A New Generation of LNG Terminals Brings New Safety Challenges

There is increasing pressure to expand the LNG industry which will open the door to new and existing players with unproven concepts and technology. Companies are looking to construct even larger storage terminals in a shorter time and at a reduced cost.

This presents new challenges in protecting the impressive safety record for LNG, which must not be jeopardised by the development of new generation terminals. All of the solutions being sought must satisfy the environmental and safety requirements, and some concepts will require the merging of technology and combined application of their associated codes and standards.

Independent certification is essentially the confirmation by an independent third party of a project's compliance with the appropriate codes and standards, including its safety and operability. For novel concepts, the independent certifier can attest that the concept meets recognised engineering practice, or presents an equivalent, and hence tolerable, level of risk.

When performed by an independent third party, such evaluations provide an enhanced degree of confidence in the safety of a terminal and its capacity for operation without adverse impact on the environment. The consequent external perception of technical integrity projected by certification can facilitate obtaining project funding, while insurers may be more inclined to offer cover at more favourable rates.

It is clear that the excellent safety record of the LNG industry is largely due to diligent analysis of risk, continuous development of codes and standards and the rigorous application of them. Anything less potentially exposes the industry and an individual project to unnecessary risk.

The role of independent certification, carried out by organisations like the Lloyd's Register Group, is an important one in maintaining the safety record of the LNG industry, the growth of which is necessary to accommodate the global demand for safe, efficient and abundant energy sources.

Maintaining the Safety Record of LNG Shipping

By Andrew Clifton

The LNG sector has an excellent safety record. In the 42 years since commercial LNG exports started, with over 45,000 loaded voyages covering almost 100 million miles, there has not been a single loss of cargo containment or a fatality directly attributable to the cargo. Compared with other sectors in shipping, and especially other types of tankers, LNG has an enviable record.

As the LNG trade expands all of us in the business need to work not only to maintain safety standards, but also to get the message about our excellent record to the general public. Most people outside the gas industry know little about LNG or its transportation and tend to react with alarm when a terminal is proposed in their locality. Among the perceived fears about LNG are: the risk of explosion; fireball; pressurised release; atomic bomb effect; "burning seas"; "frozen harbours"; collision; and pollution.

The Society of International Gas Tanker and Terminal Operators (SIGTTO) believes such concerns are fuelled and exploited by anti-LNG pressure groups, especially in the US, which publish their views in a sensationalist and misleading way. They continually highlight the Cleveland tragedy of 1944, which happened in wartime when

LNG shipping has an excellent safety record.

steel alloy with a low nickel content was being used; tanks built to modern standards with 9% nickel steel are far more secure.

The fact is that in the event of loss of cargo containment, regardless of the cause – operational accident or intentional act – the result will be a uncontrolled release of liquid which will, very quickly, evaporate into a vapour cloud of natural gas. LNG vapour is lighter than air once its temperature rises to above about -100°C; this vapour cloud will therefore rise and be carried upwards and in a direction dictated by the wind. The cloud will carry downwind, gradually diluting until it is below its lower flammable limit and incapable of burning. Should it reach a source of ignition while in the flammable range, this will not result in an explosion, except in the unlikely event that the vapour and atmospheric air mix perfectly, but there will be uncontrolled burning.

- LNG itself is odourless, colourless, non toxic and non-corrosive. It is not carried under pressure, another common public mis-conception, and the LNG itself will not burn, it is the vapour produced by the LNG evaporating which burns.
- LNG is carried at a temperature of around -161°C and, should it spill on to the deck or ship's side, could cause damage to steelwork through brittle fractures and cracking. Likewise if liquid were to come into contact with skin, cold burns would result.
- LNG shipping is, of course, subject to the hazards the rest of shipping faces such as collision, flooding, grounding and fires.

It is interesting to compare the public's perceived hazards with the actual hazards and also to see how the anti-LNG organisations portray LNG in such a sensational manner: but what about risk itself? How is this addressed?

We are all aware that risk is a product of likelihood and consequence. However with LNG, likelihood now seems to be becoming largely ignored and the opposition to LNG is persuading the public to focus on consequence only – regardless of how remote or bizarre the scenario being portrayed is.

Since the events of September 11, 2001 and the attack on the *Limburg* in October 2002, we now, of course, have to consider intentional acts against LNG carriers in addition to risks considered during a vessel's normal operation. So how do we, as an industry, reassure the public about the safe transportation of LNG by sea?

Reassuring the public

The safety record is very well promulgated: this, of course, will be of comfort to the public. LNG is a proven mode of transport; it is not something new. However a more delicate issue is answering the highly unlikely consequences being banded about by the anti-LNG organisations. There are very few case studies we can use as examples, due mainly to the good safety record. We are, as an industry, a victim of our own success in this respect.

We can, however, point to the fact that four LPG vessels were hit by missiles in the Iran/Iraq war in the 1980s. All had hits on their cargo tanks and small fires started. But no-one was killed, the vessels did not explode, most of the cargo was salvaged and the vessels were repaired and continued trading. Not an ideal scenario by any means but not the doomsday scenario predicted by some.

LNG tankers are built in accordance with the *International Code for the Construction and Equipment of Ships carrying Liquified Gases in Bulk* (IGC Code). This is legislation provided by the International Maritime Organisation (IMO).

The IGC code specifies that LNG vessels are double hulled with a minimum of two metres separation between the outer part of the cargo tank and the ship's side. In practice there are normally at least three barriers between the outer hull and the cargo tank. This is a integral safety feature built into every LNG tanker and this safe separation ensures a adequate safety margin for the majority of credible consequences.

There have been three high-speed groundings occurring to LNG tankers since commercial

A major player in LNG

Following the successful debottlenecking of the three Qatargas LNG trains (Ras Laffan, Qatar) Technip was awarded successively the EPC contracts for Qatargas II (Trains 4 and 5), RasGas III (Trains 6 and 7) and recently for Qatargas III and IV (Trains 6 and 7). So, Technip, in joint venture, is now building the world's six largest LNG trains (7.8 Mtpa each) that will allow Qatar to become by far the largest LNG producer with some 77 Mtpa. Still in the Middle East, the Group signed in September 2005 a major lump sum turnkey contract with the Yemen LNG Company Ltd for the country's first LNG plant.

The Group is also currently executing major LNG turnkey projects in West Africa and the United States including the sixth train of Nigeria LNG Ltd. at Bonny Island and the Freeport LNG receiving terminal in Texas.

This extensive Group experience at both ends of the LNG chain is now being further extended to address the challenges of nearshore and offshore LNG terminals. By combining this know-how with our marine and subsea divisions, a range of new technologies and methods has been evolved. As well as full facility construction, this includes cryogenic flexibles, rigid pipe-in-pipes, and complete transfer systems and architectures. These compliant transfer systems are custom built to optimize LNG transfer to or from marine floating (FPSO/FSRU) or fixed structures (GBS/Platform). Through a series of Joint Industry Projects, partly sponsored by a group of major operators, LNG shipping companies and engineering companies, Technip can now propose complete EPCI onshore and offshore contracts. The cryogenic pipe-in-pipe is a key element in this overall picture as it allows a nearshore LNG loading terminal to be directly linked to onshore facilities. This pipe-in-pipe can easily be installed on land, subsea or on trestles, as it has no expansion loops or bellows, and has a highly effective, passive insulation system. Coupled with an optimal built-in double containment method, an exceptionally safe and reliable link between shoreside and marine operations can now be assured.

With a workforce of more than 20,000 people and an average annual revenue of € 5 billion, Technip ranks among the world's top five corporations in the field of oil, gas and petrochemical engineering, construction and services. Headquartered in Paris, the Group is listed in New York and Paris. The Group's main operations and engineering centers and business units are located in France, Italy, Germany, the UK, Norway, Finland, the Netherlands, the USA, Brazil, Abu-Dhabi, China, India, Malaysia and Australia. In support of its activities, the Group manufactures flexible pipes and umbilicals, and builds offshore platforms in its manufacturing plants and fabrication yards in France, Brazil, the UK, the USA, Finland and Angola, and has a fleet of specialized vessels for pipeline installation and subsea construction.

A pioneer and world leader in the gas sector: NGL, GTL, LNG

With over 40 years of experience, the Technip group has established itself as a world leader in the conceptual design, engineering and construction of gas production, transport, processing, liquefaction and storage facilities and terminals.

References cover grassroots facilities, ranging from small individual units to gigantic complexes, in every sort of environment, as well as upgrades of existing installations.

Technip

Tour Technip - 8 allée de l'Arche
92973 Paris La Défense Cedex - France
Tel. +33 1 47 78 21 21
Fax +33 1 47 78 33 40
infopresse@technip.com

www.technip.com

Technip

Although the *Limburg*'s cargo ignited when the ship was attacked it did not explode and the internal tank structure by the hole was undamaged.

shipments began in October 1964; however, due to the safety distances incorporated in LNG vessel design, none resulted in loss of cargo containment.

The oil tanker *Limburg* and the US Navy vessel *USS Cole* were attacked by terrorists off Yemen and Aden respectively and these attacks are often used by anti-LNG organisations to highlight what could happen to an LNG tanker if attacked in a similar fashion. However, these two events can be turned around and used as a case model for LNG.

Limburg

This crude tanker was attacked on October 6, 2002 by means of a bomb carried in a small boat. One crew member was killed and the vessel was holed at the waterline. Although the cargo ignited it did not explode and the internal tank structure by the hole was undamaged.

USS Cole

This US warship was attacked on October 12, 2000, also by means of a bomb in a small boat. Although the death toll was high with 17 sailors in the compartment by the bomb being killed, the internal bulkhead was undamaged.

LNG shipping can be reassured by these incidents as they show that it would be very unlikely for the cargo tank to be damaged – again due to the safe separation employed in design.

Scientific modelling

Another tool we can use, in the absence of actual case studies from past incidents, is scientific modelling. There have been several research projects theorising about, for example, potential attacks on LNG carriers. However the most recent, and one which has been accepted by all sides as objective and independent, was the report produced by Sandia National Laboratories in September 2004 for the US Department of Energy. Sandia was asked to provide guidance on a risk-based analysis approach to assess and quantify potential threats to an LNG ship; the potential hazards and consequences of a large spill from an LNG ship; and

review prevention and mitigation strategies that could be implemented to reduce both the potential for and the risks of an LNG spill over water.

Specifically, the DOE requested an in-depth literature search of the experimental and technical studies associated with evaluating the safety and hazards of an LNG spill from an LNG ship cargo tank; a detailed review of four recent spill modelling studies related to the safety implications of the potential for breaching an LNG ship cargo tank, both accidentally and intentionally, identification of the potential for such breaches and the potential size of an LNG spill for each breach scenario, and an assessment of the potential range of hazards involved in an LNG spill; and development of guidance on a risk-based approach to analyse and manage the threats, hazards and consequences of an LNG spill over water, to reduce the overall risks of an LNG spill to levels that are protective of public safety and property. The conclusions proved positive in relation to LNG safety (see *Table 1*).

Safety features

The IGC code is very detailed in terms of the requirements for construction, design and equipment. As highlighted earlier, the code specifies safe distances for the strategic location of cargo tanks. Additionally there are requirements regarding cargo containment systems, materials of construction, pipelines, venting systems, filling limits and instrumentation. The Code dictates the way shipbuilders, owners, operators and classification societies interact at every level during the construction of LNG vessels. These requirements incorporate large safety margins – bigger than in other sectors of shipping – and use the experience gained by safely transporting LNG at sea for many years.

LNG vessels also have higher standards expected of them by classification societies, charterers and flag states in comparison to other types of vessels. Crews are invariably trained in excess of the minimum statutory requirements and the vessels are, generally, well maintained. The onboard monitoring systems fitted to modern LNG tankers are highly sophisticated and allow the crew to ensure all operating parameters are maintained.

The safety equipment fitted to LNG tankers which is not found on other types of tankers, with the exception of some LPG tankers, includes fixed dry powder installations, a deck water spray system, a water drenching system by the manifold, a fixed gas detection system, nitrogen purging of containment spaces and a fixed ship-to-shore link carrying emergency shut down, a "hot line", telephones and mooring tension monitoring equipment.

A full compatibility study is required for LNG vessels which have not previously visited a terminal. This is the only sector of shipping which undertakes a study in such depth. This will look at the physical constraints of the terminal and determine if the vessel will "fit", it will also involve a comprehensive mooring study. All aspects of the ship/shore interface would also be analysed including the emergency shutdown (ESD) link, the manifold arrangements and gangway.

Other factors which are also included as part of the compatibility study include vetting, vessel and operator history and, for some terminals, a pre-discharge/loading meeting.

SIGTTO has recently designed a web portal for all LNG terminal information where terminal oper-

SANDIA REPORT SUMMARY OF CONCLUSIONS

- Risks from accidental spills are small and manageable
- Intentional events can be significantly reduced with security
- Expected sizes for intentional threats are nominally five square metres
- Most significant impacts to public safety within 500 metres of spill
- Large, unignited LNG vapour releases are unlikely
- Cascading events are not expected to greatly increase hazard ranges

LEFT
Table 1.

ators input the information themselves, using a specially designed web editor. This ensures the information can be kept up to date. The information covers all terminals including those under construction and can be found at www.lngterminalinfo.org.

It is intended to further develop this site to include all LNG vessel information so that those conducting LNG ship/shore compatibility studies have all the necessary information in the one location.

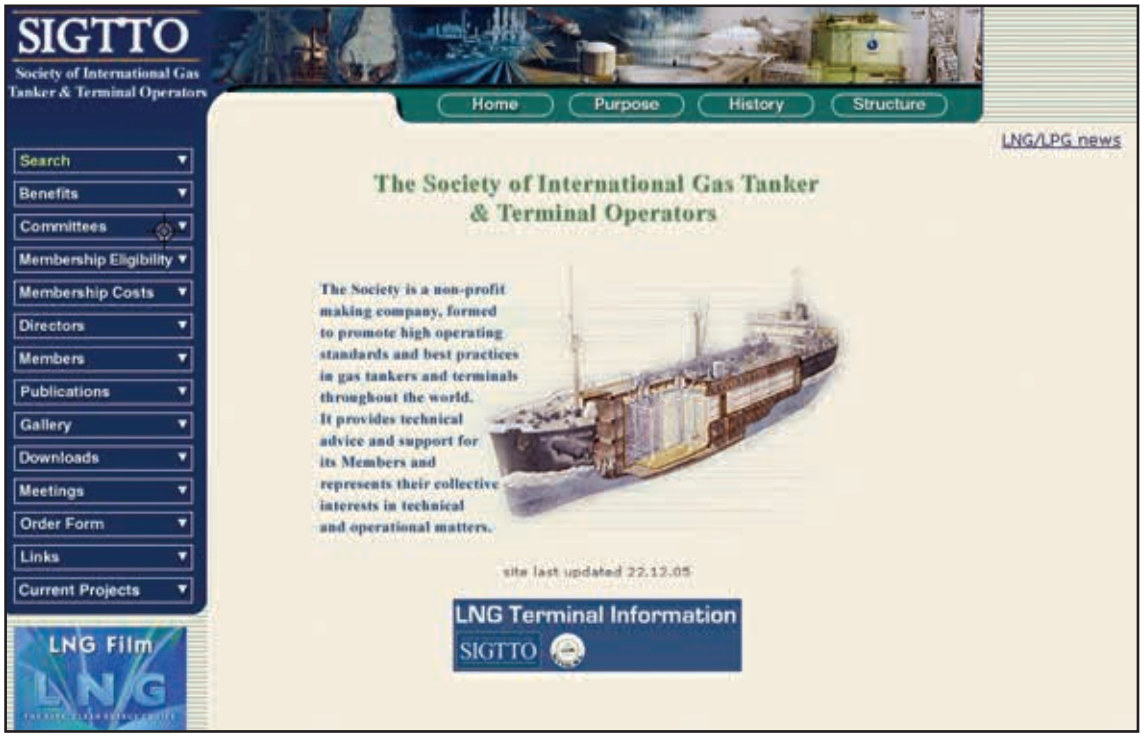
Training standards

SIGTTO believes that the greatest challenge facing LNG today is finding sufficient experienced crews for the LNG fleet.

There is a shortage of LNG and steam experience among seafarers at a time when there is a global shortage of seafarers in general and the average age of those remaining at sea is increasing each year. Hypothetically, if the number of LNG tankers remained constant, the industry would be struggling to replace those retiring or leaving the sea. However the fleet is experiencing a dramatic increase in size, from 100 ships in 1997, to 186 today, with 131 on order and is expected to peak at about 380 at the end of the decade.

If you take an average of 10 officers a vessel and the best part of two crews required for each vessel to include leave, training, sicknes and so on, clearly thousands of ships' officers are going to have to fill the void in LNG by moving from other sectors of shipping; and this is without allowing for retirements from the aging existing personnel.

A short-term answer for operators is to poach but clearly the long-term answer is training, training and further training. The influx of new personnel into the industry is of concern if there is a temptation by a minority of operators to cut corners and put officers into positions of responsibility on a LNG carrier before they have been properly trained.



SIGTTO has been developing LNG operational standards for officers.

At present there are no industry accepted operational training standards but, instead, a variety of standards varying widely from operator to charterer to flag state. SIGTTO has therefore been developing LNG operational standards for officers with the intention of these being accepted as the industry minimum best practice standard. The project began early in 2005 with the first of a series of working groups comprising experience taken from throughout the SIGTTO membership.

The standards are being written using the competence-based methodology which is used in Standards of Training, Certification and Watchkeeping (STCW) and widely throughout industry in general. The standards are now on sale through the SIGTTO website (www.sigtto.org). They cover all officer ranks on LNG vessels including the electrician and cargo engineer, where carried. These standards will be available to vessel operators and industry in general. The operators can then train their officers using whichever tools they see fit – this may be in-house training, for example.

The next stage of the project is to investigate options for a validation process and a meeting was held in mid-December 2005 by the SIGTTO Working Group. Options being investigated include a sign-off record book and/or a multiple-choice type examination. There has been a great deal of interest from training organisations who are keen to ensure training packages are available that tie in to the suggested competency standards.

The above training project will be an optional process: operators can ignore it or choose to use the standard only and not put their officers through the validation process. This standard will not be mandatory and will not replace the requirements of the flag state. However ship operators will have, if they wish to make use of it, a best practice minimum operational standard as guidance and a voluntary means of validating any seafarers trained according to the standard.

The standard was submitted to IMO's Standards of Training and Watchkeeping sub-committee in January 2006 as an information paper. Flag states can use it as they see fit. Additionally, several charterers and oil majors have indicated to the secretariat that they will include, in future charter parties, the requirement for all officers to be trained to the SIGTTO standard. The standard may then become mandatory by default, which will go a long way towards preserving the very proud safety record.

SIGTTO believes that the greatest challenge facing LNG today is finding sufficient experienced crews for the LNG fleet.

In summary, LNG shipping has a unique safety record with robust vessels which have in-built safety margins. Incidents may occur but consequences are likely to be very different from what those outside the industry may be led to believe. The public perception of risk is much greater than the actual risk and the likelihood of an incident very low. The industry is ready to face fresh challenges in the future: the shortage of experienced crews is the greatest concern.

Andrew Clifton completed his secondment as SIGTTO's Technical Adviser in November 2005 and is now working in Operational Integrity for BP Shipping. His replacement is Paul Steele also from BP Shipping. For further information on SIGTTO and LNG please visit www.sigtto.org or contact the Technical Adviser at techa2@sigtto.org.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Activities are ongoing in the Danish, British, German and Norwegian sectors of the North Sea, Qatar, Algeria, Angola, Kazakhstan, Turkmenistan, Oman, Morocco, Colombia, Brazil and Suriname.

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MÆRSK OLIE OG GAS AS

50, Esplanaden – DK-1263 Copenhagen K. – Denmark
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www.maerskoil.com

LNG Shipping – A Segment in Rapid Growth

The production of natural gas in the vicinity of the North American and European consumer markets is declining while production in the Middle East, West Africa and Australia is increasing. The distance between the producers and the consumers of natural gas is consequently getting larger, making transportation by pipeline uneconomical or even impossible. Consequently the demand for transportation of natural gas by ship is increasing.

A.P. Moller – Maersk on the LNG scene

A. P. Moller's experience of LNG shipping dates back to 1974 when it was one of the original contracting partners for the 87,500 m^3 *LNG Challenger*. The vessel was sold in 1985. In 1996 A.P. Moller chartered *Norman Lady* and entered into a charter arrangement with Spanish importer Enagas to transport LNG from Abu Dhabi to Spain until 1999.

In June 2001 A.P. Moller – Maersk contracted a 138,000 m^3 steam turbine LNG new-build from Samsung Heavy Industries in South Korea. In specifying the equipment and arrangements for the new ship, A. P. Moller utilised the experience gained with past LNG carrier activities as well as its own extensive shipping operations, including the SkandiGas Pool of about 50 semi-refrigerated LPG carriers which the group manages. Several features were upgraded beyond normal industry standard and particular attention was devoted to reducing machinery maintenance and downtime and increasing reliability and the ship's expected working life.

Negotiations with Ras Laffan Natural Gas Company Limited II of Qatar resulted in a 25-year time charter in 2002 and, later, in a similar contract for a sister vessel.

LNG/C Maersk Ras Laffan was delivered in April 2004 and has worked since without any off-service, providing 100% availability to the charterer. Her slightly larger sister vessel is set for delivery in April 2006.

Steam turbine based propulsion systems have proven extremely reliable, however to improve fuel consumption recent LNG carriers have been ordered with diesel electric propulsion.

Propulsion systems – briefly

Steam turbine propulsion combines one or two large gas and/or oil fired boiler(s) and a steam turbine driving the shaft and propeller of the vessel. Both boil-off gas (BOG) and heavy fuel oil (HFO) can be used as fuel in the main boilers and give the advantage of dual fuel burning. Exhaust emissions from "BOG only" combustion are very clean.

Traditionally all large LNG ships have been driven by steam turbine propulsion systems. Originally, there was little incentive to seek more efficient propulsion plants since there was no other use for the BOG – i.e. even if more efficient plants were available, they could not be used without wasting BOG.

Tank designs have been improved, however, aiming at conserving the loaded LNG and, with today's technology, environmental consciousness and not least cost of energy, the incentive to reduce the volume of fuel used for propulsion is significant.

The traditional HFO powered two stroke diesel engine used in the majority of large non-LNG vessels is an option. However the exhaust emissions have a high content of SOx, NOx and COx, and since the engine cannot burn the BOG this must be disposed of by other means – re-liquefaction being the most obvious. Re-liquefaction onboard is very energy consuming and only an economically viable option for very large vessels (in excess of 200,000 m^3).

Dual fuel diesel electric (DFDE) propulsion combines a number of four stroke engines with generators and an electrical motor driving the shaft and propeller. It has the advantage of being able to use BOG as fuel resulting in very clean exhaust gas emissions combined with low specific fuel consumption per generated kilowatt hour.

Vessel size and cargo capacity

When wanting to reduce the cost of shipping it is important to look at the economy of scale from increasing the cargo capacity of the vessels. A number of issues specific to the nature of the trade have to be considered. These include:

- The cargo containment system sets restrictions to the size of the individual tanks due to issues relating to tank stress resulting from cargo sloshing.
- Physical restrictions to the vessel's size apply at the ports between which the vessel is to trade.
- Storage tank size at the production and receiving terminal.
- Use of the BOG generated from the natural heating of the cargo.

When the decision was taken to expand the LNG fleet of the A.P. Moller – Maersk Group with a new series of minimum six newbuildings to be delivered in 2008/09, the various alternative sizes and propulsion systems were carefully evaluated.

To allow the maximum flexibility, a size of 165,500 m³ cargo capacity was chosen as the ideal size that will allow the vessel to trade with almost all existing and all new terminals. Given this size of vessel the choice of DFDE propulsion was made for environmental, reliability and fuel efficiency reasons combined with the advantage of the relative increase in cargo carrying capacity. The fuel economy can be further improved by opting for HFO burning as back-up fuel rather than the more expensive marine diesel oil.

Maersk Ras Laffan

So what makes the difference?

Safety and reliability are key concepts in the LNG industry, concepts which are very familiar to A.P. Moller – Maersk but nevertheless a challenge in this new venture where loading and discharging operations pose strict requirements for efficiency and accuracy.

The team of ship's officers for *Maersk Ras Laffan* has been through an extensive training period of over a year comprising some 90 days of courses, one month's supernumerary sailing on other LNG carriers and a five months familiarisation period at the yard. The comprehensive training, together with the high degree of enthusiasm and motivation shown by the crews, put the officers in a good position to take responsibility for the newbuilding with all its advanced technology. The teams for the next vessel to be delivered in April 2006 are now going through a similar preparation process.

Recruitment of the right candidates, training and experience is of paramount importance. A crucial part of A.P. Moller – Maersk's recruitment and employment strategy is an extensive cadet training programme which ensures a constant flow of well trained and dedicated young marine officers to man the expanding Maersk fleet. At present there are over 1,000 cadets employed under the programme which combines a theoretical maritime education at dedicated facilities and with hands-on experience obtained during seagoing training periods on company vessels.

A large part of the training of Maersk fleet officers takes place at Maersk Training Centre in Denmark which offers a wide variety of courses including casualty prevention and safety awareness. The modern training facilities use the latest technology and simulator training and, preparing for the training of the LNG crews, the centre invested in a state-of-the-art LNG cargo handling simulator. Many of the LNG specific courses were carried out by suppliers, either in Denmark or on site in their own countries including Norway, France, Switzerland and Japan.

Another important part of the training took place at the shipbuilding yard where the ship's officers play an important role in the supervision of the final tests on the newbuilding whilst at the same time becoming intimately familiar with the vessel and her technology. Before the officers arrived at the yard, supervision had already taken place for 1½ years. This was performed by Maersk Ship Design, the dedicated, in-house company responsible for plan approval and construction supervision during all phases until delivery. Maersk Ship Design currently oversees the world's largest newbuilding order book. Site offices at the specific yards have the responsibility of ensuring that quality requirements are met and safety and quality assurance is observed during construction.

LNG has been a natural step to expand within liquefied transportations for A.P. Moller – Maersk as this business area has been able to benefit from the Group's well-established competencies within technically advanced shipping and offshore segments. The benefits of combined technical and commercial expertise are used to provide our customers with the most appropriate solutions for their capital intensive energy projects including the flexibility of providing both short-term and long-term charter arrangements.

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WOC 2 Gets Ready to Present its Findings

By Sergei Khan, Joachim Wallbrecht, Gretta Akopova, Alexander Grigorev and Nadejda Vlasenko

Previous issues of the IGU Magazine have contained features on the work of Working Committees 1 (September 2004), 3 and 4 (October 2005), and in this issue we look at the work of WOC 2. The Committee's remit covers storage and it has three Study Groups.

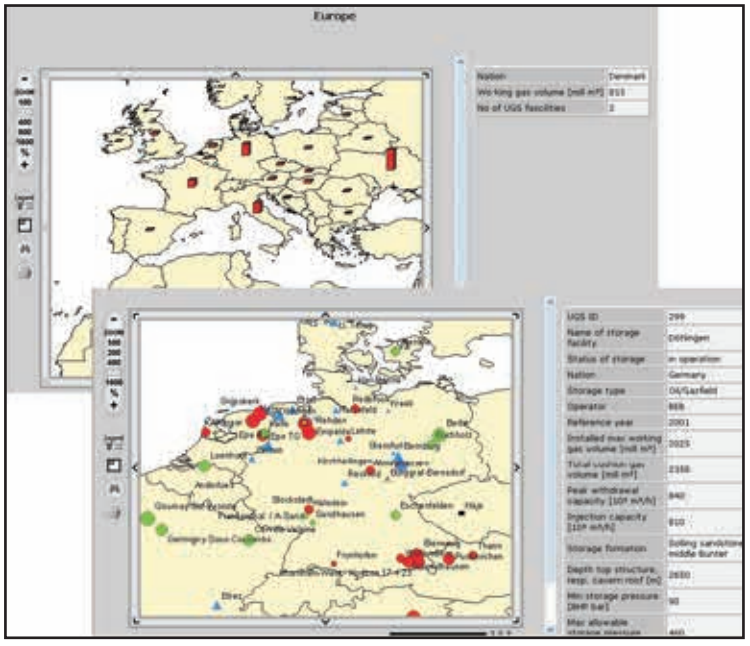
Study Group 2.1

SG 2.1 continues the work of the former Basic Activity Study Group of the 2000-2003 Triennium and its objectives are to:

- Update information on underground storage (UGS) facilities around the world resulting in the UGS database;
- Provide geo-referenced visualisation of storage data in the form of a world map of UGS facilities;
- Look at general trends in the storage industry; and
- Publish a glossary of relevant storage terminology.

The main deliverables of the work are described in more detail below.

BELOW
Figure 1. UGS World Map



UGS database

The aim is to publish a high-quality database of underground storage facilities around the world. Information on about 96% of existing UGS facilities has been received in reply to a questionnaire which was sent out. Combining this with data available from other sources and from the previous survey has produced an excellent end-result with an uncertainty of less than 1.4%. It will be made available as an Access database with tables in metric and imperial units.

UGS world map

Key data from the UGS database will be presented visually in maps. The UGS world map gives an interactive geo-referenced presentation of UGS data which allows for quick and easy extraction of relevant data (see *Figure 1*).

For the first time the UGS world map will include the underground gas storage facilities of Canada and the USA. The visualisation system will be made available in metric and imperial units.

Glossary of relevant storage terminology

The glossary covers technical terminology related to the storage of natural gas in underground gas storage facilities. The terms are listed and defined in different languages (English, French, German, Polish and Russian).

Study Group 2.2

SG 2.2 is concerned with the technologies involved in underground gas storage. To collect information it has refined a questionnaire originally developed by IGU Committee members in 1998. This covers the development of various types of storage facilities and groups questions into five areas: general aspects, reservoir related, well related, surface facilities related and safety related.

So far 20 replies from 15 countries (12 in Europe, two in the Americas and one in Asia) have been received. While the final report will be presented and discussed at sessions of the forthcoming WGC, we present some initial results here.

Clearly safety is the key issue for companies operating UGS facilities. This is followed by costs, legal requirements and market considerations.

In general, to cater for increased UGS requirements new facilities have been developed rather than expanding existing ones. The most popular new techniques are CO_2 sequestration, storage in lined hard-rock caverns and storage in abandoned mines.

3-D seismic and re-interpretation remain the most popular methods used for defining the characteristics of layers, while the role of 2-D seismic is declining. 4-D seismic, which at one time appeared to have significant potential, is used rarely.

Most UGS operators have reached their maximum allowable storage pressure and only a few respondents see growth of this parameter in the future.

Numerical reservoir simulation has become a necessary requisite for realising UGS potential. Various operators have developed their own tools to calculate special modelling issues such as gas mixing.

The most important monitoring techniques used to improve geological, technical and operational safety are:

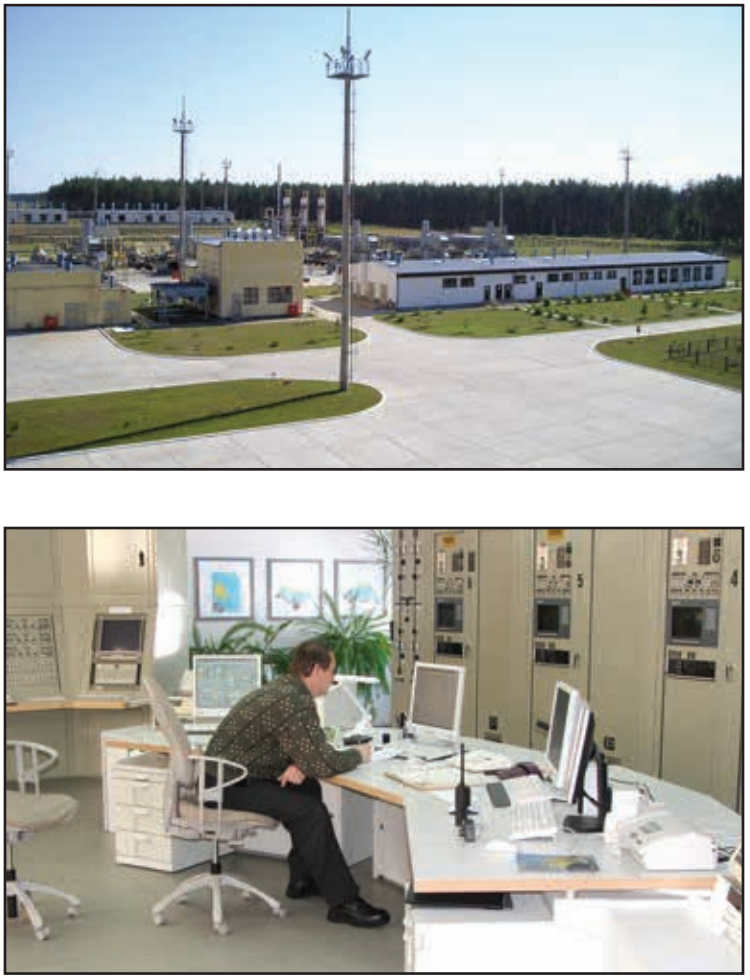
- Real time well performance monitoring (flow, pressure);
- Gas quality monitoring; and
- Automated gas quality monitoring.

The most rapidly developing technologies are:

- Permanent down hole gauges;
- Remote control; and
- Real time sand production monitoring.

Reduction of pressure losses remains the most significant measure to improve UGS performance.

The majority of UGS well chinks are traditional vertical wells in which heterogeneous collectors are combined with slanted ones. There are fewer horizontal wells, although these give additional deliverability and reduce surface environmental impact. There is increasing use of larger well bores, re-entry (including horizontal leg extensions) and extended reach wells, while the most dynamic growth has been in the use of coiled tubing drilling. There is some potential for recompletion (larger size tubulars).



A general view of the Uviazovskoe UGS in the Ryazan region of Russia (TOP) and its main operating console (ABOVE).

Two main problems are well bore damage and cement bond quality.

The most prevalent stimulation technologies to increase gas deliverability are acidising and fresh water treatments.

Advanced fracture stimulation technology includes tip-screen out fracturing, hydraulic

Dehydration units at the Kushchiovskoe UGS in Russia's Krasnodar region.

fracturing with liquid CO_2 and proppant, extreme overbalance fracturing and high-energy gas fracturing. These new technologies have high potential but are not yet in wide use.

BELOW
Table 1.

STUDY GROUP 2.3 QUESTIONNAIRE

1	Status of environmental regulations: what bodies regulate and monitor the environment?
2	Technologies and methods to reduce the impact of hazardous factors on the environment (UGS only).
3	Technologies and methods to reduce the impact of physical, mechanical and other factors on the environment (UGS only).
4	Enhancement of environmental reliability of UGS operation.
5	Air pollution: methods and means of control.
6	Regulations for sewage water, brine, and wastes of production and consumption.
7	Norms of natural gas leakages from equipment.
8	Norms of emissions from fuel-consuming facilities and control devices.
9	Ecological, sanitary and other norms for monitoring of pollutants.
10	Miscellaneous: what reserves and means of enhancing UGS environmental reliability do companies possess?

The integrity of subsurface equipment is a key factor in maintaining storage efficiency. Annulus pressure monitoring is the main means of ensuring the integrity of subsurface equipment.

Methanol inhibition, gas heating and glycol inhibition remain the most used methods of avoiding hydrate formation, while kinetic inhibitors are being investigated. Silica gel drying is the least used technique.

There have been almost no changes in corrosion management techniques and gas treatment and gas quality management since the last survey.

The wide range of techniques used to ensure high UGS safety standards includes:

- Safety studies and audits;
- Preventive technical installations;
- Subsurface safety valves;
- Diagnosis of critical operations;
- Enhanced monitoring;
- Best knowledge of the geological situation;
- Periodical gas inventory and control of cap rock tightness;
- Preventive maintenance; and
- Accident analyses.

The analysis of data shows that gas storage technologies are being developed which allow the efficiency of UGS creation and operation to be enhanced and new market requirements to be met.

Study Group 2.3

SG 2.3 covers environmental protection issues in the field of storage. Committee members developed a questionnaire to collect information on technological trends in UGS operation and views on how UGS environmental stability could be enhanced.

According to respondents, the filling out of the questionnaire *(see Table 1)* was a labour-intensive process involving specialists in various spheres and extensive searches for data. However, representatives of 15 countries took part and presented 20 surveys in response to the questions.

For the first time generalised data have been obtained for all foreseeable aspects of environ-

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mental protection activity aimed at reducing the environmental impact and ensuring the efficient operation of UGS. Data have been obtained on:

- Environmental protection regulation and the normative-legal support of UGS operation;
- Types and ecological characteristics of the power and technological equipment operating at UGS facilities;
- Existing means of controlling pollutant emissions in combustion products; and
- Real and/or potential ecological efficiency of technological decisions undertaken at UGS facilities in different periods of time (three-five years ago, at present and in the near future).

The data analysis shows the similarity of approach to environmental protection in different countries with a broadly comparable attitude to the development and application of technologies and technical means. Summing up world practice in UGS operation, the key means of enhancing UGS environmental stability are shown in *Table 2*.

BELOW
Table 2.

WORLD PRACTICE IN UGS OPERATION

Enhancement of UGS Environmental Stability	*Method/Technology*
UGS management	Optimisation of UGS operation Layout of facilities
Reduction of atmospheric emission	Exchange of gas turbines in order to meet the regulation requirements Up-to-date methods of controlling NOx, CO_2, CO, SOx, CH_4 atmospheric emissions from all equipment (GPU, boilers and flares included) New plans for reduction of flared gas emissions New technologies of well drilling: ● Drilling of horizontal wells ● Wells drilled with electrical rig
Application of new technologies and methods of natural gas burning	Adjustment of gas turbines to DL NOx technique and enhancing compressor efficiencies Reduction of CH_4 emissions to eliminate leakage Reduction of vented gas Diethylene glycol (DEG) and triethylene glycol (TEG) regeneration
Noise reduction (creation of quieter gas-pumping units as the compromise between technical opportunities and economic feasibility)	Acoustic improvement of noise source (rotary superchargers) Modular means of silencing
Development of water use system	Reduction of effluents Effluent measuring procedures Water disposal Closed-cycled systems
Wastes	Reducing the impact of liquid and solid wastes
Ways of neutralising environmental pollutants	Technologies of impact reduction: chemical; physical – radiation, electromagnetic; biological; thermal; mechanical – solid and liquid wastes, rubbish, etc.
UGS territory arrangement	Land reclamation Land compression in the areas of technological installations releasing pollutants due to asphalting or concreting
High efficiency of work	Reducing visual impact

● Final report

The main results and findings of the Study Groups' work will be published in the WOC 2 report for the WGC.

Dr Sergei A. Khan is the Head of UGS Direction at Gazprom and Chairman of WOC 2. Dr Joachim Wallbrecht is Transport & Storage Analyst at BEB Erdgas und Erdöl GmbH. Dr Gretta Akopova is Head of the Environment Protection Laboratory at VNIIGAZ and leader of SG 2.3. Dr Alexander Grigorev is a Chief Researcher at VNIIGAZ and leader of SG 2.2. Dr Nadejda Vlasenko is a Chief Researcher at VNIIGAZ and a member of SG 2.3.

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Distributed Energy Resources: Technologies and Business Perspectives

By Samuel Bernstein and Fidel Valle

The challenge in meeting surging worldwide demand for electricity is less one of generation capacity and more an issue of grid capacity. Headline-making blackouts – notably in North America and Italy – were caused by the failure of transmission lines. Moreover, approximately 10% of electricity generated is lost in transmission and distribution from centralised power plants to the end users.

Adding distributed energy resources (DER) to the generating mix can meet this challenge. In this context, DER includes renewable energies and highly efficient co-generation (which accounts for 96% of today's installed DER) as well as its extensions like tri-generation and district heating and cooling.

Historically, the first units of electrical production around the world followed principles which today we would classify as distributed generation. That is to say that these plants covered their own requirements and sold their excess power to neighbouring industries. As the electrical industry developed, larger plants were built to provide better economies of scale. These plants were progressively moved away from the centres of consumption necessitating the creation of large interconnecting grids.

Today, centralised plants retain a unit cost advantage, but where there are system constraints, particularly in transmission and distribution, modern DER technologies offer significant advantages by:

- Reducing the consumption of primary energy, due to the greater efficiency of the process (using several forms of energy e.g. combined heat and power – CHP), and avoiding the losses of energy associated with electrical transport and distribution;

The challenge in meeting surging worldwide demand for electricity is less one of generation capacity and more an issue of grid capacity.

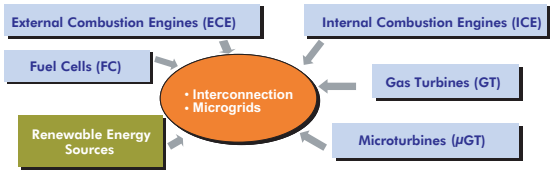


Figure 1.

- Reducing emissions of polluting agents to help meet Kyoto Protocol commitments;
- Providing a more robust grid and services to the customers; and
- Offering the means to reduce, or at least to delay, investments in new electrical distribution infrastructure.

DER is supported by a vast array of technologies, some already mature, and some emerging, that offer a great future potential. The range of DER technologies is summarised in *Figure 1* and the table and can be divided into two basic types using either fossil fuels or renewables. Fossil fuel technologies include internal and external combustion engines, gas turbines, microturbines and fuel cells. Renewable energy technologies include solar, wind, biomass and small-scale hydropower.

It is important to note that the renewable sources apart from biomass depend on an unpredictable generation schedule (wind, sun, water flow) and thus are complementary to other energy sources. Moreover, most electrical DER applications need to be linked to the grid, and interconnection technology and cost are critical to the acceptance of DER applications.

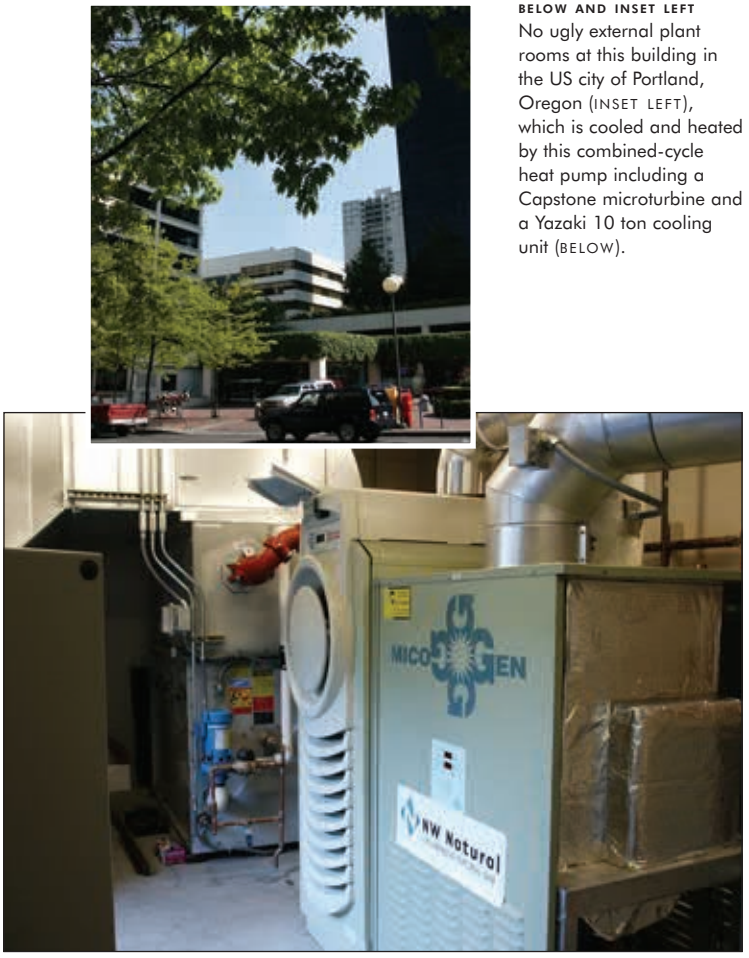
Fossil fuel technologies

Internal combustion engines

Reciprocating internal combustion engines (ICE) are reliable and mature. Extensively used in CHP systems, they can run on a wide range of liquid and gaseous fuels and offer generation capacities between 1 kilowatt electric (kWe) and 20 MWe.

ICEs have an electrical efficiency between 25% and 45% (lower calorific value – LCV). When thermal energy is captured the total efficiency of the co-generation system is normally between 65% and 85%; in units operating with flue gas condensation the overall efficiency could be above 95% (LCV). ICEs are not as susceptible to external conditions as other technologies. In general, they have a 1% power loss for each 100 metres of altitude above sea level and a 1% loss for an increase of 5.5°C in room temperature. They also maintain their efficiencies over a wide range of partial loads.

However, ICEs are considered to have relatively higher maintenance costs and higher emissions than other DER technologies. Thus the objective of current research work is to obtain engines with efficiencies of 50-55%, a reduction in the



BELOW AND INSET LEFT
No ugly external plant rooms at this building in the US city of Portland, Oregon (INSET LEFT), which is cooled and heated by this combined-cycle heat pump including a Capstone microturbine and a Yazaki 10 ton cooling unit (BELOW).

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Contacts:

Brett Olsher
brett.olsher@db.com
+44 20 7545 6459

Michael Johnson
michael.v.johnson@db.com
+1 212 250 0413

Martin Copeland
martin.copeland@db.com
+44 20 7545 7807

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SUMMARY OF MAIN TECHNOLOGIES

	ICE	*Gas turbine*	*Gas microturbine*	*PV*	*Wind energy*	*Fuel cells (*)*
Power range	1 kWe-20 MWe	500 kWe-50 MWe	25-300 kWe	1 kWe-1 MWe	10 kWe-5 MWe	1 kWe-1 MWe
Fuel	Natural gas, biogas, LPG or liquid fuels	Natural gas, biogas, LPG or liquid fuels	Natural gas, biogas, LPG or liquid fuels	Sunlight	Wind	Natural gas, biogas, hydrogen or liquid fuels
Efficiency (%)	20-45	28-60 (**)	25-33	6-19	25	30-65
Installation surface m^2/MW	20-29	37-65	27-30	~ 10,000	47,000 – 160,000 (***)	37-167
Investment, €/kW	350-700	400-900	750-1,000	5,000-6,600	800-1,000	900-3,300
Maintenance and operation costs, €/MWh	7-15	4-9	3-15	1-4	1-3	5-20
Emissions once in service (ppm)	NOx < 160 CO < 70	NOx < 25 CO < 50 @ 15% O_2	NOx < 50 CO < 50 @ 15% O_2	–	–	NOx < 1 CO < 2
Technology status	Commercial	Commercial	Some commercial models	Commercial	Commercial	Pre-commercial

(*) Given data is highly dependent on fuel cell technology analysed. (**) Natural gas-fuelled combined-cycle plant.
(***) Including the spacing between wind turbines. Data source: American Wind Energy Association.
Source: Adapted from *Generación eléctrica distribuida. Manual de diseño* (Distributed electricity generation. Design handbook). Gas Natural SDG, 2005.

ABOVE
Table 1.

generation of NOx and an increase of the reliability to reduce maintenance.

Gas turbines

The gas turbine is also a mature technology used in the applications of large installation of CHP. This technology provides capacities between 500 kWe and 50 MWe for applications of DER and up to 250 MWe for electrical generation in power stations. Gas turbines, in this power range, show simple efficiencies between 32% and 46%. But in comparison with ICE, they offer a worse efficiency at partial loads.

External conditions also have an influence on gas turbine performance. In general, 3.5% of efficiency is lost for each 300 metres above sea level, although, the determining factor is the ambient temperature. A 0.9% of efficiency is lost for each °C above the ambient temperature at sea level.

The research work in the gas turbine sector is concentrating on obtaining 60% efficiency or more, reducing emissions of NOx and CO and improving durability.

Microturbines

Microturbines are gas turbines with special construction characteristics and capacities between 25 and 300 kWe, although individual units can be combined in a modular installation for a larger power capacity. They can run on diverse fuels like natural gas, propane, biogas and liquid fuels and offer electrical efficiency of 25-30%.

The commercial offer of microturbines is still limited and investment level is still high. Nonetheless, in the near future installations based on microturbines could offer an attractive solution for DER in buildings and for small applications.

Stirling engines

Stirling engines are powered by the expansion of a gas when heated externally, followed by its compression when cooled. They contain a fixed amount of gas (either air, helium or hydrogen) which is transferred back and forth between "cold" and "hot" ends. The Stirling cycle uses an external heat source, which could be anything from fossil fuels to waste heat. Combustion takes place outside the cylinder and can be carefully controlled to reduce emissions.

Since these engines show high thermal efficiencies they are most suitable for applications where thermal requirements are significant, for example in geographical regions with a high annual heating demand.

They are generally found in small sizes (1-25 kWe) and are currently being produced in small quantities for specialised applications. The electrical efficiency is about 12-20%, with the target of higher efficiencies than 30%.

Fuel cells

Fuel cells are an emerging technology of small-scale electricity generation whose capacity depends on the type of cell and can vary between 1 kWe and 10 MWe.

In general, a fuel cell is based on the inverse principle of electrolysis. That is to say, electricity is generated from the combination of hydrogen and oxygen to form water without combustion taking place. As it is an exothermic process, applications of CHP can be made. Fuel cells include the following types detailed below.

Low temperature fuel cells which require a reformer to obtain hydrogen from the primary fuel:

- Alcaline, the first fuel cell for space applications with efficiency around 60% but purification costs make it unsuitable for DER applications.
- Polymer electrolyte membrane (PEM), hydrogen of great purity is required and an electrical efficiency between 30 and 40% or more can be achieved. The low temperatures of operation, the short time necessary for the starting and light weight and their simplicity makes the PEM attractive for automotive application. The heat recovery for CHP applications is by producing hot water.
- Phosphoric acid, relatively more mature than other fuel cell technologies providing efficiency of 36-42% but the use of a platinum catalyst contributes to a high capital cost.

High temperature fuel cells which can provide auto-reforming of several primary fuels:

- Molten carbonate, offers greater electrical efficiency (~45-55%) than the low temperature fuel cells. The high temperature of operation (650°C) permits its use for a combined cycle, taking advantage of the residual heat to generate additional electricity. In co-generation, the global efficiency can reach 85%. As it is a high temperature fuel cell, the heat recovery can be as hot water, low pressure steam or high

Ten European cities (Madrid is pictured) are involved in a trial of buses using PEM fuel cells. (INSET) The fuel cell unit with a power output of more than 200 kW and the pressurised cylinders containing hydrogen compressed to 350 bar are accommodated on the roof of the bus.

pressure steam. Questions as to the molten carbonate life remain open.

- Solid oxide, offers electrical efficiency ~45-60% and when operating at higher temperatures (800-1,000°C) can use a great variety of fuels. This is the most sulphur-resistant fuel cell type and is not affected by CO, which can even be used as fuel, allowing the use of gases made from coal. As it is a high temperature fuel cell, the heat recovery can be as hot water, low pressure steam or high pressure steam. It also has a relatively quick start-up compared with molten carbonate models.

Currently all these types of fuel cells are only available as demonstration products and there is still a lot of work to be done on reliability and durability. The fuel cells that offer the highest potential for development are the PEM for transportation, residential and mobile applications, while solid oxide offers an interesting promise for DER applications. Molten carbonate installations are being demonstrated for large power installation and biofuels.

There is still some way to go in reducing the cost of photovoltaic cells – an assembly site in Saudi Arabia.

Renewable technologies

Photovoltaic

Incentives and subsidies have stimulated wide usage of photovoltaic (PV) cells, whose efficiencies range from 7-17%. Large surfaces are required with an approximate output of 1 kWe per 10 square metres. Although once in service, PV is considered a "clean" renewable technology, a life-cycle analysis shows that the fabrication process of the cells is environmentally debatable. Inversion costs for PV cells are still too high and research efforts are aimed at lowering these costs.

Wind

The kinetic energy of wind is a promising source of renewable energy with significant potential in many parts of the world. However, the energy that can be captured by wind turbines is highly dependent on the local average wind speed. It is not just a question of lack of wind; in very high winds the turbines have to be shut down to avoid damage. Moreover, onshore installation projects are meeting resistance from environmental campaigners in some parts of the world.

Biomass

The basis of biomass energy is the use of organic matter, in most cases plant and tree residues. In other cases biogas from municipal waste water treatment is used. Up to now in industrialised countries biomass has only played a small, complementary role, while in developing countries it is far more significant. However, there is a trend towards increasing biomass crop applications.

Small scale hydropower

Typically small scale hydropower refers to installations with an output less than 10 MWe using "run of river" schemes where the river water is not stopped. Thus they do not require massive dams or

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Denmark was a pioneer in developing commercial windpower in the 1970s and today around 20% of the country's electricity is generated by wind.

pose the ecological threat of large hydro projects.

Small scale hydropower is a long-lasting and robust technology; systems can last for 50 years or more without major new investments. Power is usually continuously available on demand and after being used for power generation the water is available for other purposes (although on a lower hydrostatic level). Obviously, the viability of all hydroelectric power generation is dependent on the availability of water resources.

Interconnections

Apart from linking the DER unit to the universal electrical power grid, the interconnection system can also provide monitoring, control, metering and dispatch of the DER unit. Proper interconnection systems allow:

- DER equipment to be operated in a prime power mode and peak power demands to be supplemented with grid power purchases;
- Back-up power to be obtained from the grid in the event of a DER system outage, eliminating the common expensive redundancy with batteries;
- Advantage to be taken of the opportunity to export power to the grid, thus increasing electrical power grid rating; and
- Overall customer system reliability to be improved by providing an alternative power supply option.

There is a special concern worldwide about the interconnection of DER and the control of the resulting grid. In general, there is a lack of experience and technical ability to control a significant number of DER units linked to the same grid. More research is needed on dispatch real-time models, dynamic models for several machines, design of protection schemes and real-time operation and control,.

Several research programmes such as the EU's Fenix project are aimed to enhance the knowledge on DER interconnections and its control. Work is also required in the standardisation field, as there is a lack of standards and protocols to enable the

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integration of DER in the grid and in the market. A start has been made by the US Institute of Electrical and Electronic Engineers, whose P1547 seeks to provide a uniform standard for requirements related to the performance, operation, testing, safety considerations and maintenance of the interconnection. However, in most considerations DER must be disconnected from the grid when a power outage is being experienced.

Microgrids

The future interconnection of small modular generation sources into the low voltage grid will form a new type of power system, the microgrid. The microgrid can be seen by the utility as a controlled single unit of the power system. Microgrids can be connected to the main power network or be operated autonomously isolated from the main power grid.

There is a lack of legislation to frame the concept of microgrids in which there would be an association of a low voltage network, DER units and electrical consumers able to operate in an interconnected mode or in an autonomous isolated way.

This new scenario of operation requires the development of applied research at several levels to profit from the capabilities that this concept may offer and develop efficient strategies to manage microgrids. This includes dealing with microsource electrical modelling, power system low voltage operational impact analysis, control, power quality and network reliability, protection coordination and personnel safety, communications, economic and electrical market procedures, and standards and regulations.

Business perspective

Electricity and gas utilities, including energy services companies and other non-regulated entities, and their customers are the key constituents to benefit from DER. However, there are three types of barriers to its wider use. These are the way in which the electricity grid is managed, the legal framework and the economic regime. The key measures to address these barriers are simplifying the process of authorisation, regulating connection to the distribution network and establishing economic incentives for DER based on recognition of the avoided losses in the transmission and distribution networks and reduced emissions. Indeed, the two leading countries in the DER sector are those whose governments have actively incentivised its development.

Denmark is the pioneer country for its capacities of co-generation. DER accounts for more than 50% of electricity generated, while 80% of district heating (the predominant heating technology) is based on co-generation. Danish legislation aims at environmental protection, efficiency of energy uses and security of electricity supply. Current efforts are focusing on improving efficiency.

The Netherlands generates just under 40% of electricity via DER thanks to government policies driven by environmental and energy conservation considerations. The use of renewable energy sources has been stimulated (by measures aimed at generators as well as at consumers) and different subsidies offered for co-generation plants.

The allowance of DER cost recovery to be similar to those of large power plants will enhance its use by the electric and gas utilities.

Conclusion

DER offers an important new concept for the electricity business and interesting new market opportunities to energy companies against the background of the liberalisation of energy markets. It offers a new market to the gas industry and has the potential to reduce polluting emissions and contribute to energy savings and efficiency.

Samuel Bernstein (USA) is the Chairman and Fidel Valle (Spain) is the Vice Chairman of IGU Study Group 5.4: Distributed Energy Generation. A full version of this report will be presented at the WGC in Amsterdam. The authors wish to thank members of SG 5.4 and the staff of Gas Natural SDG for their contributions.

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Saudi Aramco: Nurturing Saudi Arabia's Gas Industry for over a Quarter Century

Saudi Aramco has played a dominant role in the Kingdom's gas sector over the last three decades and it is committed to continue this role to sustain further development of gas and downstream industries in Saudi Arabia.

Beginning in the mid-1970s, under the Government's long-term vision and direction, Saudi Aramco launched the Kingdom's Master Gas System (MGS) to add value to associated gas, develop the foundation for an industrial base, and diversify the Kingdom's sources of income. Three gas plants at Berri, Shedgum and Uthmaniyah were constructed along with a network of gas and natural gas liquids (NGL) pipelines and fractionation facilities on both coasts (Ju'aymah and Yanbu') to process and distribute the produced solution gas and valuable by-products. The availability of sales gas, ethane and NGLs from the MGS as fuel and petrochemical feedstock spawned the development of the Kingdom's two major industrial cities in Jubail and Yanbu'.

In the 1980s, Saudi Aramco embarked on its initial non-associated gas development programme to meet growing demands. The gas plants at Shedgum and Uthmaniyah were upgraded and expanded in the mid-1980s to also process non-associated gas in order to ensure reliable supplies to its customers during periods of low oil production.

With the rapid growth of sales gas demand in the Kingdom, Saudi Aramco began a major non-associated gas expansion programme in the 1990s. This gas exploration programme was highly successful, adding almost 55 TCF of non-associated gas reserves, thus doubling the non-associated gas reserves in less than a decade.

This exploration success enabled further expansion of the MGS over the last few years, initially by further upgrades and expansions in Shedgum and Uthmaniyah Gas Plants to about 2.4 BSCFD each, and the Berri Gas Plant to a capacity of 1.4 BSCFD followed by the construction of the Hawiyah and Haradh Gas Plants, each having a processing capacity of 1.6 BSCFD. These two new plants were designed to exclusively process the non-associated gas discovered in the 1990s. The Kingdom's sales gas distribution network was also expanded westward to major centres in Riyadh and Yanbu'. Gas delivery to Riyadh was established in 2000. Gas delivery to Yanbu' commenced in 2003. With the commissioning of the Hawiyah Gas Plant in 2001 and Haradh Gas Plant in 2003, the MGS processing capacity was increased to over 9 BSCFD of raw gas.

As of year-end 2004, the Kingdom has 237 TSCF of proven natural gas reserves – fourth highest in the world – consisting of both associated and non associated gases. The MGS currently has the capacity to deliver over 7 BSCFD of sales gas which is consumed locally as petrochemical feedstock or fuel and over 1 million barrels per day of NGLs for domestic petrochemical feedstock, with the surplus being exported. The Kingdom is the world's largest exporter of NGLs. Gas provides vital feedstock to the primary petrochemical industries and fuel for electric and water utilities, as well as a number of process industries. Saudi Arabia now has one of the highest per capita gas consumption rates in the world, and the gas contribution within the Kingdom's energy mix is rising ahead of the global trend.

Sales gas demand has nearly doubled in the last six years, with ethane and NGL deliveries growing proportionately over the same period. As a result of the MGS the Kingdom now boasts one of the world's leading petrochemical industries, growing from 25 petrochemical plants in the 1970s to some 500 facilities, and from $500 million in petrochemical investment in the 1970s to about $20 billion in the year 2000.

Saudi Aramco has embarked on another major expansion to its MGS centred on recovery of ethane and NGLs from the Hawiyah and Haradh Gas Plants, as well as expanding the Hawiyah Gas Plant and other associated fractionation and transmission systems.

Clear vision for gas industry

With endorsement by the Supreme Council for Petroleum and Minerals of the Kingdom's Gas Strategy in 2000, the vision for the gas industry in the future is clear. Saudi Aramco continues its aggressive non-associated gas exploration programme to meet the projected growing gas demand in the Kingdom.

To complement Saudi Aramco's gas development effort and to attract foreign direct investment in the gas sector, the Gas Strategy also envisioned inviting foreign companies to participate in the Kingdom's gas sector. Accordingly, the Kingdom and Saudi Aramco took another big step in the development of the Kingdom's gas sector with the signing of gas exploration agreements between the Kingdom of Saudi Arabia and six international companies.

H.E. Ali I. Al-Naimi, Minister of Petroleum and Mineral Resources, signed on behalf of the Kingdom the historic North Rub' al-Khali Upstream Gas Agreements. These agreements will partner Saudi Aramco with international companies like Lukoil of Russia, Sinopec of China, and a consortium of ENI of Italy and Repsol YPF of Spain, in joint ventures to explore more than 120,000 square kilometres in the Rub' al-Khali and produce non-associated gas for the Kingdom's Master Gas System. Saudi Aramco is a 20% partner in each of the three joint venture companies created by the agreements.

This is in addition to the South Rub' al-Khali joint venture agreement signed with Royal Dutch/Shell and France's Total in November 2003, which targets a 209,160 square kilometre exploration area in the South Rub' al-Khali Basin. Shell has a 40% stake in the joint venture, while Total and Saudi Aramco each have 30%.

In order to facilitate lifting of production from the upstream companies, the Government has designated Saudi Aramco to serve as the operator and aggregator of the Master Gas System (MGS).

Saudi Aramco is committed to making these joint ventures a success with representation at both the Board and management level. Saudi Aramco secondees to these companies are actively participating in technical exchanges, operations and management of these companies.

Saudi Aramco has also provided all geophysical and well data associated with each contract area to the respective companies to facilitate their processing and analysis of the data. Senior technical personnel are on loan to the JV companies to share Aramco's experience in employing best practices in the exploration and drilling operations.

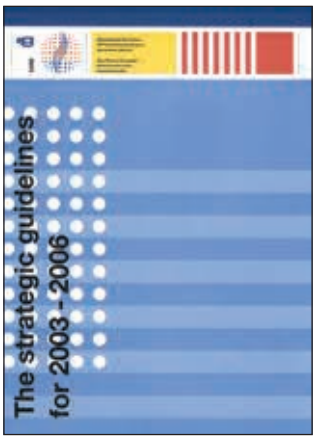
These agreements – and the massive foreign investment they will bring – are another chapter in Saudi Aramco's efforts to leverage the Kingdom's abundant hydrocarbon reserves for the Kingdom's economic well-being. In addition, through technical exchange with the world-class companies participating in these joint ventures, Saudi Aramco will ensure that future gas supplies can be developed in the most cost-effective manner to maintain the Kingdom's main competitive advantage of providing plentiful energy and feedstock to its industries.

Saudi Aramco remains committed to expanding the Kingdom's gas reserves and production to match the robust growth in demand for natural gas as fuel and petrochemical feedstock domestically and internationally.

Publications and Documents Available from IGU

As a non-commercial organisation promoting technical and economic progress in the gas industry worldwide, IGU offers its publications free of charge and you are invited to order the IGU publications currently available from the Secretariat. (All documents are A4 format unless stated otherwise.)

2003-2006 Programme

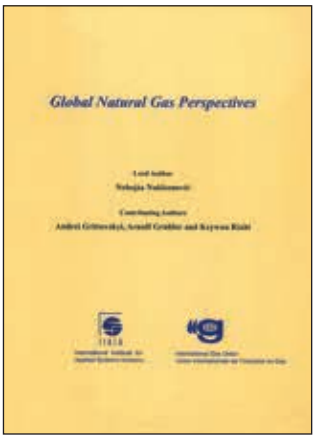


- Strategic Guidelines as approved by the IGU Executive Committee in Tatranska Lomnica on April 10, 2003, (4 pages)*.
- Triennial Work Programme as approved by the IGU Executive Committee in Cape Town on October 28, 2003, (59 pages)*.
- Summary of Triennial Work Programme, (14 pages).
- TWP 2003-2006 session on the 22nd World Gas Conference 2003, (DVD and video).
- Exhibition WGC 2006, leaflet introducing the World Gas Exhibition in Amsterdam, (3 pages).

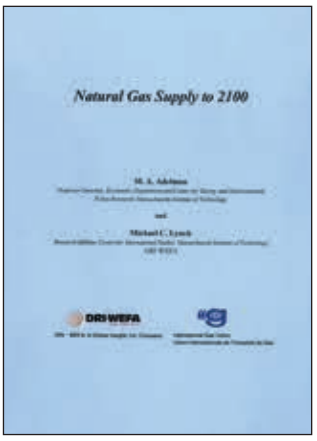
2000-2003 Programme

- Triennium 2000-2003, TCC Final report, IGU October 2003, (132 pages).
- Triennium 2000-2003, NOC Final report, IGU October 2003, (30 pages).
- 22nd World Gas Conference Tokyo 2003, (DVD).

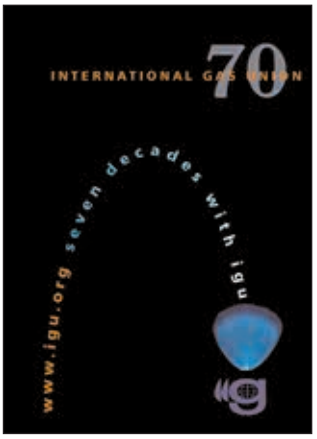
Scientific and technical papers and documentation



- Global Natural Gas Perspectives, Nebojša Nakićenović e.o., IIASA, IGU, October 2000 (71 pages 18 x 25.7cm). This booklet presents research based arguments as to how natural gas appears to be suited to provide a bridge from the current energy system to a new era of more environmentally sound energy systems.



- Natural Gas Supply to 2100, M. A. Adelman and Michael C. Lynch, DRI-WEFA, IGU, October 2002 (51 pages 18 x 25.7 cm). This booklet outlines the authors' assessment of a long-term supply curve for natural gas using recent estimates of costs and known reserves.

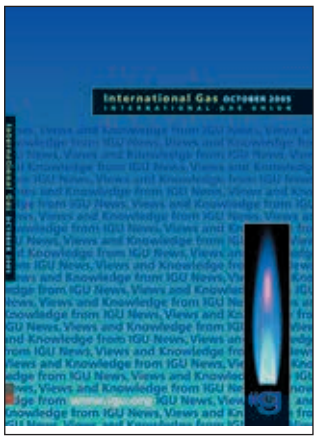


- Seven Decades with IGU, ISC 2003, (186 pages). IGU's 70th anniversary fell in 2001 and at the next World Gas Conference in 2003 this book was

launched containing articles on the organisation's history as well as on current and future issues facing the international gas industry.

- Proceedings of the 20th World Gas Conference, Copenhagen 1997, (CD Rom).
- Proceedings of the 21st World Gas Conference, Nice 2000, (CD Rom).
- Proceedings of the 22nd World Gas Conference, Tokyo 2003, (2 CD Roms).

- IGU Triennium 2000-2003 WOC 2 Basic activity study, Worldwide UGS Database, (CD Rom)**.
- International Gas, ISC October 2005 (152 pages). The fourth issue of the IGU Magazine.

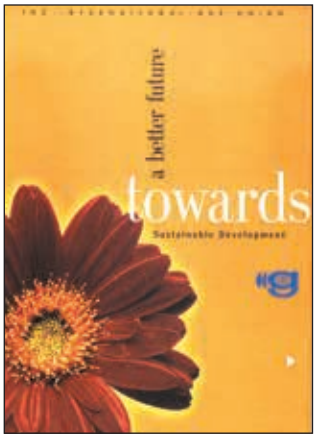


IGU organisational information

- IGU Articles of Association, as approved by the IGU Council September 18, 2002, (28 pages A5).
- IGU Guiding Principles for Sustainable Development, October 2003, (12 pages A5). This leaflet contains the recently updated and approved recommendations to IGU Members and the global gas industry regarding responsible behaviour in this context.

- News, Views and Knowledge on Gas – worldwide, (3 pages). This general brochure gives a concise introduction to the organisation together with its Vision and Mission.

- A Better Future Towards Sustainable Development, (5 pages). This brochure highlights IGU's position in promoting natural gas as a part of the solution to climate change.



- IGU Organisation Chart 2003-2006, (3 pages).

* Can also be downloaded from the IGU website

** Can also be downloaded from the IGU collaboration portal

The publications, brochures, DVDs and CD Roms can be ordered (as long as available) from:

The IGU Secretariat
P. O. Box 550
c/o DONG A/S
Agern Allé 24-26
DK-2970 Hørsholm
Denmark

Tel: +45 45 17 12 00
Fax: +45 45 17 19 00
E-mail: secr.igu@dong.dk
or from the Coordination Committee Secretariat

Energising Europe – RasGas Train 4

A little over a year ago RasGas Liquefied Natural Gas Company (II), RasGas (II), was proudly unveiling its third train and the many industry records that accompanied the world-class facility, now it's done it again.

Train 4, one of the largest LNG manufacturing facilities in the world, came onstream in late August 2005, and has again demonstrated the extraordinary teamwork, skill and efficiency at the various levels of design, construction and implementation at RasGas.

This latest major achievement began in 2001 when Italy's Edison and RasGas entered into a Sales and Purchase Agreement. Train 4, which will supply the European market with 4.0 million tonnes of LNG per year, has a total capacity of 4.7 million tonnes. The remaining capacity will serve spot sales markets. Like Train 3, its capacity is a 40% increase over Trains 1 and 2.

In fact, there are a lot of similarities between Trains 3 and 4, explains Doug Smith, RasGas Expansion Onshore Projects Manager. "This is the second train in the RasGas expansion project," Smith began, "and it benefits greatly from the replication of the Train 3 design, as well as from lessons learned during the development of Train 3."

The engineering, procurement and construction (EPC) contract for the onshore components of Train 4 was carried out by a joint venture of Japan's Chiyoda Corporation and Mitsui & Company, Italy's Snamprogetti and Al Mana Trading Company of Qatar. The same consortium carried out the work on Train 3.

"It was beneficial for us to use the same design and construction contractors for Train 4 for a number of reasons," explained Smith. "Train 3 was a great success and we were extremely pleased with the accomplishments that were achieved last year. Using the same design and construction contractors also allowed us to build Train 4 at significantly lower costs in terms of dollars per tonne of LNG produced. At its launch, Train 3 was considered the most cost-efficient train in operation. Train 4, however, has now become the benchmark: it is the most cost effective LNG train ever. Train 4 was also completed ahead of schedule in an industry-leading 33 months from EPC award."

Continuing, Deputy Venture Manager, Khoo Ching Thye, stated: "Another direct benefit to RasGas in utilising the services of the same EPC contractors is that the majority of the workforce working on Train 4 already had experience from Train 3. These are the people on the ground day to day; they are the ones that ensure that the work is conducted in a safe manner for everyone and that the project is completed on time and within budget. We achieved tremendous synergies through the overlapping design and construction of Trains 3 and 4, as well as Train 5 which is about 70% complete and will come on line next year. That said, the most important accomplishment has been the excellent safety record of these projects which benchmarks against the world's best."

But although there were many similarities between the trains, there remain distinct differences.

"Train 4 is the first application of acid gas injection for an LNG train," said Smith. "Acid gas is a waste product formed in the purification of gas used to make LNG. In most gas plants, this acid gas is refined into elemental sulphur. In Train 4 acid gas is injected into wells that are drilled deep below the earth's surface. This process minimises emissions to the atmosphere and also addresses environmental concerns over the stockpiling of elemental sulphur."

Train 4 is one of the largest LNG manufacturing facilities in the world with a total capacity of 4.7 million tonnes.

Train 4 also incorporates natural gas liquids (NGL) recovery and uses the nearby Al Khaleej gas project facilities to fractionate those liquids into their constituent products, i.e., propane, butane and condensate. Sending NGL, recovered from Train 4, to Al Khaleej means that RasGas will achieve greater economies of

scale and cost reduction. The result of this process is a "lean" LNG from Train 4. This LNG is a lower heating value product, more compatible with western markets than with Asian and Middle Eastern markets.

Commenting on the Train 4 Offshore EPC Contract, John McGettigan, RasGas Expansion Offshore Project Manager, advised that the wellhead platform WH5 for Train 4 is the first 12-well platform to be installed in the RasGas facilities.

It also involved the tie-in of the 28-inch intrafield pipeline into the operating 38-inch WH7 export pipeline. However, building on the lessons learned from the execution of the Train 3 (WH7) facilities and using the same contractor ensured that a seamless transition from construction through to start-up and commissioning was achieved. The ultimate capacity of the pipelines from WH7 and WH5 offshore facilities will be 2.0 billion standard cubic feet per day.

The contract for the platforms and pipelines was executed by J. Ray McDermott Eastern Hemisphere Ltd.

Different gas specifications

Trains 1, 2, and 3 were designed for eastern markets and therefore a "rich" LNG, with a higher heating value, is produced from those trains. But western markets have different gas specifications and must have heavier hydrocarbons removed such as the propane and butane.

Other major differences include the supply of cooling water (sea water) which is supplied through a common cooling water system built by Ras Laffan Industrial City. The system supplies about 25,000 cubic metres per hour to Train 4, and represents a strategic investment in the future since it can supply other users and plants in the city.

Train 4 is also linked to a power supply from Kharamaa in order to back up its own power system. Like past trains, Train 4 is self-generating but Kharamaa power is also used to run the acid gas injection units.

Despite all the technical and project accomplishments, Smith says RasGas is most pleased with its record of safety. Reiterating Khoo Ching Thye's earlier sentiments, Smith continued: "What we're proudest of with Train 4 is our safety record. Throughout the execution of the RasGas expansion project work, we expended 83 million man-hours onshore and offshore with a total recordable injury rate (TRIR) of 0.3. During peak construction of Train 4, we even had a span of 18.5 million hours without a lost time injury which is equivalent to about 7,000 people working full time for a year without any significant injury."

Train 4 was constructed with an excellent safety record.

On the offshore work, McGettigan emphasised how the combined efforts by all parties had made it possible to build on the Train 3 offshore safety record such that over 4 years and almost 6 million man-hours had been worked without a Lost Time Incident (LTI) by the time the Train 4 offshore facilities came on line and were producing.

Dave Marchak, Venture Manager, concluded: "We are extremely proud of our achievement in bringing Train 4 on stream with an industry-leading safety record as well as leading edge cost and schedule performance. The RasGas team together with our contractors deserve a tremendous amount of recognition for this record-setting performance. Nonetheless, there are even bigger challenges ahead; Train 5 is progressing on a schedule that is 3 months shorter than Train 4, plus Trains 6 and 7 will be 65% larger than Train 5. Through this, it's clear that RasGas remains focused on its vision; To be the Pacesetter." These are sentiments the whole company understands.

Natural Gas Businesses Contribute to South American Integration

A few years ago Petrobras decided to act as an integrated energy company by unfolding its activities to the whole value chain of natural gas up to electrical thermo power generation. This option to invest in the entire chain of a cleaner energy source, besides increasing its economic scale, also matches one of the main policies of the Global Compact Agreement, demonstrating how the Company is building its future perspective, chiefly to the neighbour countries, possible future endorsers of such policies.

This strategic perspective is driving the action of the Company beyond the borders, as a way to consolidate the position of Petrobras as a competitive and socially committed organisation, in Brazil and abroad.

Upon finding a match, both strategies are working as a propelling factor for energy integration in Latin America, as a very possible perspective considered in the Strategic Plan of Petrobras for 2006-2015.

The natural gas businesses and operations in the International Area of Petrobras in South America are underway for the energetic integration of the region, especially in the Southern Cone, which comprises Bolivia, Brazil and Argentina.

The role of Petrobras is highly relevant, chiefly because it is interconnecting the region through a network of 16,000 kilometres of pipeline routes in all three countries.

The international natural gas production of Petrobras in the Americas, both South and North America, reaches nearly 17 million cubic metres per day, 90% of which is extracted from production fields in Argentina and Bolivia. The gas is also produced and commercialised by Petrobras in four other countries – Venezuela, Peru, Colombia and territorial waters of the USA, in the Gulf of Mexico.

With a strategic commitment to regional integration, Petrobras is also working on the trade of natural gas among other countries in the Southern Cone. The International Gas and Energy area is aware of its role for the energetic development in the region, and as so, is working in new projects to enlarge the integration process.

In Argentina, the acquisition of the Grupo Perez Companc has allowed Petrobras to improve its performance as an integrated company, chiefly in the gas and energy sectors. Other potential application of capabilities development for Petrobras is related with the performance in the gas commercialisation activity. This is based on the experience of performance in a well developed and mature market, such as the Argentinean market. As an outcome, Petrobras has acquired the capability to better plan the strategies for the national and international scopes.

In Bolivia, the commercialised production of natural gas is almost reaching the whole contracted volumes exported to the Brazilian market nearly using the full volume capacity of the Bolivia-Brazil pipeline (Gasbol). The final utilisation of this fuel in the industries, commercial activities, thermo-electrical generation and motor vehicles, for example, is largely contributing to the reduction of the atmospheric emissions in the great urban centres of our country.

This environmental benefit probably will be more expressive when the pipeline reaches, still in this year of 2006, the top level of transport capacity of 30 million cubic metres per day, according to the specifics of the original project.

Petrobras also has a joint ownership in the two largest gas production fields in Bolivia, blocks of San Alberto and San Antonio, becoming, in short term, the wider Company established in this Andean country. When arriving in the year of 2015 Petrobras will be a truly integrated energy company with strong international presence and a leader in Latin America, working focused in the fundamental values in the areas of human rights, labour relations, social and environmental responsibility.

Fuelling the Future

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IGU Events and IGU-related Events 2006-2009

May 1-2
IGM 97th Session
Opatija, Croatia

May 15-16
5th ERRA Regulation Conference
Budapest, Hungary

June 5
IGU Council Meeting
Amsterdam, The Netherlands

June 5-9
23rd World Gas Conference
Amsterdam, The Netherlands

September 1-3
GASEX 2006 Conference and Exhibition
Beijing, China

September 29-30
IGM 98th Session
Budapest, Hungary

October 8-11
3rd World Forum on Energy Regulation
Washington DC, USA

October (dates to be confirmed)
IGU Council Meeting
Lima, Peru

November 7-9
10th International Conference and Exhibition on NGVs
Cairo, Egypt

2007

April 24-27
LNG-15
Barcelona, Spain

May 3-5
IGU Executive Committee
Vevey, Switzerland

October (dates and venue to be confirmed)
IGU Council Meeting
Russia

November 9-15
World Energy Congress (WEC 2007)
Rome, Italy

2008

March 26-28
IGU Executive Committee
Port of Spain, Trinidad and Tobago

June 29-July 3
World Petroleum Congress (WPC 2008)
Madrid, Spain

2009

October 19-23
24th World Gas Conference
Buenos Aires, Argentina

You can find links to many of the above events by visiting www.igu.org and clicking on "Events". Under "Energy-related Events" in the drop-down menu you can also find a link to the WEC Events Calendar displaying a multitude of energy-related events.

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A Record Council Meeting in Tianjin, China: China City Gas Society.

Information from Organisations Affiliated to IGU: Gas Natural.

Final Countdown to the 23rd World Gas Conference: RAI Congress and Exhibition Centre (42), KVGN (43).

Progress Report: Marc Roussel/Total (54), IGU (55), WPC (63), Snøhvit LNG (64), Korea Gas Union (69).

The Foundation and Early Years of IGU: Mary Evans Picture Library (84), Institution of Gas Engineers and Managers (92/3), Swiss Gas and Water Industry Association (92 lower),

Let There Be Light: Mary Evans Picture Library (96 & 97), National Gas Museum Trust (98, 99 & 102), City of Sydney Archives (100 upper), Elena Christodoulou (100 lower), www.gashistory.org (104 upper), Linda Hall Library (104 lower).

The Dutch Natural Gas System: Gasunie (106, 108 & 109), NAM (107).

Gas in Japan: Japan Gas Association (112 & 113 upper), Saibu Gas Co. Ltd (113 lower).

What Will the Gas Market Look Like in 25 Years?: ExxonMobil (118 left), Shell Photographic Services, Shell International Limited (118 centre & 128), Chevron (118 right), Leif Höegh & Co. (119 upper), BP plc (119 lower), Gas Natural (120), Northern Plains Resource Council (122), EMPICS/AP Photo/Gautam Singh (124 upper), Centrica plc (124 lower), Norsk Hydro (126), Barry Lewis/BG Group plc (130).

The Quest for Energy Independence, Globalisation of US Gas Supplies and Renaissance of LNG: US Coast Guard photo by PA3 Donnie Brzuska (134), Pennsylvania Historical & Museum Commission, Drake Well Museum, Titusville, PA, USA (139), Excelerate Energy LLC (142), Shell US Gas & Power LLC (144), Howie Garber/www.wanderlustimages.com (150).

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WOC 2 Gets Ready to Present its Findings: Gazprom.

Distributed Energy Resources: Technologies and Business Perspectives: Erik C. Pendzich/Rex Features (172), Northwest Natural Co. (173), DaimlerChrysler (177), BP plc (178), DONG A/S (180).

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has been recognized by BusinessWeek, the US leading business and financial publication, as The Asian Top Performer. This achievement together with many other awards received throughout the year can be attributed to PTT's managerial ability and its vision to be the Thai Premier Multi National Company.

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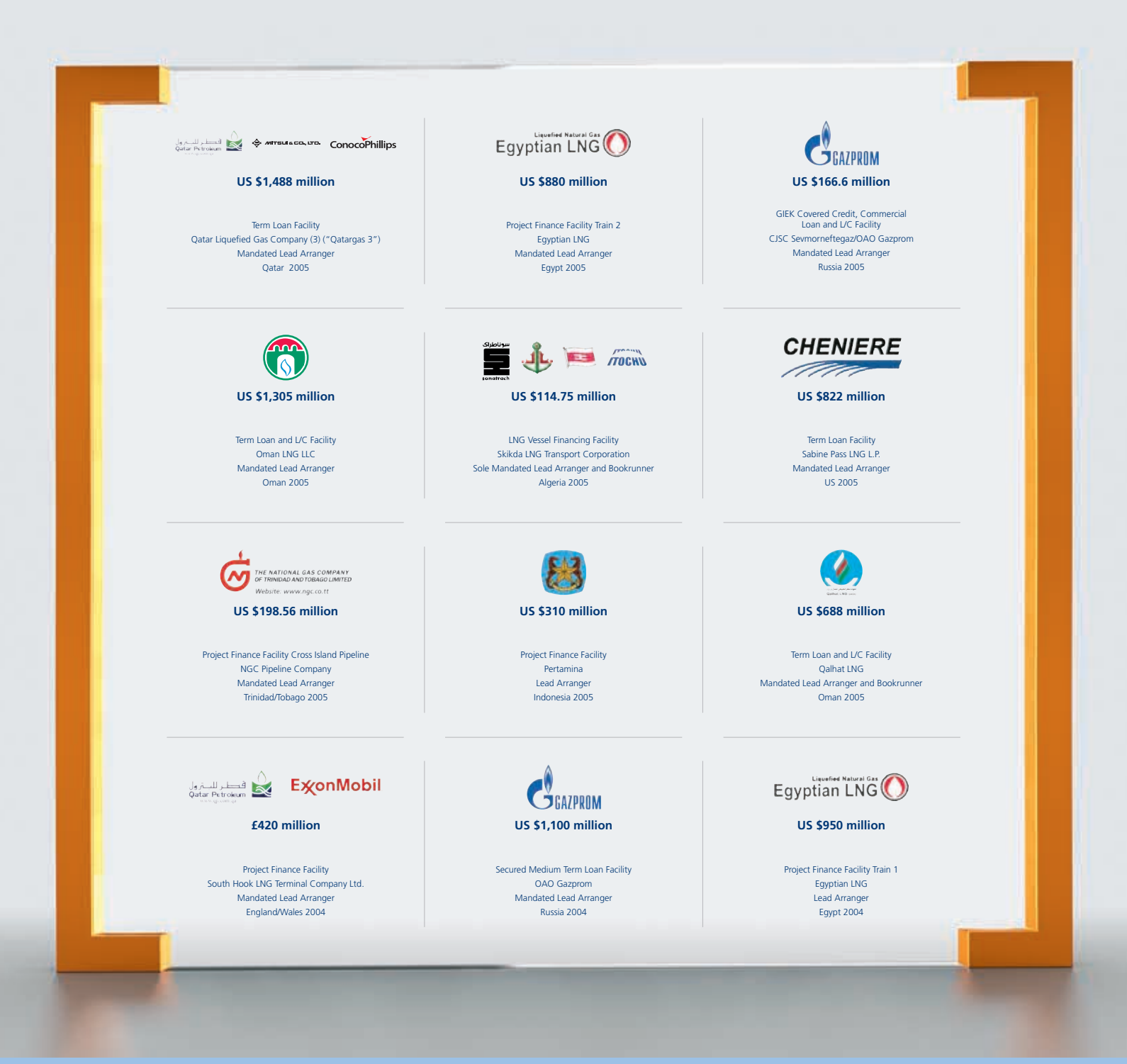

US $1,488 million

Term Loan Facility
Qatar Liquefied Gas Company (3) ("Qatargas 3")
Mandated Lead Arranger
Qatar 2005

US $880 million

Project Finance Facility Train 2
Egyptian LNG
Mandated Lead Arranger
Egypt 2005

US $166.6 million

GIEK Covered Credit, Commercial Loan and L/C Facility
CJSC Sevmorneftegaz/OAO Gazprom
Mandated Lead Arranger
Russia 2005

US $1,305 million

Term Loan and L/C Facility
Oman LNG LLC
Mandated Lead Arranger
Oman 2005

US $114.75 million

LNG Vessel Financing Facility
Skikda LNG Transport Corporation
Sole Mandated Lead Arranger and Bookrunner
Algeria 2005

US $822 million

Term Loan Facility
Sabine Pass LNG L.P.
Mandated Lead Arranger
US 2005

US $198.56 million

Project Finance Facility Cross Island Pipeline
NGC Pipeline Company
Mandated Lead Arranger
Trinidad/Tobago 2005

US $310 million

Project Finance Facility
Pertamina
Lead Arranger
Indonesia 2005

US $688 million

Term Loan and L/C Facility
Qalhat LNG
Mandated Lead Arranger and Bookrunner
Oman 2005

£420 million

Project Finance Facility
South Hook LNG Terminal Company Ltd.
Mandated Lead Arranger
England/Wales 2004

US $1,100 million

Secured Medium Term Loan Facility
OAO Gazprom
Mandated Lead Arranger
Russia 2004

US $950 million

Project Finance Facility Train 1
Egyptian LNG
Lead Arranger
Egypt 2004

Success through partnership

Our Natural Resources Sector teams have established a strong track record globally in the financing of the natural gas industry particularly the LNG chain including upstream, pipelines, liquefaction, shipping and regasification. Let us apply this expertise to your gas project financing needs. For more information please contact Michael Klemme +31 20 563 5509, Richard Ennis +1 646 424 6000 or Bert van der Toorn +65 6232 6145.

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