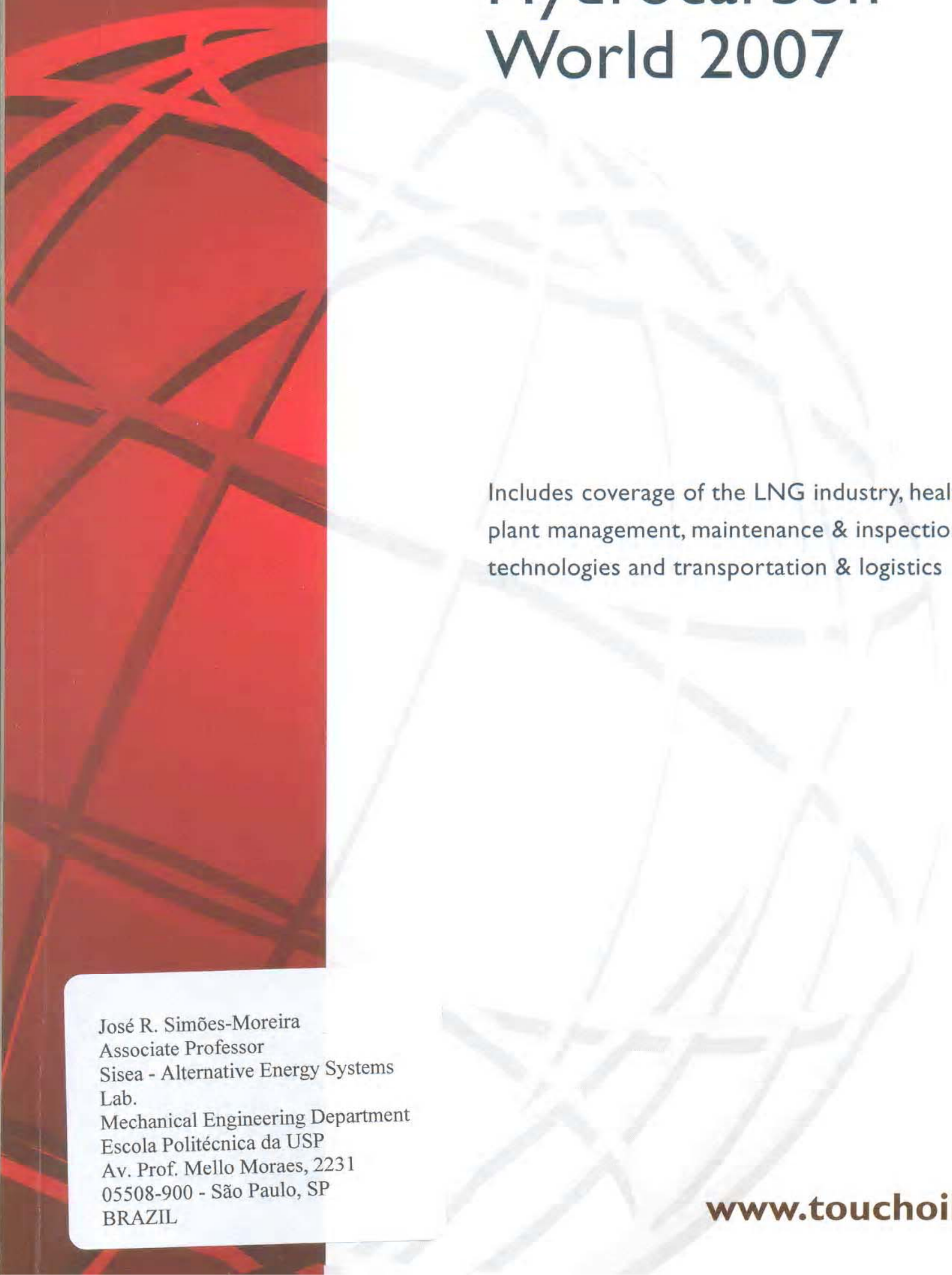
touch BRIEFINGS



Hydrocarbon World 2007

Includes coverage of the LNG industry, health & safety, plant management, maintenance & inspection, process technologies and transportation & logistics

José R. Simões-Moreira
Associate Professor
Sisea - Alternative Energy Systems
Lab.
Mechanical Engineering Department
Escola Politécnica da USP
Av. Prof. Mello Moraes, 2231
05508-900 - São Paulo, SP
BRAZIL

www.touchoilandgas.com

touch BRIEFINGS

Hydrocarbon World 2007

Publishing Director	Dr Theresa Saklatvala
Editorial	
Editor	Nigel Lloyd
Editorial Manager	Elizabeth Boulton
Association Liaison Manager	Michelle Grayson
Operations	
Head of Operations	Tim Green
Designer	Paul Scott
Head of Circulation and Production	Katie Hughes
Production Co-ordinator	Vicki Smith
Sales	
Associate Publisher	Yunus Bhatti
Project Manager	Jag Kambo
Associate Sales Director	David Ramsey

Touch Briefings wishes to thank the organisations below for their assistance and involvement in this briefing.

energy API

IPIECA
International Petroleum Industry Environmental Conservation Association

NPRA

1997-2007
Providing 10 years of excellence to the oil & gas industry
WORLD REFINING ASSOCIATION
W.R.A.

The involvement of these organisations does not constitute any official endorsement.

Please contact the following should you have any comments/queries:

Editorial
Nigel Lloyd
Tel: +44 (0) 20 7526 2407 Fax: +44 (0) 20 7452 5050
E-mail: nigel.lloyd@touchgroupplc.com

Operations
Tim Green
Tel: +44 (0) 20 7452 5023 Fax: +44 (0) 20 7452 5610
E-mail: tim.green@touchgroupplc.com

Sales
Yunus Bhatti
Tel: +44 (0) 20 7452 5071 Fax: +44 (0) 20 7452 5606
E-mail: yunus.bhatti@touchgroupplc.com

Published by
Touch Briefings

Printed by
Imprenta Colour Ltd

Worldwide distribution by
Imprenta

Touch Briefings *is the trading name of* **Business Briefings Ltd**, *a* **Touch Group plc** *company*

ISSN:1753-3902

Small-scale LNG Plant Technologies

a report by

Christian D T Begazo, **Erica C Carvalho** *and* **José R Simões-Moreira**

SISEA – Alternative Energy Systems Laboratory, Mechanical Engineering Department,
Escola Politécnica, Universidade de São Paulo

Christian D T Begazo is a graduate student in the Mechanical Engineering Department at Escola Politécnica of University of São Paulo, Brazil, where he is developing a thesis on liquefaction process simulation. He worked for four years on lubricating engineering. He graduated in 2000, from Universidade Catolica de Sta. Maria, Arequipa, Peru.

Erica C Carvalho is an undergraduate student in the Mechanical Engineering Department at Escola Politécnica of University of São Paulo.

José R Simões-Moreira is Professor of Mechanical Engineering in the Mechanical Engineering Department at Escola Politécnica of University of São Paulo. He has authored a book on Psychrometry and several technical and scientific papers on flashing mechanisms in phase change processes as well as on gas and alternative energy system studies. He has also undertaken consulting projects for electrical and oil and gas companies in Brazil.

Natural gas has grown to be an important energy in the international scenario. The world demand is steadily increasing and the last figures show that from 2004 to 2005 there was a 2.3% utilisation raise.[1] As part of the natural gas world market, liquefied natural gas (LNG) has played an important role. Historically, LNG came onto the scene when conventional natural gas gas transport through pipelines was not possible for reasons such as technical and political issues, i.e. crossing international and state borders, forests and seas or even oceans. Within that framework only large LNG plants have been built that achieve the remarkable train capacity above 7.5MMtpy.

LNG has been produced in small scale plants liquefaction (SSL) plants to supply peak shaving demands, as well as to make available natural gas to regions that need it but where it is not economically or technically feasible to build new pipelines. In many countries natural gas has also been used as fuel for city buses, trucks, boats, locomotives, or even for automobiles. Along with the economical advantage comes the environmental benefit as natural gas emission factors are usually superior to those from other hydrocarbon fuels. Today there are many companies manufacturing SSL turnkey plants in the world market. This paper succinctly reviews the main technologies available for natural gas liquefaction in SSL plants.

LNG Process

LNG is the result of cooling natural gas to a cryogenic condition to condensate methane, the natural gas main component. A -161.5°C temperature is required to produce and keep natural gas in a liquid state at standard atmospheric pressure. Preceding the liquefaction process, it is necessary to treat the natural gas in order to remove humidity, CO_2, and heavier hydrocarbon components C3+. Depending on the natural gas origin it may also be required to remove acid gases, mercury and sulphur.

A typical LNG plant is built in the following main stages: natural gas pre-treating, liquefaction, storage and LNG shipment. Usually, the liquefaction machinery is the element that demands the most investment accounting for 30–40% of the overall capital.[2]

Considering that the specific energy consumption is a non-negligible factor in the LNG industry, new processes and conventional processes technology improvements comprise the main goal pursued by the companies. Overall, thermal efficiency, safety and operational costs are some of the other issues one should also take into consideration in selecting a SSL plant technology.

Evidently most SSL plant technologies derive from the large capacity technology that were designed to produce millions of tons per year (tpy) of LNG. The first plants used natural gas liquefaction by cooling the gas using either the refrigerant cascade principle or a simple mixture of refrigerants. A typical train of liquefaction capacity was less than 1Mtpy, orders of magnitude lower than those nowadays. SSL plant capacity for supplying vehicular stations and peak shaving systems are in general around 10–500 tons per day (tpd).

Large LNG plants are long-term capital-intensive investments, which contrasts with SSL plants. Many SSL plants are available in containers or modules ready to be shipped anywhere and for immediate start-off operation. It is estimated an overall liquefaction system costs between US$1,500/MMbtu and US$2,500/MMbtu. According to Cascone,[3] a considerable amount of the investment cost is spent on the gas treating system and the main heat exchanger. *Figure 1* gives an idea of the investments costs distributed according to the several processes in a SSL plant adapted from GTI's analysis.

SSL Plant Classification

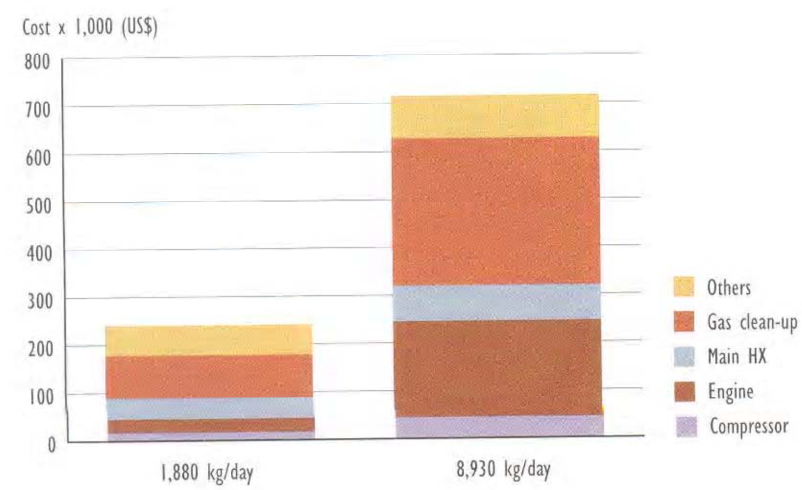
From a general point of view, the SSL processes can be grouped into two major groups, namely open-loop, in which the refrigerant fluid is part of the feed gas, and closed-loop, where the natural gas cooling and liquefaction is attained by a auxiliary refrigerant that flows continuously in a separated circuit. Open-loop systems are based mainly on a successive

Table 1: SSL Plants, Process, Efficiency and Capacity

Classification	Refrigeration cycle	Liquefaction process	Overall efficiency kW-day/ton	Capacity	Reference
Closed-loop	Mixed Refrigerant (MR)	Black and Veatch PRICO	16.8	1.3MMtpy	Salof, 2006[4]
		GTI	*	1,000gpd	GTI, 2003[5]
		Kryopak PCMR	13.0	210tpd	Salof, 2006[4]
	Turbo-Expander TEX (N_2)	Hamworthy	33.3	30 to 500tpd	Hamworthy, 2006[6]
	Turbo-Expander TEX (N_2 & C1)	Pre-cooled Dual TEX+	13.0	0.5MMtpy	Foglietta, 2004[7]
Open-loop	Turbo-Expander (TEX)	Dual TEX+	16.5	0.5MMtpy	Foglietta, 2004[7]
		Kryopak EXP	15.5	147tpd	Salof, 2006[4]
		Idaho (Letdown)	*	10,000gpd	Cascone, 2005[3]
		Stirling	*	50kg/h – 10tpd	Kirillov, 2004[8]
	Vortex tube	-	*	500kg/h	Kirillov, 2004[8]

* Data not available;
\+ Simulated.[4]

Figure 1: Capital investments (adapted from reference 5)



compression-cooling-expansion process of the natural gas. The last expansion stage is usually carried out in a turbo expander (TEX) to obtain LNG. Closed-loop systems operate using a single cryogenic refrigerant or a selected blend of refrigerants to cool the natural gas stream. Nitrogen, methane and a mix of these with other hydrocarbons are also used. In the latter case it is said a mixed refrigerant (MR) cycle. *Table 1* summarises some commercial cycles according to the two classifications presented above and other relevant information regarding technologies, efficiencies and capacity. The technologies presented are by no means exhaustive, but rather a sample of some of them.

The MR cycle is based on the idea of a continuous cooling of a natural gas stream by using a well selected and designed blend of refrigerants that can mimic the cooling curve of natural gas from room to cryogenic temperatures, so that energy usage and heat exchangers size can be optimised. The blend usually includes light hydrocarbons (methane itself) and less volatile ones along with a non-condensable gas, usually nitrogen. As the natural gas cooling proceeds, C3+ may be removed to form the liquids of natural gas to be commercialised.

From a thermodynamic analysis the TEX cycles are theoretically as efficient as the most advanced cycles used in large conventional plants that are based on MR technology. Early TEX had low efficiencies (60–70%), but nowadays they have an expansion efficiency as high as 85%.[3] The expansion machine is the heart of the process and the one that makes the mosst difference to the overall cycle efficiency. In theory, dual TEX are thought to increase the cycle efficiency, since the natural gas cooling curve is better reproduced than that with just one machine.[6]

MR plants are usually more complex, as several gas supply and storage facilities are necessary; this also makes operation and control of those plants more complex. Also, high rate of refrigerants flows through the plant causing a potential hazardous environment.

A General Description of Liquefaction Cycles

The working principle of closed-loop liquefaction cycles relies on cooling the natural gas using one or more refrigeration cycles that can be quite simple or very complex, depending on the technology. *Figure 2* displays an elementary liquefaction cycle and its most fundamental components necessary to operate a liquefaction plant. First, the refrigerant is compressed in the compressor (CP) to undergo a cooling process to reach room temperature in the heat exchanger (HE). Next the refrigerant flows into the main cryogenic heat exchanger (MCHE) where by transferring heat it cools off. Note that, depending on the composition, the refrigerant may also partially condensate. The refrigerant stream now reaches an expansion device. The expansion device may be a simple throttling valve (T-V) where the refrigerant will undergo a Joule-Thompson (J-T) expansion, bringing its temperature to a low value, or if the expansion device is a TEX a useful shaft work (in dotted lines) may be produced that may be used to totally or in part drive the compressor shaft. The nearly isentropic expansion process in a TEX will bring the fluid to a very low temperature, lessen than that obtained by the J-T process. After the expansion by either process the refrigerant returns to the MCHE to continuously cool the natural gas gas from a feeding line (feed gas). Finally, the refrigerant leaves the MCHE to go again to the compressor, concluding the refrigerant cycle. On the natural gas side, it enters the at delivering condition (feed gas) and exits the MCHE partially condensed due its heavier components (C3+) to undergo an expansion (LNG expansion) to finally be driven into a flash tank to separate the vapour from the liquid phase. The vapour (flash gas) is rich of the non-condensable gas (nitrogen) and can be used elsewhere. The LNG is pumped to a storage tank for a subsequent distribution. Usual processes yield about 90% of LNG.

Figure 3 shows a schematics of an open-loop cycle. The working principle of an open-loop cycle is based on compression-cooling-expansion processes so that a high pressure at room or moderate low temperature natural gas stream is obtained. Next, the compressed natural gas undergoes an expansion process in a TEX to obtain LNG in a flash tank. The figure is merely illustrative, as more than one CP and HE can be used. Also, liquids of natural gas can be extracted along the cycle. Some useful work can be obtained in the TEX that can be used to drive fully or partially the compressor. Depending on the cycle configuration, additional cooling may also be necessary (booster cooling). If the natural gas (feed gas) is already compressed, such as it occurs in transmission to distribution pipelines transference of custody or city gates, useful shaft work may be obtained using a TEX,[7] which may be used to obtain a fraction of LNG from the natural gas – letdown system.

Finally, a system that is less familiar is based on a vortex or Ranque-Hilsh (R-H) tube. An R-H tube is a quite simple, moving-parts-free device that can produce cold natural gas from a compressed natural gas source and its application to obtain LNG has been mentioned by Kirillov.[8] This paper revises some of the available technologies in next section.

Figure 2: A General Scheme of a SSL plant (Closed-loop)

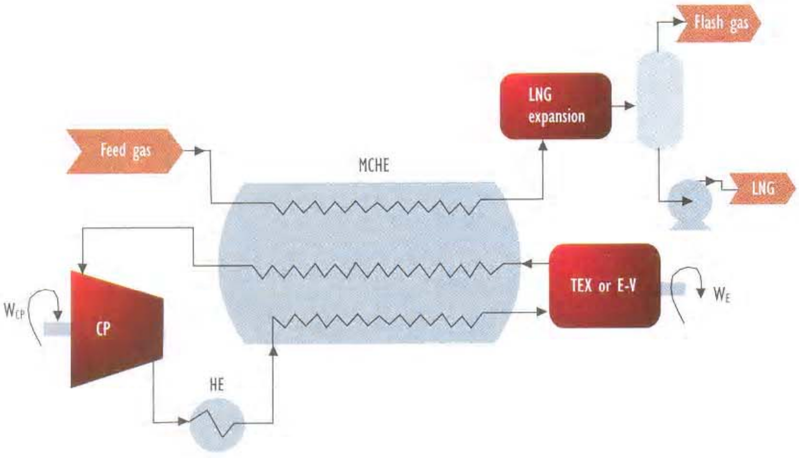
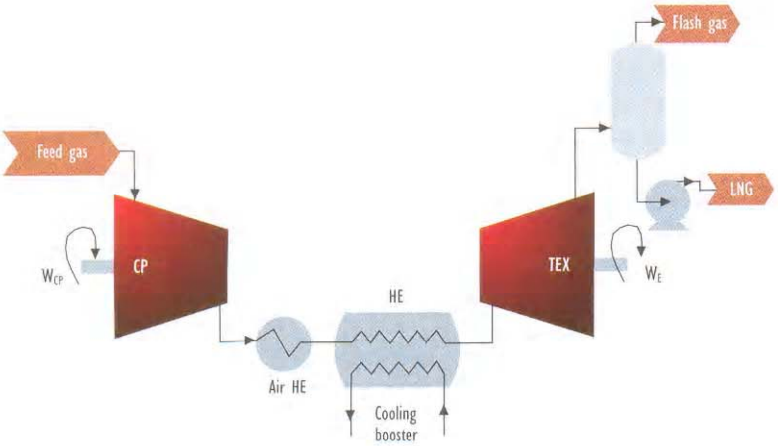


Figure 3: A General Scheme of a SSL plant (Open-loop)



Black and Veatch PRICO

In this MR process, a blend of nitrogen and hydrocarbons (methane, ethane, propane, and iso-penthane) is used as refrigerant. By controlling the composition of the refrigerant and its temperature and pressure, the cooling curve of natural gas can be followed very closely and the condensing liquids along the process can be extracted (liquids on natural gas) before the final throttling to expand the natural gas in a flash tank.

Kryopak PCMR System

According to Salof,[9] the Kryopak PCMR system uses a refrigerant composed of nitrogen, methane, ethane, propane, butane and penthane. Plate heat exchanger is used.

Hamworthy (Nitrogen Cycle)

This is a closed-loop cycle that uses nitrogen as the refrigerant. A three-stage compression with intermediate cooling is used to obtain nitrogen at high pressure to undergo a throttling process to obtain cryogenic temperature. Nitrogen remains in the vapour phase state all the time. LNG production capacity 60tpd, train annual production ~21,000 tons, estimated US$370/ton LNG and efficiency of 0.80 kWh/kg LNG of Snurrevarden LNG plant, Norway.[10]

Letdown System

This process is based on taking advantage of the high pressure in natural gas transmission pipelines to expand it to produce useful shaft work to drive a small liquefaction plant.[7] One of these small plants was developed by Idaho National Engineering and Environmental Laboratory,[11] which also introduced new technologies to remove water vapour and CO_2 from the natural gas.

Stirling System

This system is based on cryogenic gas machines (CGMs) that operate according to the Stirling cycle. This simple machine combines in a single device both compression and expansion processes of a working medium, heat exchange between the forward and reverse streams of that working medium and external heat exchange with the object being cooled and the surrounding medium; this allows these machines to be compact and have high thermodynamic efficiency. At cryogenic temperatures between 100K and 160K, the Stirling cycle has better efficiencies than 50%. According to (Kirillov,[8] the cycle can liquefy 100% of the feeding natural gas.

Vortex Tube System

This system operates based on the R-H or vortex tube. According to Kirillov,[8] an operational system has the following technical operations: natural gas working pressure 3.5MPa; natural gas flow rate between 2,000 and 7,000m^3/h; overall plant weight 3,700kg. The main advantages are zero energy consumption, as the system operates at the transmission gasline pressure (letdown system), is mechanically quite simple and it requires a low capital investment. On the other hand, it can produce a small amount of LNG (2–4%) and needs frequent stops for cleaning and unclogging.

Conclusion

SSL plants have been built and are available in the international market based on a series of technologies. Dominating technologies are based on either a blend of refrigerants to mimic the natural gas cooling curve or a compression-cooling-expanding process to bring the natural gas to cryogenic conditions. The former case is a closed-loop type where a refrigerant flows continuously in a cryogenic refrigeration cycle and latter one is an open-loop type where the natural gas itself is also the refrigerant. Turbo-expanders may also be used to produce a useful shaft work in some technologies, replacing throttling valves. Other technologies take advantage of a compressed gas line (transmission pipeline) to use the high pressure to produce small amounts of LNG as the natural gas expands in a turbo-expander. The field is still growing and new technologies at competitive costs are constantly developed. ■

References

1. *BP*, BP Statistical Review of World Energy June 2006, *BP plc (2006).*
2. *Shukri T, "LNG Technology Selection"*, Hydrocarbon Engineering *(2004);Feb.*
3. *Cascone R, "Advances in Small Scale LNG Technology Provide User Options"*, Oil & Gas Journal *(2005);April–June, Vol. 2: p. 15.*
4. *Foglietta J H, "Consider Dual Independent Expander Refrigeration for LNG Production"*, Hydrocarbon Processing, *(2004);Jan: pp. 39–44.*
5. GTI, *2003*, Development of a Small-Scale Natural Gas Liquefier, *final report GTI project 65943, Gas Technology Institute.*
6. *Barclay M, Denton N, "Selecting Offshore LNG Processes"*, LNG Journal (*2005);Oct. pp. 34–36.*
7. *Shen D M, Fernandez F, Simes-Moreira J R, "Using Gas Pipeline Pressure to Liquefy Natural Gas or Generate Electricity"*, Hydrocarbon Processing *(2006);Jan, pp. 47–50.*
8. *Kirillov N G, "Analysis of Modern Natural Gas Liquefaction Technologies"*, Chemical and Petroleum Engineering *(2004);40: pp. 7–8.*
9. *Salof Companies, 2006, LNG Processes, Available in http://www.kryopak.com/kryopak_refrigeration_processes.php – Accessed in 10 Nov 2006.*
10. *Hamworthy Gas Systems, 2006, Small Scale & Mini LNG Liquefaction System, available at: http://www.hamworthy.com/products/products.asp?strareano=27 (accessed in Nov 2006).*
11. *INL, 2006, Natural Gas Technologies – Small-Scale Methane Liquefaction Plant. Idaho National Lab. Available at http://www.inl.gov/lng/projects/liquefactionplant.shtml. Accessed in Nov 2006.*