Up to now, only few independent scientific studies[1] cover methane emissions from the LNG sector specifically. The aim of this TGD is to reference these studies and provide more guidance on the quantification of methane emissions from the LNG sector, based on best available methodology.

General introduction

The LNG liquefaction process typically starts with additional processing of pre-processed natural gas or feed gas in the slug catcher to meet the LNG standards for liquefaction. In these processing steps, non-hydrocarbon components (carbon dioxide, mercury, sulfur compounds, and water) are removed. It is also treated to remove other components that could freeze (e.g., benzene) under the cryogenic temperatures needed for liquefaction, or that could be harmful (e.g. mercury) to the liquefaction facility. Typical LNG has over 95% methane, with the remaining 5% being a combination of nitrogen and other hydrocarbons such as ethane, propane, butanes[2].

Heavy hydrocarbons are separated from the feed gas and the feed gas is then cooled as part of the liquefaction process to approximately -162°C (-260°F). At this temperature, a phase change occurs with liquefied natural gas occupying 600 times less space than in its gaseous form. The cooling of the natural gas occurs on LNG liquefaction trains which typically consist of cryogenic heat exchangers and other types of heat exchangers (e.g. refrigerant propane heat exchanger, air fin heat exchangers), scrub columns, compressors and flash vessels. This process is energy intensive, using mechanical drive turbines, power generators, compressors for cryogenic cooling, LNG pumps and compressors etc. The liquified and cooled LNG flows into a storage tank before being loaded onto a marine vessel (e.g. LNG vessel), tank truck or ISO container to be transported to an importing terminal. This transfer is done using articulated arms, hoses and permanent LNG terminal loading lines which connect the storage tank to the cargo tanks of the LNG vessel, reservoir of the transport vehicle or container. Additionally, flash gas and boil-off gas are produced as part of the liquefaction process, that could be used as a fuel gas needed for the energy intensive process[3].

System boundaries

All emission sources from LNG liquefaction, not covered by other TGDs (see list below) are included in this TGD.

All emissions from components linked to the LNG value chain, while the gas is under the custody of the Operator is to be reported under the relevant reporting category. This includes all annex operations performed at the terminal that could have associated methane emissions, such as, for example, bunkering, cool-down, transshipment, truck loading, Wobbe Index correction and gassing-up. Emissions occurring before or after the point at which the transfer of custody of the gas occurs are to be considered by the operator having the custody of the gas at that point. For example, this can be considered at the flange connecting the shore arm to the ship's manifold.

Emissions from unintended equipment leaks should be reported under the corresponding category. The distinction between incidents and leaks is to be considered based on the regulations and practices in place at

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[1] Innocenti, F. et al, *Comparative Assessment of Methane Emissions from Onshore LNG Facilities Measured Using Differential Absorption Lidar,* 2023, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiissi88P39AhVaXfEDHbr6BwAQFnoECBIQAQ&url=https%3A%2F%2Fpubs.acs.org%2Fdoi%2Fpdf%2F10.1021%2Facs.est.2c05446&usg=AOvVaw01w2GtzY2bT-Pc1NnhFjM8

[2] API, LNG Operations – Consistent Methodology For Estimating Greenhouse Gas Emissions, 2015

[3] API, LNG Operations – Consistent Methodology For Estimating Greenhouse Gas Emissions, 2015

the facility. Unintended methane emissions, considered to fall within the *leaks* category should be reported as such (*Leaks TGD*). As defined in the *General Principles TGD*, these should be allocated to the most appropriate reporting category.

Any emissions resulting from an incident, emergency stop or malfunction which are sent to a flare fall under that category (*Flaring TGD*), emissions which are vented are covered by the *Incidents TGD*.

All intended or expected emissions (vents) are to be reported under their respective category (such as pneumatics, centrifugal compressors, reciprocating compressor rod packing, glycol dehydrators and other venting and purging). Guidance on materiality is presented in the *General principles TGD*.

Many types of methane emission sources can be found at an LNG facility, most of which are covered by other TGDs and are to be reported under their specific category. The table below describes the most common emissions sources at LNG regasification facilities, and the associated TGD for assessing their emissions.

Emission source	Corresponding TGD
Leaks	Unintended equipment leaks (Leaks TGD)
Analyzers and gas chromatographs	Pneumatic Controllers, pumps, shutoff valves and control instruments
Incidents and malfunctions	Incidents, emergency stops and malfunctions
Centrifugal compressors	Centrifugal compressors
Reciprocating compressors	Reciprocating compressors
Power and heat generation	Incomplete combustion
Loading arms	Purging and venting, starts and stops and other process and maintenance vents
Main cryogenic heat exchangers	Unintended equipment leaks (Leaks TGD) Incidents, emergency stops and malfunctions *No vented emissions are typically expected from normally functioning cryogenic heat exchangers*
Slug catcher	Unintended equipment leaks Incidents, emergency stops and malfunctions *No vented emissions are typically expected from normally functioning slug catchers*
Controllers	Pneumatic controllers, pumps, shutoff valves and control instruments
Pumps	Pneumatic controllers, pumps, shutoff valves and control instruments
Flaring, thermal oxidizers and incinerators	Flare efficiency
Acid gas removal	Purging and venting, starts and stops and other process and maintenance vents
Pressure relief valves	Incidents, emergency stops and malfunctions
Storage tanks – BOG management/venting	*Covered by this TGD*
Start-up, shutdown, and other non-routine events	Purging and venting, starts and stops and other process and maintenance vents
Storage tanks – Permeation of or leaks from tank walls	*Covered by this TGD* To be reported in the corresponding category (starting from 2023 reporting template)

Loading of LNG trucks and other LNG carriers and containers	*Covered by this TGD*

Methane emissions from other processes of the LNG value chain are covered by their respective TGD (see *LNG Regasification TGD* and *LNG Shipping TGD*).

Level 3 Quantification Methodologies

Due to the wide variability of sources, there is limited documentation of source-level emission factors for LNG specific processes. However, emissions factors or other quantification methods used in other natural gas value chain processes could be relevant for use in LNG regasification facilities. For example, the gas compression or pumping following the regasification process might have similar potential venting sources as gas transmission. As these two processes have some similarities, where specific segment emission factors or other quantification methods are required but not available for LNG, emission factors from the gas processing segment can be used. In other cases, the emission factor or other quantification methods are not dependent on the segment and can be used directly for the LNG segment. The emission factors for each corresponding equipment can be used, based on their relevant OGMP TGDs, manufacturer provided EFs or other relevant quantification method.

Methane emissions from LNG liquefaction can be quantified at Level 3 using different quantification methodologies such as emission factors, manufacturer estimates or simple engineering calculations, depending on the source type.

Emission factors

Accepted source-level emission factors, as defined in the *General Principles TGD*, or those prescribed by local regulation are considered as providing Level 3 estimates, provided they are specific for the source type. Operators are encouraged to use emission factors that best represent conditions and practices at their facilities and adjust factors, where warranted, to more accurately estimate emissions given differences between the reference system on which the emission factor is based, and their systems.

Storage tanks – BOG management

LNG storage tanks could be another important source of emissions if not properly managed. LNG in tanks is kept in a near constant cryogenic temperature. The temperature is controlled by boil off gas (BOG) generation, in a process known as auto-refrigeration. Usually, the BOG is captured, condensed, and flared or vented. For the case where BOG is vented, a typical loss may be estimated as 0.050% of the total tank volume per day (under normal conditions)[4,5].

$$BOG\ from\ LNG\ Storage\ Tank: 0.050\ \%\ of\ total\ tank\ volume\ per\ day\ (Original\ Units)$$

There are typically no emissions directly associated with BOG management if the BOG is capture, recondensed for reinjection or utilization.

Permeation of tank walls

Currently, in the literature, no specific emission factors are available for permeation of LNG storage tank walls. If no satisfactory Level 3 quantification method is available for this emission source, Operators are

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[4] D. Féger. “An innovative way of reducing BOG on existing or ‘new built’ LNG storage tanks”, Proceedings LNG16 Congress, Algeria, April 2010.
[5] API, Compendium Of Greenhouse Gas Emissions Methodologies For The Natural Gas And Oil Industry, 2021 – Section 6.7

encouraged to implement Level 4 methodologies in order to develop specific measurement-based emission factors.

Loading of LNG trucks and other LNG carriers and containers

LNG can also, in some instances, be loaded into trucks or other carriers or containers to further transport the LNG (i.e. bunkering) or for other purposes. During this process methane emissions can be vented as part of the loading or storage process. Limited data is available with regards to this emission source.

Currently, in the literature, no specific emission factors are available for loading of LNG trucks and other LNG carriers and containers. If no satisfactory Level 3 quantification method is available for this emission source, Practitioners are encouraged to implement Level 4 methodologies in order to develop specific measurement-based emission factors.

Other vents

Emissions from other generic vents could be calculated using a general material balance approach based on source-specific measurements or estimates of the vent rate and concentrations, as described in Level 4 quantification.

For emission sources which are only present in the LNG segment, such as heat exchangers, emissions from cooling process, pressure valve expanders and evaporators, source-specific emission factors could be employed. References similar to the following could be used for the sources present at the facility:

- API Compendium reports Of Greenhouse Gas Emissions Methodologies For The Natural Gas And Oil Industry, 2021 – Section 6.7
- API, LNG Operations – Consistent Methodology For Estimating Greenhouse Gas Emissions, 2015
- Default national emission factors (e.g., US EPA)
- Academic papers

It is important to note that this list is non-exhaustive and that all vented sources might not be covered by the references and categories listed above. If no emission factor is available in the literature for a specific emission source, the emission factor of a similar source or reasonable estimate can be used based on the participant's best judgement and provided justification of the methodology employed to quantify emission at level 3.

Manufacturer estimates

For routine emissions coming from commercial equipment specific to LNG sector, such as but not limited to cryogenic heat exchangers, BOG rate from LNG storage or connections, manufacturer estimates can be used to quantify methane emissions at Level 3, where relevant and available.

Simple engineering calculations

Simple engineering calculations, specific to the emission source, can be used to quantify methane emissions from emission sources in the LNG segment at Level 3, where relevant.

Level 4 Quantification Methodologies

Depending on the emission source, measurements, measurement-based emission factors, process simulation and/or engineering calculations can be accepted for level 4 quantification.

Direct measurement and Measurement-based Emission factors

Measurements (including continuous and periodic monitoring) or emission factors developed based on representative measured emissions are considered Level 4 emissions quantification.

Level 4 emission factors should be based on measurements conducted on a representative sample. System configurations, environmental and operating conditions should be considered in determining 'like' systems that carry a common emission factor. Each system that is not 'like' will require determination of a separate emission factor for that system based on the appropriate measurement studies. For guidelines on the methodology to develop a statistically representative sample, please refer to the *Uncertainty and reconciliation guidance.*

For estimating total CH_4 emissions, the following data are required during the time of interest[6]:

- Gas release flowrate
- Duration of the event (purge, vent, blowdown, …)
- Methane content

Methane emissions from gas emitted for each emission category is the multiplication of these three elements.

Measuring gas release flow rate

Accepted equipment and techniques, as defined in the *General Principles TGD*, for determining gas flow are to be employed. Practitioners are encouraged to select an appropriate measurement device depending on the characteristics of the vent. Following are typical equipment to measure emissions from vents, but the list is not exhaustive[7,8]:

- Vane anemometer
- Hotwire anemometer
- Turbine meter
- Electronic packing vent monitor
- Calibrated vent bag
- Coriolis meter
- Orifice meter
- Hi-flow sampler
- Thermal mass meters
- Flow meter

Some measurement techniques allow direct measurement of total methane emissions, in which case, it is not necessary to measure methane content separately to quantify emissions.

LNG operations will typically go through large variations in operational mode which could lead to large variations in methane emissions. It is therefore important to take variability of emissions overtime from the different sources into consideration when using measurements to establish a methane inventory and when developing measurement-based emission factor to ensure the representativity of the measurements.

Methane content

It can be necessary to determine the methane content of the gas flow to quantify methane emissions from venting. Depending on the vent, the methane content can differ from the average methane content of the facility.

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[6] API, LNG Operations – Consistent Methodology For Estimating Greenhouse Gas Emissions, 2015

[7] More details on various detection and measurement equipment can be found at CCAC, *Conduction Emissions Surveys, Including Emission Detection and Quantification Equipment – Appendix A of the OGMP Technical Guidance Document*, 2017

[8] More details on various detection and measurement equipment can be found at Marcogaz, *Assessment of methane emissions for gas Transmission and Distribution system operators*, 2019 – Section 7 (p. 34-39)

Accepted equipment and techniques, as defined in the *General Principles TGD,* for determining methane content can be employed. In cases where the gas characteristics can be assumed to meet a regulated specification, methane content can be determined in accordance with the *General Principles TGD*.

Frequency and duration of events

Venting events can be random, periodic, or regular. For all types of venting events, it is recommended that operated records are maintained to accurately represent events.

Engineering calculations, process simulation and models

Accepted engineering calculations, process simulations and models, as defined in the *General Principles TGD*, which do not rely on default emission factors or values can be considered as Level 4 quantification methodologies.

For example, emissions from depressurization of systems, equipment or connections can be calculated using physical volume, pressure drop and temperature data, specific to the equipment being depressurized. It is to be noted that stored LNG is kept in its liquid state at a near constant cryogenic temperature, which is controlled by allowing the BOG to escape from the tank. The following formula would apply for volume of gas, not the volume of liquid LNG inside the tank or other equipment.

$$\frac{p_i * V_i * T_f}{p_r * T_i} = V_f$$

Where:

p_i = Initial pressure of the equipment/system
p_r = Remaining pressure of the equipment/system (generally, atmospheric pressure)
T_i = Initial temperature of the gas being released (kelvin)
T_f = Temperature of the gas after being released (generally, atmospheric temperature) (kelvin)
V_i = Physical volume of the vented equipment or system (m^3)
V_f = Volume of gas released (scm)

Where applicable, standard/normal/atmospheric conditions for the vented equipment or system may be considered (typically, atmospheric pressure and 0 or 20°C atmospheric temperature).