INTERNATIONAL JOURNAL OF ENERGY RESEARCH
Int. J. Energy Res. 2008; **32**:1058–1064
Published online 25 February 2008 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/er.1411

SHORT COMMUNICATION

Potential applications using LNG cold energy in Sicily

Antonio Messineo*,† and Domenico Panno

Department of Energy and Environmental Researches (DREAM), University of Palermo, Viale delle Scienze, Palermo 90128, Italy

SUMMARY

According to previsions, natural gas could be the main energy source worldwide, inducing relevant geopolitical changes. Most likely, such problems will be solved with the development of a gas transportation mode alternative to traditional pipelines: liquefied natural gas (LNG). The global LNG trade has increased rapidly during recent years. A significant amount of energy is consumed to produce low-temperature LNG, which has plenty of cryogenic exergy/energy. Therefore, the effective utilization of the cryogenic energy associated with LNG vaporization is very important. Sicily, with more than five million inhabitants, is the second biggest region of Italy and in this region will be realized two of the 11 gasification plants planned in Italy according to the regional energy master-plan. This paper shows some interesting applications for the cold produced in gasification plants, e.g. for seawater desalination and for fresh and frozen food production and conservation. These applications seem very interesting for Sicilian situation and also can contribute to energy saving and greenhouse gases reduction to match Kyoto Protocol targets. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: LNG; energy recovery; seawater desalination; cold chain

1. INTRODUCTION

The combustion of fossil fuels has played a dominating role in the build up of greenhouse gases in the atmosphere. It is estimated that the energy sector accounts for about half the global emissions of greenhouse gases [1].

The Kyoto Protocol commits the signatory countries to undertake measures finalized to reducing greenhouse gas emission, in order to reach the set goals. For Italy, the commitment is the reduction in the greenhouse emissions by 6.5% below 1990 levels over the commitment period 2008–2012 [2].

It requires the introduction of suitable political strategies and programs aimed at establishing a sustainable energy system together with the application of a set of actions either at national scale or at regional one [3].

Local authorities are called to play a remarkable role in carrying out environmentally oriented strategies to manage energy resources efficiently

*Correspondence to: Antonio Messineo, Department of Energy and Environmental Researches (DREAM), University of Palermo, Viale delle Scienze, Palermo 90128, Italy.
†E-mail: messineo@dream.unipa.it

Received 26 July 2007
Revised 2 January 2008
Accepted 13 January 2008

and to address the life quality towards the sustainability.

Hence, the energetic efficiency of industrial plants and equipment must be increased. Thus, the use of primary energy derived from fossil fuels will be reduced and the energy management in industrial activities will be improved.

In industrialized countries, about 15% of electric energy is used for air conditioning and refrigeration. In order to solve the problem of exhausting fossil fuel, there are many attempts to utilize the waste energy more effectively. Energy can be saved in this field, for example, recovering the cold energy produced in gasification plants when liquefied natural gas (LNG) is gasified, thus contributing to rationalize energy and achieving the Kyoto Protocol aims [4–8].

2. LNG LIQUEFACTION PLANTS

Natural gas is one of the most widely used conventional mineral energy resources. In contrast to other mineral resources, such as coal and gasoline, natural gas has higher combustion heat and produces much less pollution. The disadvantage is that it is in a gaseous state under ambient temperature and pressure; hence, it must be usually liquefied to LNG for long-distance transportation and storage.

LNG is produced by cryogenic refrigeration of natural gas after removing the acid and water. Liquefying natural gas is a high-energy consumption process, producing one ton of LNG consuming about 850 kWh of electric energy. In addition, it should be gasified for normal use at the receiving site. Gasification also consumes energy. If we can make use of the cold heat of LNG, it is evident that the overall efficiency will improve.

LNG is a low-temperature multi-component liquid mixture. Its main component is methane, whose concentration is usually above 80% in the mixture. It also contains nitrogen, ethane, propane, normal butane and isobutane, normal pentane and isopentane. Its exergy depends on the system pressure, temperature, ambient temperature and component concentrations [9].

Natural gas liquefaction requires relevant investments and conspicuous amounts of energy that is furnished by the same gas and by other fossil fuels. The used plants utilize several industrial processes; the most common types are as follows:

- cascade cycles with several fluids (i.e. for decreasing temperature: propane, ethylene, methane);
- cascade cycle exploiting binary or tertiary hydrocarbon mixtures;
- turbo-expansion cycles.

Liquefaction is carried out through cascade cycles: at the higher temperatures through a propane cycle, latter through an ethylene and ethane cycle and in the end through a methane cycle. Natural gas, cooled from top to bottom by propane, ethane and methane, liquefies and drops to -158°C, later, through a lamination valve, flows into the cryogenic tank where it keeps cooling down to a temperature of -161°C.

Figure 1 shows the scheme of a cryogenic plant where the following processes are carried out: natural gas liquefaction, methane, ethylene and propane cryogenic cycle.

3. LNG GASIFICATION

Most of the gasification processes occur in plants located on coasts where there is a wide availability of seawater to be used as heating water for LNG gasification. The equipment is made of a series of open vaporizers (open rack vaporizers) constituted by several heat exchangers where seawater flows on the outside surfaces and vaporizes LNG flowing inside the ducts at pressure between 80 and 85 bar.

A plant using seawater for gasification processes works through a thermal gap equal to 4–8°C between the entrance and the exit of the heat exchanger and with a water load between 100 and 180 $\mathrm{l\,s^{-1}}$.

Another gasification system is the submerged combustion types (submerged combustion vaporizers); these use send-out gas as fuel for the combustion that provides vaporizing heat.

Growing costs and environmental problems linked to energy conversion processes lead to

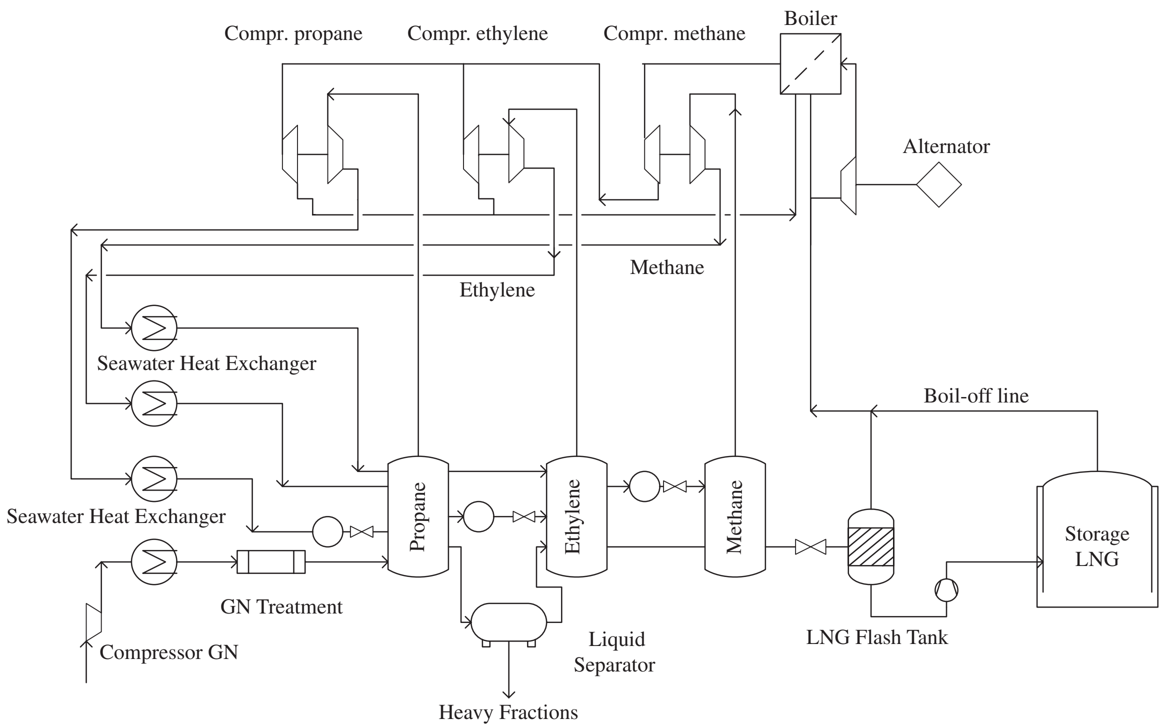

Figure 1. Cryogenic plant scheme.

recover a good portion of the energy used during the liquefaction process.

Gasification produces about 840 kJ kg^{-1} of low-temperature energy [9, 10]; hence, it is possible to use this cold energy for several applications, such as nitrogen, oxygen and argon production through air liquefaction, frozen food production, fresh and/or frozen food storage, fresh water production through seawater desalination, etc.

According to previsions, the demand for natural gas will increase about 2.1% yearly reaching a value of 4800×10^9 Stm^3 $year^{-1}$ in 2030. This growing gas demand requires increasing investments in gas pipeline building, in liquefaction and gasification plants, and for the transport from the producer to the consumer countries. Figure 2 shows the growing reliance on gas imports for 2000–2030 period [11].

LNG transportation plants are needed both for an adequate diversification of the supply sources and to satisfy the consumption of those countries unreachable through pipelines.

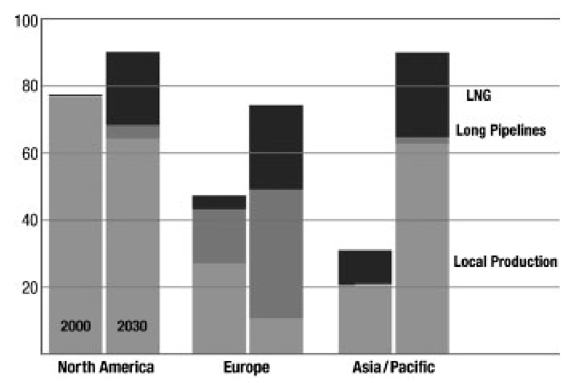

Figure 2. Growing reliance on gas imports for 2000–2030 period in Billion cubic feet per day.

The gasification potentiality existing on our planet (August 2005) is equal to 22.7×10^6 m^3 shared among 50 plants distributed as follows: 13 plants (2.84×10^6 m^3) in Europe, 30 plants (18.54×10^6 m^3) in Asia, 1.00×10^6 m^3 (5 plants) in North America and 0.32×10^6 m^3 (2 plants) in South America.

Italy has only a rather small gasification plant (Panigaglia, Liguria) in function since 1971. Eleven gasification plants, of which three are offshore, are planned in Italy. In Sicily, the two gasification plants planned will be realized in Porto Empedocle (Agrigento) and Priolo (Siracusa) according to the regional energy master-plan [12].

4. LNG COLD ENERGY FOR SEAWATER DESALINATION PROCESSES

The first proposed application concerns the possibility of producing fresh water through seawater desalination recovering LNG cold energy.

In the last decades of the 20th century, the problem of drought has significantly affected Sicily, giving rise to the construction of a number of desalination plants for civil, agricultural and industrial uses.

Although the northern part of Sicily has always been helped by the presence of mountain chains that have significantly contributed to the water needs, in the southern part of Sicily the availability of water sources has been continuously worsening due to a decrease in rainfall, which reached, in some areas, values of only 400 mm of water per year.

The population affected by severe water scarcity can be estimated in as many as 500 000 inhabitants, distributed along the southern and western coasts in the districts of Caltanissetta, Agrigento and Trapani. However, almost 50% of the island is actually characterized by very low rainfalls [13].

Scientific studies and experiences carried on different countries allowed developing separation systems and processes through freezing that have not yet had an adequate spread on industrial scale.

It is known that the separation of salt contained in solution can be carried out through both freezing and vaporizing water. The latter case (liquid–vapor passage), working at normal pressure, requires $2257\,\mathrm{kJ\,kg^{-1}}$, whereas the liquid–solid passage requires about $334\,\mathrm{kJ\,kg^{-1}}$. The second process appears energetically economical, even if separating pure liquid water from the salt solution is more complex and requires greater care.

The huge amount of cold energy from gasification plants makes freezing desalination procedures more appealing. It essentially consists of three basic operations: freezing, washing and melting. Other auxiliary operations, as filtration and air removal, are needed to remove the amounts of solids in suspension.

High salinity water is sent to a heat exchanger where it is progressively cooled down to almost freezing temperatures. Next, the suspended solids are screened out in the filtering section, whereas the dissolved gasses are separated by rest of the fluid to obtain better freezing. The cooled and pre-treated water is sent to the next freezing stage where crystal formation takes place.

Crystal size is very important in order to obtain an effective salt–water separation. If the crystal size is too big, it could trap within saltwater sacks; otherwise, if the crystal size is too small, the next washing procedure may be too difficult.

Since their formation, the crystals are covered with salty water; therefore, before undergoing the fusion stage, they will have to be washed to remove the high amount of salt stuck on the solidified mass. After the washing procedure, the cleaned ice goes in the fusing section. Figure 3 shows the scheme of a plant using LNG cold energy for fresh water production.

The availability of LNG cold energy may undoubtedly contribute to make desalination processes less expensive. The possibility of placing these plants next to gasification stations facilitates the use of the available cold energy and constitutes a stimulus to develop this technology.

5. LNG COLD ENERGY IN THE COLD CHAIN

The second proposed application utilizes LNG cold energy in some loops of the cold chain as storage warehouses for raw materials and finished products, frozen food manufactures and hypermarkets. Productive settlements or big commercial centers in need of cold energy could rise near gasification plants.

Both cases require building pipelines to transfer, through a secondary fluid, some of the cold energies recovered in the gasification plant to users.

DOI: 10.1002/er

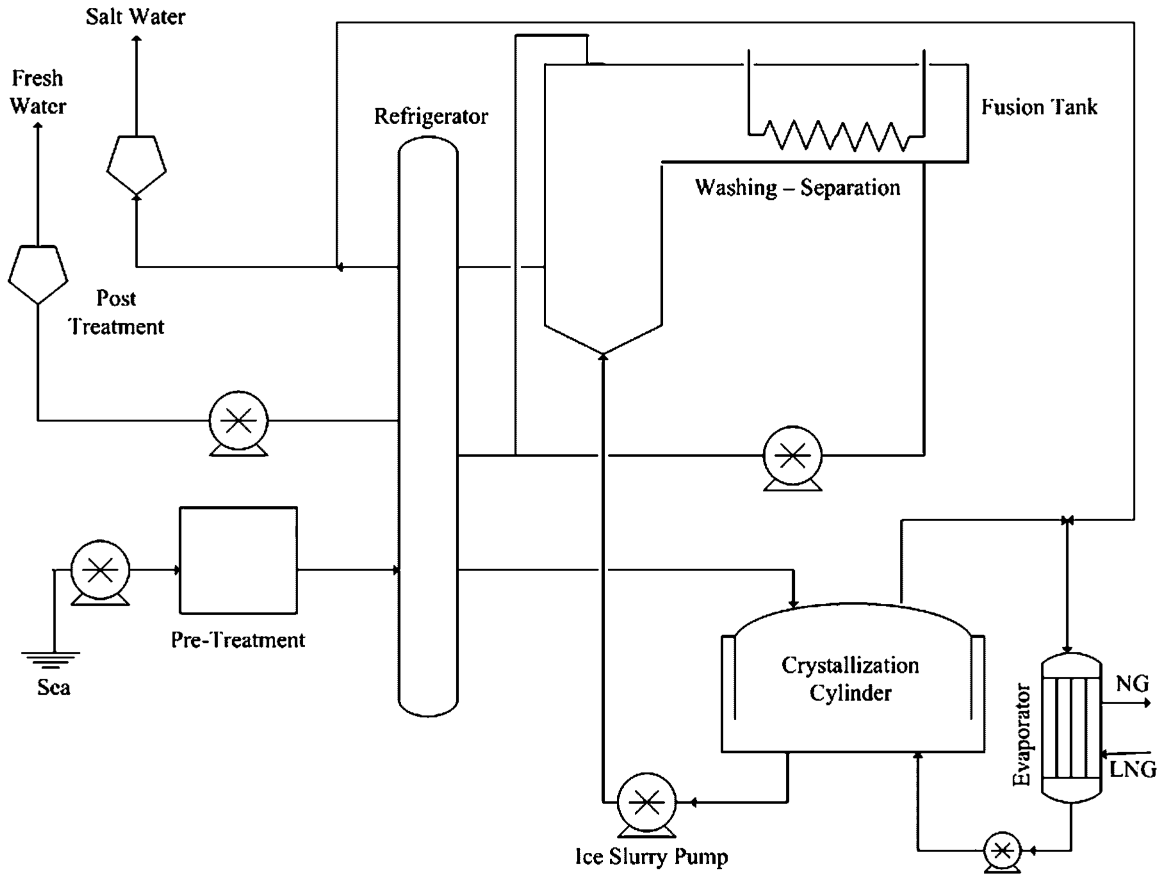

Figure 3. System using LNG cold energy for fresh water production.

Among the secondary fluids, carbon dioxide seems to be interesting since it, due to its thermo-elastic characteristics (low specific volumes and good thermal exchange properties) [14, 15], lends itself to work as a good thermal vector in transferring the recovered cold energy to users.

Liquid CO_2 is carried to the gasification plants and, through adequately insulated tubes, to the different stations where heat exchangers, working as vaporizers, are set up.

Carbon dioxide produces the needed cold by passing from the liquid to the vapor state, and through a feedback loop if returns to the gasification plant, thus restarting the cycle.

Using CO_2 as a secondary fluid allows reaching the users' required cold temperatures, which in the case of frozen food production may reach -40°C.

The above-described type of cold distribution system means a remarkable reduction in energy consumption since refrigerating equipments are no longer needed. This means significant saving in electric energy since electricity is required only to pump the secondary fluid.

The advantage is significant enough even for big hypermarkets, where electricity consumption to produce cold is over 50% of the general consumption. Choosing CO_2 is also convenient due to its good safety properties (A1, classification ASHRAE).

Figure 4 shows the scheme of a system using LNG cold energy to store fresh and/or frozen food

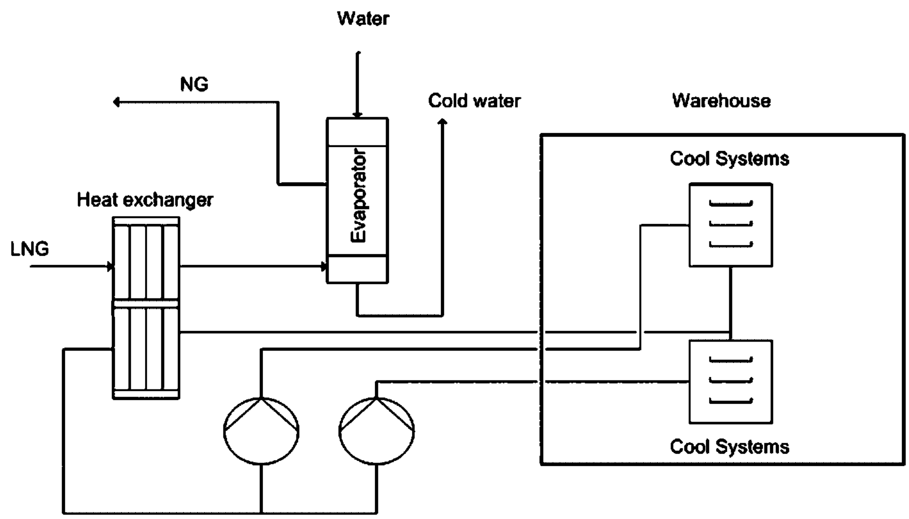

Figure 4. Conservation plant for fresh and/or frozen food.

in refrigerated warehouses in place of a conventional refrigerating system.

6. ENERGETIC AND ENVIRONMENTAL ANALYSIS

In order to evaluate energy savings and greenhouse gases reduction connected with LNG cold energy utilization, the yearly primary energy required by a refrigerating warehouse must be calculated.

A refrigerating warehouse with a volume of 70 000 m^3 used for ice-cream and frozen food storage is taken in consideration. The required annual electricity in the Mediterranean climate (Southern Italy and Islands) may be estimated to be 60 $kW\,h\,m^{-3}$ [16] a year. Therefore, the needed energy is equal to 4 200 000 $kW\,h\,year^{-1}$. If it is produced thermo-electrically, the primary energy needed—in Italy the average energy efficiency is equal to 0.34 [17]—amounts to 12 352 941 $kW\,h\,year^{-1}$, equal to 1062 toe $year^{-1}$.

In economic terms, the energetic recovery from gasification plant leads to a smaller yearly cost of 462 000 €, considering an electricity average price of 0.11€ $kW\,h^{-1}$.

The estimation of CO_2 equivalent emission of greenhouse gases according to the energy use in the refrigerating warehouse was calculated using the following emission index: 0.50 $kg\,kW\,h^{-1}$ [18].

The reduction in CO_2 emission for a working 70 000 m^3 refrigerating warehouse using LNG cold energy should be approximately equal to 2100 $t\,year^{-1}$.

An ulterior benefit derives from the lesser amount of cold to be poured in the sea areas next to gasification plants with obvious advantages for the marine ecosystem equilibrium.

7. CONCLUSIONS

The purpose of this paper is to bring the researchers' attention to the benefits obtainable through the utilization of LNG cold energy in terms of energetic saving and environmental safety.

It is obvious that it requires lots of commitment since it is necessary to coordinate the various sites in a rational way and successively realize the infrastructures necessary to connect the gasification and the cold user plants.

Italy, with several LNG plants in construction, has the possibility of becoming, on the one hand, a sort of European gas hub by exploiting its geographic centrality between producer countries in North Africa and Middle East and consumer countries in continental Europe and, on the other

DOI: 10.1002/er

hand, reducing its dependence from the furnishers', with possible gas cost benefits for national consumption and with positive energetic and environmental repercussions.

REFERENCES

1. Karekezi S. Renewables in Africa—meeting the energy needs of the poor. *Energy Policy* 2002; **30**:1059–1069.
2. *United Nations Framework Convention on Climate Change*. Kyoto, Japan, 1997.
3. Beccali M, Cellura M, Mistretta M. Environmental effects of energy policy in Sicily: the role of renewable energy. *Renewable and Sustainable Energy Reviews* 2007; **11**:282–298.
4. Beccali M, Messineo A. Rigassificatori: e se l'Italia diventasse lo snodo d'Europa? *Bollettino dell'Ordine degli Ingegneri della Provincia di Palermo* 2006; **1**:18–19 (in Italian).
5. Lee G, Ro S. Analysis of the liquefaction process of exhaust gases from an underwater engine. *Applied Thermal Engineering* 1998; **18**:1243–1262.
6. Akiwasa A, Miyazaki T, Yuzawa A, Kashiwagi T. Multistage energy recovery system using LNG cold energy. *Proceedings of Japanese Energy Resources Conference*, Japan, 1998.
7. Hisazumi Y, Yamazaki Y, Sugiyama S. A proposal of high efficiency LNG power generation system utilizing waste heat of combined cycle. *Energy and Resources* 1996; **17**:587–592.
8. Hisazumi Y. LNG cold energy utilization and future problem. *Journal of the Japan Institute of Energy* 1996; **75**:308–315.
9. Liu H, You L. Characteristics and applications of the cold heat exergy of liquefied natural gas. *Energy Conversion and Management* 1999; **40**:1515–1525.
10. Miyazaki T, Kang YT, Akisawa A, Kashiwagi T. A combined power cycle using refuse incineration and LNG cold energy. *Energy* 2000; **25**:639–655.
11. IEA. *World Energy Outlook Edition*. IEA, 2005.
12. DREAM. *Regional Energy Master-plan*. Palermo, 2007 (in Italian).
13. Cipollina A, Micale G, Rizzuti L. A critical assessment of desalination operations in Sicily. *Desalination* 2005; **182**:1–12.
14. Billiard F. Use of carbon dioxide in refrigeration and air conditioning. *International Journal of Refrigeration* 2002; **25**:1011–1013.
15. Pearson A. Carbon dioxide—new uses for an old refrigerant. *International Journal of Refrigeration* 2005; **28**: 1140–1148.
16. IIR. *Energy Guidelines for Refrigeration Systems in Cold Stores and Freezers*. Thematic Files Commission Dl, 2002.
17. ENEA. *Rapporto Energia Ambiente 2004*, Italy, 2005. See also: http://www.enea.it/default.htm (in Italian).
18. Romano D, Condor R, Contaldi M, De Lauretis R, Di Cristofaro E, Gaudioso D *et al. Italian Greenhouse Gas Inventory 1990–2003—National Inventory Report 2005*, Agency for the Protection of the Environment and for Technical Services (APAT), Italy, 2005 (in Italian).