Small is beautiful – Mini LNG concept

Paper

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The MiniLNG concept

Biogas is gaining more and more attention world wide in the struggle to achieve more sustainable energy supply. The EU has a target to use 10% bio fuel within 2020. Biogas will probably play an important role to meet this target. Biogas can be produced from a variety of products, starting with energy crops to manure, and of course any other form of waste we spent in our daily lives.

With biogas becoming such an important and marketable commodity, producers would like to recover and convert it to CNG or LNG in order to meet the growing demand.

As a way to meet these demands there is a growing interest in small scale LNG process and plant solutions to help solve the challenges mentioned above from a number of countries on almost all continents. Production capacities of small scale LNG plants vary in the range from 2000 up to 500 000 tons of LNG per year. By comparison, a typical large scale plant has a production capacity of between 2.5 and 7.5 million tons of LNG per year.

Hamworthy has a designed a containerized MiniLNG plant with specialized pre-treatment and liquefaction technologies optimized for low pressure gases with high contaminants content. SINTEF's LNG liquefaction technology for MiniLNG plants with a capacity up to about 6000 tons per year is the chosen solution for these plants, utilising refrigeration cycle with mixed refrigerant for low energy demand. The plant concept is to use standard equipment for low investment cost and fast manufacture of the liquefaction unit. The plant is integrated into a standard 40" ISO container, manufactured at an assembly site, then easily shipped and installed at the chosen location.

Beyond biogas, the MiniLNG Plant seems to be particularly interesting for the recovery of waste gases from various organic processes (biogas), including coal bed and coal mine methane recovery. A successful development in this area is also depending on the application of a suitable gas pre-treatment technology.

Again, on the supply side, biogas, flare gas, landfill, coal bed methane, or even flare gas reserves are abundant but had not been economical viable in recent years. Turning these reserves of gas into value-added liquid fuels seem to be both economically feasible and very attractive for an environmental stand point. The MiniLNG concept may play a vital role in terms of energy provision, minimizing ecological footprints, reducing greenhouse gas emissions, and creating new markets for the use of such gases.
The essence of the MiniLNG concept is a sound combination of pre-treatment and liquefaction. Minimizing methane losses and thus producing a maximum possible amount of LNG, Hamworthy, together with others, is able to handle gas sources over a wide span of impurities with new and innovative techniques.

The economical challenge

Talking MiniLNG, Hamworthy sees market opportunities producing LNG in the range of 1 – 15 tonnes per day (1 000 – 15 000 kg/day). By comparison, Hamworthy's small scale LNG activities cover the range from 50 000 to 1 400 000 kg/day. Generally, efficiency is reduced and cost increases when the production rate per day of the plant decreases. Regardless of its contribution to the environment, operating the MiniLNG using standard off-the-shelf equipment plants at high efficiency and keeping the process as simple as possible to reduce investment costs are essential factors. The plant design is therefore standardized, containerized and set for mass production in a relatively low cost country to make it as attractive as possible economically.
Achieving high efficient and low cost liquefaction systems for the MiniLNG plants in the future, Hamworthy is using a liquefaction concept developed by SINTEF. Figure 1 and Figure 2 /1/ illustrate how the concept principally can be compared to other known concepts regarding cost and energy efficiency.

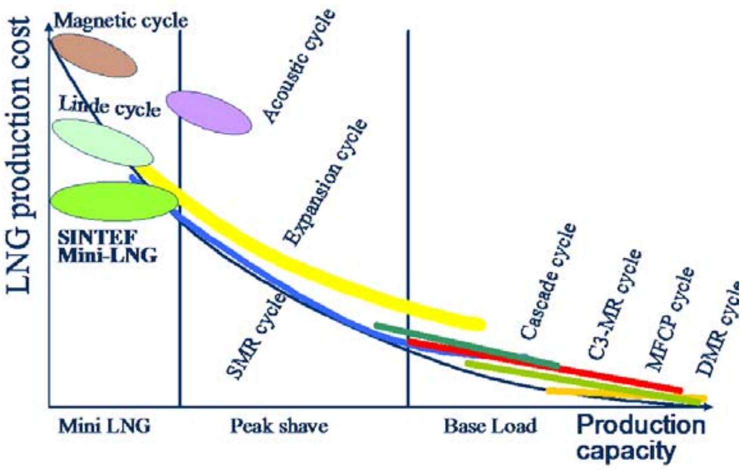

Figure 1: LNG cost challenge

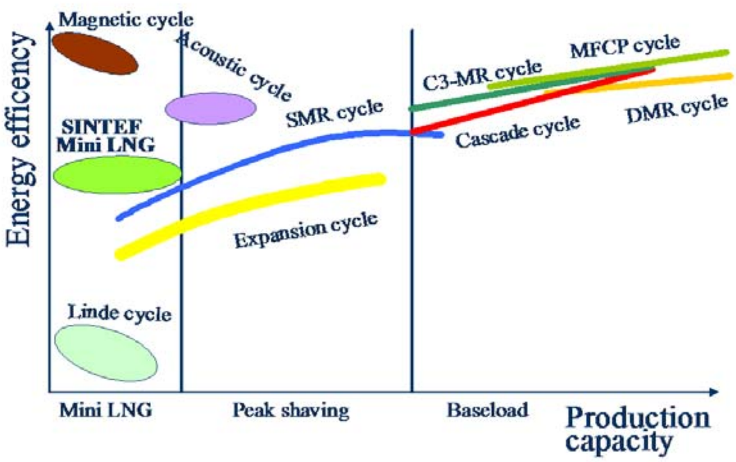

Figure 2: LNG efficiency challenge

The pre-treatment challenge

The large variety of gas sources that the the MiniLNG plant is able to cover, is offering world-wide opportunities but, nevertheless, creates a real pre-treatment challenge upfront of the liquefaction process, which finally produces the LNG. Figure 3 shows a pre-treatment matrix, covering various low-pressure, high-impurity gas sources and the necessary pre-treatment methods. For comparison, high-pressure pipeline gas is included. In order to meet the given, general, requirements in order to produce successfully LNG, several impurity criteria need to be reached. Water and carbon dioxide, hydrogen sulphide and siloxanes must be removed and a variety of technologies can be provided to take them out to the required level. Nitrogen and oxygen, if found in the gas source, need to be removed as well. Therefore, Figure 3 shows also the level of complexity by adding up more impurities to the gas source. LNG plants with very low capacity output and rising complexity requires innovative, reliable, and medium-cost pre-treatment technologies. The MiniLNG plant pre-treatment approach, like small-scale LNG and base load LNG plants, is based on adsorption and absorption technologies.

Feed Gas	Pipeline	Coal mine methane	Biogas	Landfill	Flare gas
Pressure	high	low	low	low	low
Impurities	low	high	high	high	high
Bulk H2O	/	/	/	KO Drum	
H2S, Aromatics		Adsorption	Absorption	Adsorption	Adsorption
Siloxanes	Adsorption	/	/	Adsorption	/
MEG/TEG		/	/	/	/
Hg		/	/	/	/
Ammonia		/	/	/	/
H2O		Adsorption	Adsorption	Adsorption	Adsorption
CO2	Absorption/ Absorption	Absorption	Absorption	Adsorption	Absorption
O2/N2	/	Adsorption	/	Adsorption	Adsorption

Removal prior to liquefaction

Liquefaction with heavy hydrocarbon separation (C2 - C23+)

General Requirements	
H2S	4 ppm
Hg	< 10 ng/Nm3
H2O	1 ppm
CO2	50 ppm
O2	< 1 mole%
N2	< 3 mole%
BTX	< 2 ppm
Halogens	< 2 ppm
Aromatics	< 2 ppm
Ammonia	< 2 ppm
C3H8	< 6 mole%
C2H6	< 2 mole%
CH4	**> 90 mole%**

LNG

Hamworthy

Figure 3: Pre-treatment matrix

The engineering challenge

Liquefaction of natural gas in Hamworthy's small-scale applications is currently done by using the Brayton nitrogen cycle of compressing and expanding nitrogen to create a sufficiently low temperature, and securing a robust and reliable service. The unique characteristics of mixed refrigerants, on the other hand, have enhanced conventional refrigerant cycles for natural gas liquefaction. Normally, they have been used in base load LNG applications; because mixed refrigerants permit large temperature changes that occur in boiling and condensing phase transitions, see also Figure 4. The indicated blue area between the two curves, natural gas vs. mixed refrigerant is the loss in exergy. Using mixed component refrigerants, the MiniLNG concept is following the same thermodynamics, thus minimizing any exergy loss is paramount to keep the efficiency up.

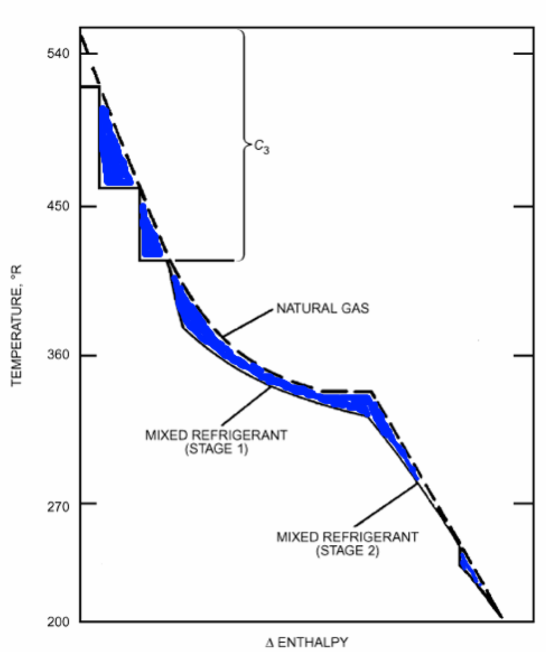

Figure 4: Base load natural gas liquefaction using mixed refrigerants and propane pre-cooling; Temperature-Enthalpy diagram. Source: ASHRAE Refrigerant Handbook 2002

In the MiniLNG plants, Hamworthy includes an oil-flooded screw compressor, after-cooler, off-the-shelf heat exchangers, and expansion valves to the liquefaction system, enabling the creation of multiple phase-changes within the heat exchangers; ultimately resulting in descending temperature of the mixture which condensates the feed gas and produces LNG. For a non-disruptive production of LNG the MiniLNG plants will be powered by a gas engine with feed gas or regeneration gas, or both.

The main components for the liquefaction part are copper brazed heat exchangers and an oil-flooded screw compressor. Also, cryogenic valves, vessels and necessary tubing are required. Since standard refrigerant components are relatively low in cost and short in delivery time, the used technology offers potential for reduced capital expenditure over other conventional liquefaction system.

In the MiniLNG system the mixed refrigerant is repeatedly compressed, sub-cooled, condensed, vaporized, separated, and expanded. As a result, the circulation process requires a sophisticated design approach and more complete knowledge of gaseous mixture than expander or cascade process cycles.

Again, exergy losses are reduced to a minimum by optimising the refrigerant composition to the boundary conditions. The gas composition, pressure and temperature will have to be considered. This enables small temperature differences in the heat exchangers by utilising the temperature glides of the two streams, even with a relatively simple system layout. A relatively energy efficient concept is thereby obtained without using more sophisticated system layouts as for large scale plants, cascade systems or gas processes requiring at least one expander.

Using a standard lubricated compressor introduces the need of a good lubricant handling system. Even smaller amounts of lubricant brought down to the lowest temperatures may cause clogging of the heat exchangers and smaller flow channels in other components. The concept ensures all lubricant to be kept at the higher temperature levels.

The cooling down process – functionality

Figure 5 shows a flow sheet of the concept as described by Brendeng and Neraas /2,3/ In the cold-box, two parallel rows of heat exchangers are used. This is required since plate heat exchangers only enable two parallel flows. With two hot streams to be cooled by the cold low pressure refrigerant, namely the natural gas to be liquefied and the high pressure refrigerant, it is not possible to perform this with only one plate heat exchanger.

The heat exchangers are connected in series counter flow in the two rows, for respectively the hot and cold streams, in order to utilize the temperature glides of the two streams to achieve a lowest possible temperature difference.

The flow sheet of the system can be briefly described as follows:

a) The refrigerant is compressed in the *COMPRESSOR*.
b) After lubricant separation the refrigerant is sub-cooled and partly condensed by the *COOLANT HX* by heat exchange with an external heat sink.
c) In *VC1* vapour and liquid are separated. The vapour will have a larger fraction of the more volatile components, while the liquid contains the less volatile.
d) The liquid is throttled to lower pressure and used as refrigerant in the upper heat exchanger pair *(REF HX3/LNGHX1)* together with the low pressure refrigerant coming from the heat exchanger pairs at the lower temperature levels.
e) Natural gas (NG) entering with a temperature close to ambient is de-superheated in *LNG HX1*.
f) The high pressure refrigerant vapour from *VC1* is cooled and partly condensed in *REF HX3*.
g) Vapour and liquid is then separated in *VC2*.
h) Liquid is throttled to lower pressure and used as refrigerant in the middle pair of heat exchangers *(REF HX2/LNG HX2)* together with the low pressure refrigerant coming from the heat exchanger pair at the lowest temperature level.
i) NG is condensed in *LNG HX2*, while the vapour from *VC2* is condensed in *REF HX2*.
j) This refrigerant flow is further sub-cooled in *REF HX1*, before it, after being throttled to even lower pressure, is used as refrigerant in the pair of heat exchangers at the lowest temperature level.
k) NG is finally sub-cooled in *LNG HX3*, before it is throttled to LNG temperature of below minus 160 degrees centigrade and storage tank pressure.
l) Suction gas to the compressor is low pressure superheated vapour leaving the upper pair of heat exchangers (*REF HX3* /*LNG HX1*).

The cooling down process - features

The low pressure refrigerant will have different composition in the different pair of heat exchangers and thereby achieving the desired small temperature difference between the cold evaporating refrigerant and the hot streams.

The pressure energy released during the throttling of the liquid from *VC2* is utilised in an ejector to achieve a pressure lift of the refrigerant coming from the lowest pair of heat exchangers. The low pressure refrigerant is mixed and split between each pair of heat exchangers. The refrigerant leaving the upper pair of heat exchangers is slightly superheated.

The concept makes it possible to have a robust lubricant management system without special measures. Small traces of lubricant from the lubricant separator after the compression will end up in the liquid of the first separator, *VC1*, and after throttling to low pressure, being carried back to the compressor without being transported down to the lowest temperature parts of the system.

Typical constraints of the process will be pressure limitations of the heat exchangers and the compressor and component size limitations. Available lubricated screw compressors today give a maximum operational pressure of 25 bara at the refrigerant side. The maximum design operating pressures for the available copper brazed plate heat exchangers is typically 31 bara or 50 bara.

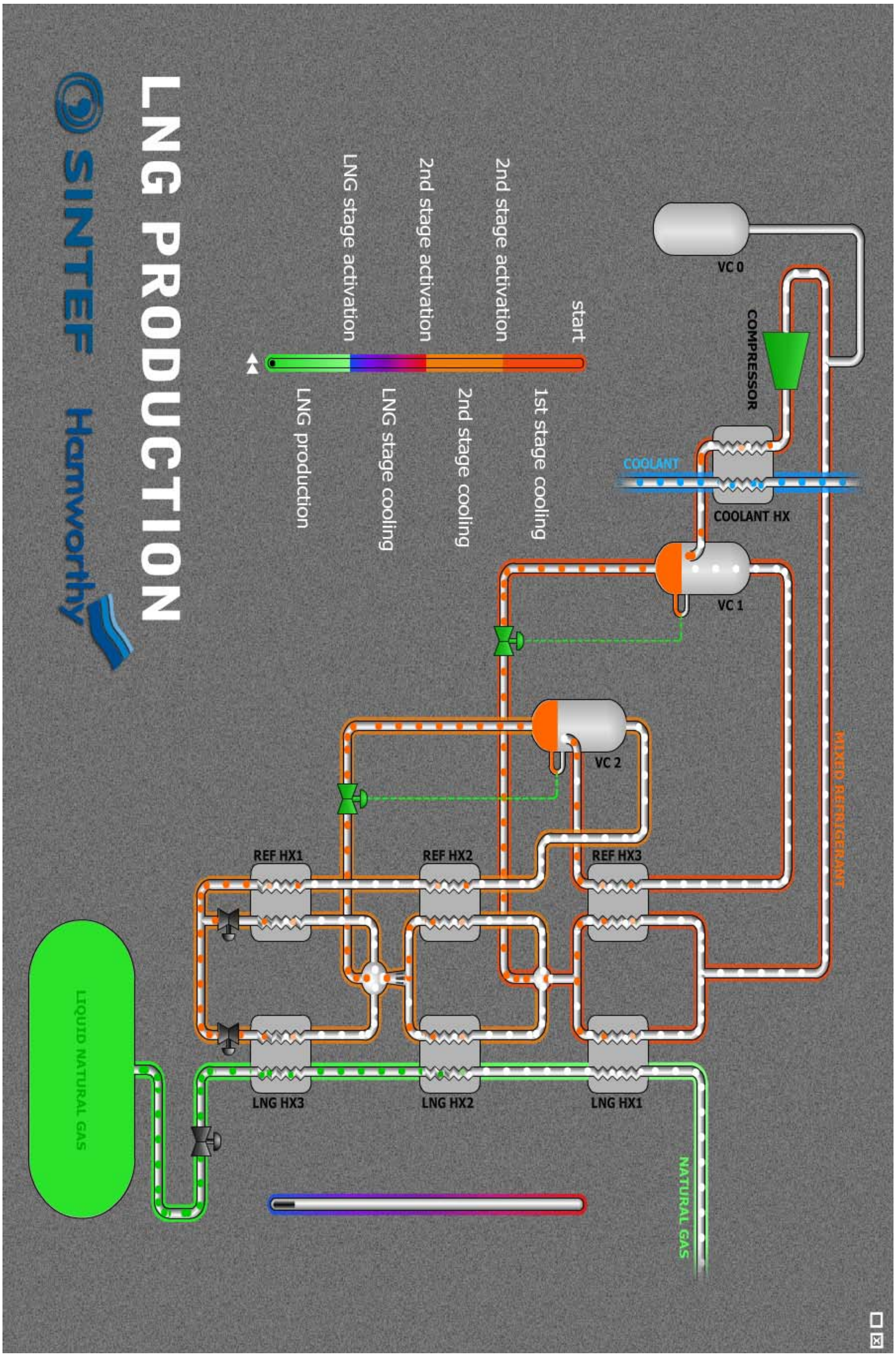

Figure 5: Flow sheet MiniLNG - Liquefaction

The cooling down process – operation

The specific energy consumption and specific volume requirement of the compressor for the process will depend on a variety of parameters, feed gas composition and the boundary conditions applied. For an ambient temperature of 30°C, LNG temperature before throttling -150°C and feed gas pressure set to 50 bara, a specific energy consumption for a one-stage system of about 0.6 – 0.9 kWh/kg LNG can be obtained. Specific compressor swept volume requirement may be about 2 m^3/kg LNG. Using a two stage compression concept for the mixed refrigerant circuit will reduce the energy consumption further, but with an increased system cost and complexity.

The SINTEF laboratory prototype

A laboratory prototype liquefaction plant with a production capacity of 1 tonne LNG per day has been built in SINTEF's laboratory (Figure 6). Natural gas is circulating in a closed loop. This enables investigation of liquefaction with different natural gas compositions.

The plant is fully instrumented to be able to monitor all relevant parameters and compare them to theoretical results from the simulation model. Refrigerant and natural gas mass flow, refrigerant composition in different parts of the system, temperatures and pressures at various locations and power input, is examples of measured parameters. This enables calculation of i.e. specific power consumption of the plant.

The plant has been in operation since 2003. Until now more than 10 000 hours of operation and more than 100 successful start and stops has been performed with success. A period of more than 500 hours continuous operation has also been performed in order to verify that the lubricant management concept is working successfully.

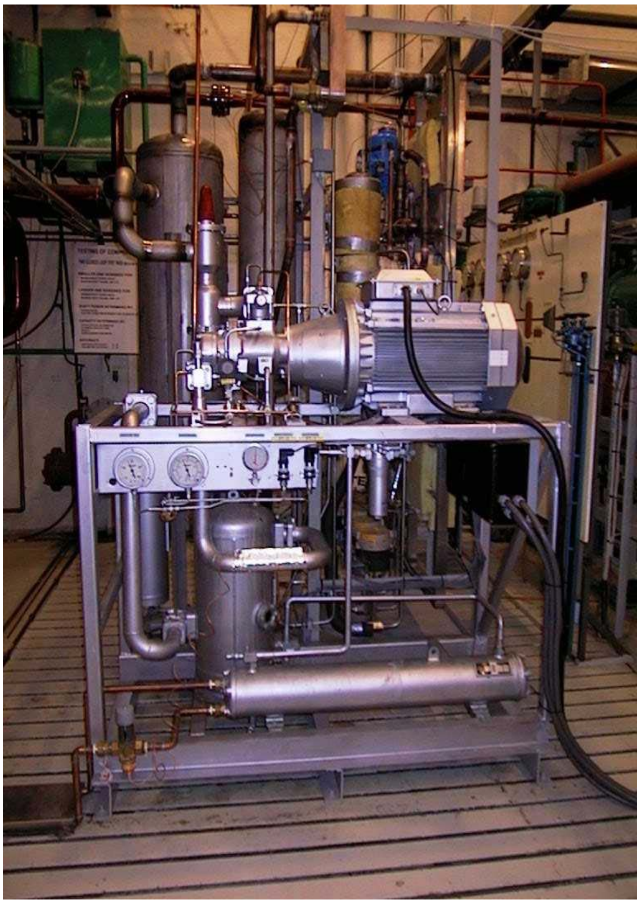

Figure 6: Laboratory plant during erection. Liquefaction capacity 1 tonne LNG/day; Photo: SINTEF

The concept ensures that lubricant not captured in the lubricant separator after the compressor is actually trapped in the liquid of the first separator. This refrigerant liquid is throttled to low pressure and used for refrigeration in the upper pair of heat exchangers, always at relatively moderate to high temperatures.

Figure 7 shows an example of measured mass flow and natural gas temperature at start-up. The natural gas temperature at start-up from stand still conditions is 20°C, measured before the throttling to storage pressure. 15 minutes after start-up, cool down starts and pull-down to full capacity production is achieved after another 15 minutes, with an LNG temperature of about -140°C.

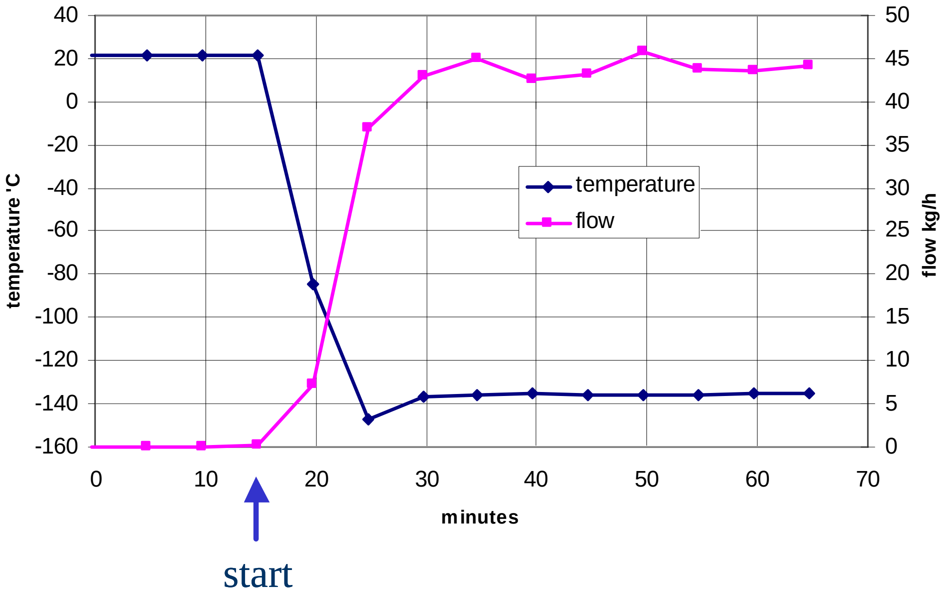

Figure 7: Laboratory plant measurements of LNG mass flow and temperature before throttling to storage during plant start-up from stand-still conditions. Source: SINTEF

Experience and technology drive

Hamworthy's first small scale LNG liquefaction plant with a capacity of 20 000 tons per year has been in operation successfully for almost 5 years. This was the first plant of its kind in Norway and the buyer, Gasnor, followed up with an additional order from Hamworthy for a plant with 4 times the capacity. The larger plant, at Kollsnes outside Bergen in Norway, went into operation in August 2007.

Applications where Hamworthy's small scale LNG solutions can be used are in:

- Peak shaving plants have been in operation for many years. Natural gas is liquefied and stored as LNG in tanks. In periods with high demand, LNG is regasified and distributed in the pipeline grid.
- Satellite distribution of gas to customers due to lack of infrastructure/pipelines. Customers may be in remote locations where a pipeline distribution is not available or too expensive to build.
- Small gas reserves can be utilized e.g. associated gas from oil production, small gas fields, land fill gas, etc.
- LNG as fuel to small local power plants, local industry or vehicles and ships.
- Flare gas recovery from single or multiple oil wells using a gathering system
- Coal Bed Methane recovery from coal resources prior to exploitation of the coal reserves
- Landfill gas or biogas production with no outlook for pipeline distribution, the demand is dispersed and small, and the incentives for to local government

As far as the MiniLNG system is concerned, this technology seems to be particularly interesting for the recovery of waste gases from various organic processes (biogas) and coal bed methane recovery. A successful development in this area is also depending on the application of a suitable gas pre-treatment technology.

The production of LNG, using the MiniLNG concept is arguably a higher value product than on-site produced electricity or even CNG. The unique combination of proprietary and off-the-shelf system components can transform any low value gas into high value LNG without incurring excessive capital and operating costs.

Again, turning gases into value-added liquid fuels seems to be both economically feasible and very attractive from an environmental stand point. The MiniLNG concept may play a vital role in terms of energy provision, minimizing ecological footprints, reducing greenhouse gas emissions, and creating new markets for the use of such gases. Therefore, small or even smaller seems beautiful to our clients.

Sources:

/1/ Paper: Small scale LNG liquefaction plants; Nekså P. and Brendeng E.; SINTEF Energy Research, Trondheim – Norway; presented at *22nd IIR International Congress of Refrigeration, Beijing, China, August 21 – 26, 2007*

/2/ Brendeng, E. and Neeraas, B.O. (2000): *Fremgangsmåte og anlegg for flytendegjøring av gass,* Norwegian patent no. 312736, priority date 2000-02-10

/3/ Brendeng E. and Neeraas, B.O. (2006): *Method and device for small scale liquefaction of product gas*, EPO patent no. 1255955