LNG CARGO TRANSFER
CALCULATION METHODS AND ROUNDDING-OFFS

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. Unloading (or reloading) certificate and unloading (or reloading) assessment
   Appendix 1 – Data from NBS - Technical note 1030, December 1980
   Appendix 2 – Data from ISO 6976-1995
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.

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 arriving; 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, EG):
  \[
  E = E_{\text{LNG}} - E_{\text{NG}} - E_{\text{EG}}
  \]

- 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, EG):
  \[
  E = E_{\text{LNG}} - E_{\text{NG}} + E_{\text{EG}}
  \]
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 evaporation 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),
- \( E_{\text{EG}} = 0.04 \% \) of the transferred LNG (if no metering system for engine gas consumption onboard),
- \( E_{\text{EG}} \): 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.
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) method¹ 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>
<tr>
<td>Temperature (T)</td>
<td>&lt; 115 K</td>
</tr>
<tr>
<td></td>
<td>(equivalent to &lt; -158.15 °C)</td>
</tr>
</tbody>
</table>

- **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:

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

  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 Klosek-McKinley method: Four mathematical models for the prediction of LNG densities - NBS Technical Note 1030 - December 1980.
with:

- \( M_i \): molar mass of component \( i \) according to table 1 of ISO 6976-1995 (cf. appendix 2 of this note)
- \( x_i \): molar fraction of component \( i \)

\( \mathcal{V}_{\text{LNG}} \): molar volume of LNG in L.mol\(^{-1}\), defined as:

\[
\mathcal{V}_{\text{LNG}} = \sum x_i \mathcal{V}_i - \left[ K_1 + (K_2 - K_1) \cdot \left( \frac{x_{N_2}}{0.0425} \right) \right] \cdot x_{\text{CH}_4}
\]

with:

- \( \mathcal{V}_i \): molar volume of component \( i \) at LNG temperature
- \( K_1, K_2 \): correction factors
- \( \mathcal{V}_{\text{mol}} = \sum x_i \mathcal{V}_i \)

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 \( C_6 \) 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 \( \mathcal{V}_{\text{mol}} \).**

### 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 \( H_{\text{LNG}} \)

### 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 6976-1995 « Natural gas - Calculation of calorific values, density, relative density and Wobbe index from composition ».

The relation used is produced thus:

\[
H_{\text{LNG}} = \sum_{i=1}^{N} \left( x_i \cdot \frac{M_i}{M_{\text{LNG}}} \right) \cdot \hat{H}_i(t_i)
\]

where:

- \( H_{\text{LNG}} \): LNG gross heating value on a **mass** basis
- \( x_i \): molar fraction of component \( i \)
- \( M_i \): molar mass of component \( i \)
- \( M_{\text{LNG}} = \sum_{i=1}^{N} x_i \cdot M_i \): molar mass of LNG
\[ \hat{H}_i^\circ(t_i) = \frac{H_i^\circ(t_i)}{M_i} \]

**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 6976-1995. **No rounding-off of** \(H_{\text{LNG}}\) **is made to calculate the gross transferred energy.**

### 2.2 Calculating the return gas energy

The calculation of the returned energy (gas return NG) \(E_{\text{NG}}\) is based on the following terms:

- the volume of return gas, \(V_{\text{NG}}\),
- the gross heating value (on a volumetric basis) of the return gas \(H_{\text{NG}}\).

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

#### 2.2.1 Calculating the return gas volume \(V_{\text{NG}}\)

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 evaporations 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 evaporations 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.

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

where:

- \(V_{\text{NG}}\): 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 ºC. 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 ºC 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 ºC; 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 6976-1995 «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 8,314 510 J.mol⁻¹.K⁻¹
- $T_2 = (t_2 + 273.15)$ : absolute temperature in K, with $t_2$ in ºC

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

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

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:

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

where:
\( H_{NG} \): actual gross heating value (on a **volumetric** basis) of the return gas

\( Z_{net} \): compressibility factor of the return gas equal to

\[ 1 - \left( \sum_{i=1}^{N} x_i \sqrt{b_i} \right)^2 \]

with \( \sqrt{b_i} \): so-called summation factor of component i

**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 - 1995. **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

**Cas n° 1 :** no gas consumption by carrier’s engine 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 0.04 % of the gross energy of the transferred LNG is applied:

\[ E_{EG} = 0.0004 \times E_{LNG} \]

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:

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

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 6976-1995, 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:

- \( H_{NG} \): gross heating value (on a mass basis) of NG in MJ.kg\(^{-1}\) at \( T_{\text{reference combustion}} = 0 \, ^\circ C \),
- \( H_i \): gross heating value (on a mass basis) of component \( i \) in MJ.kg\(^{-1}\) at \( T_{\text{reference combustion}} = 0 \, ^\circ C \), 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:

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

where:

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

As mentioned above, \( H_{EG} \) is equivalent to \( H_{NG} \). 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, \( V_{EG} \)

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

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

where:

- \( Z_{ref}, Z_{NG} \): compressibility factor of BOG or return gas, at reference conditions and actual conditions respectively;
- \( T_{ref}, T_{NG} \): respectively reference temperature and BOG or return gas actual temperature (measured at the volume gas flowmeter);
- \( P_{ref}, P_{NG} \): 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:
  \[ E = V_{\text{LNG}} \left( \rho_{\text{LNG}} \cdot \text{H}_{\text{LNG}} \right) - \left( \frac{273.15}{273.15 + t} \cdot \frac{P}{1.01325} \cdot \text{H}_{\text{NG}} \right) + E_{\text{EG}} \]

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

❖ 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 m³ 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,

$\text{H}_{\text{LNG}}$: 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,

$\text{H}_{\text{NG}}$: gross heating value of the evaporation gas or of the return gas expressed in MJ/m³(n) or kWh/m³(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 m³ to be rounded to nearest kg or m³.

If no gas metering, a fixed rate of 0.04 % 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 CO₂ traces in the LNG, the CO₂ molar fraction is added to the N₂ molar fraction for all energy calculations.

❖ Conversions

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

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

For other $T_{reference.combustion}$, conversion factors are not the same. For instance:

1 MMBtu (T_{reference.combustion} = 15 °C) = 1 055.119 MJ (T_{reference.combustion} = 60 °F)
3. Unloading (or reloading) certificate and unloading (or reloading) assessment

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 m$^3$ to (3) three decimal places
- **Volume of LNG after transfer**: in m$^3$ to (3) three decimal places
- **Volume of transferred LNG**: in m$^3$ 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
- **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)
**APPENDIX 1 – Data from NBS - Technical note 1030, December 1980**

**COMPONENT MOLAR VOLUMES (L/mol)**

<table>
<thead>
<tr>
<th>Component</th>
<th>118 K</th>
<th>116 K</th>
<th>114 K</th>
<th>112 K</th>
<th>110 K</th>
<th>108 K</th>
<th>106 K</th>
<th>Molar mass**, kg.kmol⁻¹**</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>0.038817</td>
<td>0.038536</td>
<td>0.038262</td>
<td>0.037995</td>
<td>0.037735</td>
<td>0.037481</td>
<td>0.037234</td>
<td>16.043</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>0.048356</td>
<td>0.048184</td>
<td>0.048014</td>
<td>0.047845</td>
<td>0.047678</td>
<td>0.047512</td>
<td>0.047348</td>
<td>30.070</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>0.062939</td>
<td>0.062756</td>
<td>0.062574</td>
<td>0.062392</td>
<td>0.062212</td>
<td>0.062033</td>
<td>0.061855</td>
<td>44.097</td>
</tr>
<tr>
<td>iC₄H₁₀</td>
<td>0.078844</td>
<td>0.078640</td>
<td>0.078438</td>
<td>0.078236</td>
<td>0.078035</td>
<td>0.077836</td>
<td>0.077637</td>
<td>58.123</td>
</tr>
<tr>
<td>nC₄H₁₀</td>
<td>0.077344</td>
<td>0.077150</td>
<td>0.076957</td>
<td>0.076765</td>
<td>0.076574</td>
<td>0.076384</td>
<td>0.076194</td>
<td>58.123</td>
</tr>
<tr>
<td>iso + neo-C₅H₁₂</td>
<td>0.092251</td>
<td>0.092032</td>
<td>0.091814</td>
<td>0.091596</td>
<td>0.091379</td>
<td>0.091163</td>
<td>0.090948</td>
<td>72.150</td>
</tr>
<tr>
<td>C₆⁺ + n-C₅H₁₂</td>
<td>0.092095</td>
<td>0.091884</td>
<td>0.091673</td>
<td>0.091462</td>
<td>0.091252</td>
<td>0.091042</td>
<td>0.090833</td>
<td>72.150</td>
</tr>
<tr>
<td>N₂ (+ CO₂)</td>
<td>0.050885</td>
<td>0.049179</td>
<td>0.047602</td>
<td>0.046231</td>
<td>0.045031</td>
<td>0.043963</td>
<td>0.043002</td>
<td>28.0135</td>
</tr>
</tbody>
</table>

*Source: NBS - Technical note 1030, December 1980

**Source: ISO 6976–1995 Table 1

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

<table>
<thead>
<tr>
<th>Molecular weight of mixture g.mol⁻¹</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>
<td>16</td>
<td></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>
</tr>
<tr>
<td>17</td>
<td></td>
<td>0.165</td>
<td>0.180</td>
<td>0.220</td>
<td>0.250</td>
<td>0.295</td>
<td>0.345</td>
<td>0.400</td>
</tr>
<tr>
<td>18</td>
<td></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>
</tr>
<tr>
<td>19</td>
<td></td>
<td>0.475</td>
<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></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>
<td>21</td>
<td></td>
<td>0.735</td>
<td>0.835</td>
<td>0.945</td>
<td>1.055</td>
<td>1.210</td>
<td>1.370</td>
<td>1.590</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>0.840</td>
<td>0.950</td>
<td>1.065</td>
<td>1.205</td>
<td>1.385</td>
<td>1.555</td>
<td>1.800</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>0.920</td>
<td>1.055</td>
<td>1.180</td>
<td>1.330</td>
<td>1.525</td>
<td>1.715</td>
<td>1.950</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>1.045</td>
<td>1.155</td>
<td>1.280</td>
<td>1.450</td>
<td>1.640</td>
<td>1.860</td>
<td>2.105</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>1.120</td>
<td>1.245</td>
<td>1.380</td>
<td>1.550</td>
<td>1.750</td>
<td>1.990</td>
<td>2.272</td>
</tr>
</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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>105 K</td>
</tr>
<tr>
<td>16</td>
<td>-0.010</td>
</tr>
<tr>
<td>17</td>
<td>0.240</td>
</tr>
<tr>
<td>18</td>
<td>0.420</td>
</tr>
<tr>
<td>19</td>
<td>0.610</td>
</tr>
<tr>
<td>20</td>
<td>0.750</td>
</tr>
<tr>
<td>21</td>
<td>0.910</td>
</tr>
<tr>
<td>22</td>
<td>1.050</td>
</tr>
<tr>
<td>23</td>
<td>1.190</td>
</tr>
<tr>
<td>24</td>
<td>1.330</td>
</tr>
<tr>
<td>25</td>
<td>1.450</td>
</tr>
</tbody>
</table>

Source: NBS - Technical note 1030, December 1980

### APPENDIX 2 – Data from standard ISO 6976-1995

<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$^{-1}$) $H_i(t_i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>16.043</td>
<td>892.97</td>
</tr>
<tr>
<td>Ethane</td>
<td>30.070</td>
<td>1564.34</td>
</tr>
<tr>
<td>Propane</td>
<td>44.097</td>
<td>2224.01</td>
</tr>
<tr>
<td>n-Butane</td>
<td>58.123</td>
<td>2883.82</td>
</tr>
<tr>
<td>2-Methyl propane</td>
<td>58.123</td>
<td>2874.20</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>72.150</td>
<td>3542.89</td>
</tr>
<tr>
<td>2-Methyl butane</td>
<td>72.150</td>
<td>3535.98</td>
</tr>
<tr>
<td>2,2-Methylpropane</td>
<td>72.150</td>
<td>3521.72</td>
</tr>
<tr>
<td>C$_6$+</td>
<td>86.177</td>
<td>4203.23</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>28.0135</td>
<td>0</td>
</tr>
</tbody>
</table>