CONTENTS

1. Method for determining transferred energy during LNG cargo transfer

2. Calculating the transferred energy
   2.1 Calculating the gross transferred energy
      2.1.1 Calculating the transferred LNG volume \( V_{\text{LNG}} \)
      2.1.2 Calculating the transferred LNG density \( \rho_{\text{LNG}} \)
      2.1.3 Calculating the transferred LNG gross heating value \( H_{\text{LNG}} \)
   2.2 Calculating the return gas energy
      2.2.1 Calculating the return gas volume \( V_{\text{NG}} \)
      2.2.2 Calculating the return gas gross heating value \( H_{\text{NG}} \)
   2.3 Calculating the energy consumed by the LNG carrier’s engine
      2.3.1 Determining the gross heating value of the gas consumed by the LNG carrier’s engine \( H_{\text{EG}} \)
      2.3.2 Determining the volume of the boil-off gas or return gas consumed by the LNG carrier’s engine, at reference combustion conditions, \( V_{\text{EG}} \)
   2.4 Calculating the net transferred energy

3. Calculating the energy required for gassing-up

4. Calculating the cool down energy
   4.1 Cool down with LNG heel
   4.2 Cool down before reloading

5. Status of Cargo lines
   5.1 Unloading case
   5.2 Loading case

6. Cargo report : Certificate of Quality and Certificate of Quantity

Appendix 1 – Data from NBS - Technical note 1030, December 1980
Appendix 2 – Data from ISO 6976-2016
1. Method for determining transferred energy during LNG cargo transfer

A schematic representation (Figure 1) of an LNG cargo transfer from an LNG carrier to the LNG terminal (unloading) or from the LNG terminal to an LNG carrier (reloading) illustrates the amount of energy transferred.

![Diagram showing phases of LNG cargo transfer](image)

*Figure 1: Phases of LNG cargo transfer (before and after)*

During these transfer operations:

- **cargo unloading**: the volume of LNG unloaded is replaced by LNG evaporation gas sent back by the terminal;
- **cargo reloading**: the volume of LNG reloaded replaces the gas phase present in the LNG carrier’s tanks when upon arrival; gas is sent to the terminal during LNG transfer.

In this document, this gas (sent by or to the terminal) will be referred to as « return gas » (NG).

From a general point of view, it is considered that an LNG heel:

- remains in the carrier’s tanks at the end of a cargo unloading;
- is present at the bottom of the carrier’s tanks before starting a cargo reloading.

The net energy transferred, \( E \), is equal to:

- **cargo unloading**: the energy of the LNG unloaded potentially reduced by the return gas (gas returned from the terminal to the carrier, NG) and by the engine gas (gas consumed by the carrier’s engine, \( E_{EG} \)):
  \[
  E = E_{LNG} - E_{NG} - E_{EG}
  \]

- **cargo reloading**: the energy of the LNG reloaded potentially reduced by the return gas (gas returned from the carrier to the terminal, NG) and increased by the engine gas (gas consumed by the carrier’s engine, \( E_{EG} \)):
  \[
  E = E_{LNG} - E_{NG} + E_{EG}
  \]
These energies are evaluated by determining the transferred volumes and/or masses, the LNG density, and the mean gross heating value on a volumetric and/or mass basis for the duration of the cargo transfer:

❖ **LNG:**

\[
E_{\text{LNG}} = V_{\text{LNG}} \cdot \rho_{\text{LNG}} \cdot H_{\text{LNG}}
\]

where:

- \( V_{\text{LNG}} \): volume of LNG measured in the LNG carrier’s tanks;
- \( \rho_{\text{LNG}} \): mean density of the LNG calculated from the chromatographic analysis of the LNG;
- \( H_{\text{LNG}} \): mean gross heating value (on a mass basis) of the LNG calculated using the mean value of the chromatographic analyses of the LNG.

❖ **Return gas (NG):**

\[
E_{\text{NG}} = V_{\text{NG}} \cdot H_{\text{NG}}
\]

where:

- \( V_{\text{NG}} \): volume of natural gas replacing the unloaded LNG in the carrier’s tanks (if cargo unloading) or sent back from the LNG carrier to the LNG terminal (if cargo reloading). This volume, converted at normal conditions (0 °C and 1.01325 bar), is calculated from the volume of transferred LNG and the pressure and temperature conditions of the gas phase in the carrier’s tanks at the end (if unloading) or at the beginning (if reloading) of cargo transfer;
- \( H_{\text{NG}} \): mean gross heating value of the gas (on a volumetric basis) calculated from the chromatographic analysis of the return gas.

Figure 2 illustrates the principle for determining the transferred energy based on the transferred LNG and the return gas.

**Nota:** the natural evaporations of the cargo during transfer are not taken into account as the missing quantity of LNG is balanced by a lesser quantity of return gas.

❖ **Boil-off gas (BOG) or return gas consumed by LNG carrier’s engine (EG):**

Several cases can be considered:

- \( E_{\text{EG}} = 0 \) (no gas is consumed),
- \( E_{\text{EG}} = 0.1 \% \) of the transferred LNG (if no metering system for engine gas consumption onboard or in case of failure of the metering system or in the event of no record during custody transfer measurement),
- \( E_{\text{EG}} \): calculated from the volume (or mass) of BOG or return gas consumed and measured onboard and from heating value on a volumetric (or mass) basis.

**NB:** Gas consumed by the carrier’s engine (EG) included Gas to engine (GTE) and Gas Combustion Unit (GCU).
2. Calculating the transferred energy

2.1 Calculating the gross transferred energy
The calculation of the gross transferred energy $E_{\text{LNG}}$ is a function of:

- $V_{\text{LNG}}$: volume of LNG transferred
- $\rho_{\text{LNG}}$: density of the LNG transferred
- $H_{\text{LNG}}$: gross heating value (on a mass basis) of the LNG transferred

$$E_{\text{LNG}} = V_{\text{LNG}} \cdot \rho_{\text{LNG}} \cdot H_{\text{LNG}}$$

2.1.1 Calculating the transferred LNG volume $V_{\text{LNG}}$

**Calculation method**

The volume of LNG transferred is calculated as the difference between the volumes of LNG contained in the tanks before and after the cargo transfer.

The calculation of the volume of LNG contained in a tank, at a given moment, is determined by reading from a measurement table according to the corrected level of LNG.

This corrected level of LNG is obtained from the level measured in a tank (by means of level gauges), to which are applied, if necessary, the corrections referred to above.
The volume of LNG onboard at a given moment is the sum of the volumes contained in each of the carrier’s tanks.

❖ **Units and rounding-offs**
The volume is expressed in m³.

The volume of LNG, before and after cargo measurement, is determined with three decimal places; the net volume of transferred LNG is the difference between these measurements and is taken with three decimal places for calculating the energy.

2.1.2 Calculating the transferred LNG density $\rho_{\text{LNG}}$
The density is calculated from various models based on state equations, corresponding state equations, etc. with as starting data:

- the composition of the LNG taken from the chromatographic analysis after sampling and vaporization of the sample; **the molar composition values are taken with 5 decimal places**;
- the mean value of the temperature of the LNG measured in the LNG carrier’s tanks; **the temperature of the LNG is taken in °C with 1 decimal place**.

Elengy uses the revised Klosek-McKinley (KMK) method to determine the density of the LNG.

❖ **Klosek-McKinley method: range of application**
The limits of the Klosek-McKinley method regarding the composition and the temperature of LNG are the following:

<table>
<thead>
<tr>
<th>Component</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (CH₄)</td>
<td>&gt; 60 % mol.</td>
</tr>
<tr>
<td>Iso and normal butanes (iC₄ + nC₄)</td>
<td>&lt; 4 % mol.</td>
</tr>
<tr>
<td>Iso and normal pentanes (iC₅ + nC₅)</td>
<td>&lt; 2 % mol.</td>
</tr>
<tr>
<td>Nitrogen (N₂)</td>
<td>&lt; 4 % mol.</td>
</tr>
</tbody>
</table>
| Temperature (T)           | < 115 K     
  (equivalent to < -158.15 °C) |

❖ **Klosek-McKinley method: formula**
The method for calculating the density of LNG is based on an empirical evaluation of the molar volumes of the mixture in the considered thermodynamic state. The density is calculated as follows:

$$\rho_{\text{LNG}} = \frac{M_{\text{LNG}}}{V_{\text{LNG}}}$$

where:

$\rho_{\text{LNG}}$: density of LNG in kg.m⁻³

$M_{\text{LNG}} = \sum x_i \cdot M_i$ : molar mass of LNG in g.mol⁻¹

1 The average liquid temperature is calculated using the temperature reading at each individual temperature sensor that is in the liquid, and not the average temperature of each cargo tank.

2 Klosek-McKinley method: Four mathematical models for the prediction of LNG densities - NBS Technical Note 1030 - December 1980.
The values of $K_1$ and $K_2$, expressed in L.mol$^{-1}$, are determined by tables according to the LNG molar mass and the LNG temperature (between 105 K and 135 K). Tables indicating the molar volumes in L.mol$^{-1}$ for the hydrocarbons $C_1$ to $C_5$, as functions of temperatures in the range 106 K - 118 K, are used by the calculation method (see values in appendix 1 of this note). **No rounding-off is performed during these calculations of $K_1$, $K_2$ and $V_{mol}$.**

### Units and rounding-offs

The density is expressed in kg.m$^{-3}$.

The density calculations will be performed without any rounding-off using the KMK calculation codes (note NBS 1030, December 1980).

#### 2.1.3 Calculating the transferred LNG gross heating value $H_{LNG}$

**Calculation method**

The gross heating value on a **mass** basis of the LNG is calculated from the molar composition, the molar mass and the gross heating value on a molar basis of the various components. These values are taken from standard ISO 6976-2016 « Natural gas - Calculation of calorific values, density, relative density and Wobbe index from composition ».

The relation used is produced thus:

$$H_{LNG} = \sum_{i=1}^{N} \left( x_i \cdot \frac{M_i}{M_{LNG}} \right) \cdot H_i^{\hat{}}(t_1)$$

where:

- $H_{LNG}$: LNG gross heating value on a **mass** basis
- $x_i$: molar fraction of component $i$
- $M_i$: molar mass of component $i$
- $M_{LNG} = \sum_{i=1}^{N} x_i \cdot M_i$: molar mass of LNG

$H_i^{\hat{}}(t_1)$: gross heating value (on a **mass** basis) of the component $i$ calculated without rounding-off from « table 3 - calorific value on a molar basis » (kJ.mol$^{-1}$) and « table 1 - molar mass of constituents » (kJ.mol$^{-1}$) of standard ISO 6976-2016 according to the relation:
Elengy – LNG Cargo Transfer – Calculation methods and rounding-offs

7/20

Version of Dec 2021

Units and rounding-offs
The gross heating value (on a mass basis) is expressed in MJ.kg\(^{-1}\) or in other units such as kWh.kg\(^{-1}\) in the reference combustion conditions at 0°C at atmospheric pressure of 1.01325 bar. The physical constants of gross heating value on a mass basis and the molar masses of the components are taken from standard ISO 6976-2016. No rounding-off of H\(_{\text{NG}}\) is made to calculate the gross transferred energy.

2.2 Calculating the return gas energy
The calculation of the returned energy (gas return NG) \(E_{NG}\) is based on the following terms:
- the volume of return gas, \(V_{NG}\),
- the gross heating value (on a volumetric basis) of the return gas \(H_{NG}\).

\[ E_{NG} = V_{NG} \cdot H_{NG} \]

2.2.1 Calculating the return gas volume \(V_{NG}\)
The volume of NG is calculated by difference from the volume of LNG transferred, corrected according to:
- the temperature of the gas phase,
- the pressure in the gas phase.

Between two cargo measurement operations, the natural evaporation are taken into account when determining the volume of LNG transferred, since the reduction in the corresponding LNG level is measured.

Before and after cargo measurements (i.e. before starting and after ending cargo transfer), these evaporation are not taken into account, although they may be reincorporated by the terminal.

Calculation method
The volume of return gas between two cargo measurement operations, corresponding to the geometric volume of the transferred LNG, must be converted at the temperature and pressure conditions of 0°C and 1.01325 bar respectively; it must be corrected according to the temperature and pressure conditions of the return gas phase to the LNG carrier (unloading) or according to the temperature and pressure conditions of the initial gas phase in the LNG carrier (reloading). The correction of the compressibility factor of the return gas is not taken into account in this calculation because of its negligible impact on the measurement of the volume of the return gas.

\[ V_{NG} \approx V_{LNG} \cdot \frac{273.15}{273.15 + t} \cdot \frac{P}{1.01325} \]

where:
- \(V_{NG}\) : volume of gas converted at normal conditions of pressure and temperature, expressed in m\(^3\); no rounding-off is performed for the return gas calculation;
- \(P\) : absolute pressure, expressed in bar, in the tanks of the LNG carrier; the measurement is taken to the nearest mbar \((10^{-3}\) bar\) for the calculation;
- \(t\) : temperature of the gas phase expressed in °C. The value of this temperature is equal to the mean of the temperature means from each tank calculated as the mean of the values indicated by the temperature sensors not immersed in the LNG left in the carrier’s tanks; the temperature is taken to the nearest 0.1°C for the calculation.
Units and rounding-offs

The volume of the return gas $V_{NG}$ is expressed in m³ in normal conditions of temperature and pressure (0 °C; 1.01325 bar), without rounding-off when calculating the energy of the return gas.

2.2.2 Calculating the return gas gross heating value $H_{NG}$

The gross heating value (on a volumetric basis) of the NG is calculated from the molar composition and the gross heating value (on a molar basis) of the components. These values are taken from standard ISO 6976-2016 « Natural gas - Calculation of calorific values, density, relative density and Wobbe index from composition ».

In all cases, the terminal operator takes into account the gross heating value of the return gas and use this when calculating the transferred energy.

Calculation method

The gross heating value (on a volumetric basis) of the ideal gas for a combustion temperature $t_1$ of a component $i$ measured at a temperature $t_2$ and under pressure $P_2$ is calculated using the following equation:

$$
\tilde{H}_i^v[t_1, V(t_2, P_2)] = \tilde{H}_i^m(t_1) \cdot \frac{P_2}{R \cdot T_2}
$$

where:

- $\tilde{H}_i^v[t_1, V(t_2, P_2)]$ : ideal gross heating value (on a volumetric basis) of component $i$
- $\tilde{H}_i^m(t_1)$ : ideal gross heating value (on a molar basis) of component $i$
- $R$ : molar constant of the gases being equal to 8,314.462 1 J.mol⁻¹.K⁻¹
- $T_2 = (t_2 + 273.15)$ : absolute temperature in K, with $t_2$ in °C

For a mixture of known composition, the ideal gross heating value (on a volumetric basis) is expressed thus:

$$\tilde{H}_{vel}^v = \sum_{i=1}^{N} x_i \cdot \tilde{H}_i^v[t_1, V(t_2, P_2)]$$

where $x_i$ is the molar fraction of the component $i$ in the mixture.

The ideal gross heating value (on a volumetric basis) of the return gas is then:

$$H_{NG} = \frac{\tilde{H}_{vel}^v}{Z_{vel}} = \frac{\sum_{i=1}^{N} x_i \cdot \tilde{H}_i^v[t_1, V(t_2, P_2)]}{1 - \left[ \sum_{i=1}^{N} \left( x_i \sqrt{b_i} \right) \right]^2}$$

where:

- $H_{NG}$ : actual gross heating value (on a volumetric basis) of the return gas
- $Z_{vel}$ : compressibility factor of the return gas equal to $1 - \left[ \sum_{i=1}^{N} \left( x_i \sqrt{b_i} \right) \right]^2$
Units and rounding-offs
The actual gross heating value (on a volumetric basis) is expressed in MJ.m\(^3\) or in other units such as kWh.m\(^3\) in reference combustion conditions at 0°C at atmospheric pressure of 1.01325 bar and reference volume conditions at 0°C at atmospheric pressure of 1.01325 bar. The physical constants of gross heating value are on a molar basis and the molar masses of the various components are taken from standard ISO 6976-2016. No rounding-off is performed when calculating the energy of the return gas.

2.3 Calculating the energy consumed by the LNG carrier’s engine (EG)

- **Cas n° 1**: no gas consumption by carrier’s engine\(^3\) during cargo transfer:

  \[ E_{EG} = 0 \]

- **Cas n° 2**: gas is consumed by carrier’s engine during cargo transfer:

  Gas consumed by the carrier’s engine is evaporation gas or return gas. Its heating value is thus the same as the heating value of the evaporation gas or of the return gas. As a consequence:

  \[ H_{EG} = H_{NG} \]

  where \(H_{EG}\) is the gross heating value of the gas consumed by the carrier’s engine and \(H_{NG}\) is the gross heating value of the evaporation gas or of the return gas.

  A) no gas metering at carrier’s engine or malfunctioning flowmeter; a fixed rate of 0.1 % of the gross energy of the transferred LNG is applied:

  \[ E_{EG} = 0.001 \, E_{LNG} \]

  B) **mass flowmeter at carrier’s engine**; the energy of the BOG or of the return gas consumed at carrier’s engine (engine gas) is calculated from the measured mass in kg using the following equation:

  \[ E_{EG} = H_{EG} \cdot m_{EG} \]

  where:

  \[ H_{EG} = H_{NG} \]: gross heating value (on a mass basis) of the NG (BOG or return gas) in MJ.kg\(^{-1}\)

  \[ m_{EG} \]: mass of engine gas in kg.

  The gross heating value (on a mass basis) of NG is calculated from standard ISO 6976-2016, according to the following formula:

  \[ H_{NG} = \frac{\sum_i (H_i \cdot x_i \cdot M_i)}{\sum_i (x_i \cdot M_i)} \]

  where:

\(^3\) EG = Gas to engine + Gas Combustion Unit
\( H_{\text{NG}} \): gross heating value (on a mass basis) of NG in MJ.kg\(^{-1}\) at \( T_{\text{reference combustion}} = 0 \, ^\circ\text{C} \),

\( H_i \): gross heating value (on a mass basis) of component \( i \) in MJ.kg\(^{-1}\) at \( T_{\text{reference combustion}} = 0 \, ^\circ\text{C} \), equal to the gross heating value (on a molar basis) of the component \( i \) divided by its molar mass \( M_i \) (see appendix 2 of this note),

\( x_i \): molar fraction of the component \( i \) in NG,

\( M_i \): molar mass of component \( i \) (see appendix 2 of this note).

**C) volume flowmeter at carrier’s engine:** the energy of the BOG or of the return gas consumed at carrier’s engine (engine gas) is calculated from the measured volume in m\(^3\) using the following equation:

\[
E_{\text{EG}} = H_{\text{EG}} \cdot V_{\text{EG}}
\]

where:

\( H_{\text{EG}} = H_{\text{NG}} \): gross heating value (on a volumetric basis) of the NG in MJ/m\(^3\)(n),

\( V_{\text{EG}} \): volume of engine gas at combustion reference conditions in m\(^3\)(n).

**2.3.1 Determining the gross heating value of the gas consumed by the LNG carrier’s engine \( H_{\text{EG}} \)**

As mentioned above, \( H_{\text{EG}} \) is equivalent to \( H_{\text{NG}} \). See § 2.2.2 of this note for gross heating value calculation.

**2.3.2 Determining the volume of the boil-off gas or return gas consumed by the LNG carrier’s engine, at reference combustion conditions, \( V_{\text{EG}} \)**

The actual volume of engine gas (BOG or return gas) \( V_{\text{EGactual}} \) is converted to combustion reference conditions by means of \( P, T, Z \) correction, using the following equation:

\[
V_{\text{EG}} = \frac{Z_{\text{ref}}}{Z_{\text{NG}}} \cdot \frac{T_{\text{ref}}}{T_{\text{NG}}} \cdot \frac{P_{\text{ref}}}{P_{\text{NG}}} \cdot V_{\text{EGactual}}
\]

where:

\( Z_{\text{ref}}, Z_{\text{NG}} \): compressibility factor of BOG or return gas, at reference conditions and actual conditions respectively;

\( T_{\text{ref}}, T_{\text{NG}} \): respectively reference temperature and BOG or return gas actual temperature (measured at the volume gas flowmeter);

\( P_{\text{ref}}, P_{\text{NG}} \): respectively reference pressure and BOG or return gas actual pressure (measured at the volume gas flowmeter).

Generally, in case of a volumetric-type flowmeter, the information transferred to the carrier’s cargo control room is already expressed at the reference combustion conditions. Therefore, no correction is necessary, except for checking the homogeneity of the reference conditions of the measured volume of gas with gross heating value on a volumetric basis of the gas.
2.4 Calculating the net transferred energy

❖ Calculation method

In summary, the net transferred energy, \( E \), is expressed according to the following formula:

- cargo unloading:
  \[
  E = V_{\text{LNG}} \left[ \rho_{\text{LNG}} \cdot H_{\text{LNG}} \right] - \left( \frac{273.15}{273.15 + t} \cdot \frac{P}{1.01325} \cdot H_{\text{NG}} \right) \cdot E_{\text{EG}}
  \]

- cargo reloading:
  \[
  E = V_{\text{LNG}} \left[ \rho_{\text{LNG}} \cdot H_{\text{LNG}} \right] - \left( \frac{273.15}{273.15 + t} \cdot \frac{P}{1.01325} \cdot H_{\text{NG}} \right) + E_{\text{EG}}
  \]

❖ Units and rounding-offs

All calculations that lead to the net transferred energy are made without rounding-off via the calculator and use as starting data those mentioned below:

- \( V_{\text{LNG}} \): volume of transferred LNG, expressed in m\(^3\) to 3 decimal places,
- \( \rho_{\text{LNG}} \): density of the LNG, expressed in kg.m\(^{-3}\) without rounding-off for the calculation; no rounding-off for the calculations of \( K_1 \), \( K_2 \) and \( V_{\text{mol}} \); the molar composition of the LNG is given to 5 decimal places or if %molar three decimal places; the temperature of the LNG in °C is given to one decimal place,
- \( H_{\text{LNG}} \): gross heating value (on a mass basis) of the LNG expressed in MJ.kg\(^{-1}\) or kWh.kg\(^{-1}\) without rounding-off for the calculation; the molar composition of the LNG is given to 5 decimal places or if %molar three decimal places,
- \( t \): temperature of the evaporation gas or of return gas expressed in °C, given to one decimal place,
- \( P \): pressure of the evaporation gas or of the return gas expressed in bar to three decimal places, or in mbar to the nearest mbar,
- \( H_{\text{NG}} \): gross heating value of the evaporation gas or of the return gas expressed in MJ/m\(^3\)(n) or kWh/m\(^3\)(n) without rounding-off for the calculation; the molar composition of the LNG is given to 5 decimal places or if %molar three decimal places,
- \( E_{\text{EG}} \): energy calculated with no rounding-off, using gross heating value (on a mass or a volumetric basis), calculated with no rounding-off from a gross heating value on a molar basis; mass and volume in kg or m\(^3\) to be rounded to nearest kg or m\(^3\).
- If no gas metering, a fixed rate of 0.1 % of \( E_{\text{LNG}} \) is applied.
- If no gas is consumed at carrier’s engine, \( E_{\text{EG}} = 0 \).

\( E \): net transferred energy expressed in MJ or kWh with no rounding-off.

N.B. In case of CO\(_2\) traces in the LNG, the CO\(_2\) molar fraction is added to the N\(_2\) molar fraction for all energy calculations.

❖ Conversions

- from MJ to kWh : 1 Wh (\( T_{\text{reference combustion}} \)) = 3 600 J (\( T_{\text{reference combustion}} \))
- from MJ to MMBtu (ASTM E380-72) : 1 MMBtu (\( T_{\text{reference combustion}} \)) = 1 055.056 MJ (\( T_{\text{reference combustion}} \))

  with \( T_{\text{reference combustion}} = 0 \) °C or 15 °C or 20 °C or 25 °C or 60 °F (15.556 °C)

For other \( T_{\text{reference combustion}} \), conversion factors are not the same. For instance:

\[
1 \text{ MMBtu (} T_{\text{reference combustion}} = 15 \, ^\circ\text{C}) = 1 \, 055.119 \, \text{MJ (} T_{\text{reference combustion}} = 60 \, ^\circ\text{F})
\]
3. Calculating the gassing-up energy

Gassing-up operation consists of replacing inert exhaust gas (containing carbon dioxide or nitrogen) with warm LNG vapor prior to cooling down operation. Gassing-up operation is considered to be achieved when dioxide content is lower than 0.1 % mol. LNG terminal provides a significant quantity of LNG to perform the gassing-up process. This LNG quantity required for gassing-up is given by cargo tank gassing-up tables. Indeed, the LNG quantity depends on vessel’s technical and dimensional characteristics (database supplier).

From this quantity, an equivalent gas volume is deduced from expansion factor :

\[ V_{\text{Gas}} = V_{\text{LNG}} \times \text{Expansion factor} \]

where:

- \( V_{\text{LNG}} \): volume of LNG given by cargo tank gassing-up tables, expressed in \( m^3_{\text{GNI}} \)
- \( \text{Expansion Factor} \): from the LNG composition and temperature measured in the terminal tank (usually between 569 and 576), expressed in \( m^3(n)/m^3_{\text{LNG}} \)

The gassing-up energy is given by :

\[ E_{\text{Gassing-up}} = V_{\text{Gas}} \times H_{\text{vol. LNG}} \]

where:

- \( E_{\text{Gassing-up}} \): energy for gassing-up, expressed in kWh/m\(^3\)(n)
- \( V_{\text{Gas}} \): gas volume expressed in reference pressure and temperature conditions (0°C ; 1,01325 bar) and expressed in \( m^3(n) \).
- \( H_{\text{vol. LNG}} \): mean gross heating value of LNG (on a volumetric basis) calculated using the mean value of the chromatographic analyses of the LNG, expressed in kWh/m\(^3\)(n).

There is no cargo report produced for gassing-up operation by Elengy. This is purely a trade agreement.
4. Calculating the cool down energy

Cooling down consists in decreasing gas phase temperature inside tanks of cargo (usually up to -130 °C) before loading vessel with LNG.

Before cooling down, the vessel is considered to contain natural gas with a dioxide carbon content lower than 0.1 % mol.

4.1 Cooling down operation with LNG heel (without reloading operation)

Before COOLING DOWN

Gas Phase = CH₄

No liquid phase
Usually, positive gas temperature
Energy in gaseous form only (E_G1)

After COOLING DOWN

Possible presence of a measurable LNG heel
Energy in liquid form (E_{LNG}) and in gaseous form (E_{G2})

Figure 3: Cool down operation

The net Cool Down energy $E_{CD}$ is then:

$$E_{CD} = E_{LNG} + E_{Gas\ phase} - E_{NG} + E_{EG}$$

The evaluation of these energies is done by determining volumes and mass transferred, density and gross heating value (on volumetric and/or mass basis):

❖ For the liquide phase:

Energy supplied by possible LNG heel

$$E_{LNG} = V_{LNG} \times \rho_{LNG} \times H_{LNG}$$

where:

- $\rho_{LNG}$: mean density of the LNG calculated from the chromatographic analysis of the LNG
- $H_{LNG}$: mean gross heating value (on a mass basis) of the LNG calculated using the mean value of the chromatographic analysis of the LNG
- $V_{LNG}$: volume of LNG in the LNG carrier’s tanks

❖ For the gas phase:

Energy supplied by lowering gas temperature inside cargo tanks

$$E_{Gas\ phase} = E_{G2} - E_{G1}$$

where:

- $E_{G1}$: gas phase energy before the beginning of cool down operation
- $E_{G2}$: gas phase energy after the cool down operation
\[ E_{G2} = (V_{\text{vessel}} - V_{\text{LNG2}}) \times \left( \frac{273.15}{273.15 + t_2} \right) \times \frac{P_2}{1.01325} \times H_{\text{vol,LNG}} \]

\[ E_{G1} = V_{\text{vessel}} \times \left( \frac{273.15}{273.15 + t_1} \right) \times \frac{P_1}{1.01325} \times H_{\text{vol,CH4}} \]

where:

- \( V_{\text{vessel}} \): 100% capacity of vessel's tanks
- \( V_{\text{LNG2}} \): volume of LNG heel after cooling down
- \( t_1, t_2 \): respectively gas temperature before and after cooling down
- \( P_1, P_2 \): respectively gas pressure before and after cooling down
- \( H_{\text{Vol,GNL}} \): mean gross heating value (on a volumetric basis) of the LNG used or reloaded. The gas phase inside cargo tanks after cooling down comes from forced LNG vaporized.
- \( H_{\text{Vol,CH4}} \): mean gross heating value (on a volumetric basis) of methane. The gas phase inside cargo tanks before cooling down is considered as pure methane.

❖ For the return gas (NG):

\[ E_{\text{NG}} = V_{\text{NG}} \times H_{\text{NG}} \]

where:

- \( V_{\text{NG}} \): volume of return gas between two cargo measurement operations; volume of gas converted at normal conditions of pressure and temperature (0°C; 1.01325 bar), expressed in m³ is calculated from the volume of LNG heel. **no rounding-off is performed for the return gas calculation**

Refer to paragraph 2.2.1

- \( H_{\text{NG}} \): mean gross heating value (on a volumetric basis) of the return gas, measured by gas chromatograph.

❖ For the gas consumed by LNG carrier’s engine (EG):

Gas consumed by the carrier’s engine is gas from the vaporized LNG. Its heating value is thus the same as the heating value of the LNG. As a consequence:

\[ H_{\text{EG}} = H_{\text{LNG}} \]

where \( H_{\text{EG}} \) is the gross heating value of the gas consumed by the carrier’s engine and \( H_{\text{LNG}} \) is the gross heating value of the LNG.

A) no gas metering at carrier’s engine or malfunctioning flowmeter; a fixed rate of 0.1% of the gross energy of the transferred LNG is applied:

\[ E_{\text{EG}} = 0.001 \times E_{\text{LNG}} \]

B) mass flowmeter at carrier’s engine; the energy of the gas consumed at carrier’s engine (engine gas) is calculated from the measured mass in kg using the following equation:

\[ E_{\text{EG}} = H_{\text{EG}} \times m_{\text{EG}} \]

where:

- \( H_{\text{EG}} = H_{\text{LNG}} \): gross heating value (on a mass basis) of the LNG in MJ/kg⁻¹
\textbf{m}_{EG} : \text{mass of engine gas in kg.}

\textbf{C) volume flowmeter at carrier’s engine}; the energy of the gas consumed at carrier’s engine (engine gas) is calculated from the \textbf{measured volume in m}^3 using the following equation:

\[ E_{EG} = H_{EG} \cdot V_{EG} \]

where:

\[ H_{EG} = H_{LNG} : \text{gross heating value (on a volumetric basis) of the LNG in MJ/m}^3(n), \]
\[ V_{EG} : \text{volume of engine gas at combustion reference conditions in m}^3(n). \]

\textbf{4.2 Cooling down operation and reloading}

In the case of cooling down before reloading, the cooling down energy and the net loaded energy are not dissociated. A single cargo report is produced including the cool down energy.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure4.png}
\caption{Cooling down operation with reloading}
\end{figure}

In this specific case, the initial volume of LNG in the cargo tanks is zero and the volume of LNG reloaded corresponds to the measured volume during the closing custody transfer.

Only gas phase pressure and temperature before cooling down are recorded and taken into account for the calculation of return gas energy \( E_{NG} \).

Refer to the paragraph 2.4 for the calculating of the net transferred energy.
5. **Status of cargo lines**

LNG contained inside cargo lines during the closing custody transfer is taken into account if the fill-status of the cargo lines is different during both custody transfer (opening and closing). In this case, this volume of LNG is added or reduced to the final volume measured inside the cargo tanks.

### 5.1 Unloading case

**Before UNLOADING**

During the opening custody transfer, cargo lines are empty.

**After UNLOADING**

During the closing custody transfer, cargo lines are full.

After the closing custody transfer, LNG into cargo lines ($V_{\text{Lines}}$) is transferred into the cargo tanks.

![Figure 5: Transfer during unloading operation](image)

The net energy transferred « $E$ » is then:

- if cargo lines are full during the **closing** custody transfer (and empty during the opening custody transfer) then:

  $$ E = E_{\text{LNG}} - E_{\text{Lines}} - E_{\text{NG}} - E_{\text{EG}} $$

- vice versa, if the cargo lines are full during the **opening** custody transfer (and empty during the closing custody transfer) then:

  $$ E = E_{\text{LNG}} + E_{\text{Lines}} - E_{\text{NG}} - E_{\text{EG}} $$

where:

- $E_{\text{Lines}} = V_{\text{Lines}} \times \rho_{\text{GNL}} \times H_{\text{GNL}}$
- $E_{\text{LNG}}$: the gross transferred energy
- $E_{\text{Lines}}$: energy contained in cargo lines
- $E_{\text{NG}}$: return gas energy
- $E_{\text{EG}}$: energy consumed by the LNG carrier's engine
5.2 Loading case

Before LOADING

During the opening custody transfer, cargo lines are empty.

After LOADING

During the closing custody transfer, cargo lines are full.

After the closing custody transfer, LNG contained in cargo lines ($V_{\text{Lines}}$) is transferred into the cargo tanks.

By contrast, in the case of loading operation, LNG contained into cargo lines during the closing custody transfer is added to the final volume already transferred:

The net energy transferred $\langle E \rangle$ is then:

- If cargo lines are full during the closing custody transfer (and empty during the opening custody transfer) then:
  \[
  E = E_{\text{LNG}} + E_{\text{Lines}} - E_{\text{NG}} + E_{\text{EG}}
  \]

- If cargo lines are full during the opening custody transfer (and empty during the closing custody transfer) then:
  \[
  E = E_{\text{LNG}} - E_{\text{Lines}} - E_{\text{NG}} + E_{\text{EG}}
  \]

Whatever the type of transfer (unloading or loading), the volume of LNG contained in the cargo lines ($V_{\text{Lines}}$) is:

- Given by vessel’s tables,
- Or fixed to the standard value of 75 m$^3$ of LNG if this volume could not be established by using vessel’s tables.
6. **Cargo report : certificate of Quality and certificate of Quantity**

For unloading (or reloading) certificates and unloading (or reloading) assessments, the characteristics of the cargo are given as follows:

- **Volume of LNG before transfer**: in m³ to (3) three decimal places
- **Volume of LNG after transfer**: in m³ to (3) three decimal places
- **Volume of LNG from cargo lines**: in m³ to nearest m³ (no decimal places)
- **Volume of gross transferred LNG**: in m³ to (3) three decimal places
- **Volume of net transferred LNG**: in m³ to (1) one decimal place
- **Mass of LNG (before/after transfer, transferred)**: in kg to (1) one decimal place
- **LNG temperature before or after transfer**: in °C to (1) one decimal place
- **Carrier’s tank pressure before or after transfer**: in mbar to the nearest (1) one mbar
- **NG temperature before or after transfer**: in °C to (1) one decimal place
- **LNG composition**: in % molar to (3) three decimal places
- **Return gas composition**: in % molar to (3) three decimal places
- **Wobbe index**: in kWh.m⁻³ to (2) two decimal places
- **Gross heating value (on a volumetric basis)**: in kWh.m⁻³ to (2) two decimal places
- **Gross heating value (on a mass basis)**: in kWh.kg⁻¹ to (2) two decimal places
- **LNG density**: in kg.m⁻³ to (1) one decimal place
- **Gas phase density**: in kg.m⁻³ to (3) three decimal places
- **Gas phase relative density**: without unit, to (3) three decimal places
- **Methane number⁴**: without unit (no decimal places)
- **Gross transferred energy**: in kWh to nearest kWh (no decimal places)
- **Return gas energy**: in kWh to nearest kWh (no decimal places)
- **Energy consumed by carrier’s engine**: in kWh to nearest kWh (no decimal places)
- **Net transferred energy**: in kWh to nearest kWh (no decimal places)

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⁴: Methane number calculated according PKI method in accordance with Annex A NF EN ISO 23306
### APPENDIX 1 – Data from NBS - Technical note 1030, December 1980

**COMPONENT MOLAR VOLUMES (lit)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Molar volume*, L.mol⁻¹</th>
<th>Molar mass**, kg.kmol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>118 K</td>
<td>116 K</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.038817</td>
<td>0.038536</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>0.048356</td>
<td>0.048184</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>0.062939</td>
<td>0.062756</td>
</tr>
<tr>
<td>iC₄H₁₀</td>
<td>0.078844</td>
<td>0.078640</td>
</tr>
<tr>
<td>nC₄H₁₀</td>
<td>0.077344</td>
<td>0.077150</td>
</tr>
<tr>
<td>iso + neo-C₅H₁₂</td>
<td>0.092251</td>
<td>0.092032</td>
</tr>
<tr>
<td>C₆⁺ + n-C₅H₁₂</td>
<td>0.092095</td>
<td>0.091884</td>
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<tr>
<td>N₂ (+ CO₂)</td>
<td>0.050885</td>
<td>0.049179</td>
</tr>
</tbody>
</table>

*Source: NBS - Technical note 1030, December 1980
**Source: ISO 6976–2016 Table 1

**VOLUME CORRECTION FACTOR - K₁ x 10⁻³**

<table>
<thead>
<tr>
<th>Molecular weight of mixture g.mol⁻¹</th>
<th>105 K</th>
<th>110 K</th>
<th>115 K</th>
<th>120 K</th>
<th>125 K</th>
<th>130 K</th>
<th>135 K</th>
</tr>
</thead>
<tbody>
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<td>16</td>
<td>-0.007</td>
<td>-0.008</td>
<td>-0.009</td>
<td>-0.010</td>
<td>-0.013</td>
<td>-0.015</td>
<td>-0.017</td>
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<td>0.180</td>
<td>0.220</td>
<td>0.250</td>
<td>0.295</td>
<td>0.345</td>
<td>0.400</td>
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<tr>
<td>18</td>
<td>0.340</td>
<td>0.375</td>
<td>0.440</td>
<td>0.500</td>
<td>0.590</td>
<td>0.700</td>
<td>0.825</td>
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<tr>
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<td>0.535</td>
<td>0.610</td>
<td>0.695</td>
<td>0.795</td>
<td>0.920</td>
<td>1.060</td>
</tr>
<tr>
<td>20</td>
<td>0.635</td>
<td>0.725</td>
<td>0.810</td>
<td>0.920</td>
<td>1.035</td>
<td>1.200</td>
<td>1.390</td>
</tr>
<tr>
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<td>0.835</td>
<td>0.945</td>
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<td>1.210</td>
<td>1.370</td>
<td>1.590</td>
</tr>
<tr>
<td>22</td>
<td>0.840</td>
<td>0.950</td>
<td>1.065</td>
<td>1.205</td>
<td>1.385</td>
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<td>1.800</td>
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<td>1.640</td>
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<td>1.550</td>
<td>1.750</td>
<td>1.990</td>
<td>2.272</td>
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</tbody>
</table>

Source: NBS - Technical note 1030, December 1980
### VOLUME CORRECTION FACTOR - $K_2 \times 10^{-3}$

<table>
<thead>
<tr>
<th>Molecular weight of mixture</th>
<th>Volume reduction, L.mol$^{-1}$</th>
<th>105 K</th>
<th>110 K</th>
<th>115 K</th>
<th>120 K</th>
<th>125 K</th>
<th>130 K</th>
<th>135 K</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-0.015</td>
<td>-0.024</td>
<td>-0.032</td>
<td>-0.043</td>
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<tr>
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<td>0.320</td>
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<tr>
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<td>0.920</td>
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<td>2.600</td>
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<td>21</td>
<td>0.910</td>
<td>1.070</td>
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<td>1.630</td>
<td>1.980</td>
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<td>3.000</td>
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<tr>
<td>22</td>
<td>1.050</td>
<td>1.220</td>
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<td>1.850</td>
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<tr>
<td>23</td>
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<td>2.480</td>
<td>3.000</td>
<td>3.770</td>
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</tr>
<tr>
<td>24</td>
<td>1.330</td>
<td>1.520</td>
<td>1.650</td>
<td>2.300</td>
<td>2.750</td>
<td>3.320</td>
<td>3.990</td>
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<tr>
<td>25</td>
<td>1.450</td>
<td>1.710</td>
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<td>2.450</td>
<td>2.900</td>
<td>3.520</td>
<td>4.230</td>
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</tbody>
</table>

Source: NBS - Technical note 1030, December 1980

### APPENDIX 2 – Data from standard ISO 6976-2016

<table>
<thead>
<tr>
<th>Component</th>
<th>Molar mass (kg.kmol$^{-1}$) $M_i$</th>
<th>Gross heating value on a molar basis (kJ.mol$^{-1}$) $H_i(t_1)$ @ 0°C</th>
<th>Gross heating value on a volumetric basis (MJ.m$^{-3}$) $H_i(t_1; V(t_2, p_2))$ @ 0/0°C</th>
<th>Summation factor $\sqrt{b_i} @ 0°C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>16.04246</td>
<td>892.92</td>
<td>39.838</td>
<td>0.04886</td>
</tr>
<tr>
<td>Ethane</td>
<td>30.06904</td>
<td>1564.35</td>
<td>69.79</td>
<td>0.0997</td>
</tr>
<tr>
<td>Propane</td>
<td>44.09562</td>
<td>2224.03</td>
<td>99.23</td>
<td>0.1465</td>
</tr>
<tr>
<td>n-Butane</td>
<td>58.12220</td>
<td>2883.35</td>
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</tr>
<tr>
<td>2-Methyl propane</td>
<td>58.12220</td>
<td>2874.21</td>
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</tr>
<tr>
<td>n-Pentane</td>
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<tr>
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<td>0.2458</td>
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