TECHNICAL SPECIFICATION

StirLNG-4
Stirling Cryogenics gas liquefier for LNG production

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Stirling Cryogenics is a registered trade name of DH Industries BV
For more information on the Stirling Cryogenics product range, please contact:
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1. INTRODUCTION

Since more than sixty years Stirling Cryogenics has designed and manufactured gas liquefaction system, serving customers all over the world under all possible climatic conditions. This experience is used for our methane liquefiers called StirLNG. These have 3 specific fields of application:

- Production of LNG from a purified gas source such as pipe line or biogas to make it suitable for transport and/or to use it as fuel.
- Re-liquefaction of boil off gas to compensate for losses in a cryogenic (storage) system (fuel stations, storage tanks, etc.).
- Re-liquefaction of boil-off gas on vessels. The StirLNG-4 is available in an adapted version specifically for maritime use.

In this technical specification for the StirLNG-4 you will find all technical information for this system and the different optional sub-systems to integrate the StirLNG-4 into the total system.

We trust that this information demonstrates that our system will be a valuable asset in meeting your methane liquefaction demand.

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2. WORKING OF THE STIRLNG

2.1 Creation of cooling power

Creation of cooling power by the StirLNG-4 is done by the so called reversed Stirling cycle which is based on the compression and expansion of helium gas in a closed cycle. The Stirling cycle efficiently produces cooling power at cryogenic temperatures by input of shaft power from an electric motor.
For more detailed information on this creation of cooling power we refer to our leaflet "The Stirling Cycle" which is available on our website.

2.2 Cooling power to LNG

One main advantage of the StirLNG-4 is that the gas to be liquefied is not part of the cycle to create the cold. The gas will just flow through a cold heat exchanger in the StirLNG-4, where energy is extracted so the gas will cool down and then condensate against the cold surface.
This is a phase change at saturated equilibrium so there is no pressure change.

The (re-) liquefaction capacity of the StirLNG-4 depends on the specific process conditions. Main parameters are the gas inlet temperature, gas inlet pressure and gas composition.
The influence of gas inlet temperature is obvious: with lower inlet gas temperature, the StirLNG-4 needs to extract less energy and the liquefaction rate increases.

The influence of pressure is more complicated. The pressure of the gas determines the liquefaction temperature. At higher pressure the liquefaction temperature goes up. Higher liquefaction temperature results in a higher production rate, due to 2 reasons:

- First, less energy needs to be extracted to reach liquefaction temperature.
- Secondly, at higher temperatures the Stirling Cycle will generate more cooling power, while also using less input power.

Please refer to Appendix 2, for the production rate as function of pressure to determine the exact capacity.

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3. SYSTEM BACKGROUND

In this chapter different ways to integrate (by e.g. the System Integrator) the StirLNG-4 into a total system are discussed. In the schematics only one StirLNG-4 is shown, but these can be multiple units to match the required liquefaction capacity.

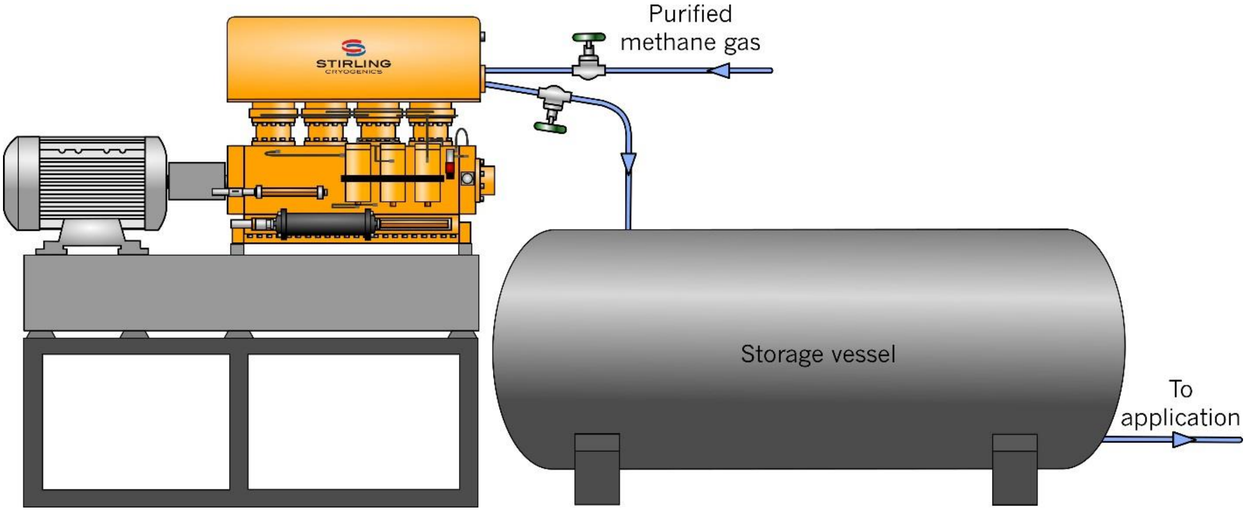
The StirLNG-4 needs to be installed in a housing to protect it from ambient environment. This can be a simple shed or a container in which several StirLNG-4 can be placed.

The LNG storage vessel size is determined by the actual use of the LNG. A larger LNG production will need a larger storage vessel, but also the distribution frequency (demand for LNG) is of influence. When the LNG is distributed only a few times per week, the LNG storage vessel needs to be larger than when this is several times per day (sizing of the storage vessel to be determined by the System Integrator).

The LNG produced by the StirLNG-4 flows out downwards by gravity, meaning it is required to be placed above the LNG (storage) vessel. The configuration of the total system will ultimately determine the final location of the StirLNG-4.

3.1 Liquefaction directly into the main storage

The purified methane gas is fed from the customer’s gas source to the StirLNG-4.
The most easy approach is to locate the StirLNG-4 above the main storage vessel so the liquid can flow into the storage vessel directly by gravity (see Drawing 1). This configuration is limited by the height of the main storage vessel. When location of the StirLNG-4 above the storage vessel is not possible, we refer to paragraph 3.2.



Drawing 1, Production of LNG directly into the storage vessel.

Direct liquefaction can be a continuous process. A control system will monitor the storage vessel liquid level and stops the StirLNG-4 when the storage vessel reaches a pre-set level.

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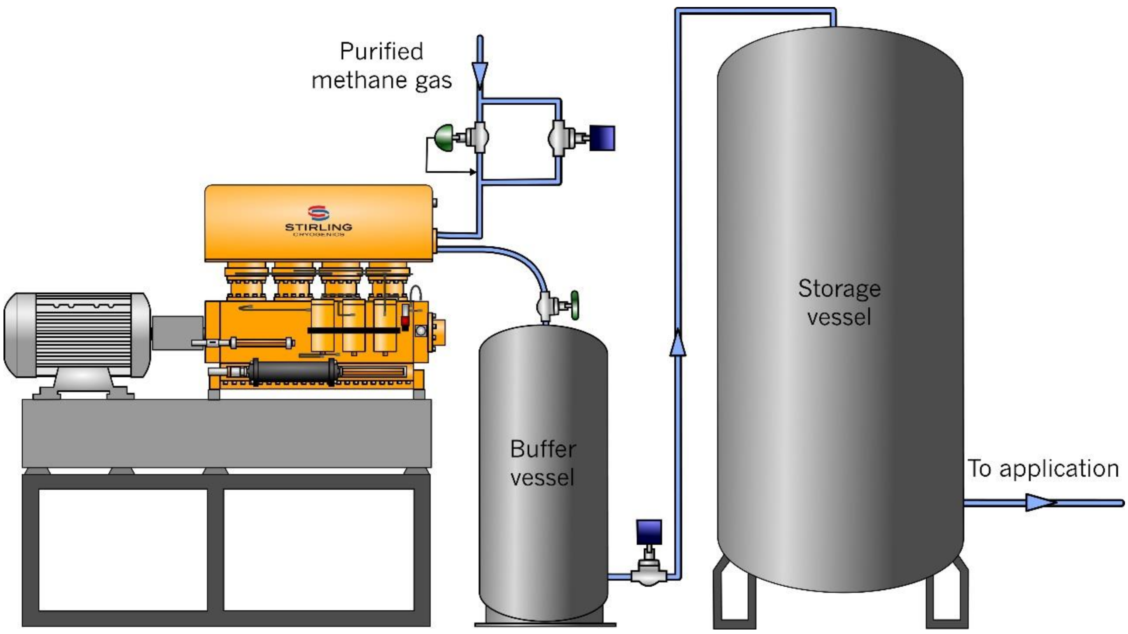
3.2 Through transfer vessel

When the StirLNG-4 cannot be located above the storage vessel, a separate transfer (buffer) vessel is required (see Drawing 2). This transfer vessel can be small in size and is only intended to store a limited amount of liquid (approx. 200-500 liters). Transferring liquid from the transfer vessel to the storage vessel (batch wise) operates in the following way:

The feed gas pressure produced by the gas purification system will - in general - be higher than the final required pressure in the main storage vessel. Therefore this pressure needs to be reduced to allow the StirLNG-4 to produce the LNG at this final pressure and temperature.

When the transfer vessel is full, a by-pass valve is opened to pressurize the liquid using the available feed gas pressure. Another (cryogenic) valve in the (bottom) connection to the storage vessel is opened so the feed gas pressure will push out the liquid into the main storage vessel. In the meantime, the StirLNG-4 will remain in full production mode. When the transfer vessel is almost empty, both valves are closed and the transfer vessel will fill up again. This cycle repeats until the storage vessel is full (at pre-set level). A control system will monitor the storage vessel liquid level and stops the StirLNG-4 when the storage vessel reaches the pre-set level.

The extra transfer vessel, valves and piping will influence the net liquefaction capacity of the total system set-up (these specific capacity losses to be determined by the System Integrator).



Drawing 2, Production of LNG through a transfer vessel.

4. TECHNICAL SPECIFICATIONS

This technical specification below describes the functionality for the StirLNG-4 only. Other system components such as vessels, valves, piping and pumps are to be designed and supplied by the system integrator. These components will influence the final net production capacity of LNG of the system since these will create losses and consume a part of the liquefaction capacity available from the StirLNG-4.

4.1 Functional specifications StirLNG-4

Methane liquefaction rate	Depending process conditions, refer to the graph Appendix 2
Power consumption	Depending process conditions, refer to the graph Appendix 2
Maximum gas pressure	20 bar(g)
Electricity supply	3 Phase 400 V (+/- 5%), 50 Hz (+/- 2%), OR 3 Phase 480 V (+/- 5%), 60 Hz (+/- 2%), Others upon request
Ambient operating conditions	Standard between 5°C and 45°C (40 to 110°F)
Ambient humidity	20 – 95%
Preferred cooling water flow	4.000 L/hr @ 15ºC per StirLNG-4 (1060 gal/hr @ 68ºF); 20% glycol (other water temperatures upon request)
Explosion proof classification	ATEX, Zone 2
Dimensions	See enclosed drawing (dimensions in mm) in Appendix 1
Weight	1,400 kg per StirLNG-4

(note: dimensions and weights are subjected to the final scope of supply)

4.2 Liquefaction capacity of the StirLNG-4

The liquefaction capacity of the StirLNG-4 for production depends on the gas inlet temperature, the gas inlet pressure and gas composition. The production capacity for pure methane can be found in the graph per Appendix 2.

To increase LNG production capacity, multiple StirLNG-4's can be combined (in parallel). Using manifolds the gas flow will be divided over the StirLNG-4's. This is also applicable for the liquid produced. Technically there is no limit to the amount of StirLNG-4's to be combined.

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4.3 Methane feed gas specification

The required methane feed gas specification to the StirLNG-4 is:

- Main stream CH_4
- CxHy (C_2 to C_4)   < 10%
- CxHy (C_5^+)   < 1 ppm
- CO_2 See appendix 2, refer to Note 1
- H_2O < -70ºC dew point
- H_2S < 3,3 ppm
- Oil content   < 0,01 mg/m³
- Particles   < 0,1 micron
- N_2/O_2 < 10%, refer to Note 2

Note 1.)
The CO_2 stated level stated in the table is not a specific requirement for the StirLNG-4, but for the entire LNG logistic chain at that given pressure.
It must be considered that when, down-stream in the logistic chain, the LNG pressure is decreased, solid CO_2 will deposit. This deposit will collect in vessels and potentially block or even damage valves and pumps. Therefore, the lowest LNG temperature in the logistic chain determines the maximum CO_2 content of the feed gas.

Note 2.)
Non-condensable gases might be liquefied only partially in the LNG flow, dependent on their solubility. The remainder needs to be vented from the liquefaction heat-exchanger. This will be a mixture of methane/oxygen/nitrogen gas that needs to be processed. This venting will have minor effect on liquefaction rate, but it will increase the rate of gas consumption against liquid production, depending on the quantity of non-condensables.

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4.4 Installing a StirLNG-4 liquefier

Installation of a StirLNG-4 liquefier is relatively easy. It involves locating the StirLNG-4 at its (final) position and connecting it to all interfaces:

- Methane gas inlet line
- LNG outlet line
- Cooling water lines
- Signal cables to the control box.
- Power cables from mains supply to the electric motor (via either a star/delta switch or frequency convertor).

The StirLNG-4 can only be installed in a hazardous area depending on the ATEX or NEC configuration. Recommended installation footprint is approx. 3 x 3 meter.

The control box, optionally supplied as part of the StirLNG-4, must be located in a non-hazardous area.

Electric power availability and connections is part of the customer site preparation (according to local regulations).

Installation of the StirLNG-4 is mandatory required to be performed by one of our service engineers.

Note:
Each StirLNG-4 liquefier will be tested at the factory for its performance using liquid Nitrogen.
A customer can witness the standard Factory Acceptance Test (max. 2 days) at their own cost.
Additional factory acceptance test(s) and/or special requirements need to be discussed upfront and might be subject to additional charges.

(see Appendix 1 for StirLNG-4 dimensions and connection positions).

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5. SCOPE OF SUPPLY

Standard configuration:

1) The standard delivery consist of:

- One basic 4-cylinder Cryogenerator, model SPC-4, suitable for Methane (re-)liquefaction, including safety switches, signal connection box and motor coupling.
- ATEX Zone 2 compliant
- ATEX Zone 2 motor
- Base frame with cushion feet
- Internal helium gas and water lines
- Connections for water and helium supply
- Gas and liquid counter couplings, suitable for cryogenic use, separately delivered, to be welded on customer lines
- Documentation (in English):
    - Pre-installation manual
    - Operating and maintenance instructions
    - CE declaration of conformity or incorporation (depending on which is applicable)

Options

2) Certification:

The standard StirLNG-4 will be certified according ATEX Zone 2 classification. Optionally the unit can be executed and certified according:

2a) ATEX Zone 2 (standard incl. with each StirLNG-4)
2b) ATEX Zone 1
2c) NEC 500, Class 1, Div. 2
2d) NEC 500, Class 1, Div. 1
2e) Others upon request

3) Electrical motor:

The standard StirLNG-4 will be equipped with a ATEX Zone 2 motor. Optionally the unit can be equipped with another motor type according specified area class:

3a) ATEX Zone 2 motor (standard incl. with each StirLNG-4)
3b) ATEX Zone 1 motor
3c) NEC 500, Class 1, Div. 2 motor
3d) NEC 500, Class 1, Div. 1 motor
3e) Others electrical motors upon request

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4) Start-up / Power supply:

In order to (smoothly) start up the StirLNG-4 and to reduce the starting current, electrical equipment is required. This is not included in the standard StirLNG-4 configuration. The unit must be equipped with either:

- 4a) Start/delta switch: this component will be either CE or UL compliant, non-explosion proof, to be placed in the non-hazardous area.
- 4b) Frequency converter: this component will be either CE or UL compliant, non-explosion proof, to be placed in the non-hazardous area.

Note: In case of 60Hz power supply a frequency converter is mandatory to be part of the standard StirLNG-4 configuration.

5) Controls:

The StirLNG-4 is standard equipped with safety sensors and a termination box. In addition, the StirLNG-4 requires a Control Panel to start and stop, and to safeguard the proper operation, protecting it from internal and external faults (no oil pressure, no water flow, etc.).

Each Control Panel/Unit (in a IP 54 cabinet) is non-explosion proof and has to be placed in a non-hazardous area. Start & stop signals need to be provided by the customer's control system. Error signals can be provided by the Control Panel/Unit (Ethernet communication by Profibus or other protocols can be made available on request). Our control units are delivered with a Siemens PLC (S7-1200 version 12) and other required components;. Also max. 10m of wiring is included. The Control Unit has no User Interface.

- 5a) Control panel CE (non-Ex. proof)
- 5b) Control panel UL (non-Ex. proof), NEC 500, Div. 2
- 5c) Control panel UL (non-Ex. proof), NEC 500, Div. 1 (incl. conduits between cooler and panel according NEC 500, Div. 1 requirements).
- 5d) Control unit CE (non-Ex. proof)

Both the Control Panel and the Control Unit have an option for data logging to enable fast troubleshooting and reduce downtime. They can (optionally) be supplied with an industrial VPN router for easy remote access. This offers the possibility to troubleshoot machines remotely without going on site.

When the StirLNG-4 control need to be part of the customers control system, it is also possible to deliver the system without a Control Panel/Unit. On request we can provide more details.

6) Support frame:

Our standard support frame for the StirLNG-4 is delivered with a height of 830mm.
Other heights are available on request.

7) 500 liter horizontal transfer vessel:

- Either ASME or PED certified
- 1 explosion proof level sensor, 1 pressure transmitter and 2 automated valves
- Connection for gas inlet and liquid outlet incl. bayonet coupling
- Liquid and gas connection for the StirLNG-4 including 2 x 1,5m hoses and hand valves
  - 7a) Maximum operating pressure 10 barg (145 psig)
  - 7b) Maximum operating pressure 20 barg (290 psig)

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8) **Suitable for outdoor placement:**

Each StirLNG-4 liquefier can be made suitable for outdoor placement with temperature conditions in the range of -5°C to + 45°C (23°F to 113°F).

For this option, the StirLNG-4 will be supplied with:

- Additional stainless steel components and a special surface coating for corrosion protection
- IP 65 enclosures for electrical equipment

When placed outside, the customer needs to provide a canopy (e.g. for rain, snow or debris protection) for the StirLNG-4 and other equipment (if applicable).

For more extreme outdoor conditions (in the range of -5°C to -20°C) , suitable pre-cautions and/or modifications need to be applied; this specific StirLNG-4 configuration needs to be designed case-by-case.

9) **Water chiller:**

This option will supply a stand-alone water chiller to provide cooling water to the Cryogenerator, suitable for the conditions specified. The water chiller will be non-explosion proof and needs to be placed in the non-hazardous are (20m connection lines are included). The water chiller will be either CE or UL/ASME.

10) **Cylinder of Helium gas:**

The StirLNG-4 needs to be filled with helium gas during installation, min. purity of 99,99%. Only after maintenance the unit needs to be refilled. This option contains a European certified 200 bar, 50L gas cylinder of Helium including suitable pressure regulator.

11) **Consumable parts and tools:**

Consumable parts for xxx hours of operation (several packages are available) + required tools.

12) **Training Maintenance Engineer:**

1 Week of training at the manufacturer's site in The Netherlands for operation and maintenance. Lodging, breakfast and lunch is included. Travel expenses are at customer's account.

Not included in the StirLNG-4 Scope of Supply are:

- Any housing/enclosure for the StirLNG-4
- Piping for liquid and/or gas
- Main power (connection) box, cables and fuses
- Any of the lines, pumps and vessels described in this specification unless quoted separately
- Commissioning, site installation & site acceptance test, unless explicitly mentioned

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6. SERVICE AND MAINTENANCE

Service

With our Service Agreements we cover all required (preventive) maintenance to ensure a reliable operating of the StirLNG-4. Depending on customer's personal needs, the service concept can be individualized and tailored to the specific requirements.

With this approach we offer a choice of options for planning and performing maintenance. Whether you're prioritizing high levels of product safety, want to keep a tight hold on your maintenance costs at all times, or wish to optimize your total cost of ownership.

Maintenance

Each StirLNG-4 reliquefier requires preventive (minor) maintenance only after each 6,000 operating hours. Specific Consumable parts sets are available for this maintenance (please see our price quotation).
At 36,000 operating hours each StirLNG-4 reliquefier requires a more extensive (major) maintenance.

All maintenance inspections can be done at site by our Service engineers.

As an option, also customer technicians can be trained to perform this maintenance but they need to be officially certified. A (regular) training at our premises is mandatory in this case.

Maintenance inspection	Interval [operating hours]	Duration (on site)
Preventive (minor) maintenance	every 6,000 hours	8 hours
Extensive (major) maintenance	36,000 hours	16 hours

Note: the StirLNG-4 liquefier has to be shut down (to be warmed up) at least 24 hours before commencing with each maintenance

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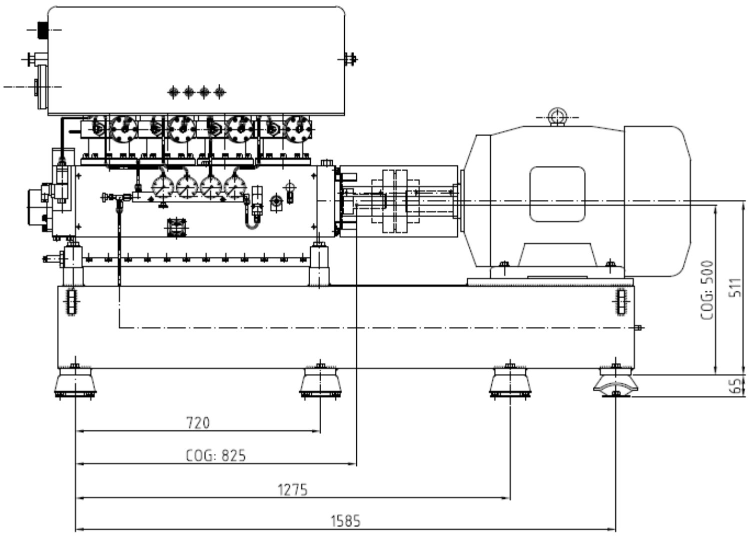
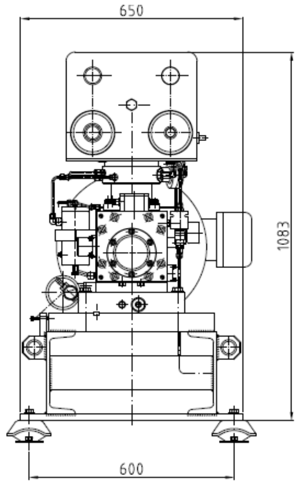
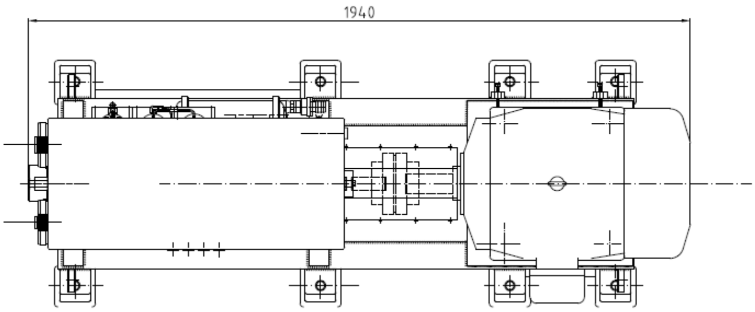
APPENDIX 1
General sizes of the StirLNG-4







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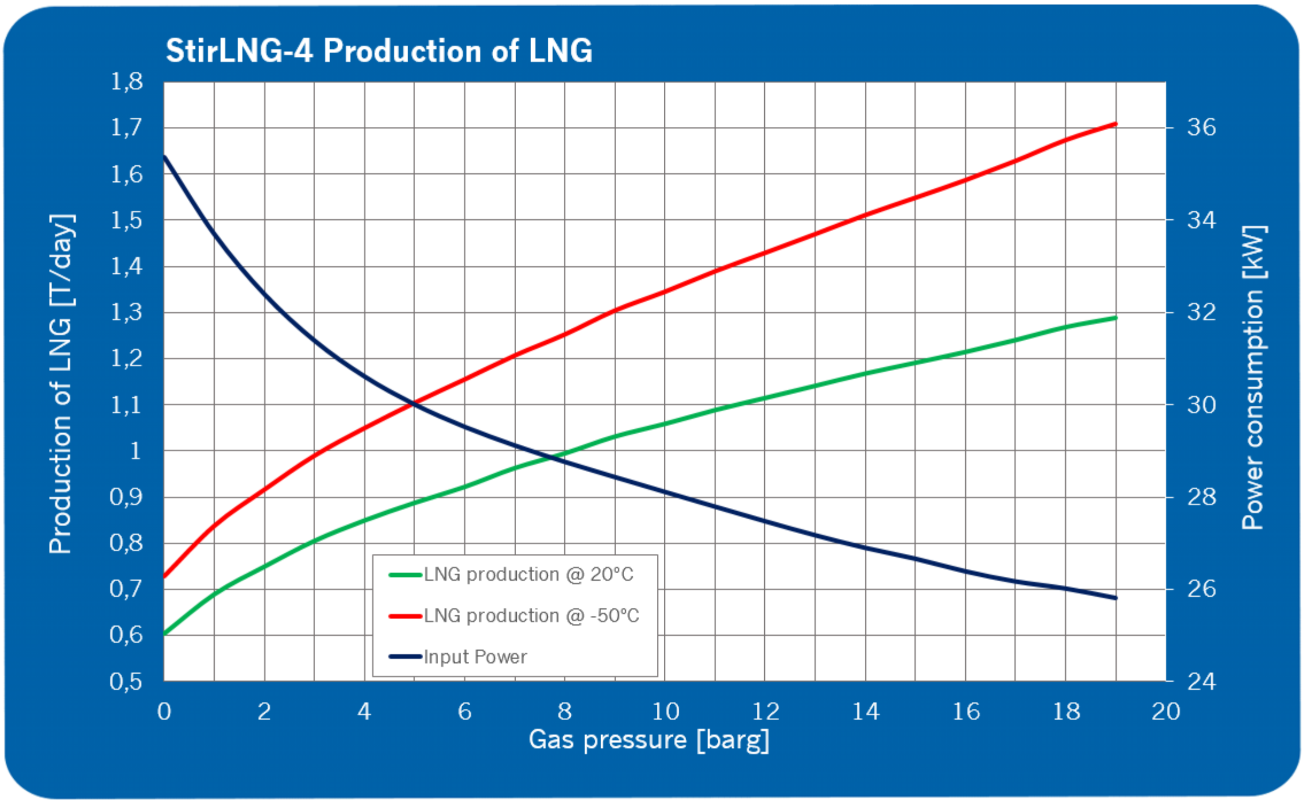
APPENDIX 2

Production capacity of the StirLNG-4 as function of gas temperature and pressure



Gas Pressure	Temp. Liquid	CO_2 (1)	Cooling Power	Electrical Input	Capacity Inlet gas temperature 20°C based on pure methane					Capacity Inlet gas temperature -50°C based on pure methane				
Barg	K	PPM	W	kW	Nm³/hr	kg/hr	l/hr	T/day	Gal/day	Nm³/hr	kg/hr	l/hr	T/day	Gal/day
0	111	66	6250	35,4	34,9	25,1	59,3	0,60	376	42,0	30,1	71,3	0,72	452
2	126	230	7350	32,3	43,8	31,5	78,8	0,75	499	53,5	38,4	96,1	0,92	609
4	135	486	7950	30,7	49,4	35,5	92,1	0,85	584	61,0	43,8	113,7	1,05	721
6	141	800	8400	29,6	53,9	38,7	103,5	0,93	656	67,2	48,2	129,0	1,16	818
8	146	1213	8750	28,8	57,8	41,4	113,8	0,99	722	72,7	52,2	143,3	1,25	909
10	151	1837	9050	28,0	61,3	44,0	123,7	1,05	784	77,9	55,9	157,2	1,34	997
12	155	2562	9300	27,5	64,5	46,3	133,3	1,11	845	82,8	59,4	171,0	1,43	1084
14	158	3287	9500	26,9	67,7	48,5	142,9	1,16	906	87,6	62,9	185,0	1,51	1173
16	161	4217	9700	26,5	70,7	50,7	152,5	1,22	967	92,4	66,3	199,4	1,59	1264
18	164	5412	9900	26,1	73,6	52,8	162,3	1,27	1029	97,2	69,7	214,3	1,67	1359
20	167	6944	10050	25,7	76,5	54,9	172,4	1,32	1093	102,1	73,2	230,0	1,76	1458