exclusively for mid-sized ships. On the other hand, the number of mid-sized ship was decreasing. So, the amount of LNG handled in Terminal 1 peaked around the year 2000. In order to increase the use of LNG cold energy, it was necessary to increase the amount of LNG handled. Therefore, a 1.3 kilometer-long undersea pipeline was installed between Terminals 1 and 2,, as shown in Figure 11.

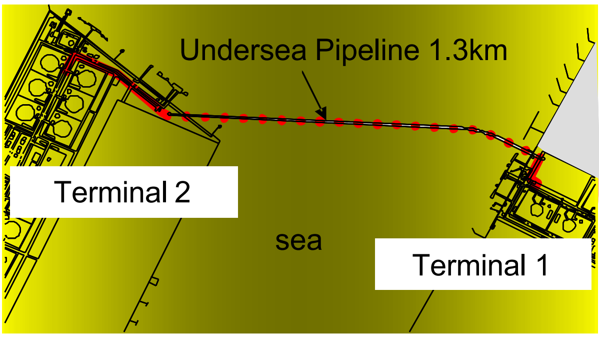

Figure 11.Undersea pipeline layout

Since 2006, the aggregate LNG supply received in Terminal 2 has been transferred to Terminal 1 through the undersea pipeline in order to increase the amount of LNG handled in Terminal 1. Thanks to the improvement in the method of receiving LNG, the amount of LNG received by Terminal 1 has been increased from 0.75 million tons to over 1 million tons [Figure12].

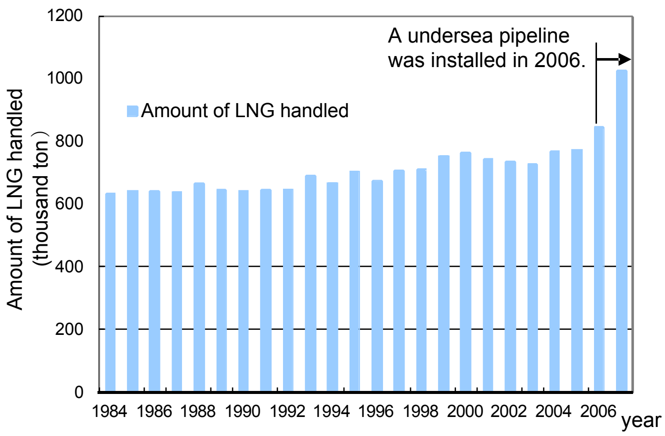

Figure 12.Increase in the amount of LNG handled

4.2. Increasing LNG cold energy supply to a neighboring factory

4.2.1. General remarks

In Terminal 1, we could try to develop a new process utilizing LNG cold energy, by increasing the amount of LNG received as I described in the previous chapter. In developing the process, focus was placed on an ethylene plant at a chemical factory lo cated adjacent to Terminal 1 of Osaka Gas [3] [Figure 13]. Requiring cryogenic energy at an extremely low temperature, the ethylene plant at the factory used conventional refrigeration equipment. Attention was paid to the low temperature range with a lowered COP rate, to which LNG cold energy was to be applied. When LNG cold energy replaces conventional refrigeration equipment, it has the advantage of lowering electricity consumption, because LNG cold energy only requires electricity to drive a pump for transferring LNG the regardless of temperature range, resulting in considerable power requirement saving [Figure 14]. At the plant, ethylene and propylene are manufactured through low-temperature distillation after the cracking of naphtha and off-gas [Figure 15]. In the conventional process, the cold energy is generated by a refrigeration compressor driven by a steam turbine, and the required steam is generated by a steam boiler using fuel oil or off-gas. In the new process, its cold energy requirement is partially replaced by LNG cold energy, and it results in reduced power consumption for compression as well as lower fuel consumption for steam generation.

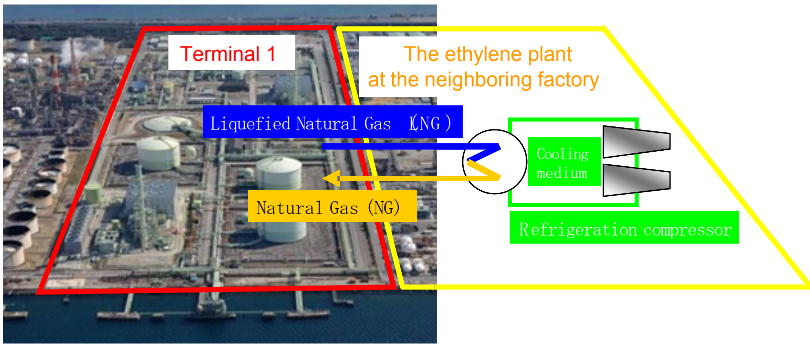

Figure 13.New process utilizing LNG cold energy at the ethylene plant

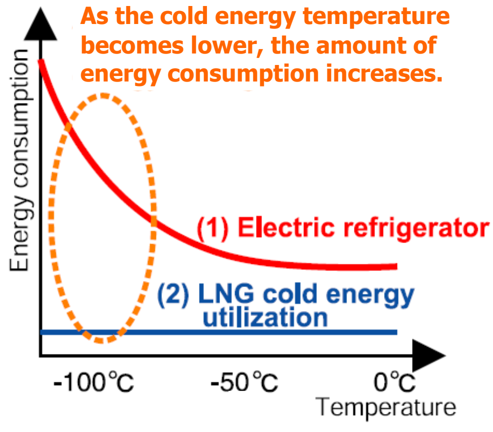

Figure 14.Advantage of LNG cold energy utilization

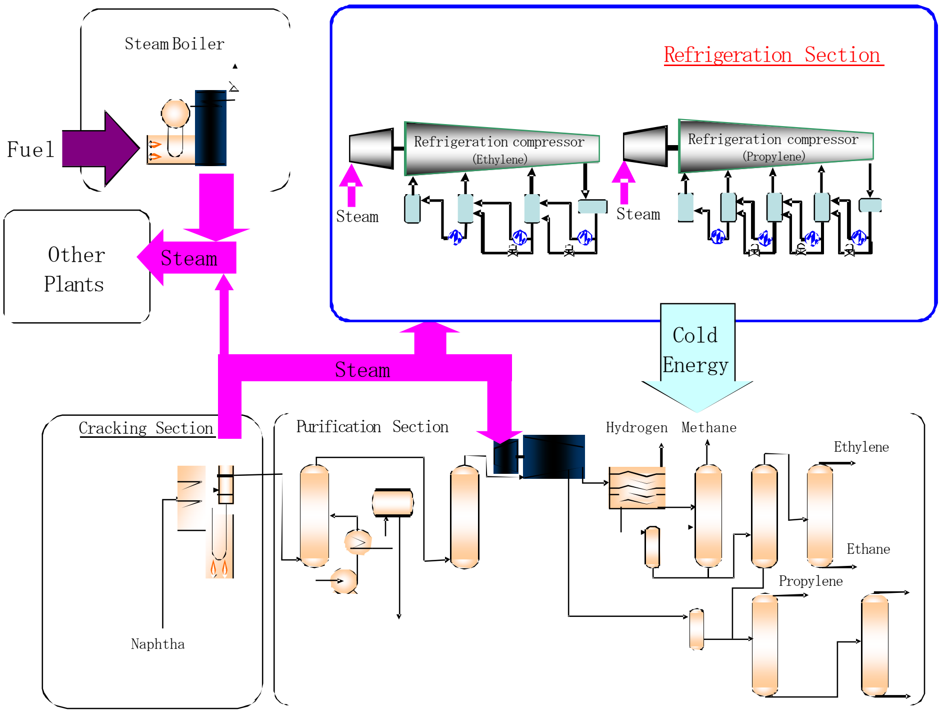

Figure 15.Conventional refrigeration system in ethylene plant

4.2.2. Details in developing the new process

(a) Developing the new process: challenges

Major challenges in developing the new process utilizing LNG cold energy included the following:

(1)

Due to the already existing high utilisation of LNG cold energy in Terminal 1 and the seasonal and hourly fluctuation of Osaka Gas's gas supply (70-200 tons/hour), there could be a shortage in the supply of LNG by the terminal [Figure 16].

(2)

The volume of LNG for the new process had to be matched with the seasonal and hourly fluctuation of Osaka Gas's gas supply.

With these challenges in the background, the new process needed to realize a high level of stability unaffected by gas supply operations, since the plant was a key facility for the neighboring chemical factory. It also needed to maximize energy conservation to achieve a high utilisation of LNG cold energy.

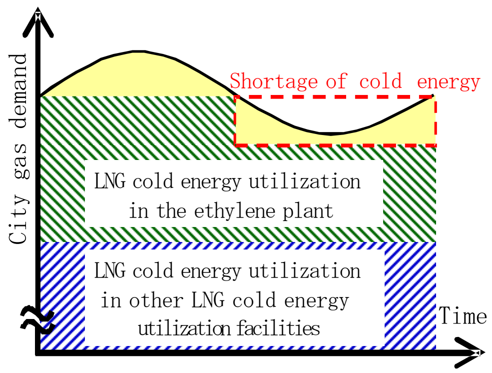

Figure 16.Shortage of cold energy in the ethylene plant

(b) Developing the new process: achieving operational stability

In order for the process to achieve operational stability, it was understood that LNG cold energy could be used in combination with the cold energy derived from the existing refrigeration compressor. By this means, the cold energy could be supplemented in the case of LNG supply shortage for the ethylene plant. Furthermore, the process could be operated by the compressor alone in the case of a shutdown of LNG supply due to periodic repair or power outage, etc. When the process was operated with the combined supply of cold energy, there were no major capital cost additions for the new compressor because of the use of the existing compressor.

(c) Developing the new process: achieving energy conservation

Some issues were identified in examining the process's energy conservation effects:

(1)

When LNG is the single source of cold energy in the new process, a maximum energy saving can be achieved due to the total elimination of the power load for the compressor [Figure 17]. From the operational perspective, however, ethylene plant operation needs to be adjusted when meeting the LNG supply shortage.

(2)

When LNG cold energy is combined with the refrigeration compressor, the lowered-power portion for the compressor replaced by LNG cold energy translates into saved steam turbine power. Due to the risks of surging pressure and flow rate of the centrifugal compressor caused by excessively reduced loads, the minimum operational load for the compressor was about 70% of the rated load, i.e., the remaining 30% of the cold energy requirement was to be supplied by LNG.

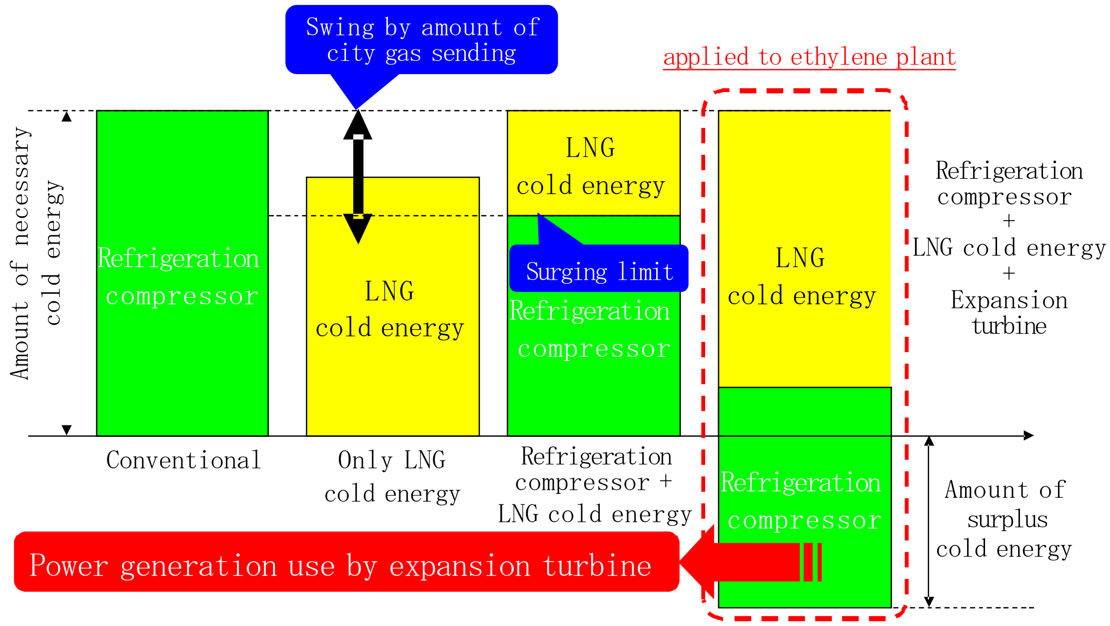

Figure 17.Cold energy balance of ethylene plant

To address the above issues, an examination of the process was conducted to maximize the use of LNG to meet demand without restricting the LNG cold energy supply for the cold energy requirement at the ethylene plant. As a result, a process was successfully developed in which the LNG volume could be increased to a maximum. This was made possible by employing an expansion turbine which removed the surge limit restrictions of the compressor [Figure 18]. The advantages of the process include efficient utilisation of LNG cold energy through phases along the broad temperature ranges of the ethylene plant (-100 C to 20 C). With the use of LNG cold energy in the process, significant energy saving is expected, equivalent to a CO_2 emission reduction of 38,000 tons annually.

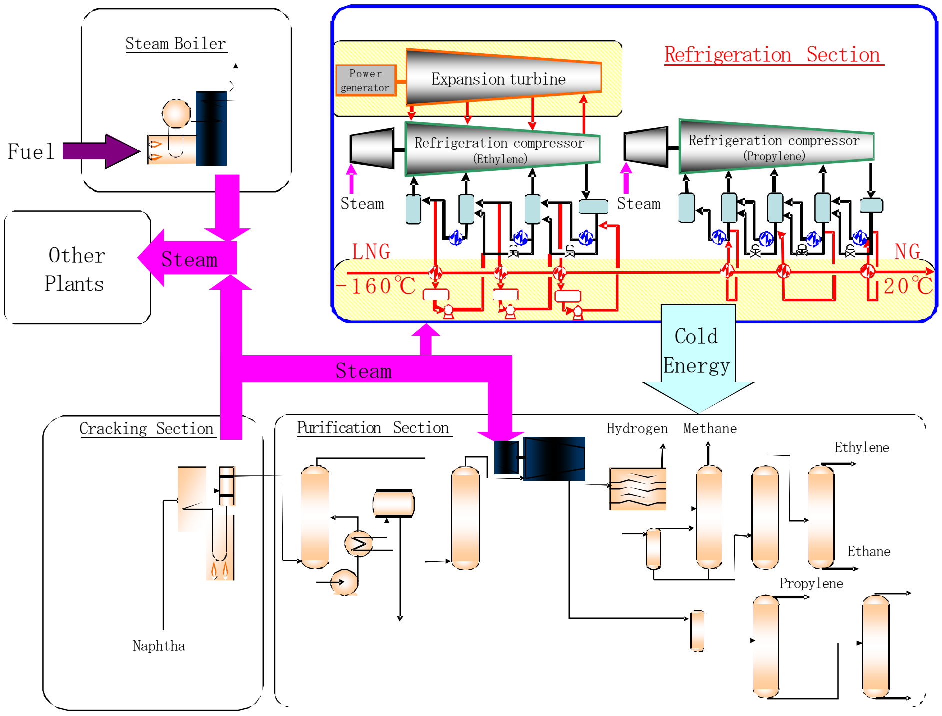

Figure 18.New refrigeration system in ethylene plant

4.3. The accomplishment of 100% cold energy utilisation

With the start of the new LNG cold energy utilisation process, the entire LNG supply in Terminal 1 is supplied to the pipeline network through LNG vaporisation at LNG cold energy utilisation facilities [Figure 19]. Unlike in the conventional vaporisation process of using seawater, in which LNG cold energy is wasted into seawater, natural gas is released without the use of vaporizers. Thus we were able to achieve 100% utilisation of LNG cold in Terminal 1. Figure 20 shows the actual data on LNG flow rates at the facilities vaporizing LNG after the start of the new LNG cold energy utilisation process.

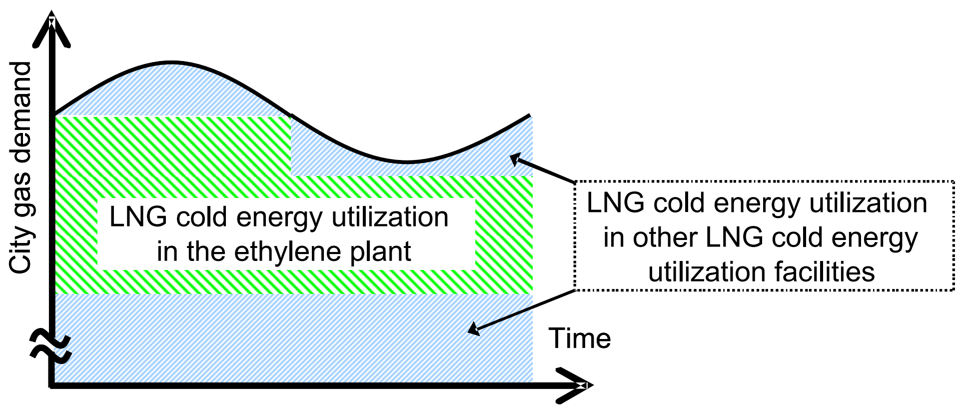

Figure 19.Image of present structure of LNG cold utilisation

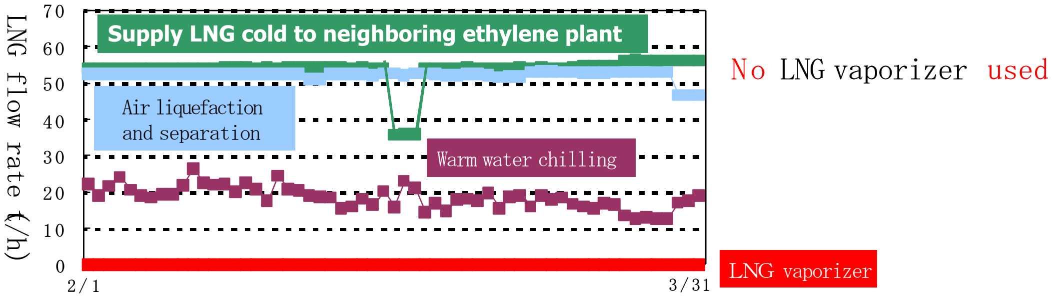

Figure 20.Actual data of the present situation（February 1 to March 31, 2011）

5. EVALUATION OF LNG COLD ENERGY UTILISATION

5.1. Improvement in exergy efficiency

In order to promote energy saving by using LNG cold, it is important to not only increase the rate (or quantity), but also improve the quality of LNG cold utilisation. So, in addition to the aforementioned efforts toward 100% use of cold energy, we have striven additionally to improve quality in the use of LNG cold energy.

The quality of LNG cold energy utilisation can be evaluated by “exergy efficiency.” “Exergy” is the maximum potential work as we introduced at chapter 2.1.

“Exergy efficiency” is considered one of the indicators representing how efficiently LNG cold is transferred to the targeted material [5]. Figure 21 shows the concept of exergy efficiency.

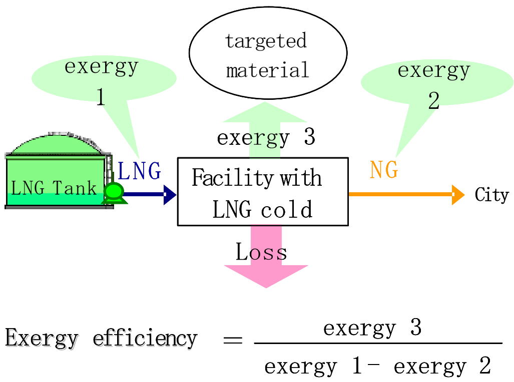

Figure 21.Concept of “exergy efficiency”

In this paper, we define “20 degrees Celsius (Temperature), 101.3kPa (Pressure)” as the condition for equilibrium with the environment. Under these conditions, we calculate the exergy efficiency of existing facilities using LNG cold in Terminal 1 or supplying LNG cold to the ethylene plant [Figure 22]. Exergy efficiency is defined as below [Formula 1].

$$h^{i} = \frac{\Delta E^{i}{}_{user}}{\Delta E^{i}{}_{LNG}} \times 100$$

[Formula 1]

η^i : *the exergy efficiency of the facility i* (%)

ΔE^i_{user} : *amount of the exergy the targeted material obtains at the facility i* $(kWh/LNG-t)$

ΔE^i_{LNG} : *amount of the exergy of LNG cold energy consumued at the facility i* $(kWh/LNG-t)$

The denominator of the fraction [Formula 1] represents the value when the exergy of LNG at the outlet of the facility is subtracted from that at its inlet. The numerator of the fraction [Formula 1] represents the value of the exergy which the targeted material obtains in the facility. Table 3 shows the values of ΔE^i_{user}, ΔE^i_{LNG}, and η^i in each facility using LNG cold.

Table 3.The value of exergy of LNG (NG) under each set of conditions

	ΔE^i_{user} (kWh/LNG-t)	ΔE^i_{LNG} (kWh/LNG-t)	η^i (%)
Ethylene Plant	82.41	111.64	74
Air Liquefaction and Separation	77.14	112.85	68
Carbon Dioxide Liquefaction	37.45	102.76	36
Brain Chilling	9.29	89.85	10
Warm Water Chilling	0.00	102.28	0
Expansion Turbine	33.22	45.59	73

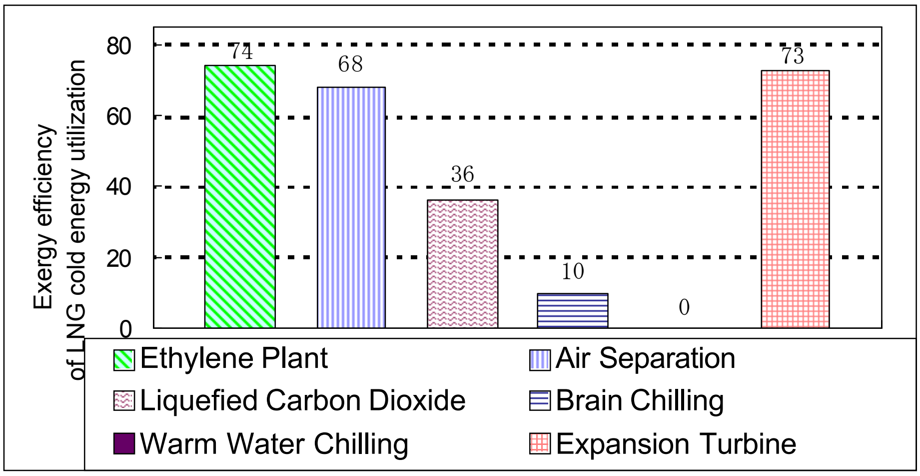

Figure 22.Exergy efficiency of LNG cold energy utilisation facilities

Figure 22 shows that the exergy efficiency in supplying LNG cold to the ethylene plant is the highest in Terminal 1. This means that LNG cold is most efficiently used there. This high efficiency is achieved by installing heat exchangers in series to exchange heat between LNG and targeted materials at six stages between low temperature (-100 C) and atmospheric temperature (20 C).

Next, we try to understand how the quality of LNG cold used in Terminal 1 comprehensively has changed by starting to supply LNG cold to the ethylene plant. In this paper, we defined "the exergy efficiency of LNG cold utilisation in Terminal 1." Figure 23 shows the concept of the efficiency.

We need to make use of some of LNG exergy as pressure energy to supply city gas to pipelines. After LNG is gasified to natural gas through a LNG cold utilisation facility, a part of the vaporized gas is introduced to the expansion turbine and then supplied to a trunk line at 0.75 MPa, and the rest of the gas is directly supplied to another trunk line at 2.35 MPa. Table 4 shows the exergy value of LNG (NG) under each set of conditions.

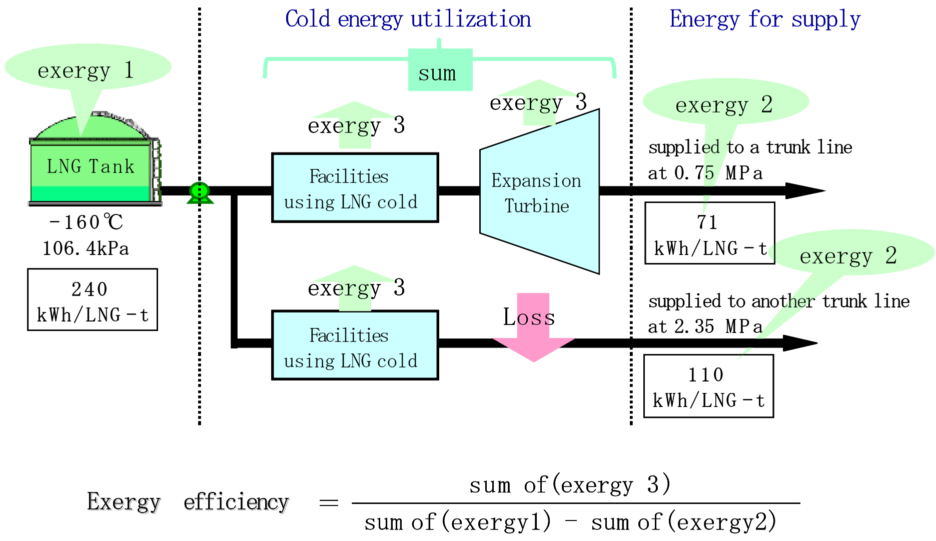

Figure 23.Concept of "exergy efficiency in Terminal 1"

Table 4.The value of exergy of LNG (NG) under each set of conditions

Condition (Temperature, Pressure)		The value of the exergy (kWh/LNG-t)
LNG	-160 degrees Celsius, 106.4 KPa	239.8
NG	20 degrees Celsius, 0.75 MPa	70.6
NG	20 degrees Celsius, 2.35 MPa	109.5

So, we calculate "the exergy efficiency of LNG cold utilisation in Terminal 1" by the formulae below [Formula 2 ~ Formula 4]. The numerator of Formula 2 (i.e., Formula 3) means the sum of the exergy obtained by the targeted materials at each facility in Terminal 1. The denominator of Formula 2 (i.e., Formula 4) means the available exergy of total LNG cold in Terminal 1 minus the exergy used for supplying city gas.

In this paper, we take no account of the effect of the LNG pump on the exergy of LNG cold because the effect is very small.

$$h^{all} = \frac{E_{used}}{E_{utilizable}} \times 100$$

[Formula 2]

$$E_{used} = \sum_{all\ i} \Delta E^{i}{}_{user} \times LNG^{i}$$

[Formula 3]

$$E_{utilizable} = 239.8 \times LNG^{total} - \{70.6 \times LNG^{\exp ander} + 109.5 \times (LNG^{total} - LNG^{\exp ander})\}$$

[Formula 4]

h^{all} : *the exergy efficiency in Terminal* 1 (%)

$E_{utilizable}$: *total amount of available exergy of LNG cold energy in Terminal* 1 (*kWh*)

LNG^{i} : *volume of LNG vaporized at the facilitiy i* (*ton*)

LNG^{total} : *total volume of LNG* (*ton*)

$LNG^{\exp ander}$: *volume of LNG supplied through Expansion Turbine* (*ton*)

Table 5 shows that LNG cold energy utilisation in the ethylene plant improves the quality of the LNG cold energy in the terminal.

Table 5.Improvement of the exergy efficiency of LNG cold energy utilisation in Terminal 1

LNG cold energy utilization facilities and LNG vaporizer	The exergy efficiency of each facility	Total LNG mass of each facility for two months [t]	
		LNG cold energy utilization in Ethylene	
		before	after
Ethylene Plant	74	0	75805
Air Separation	68	75129	72268
Liquefied Carbon Dioxide	36	9222	8105
Brain Chilling	10	4951	7531
Warm Water Chilling	0	34645	28035
LNG Vaporizer	0	466	0
Expansion Turbine	73	74069	96951
The exergy efficiency of LNG cold energy utilization at Terminal 1 [%]		44	52

5.2. Improvement in CO_2 reduction effect

As a result of improving the rate (or quantity) and the quality of LNG cold utilisation, the amount of CO_2 reduction increased considerably in Terminal 1. Figure 24 shows the total amount of CO_2 reduction by using LNG cold in Terminal 1 per year before and after supplying LNG cold to the ethylene plant.

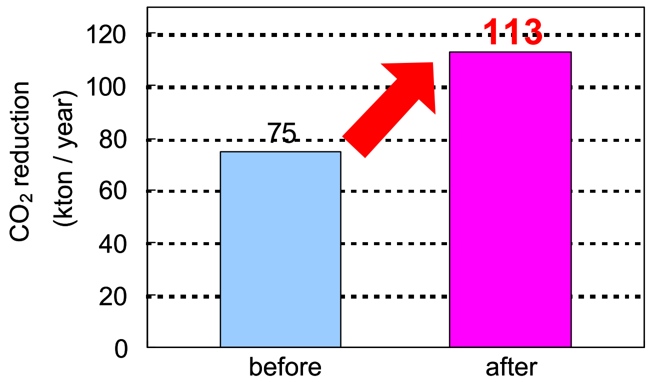

Figure24.CO_2 reduction by using LNG cold in Terminal 1
(before / after supplying LNG cold to the ethylene plant)

6. CONCLUSION

Osaka Gas has been making efforts towards advancements in the utilisation of LNG cold energy. In particular, Senboku LNG Terminal 1 has been making efforts to improve the utilisation of LNG cold. In addition, by increasing the amount of LNG handled and newly supplying LNG cold to the ethylene plant, we were able to accomplish 100% utilisation and improve the quality of LNG cold utilisation. As a result, CO_2 reduction there has been increased considerably through the utilisation of LNG cold.

Osaka Gas intends to continue its efforts toward advancement in the utilisation of LNG cold energy for further energy conservation and CO_2 reduction in the future.

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(*1) This is the method for using LNG cold efficiently. Research and development of this method has been implemented as an effort by the Research Association of Refinery Integration for Group-Operation (RING).

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