LNG CARGO TRANSFER

CALCULATION METHODS AND ROUNDING-OFFS

CONTENTS

Elengy – SA au capital de 132 202 620 Euros – RCS Nanterre 451 438 782
Siège social : 11 avenue Michel Ricard – 92270 Bois-Colombes – France
www.elengy.com

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.

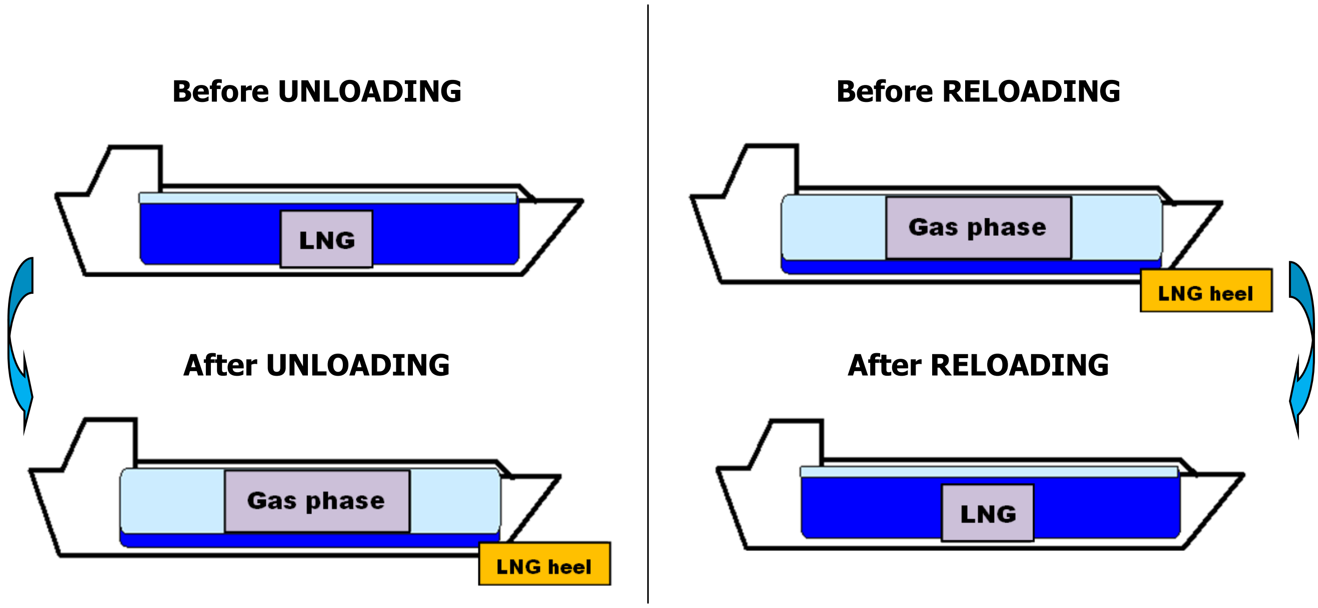


Figure 1: Phases of LNG cargo transfer(before and after)

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, EG):

$$\mathbf{E = E_{LNG} - E_{NG} - E_{EG}}$$

- 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, EG):

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

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:**

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

where:

V_{LNG} : volume of LNG measured in the LNG carrier's tanks;

ρ_{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 analyses of the LNG.

- **Return gas (NG) :**

$$E_{NG} = V_{NG} \cdot H_{NG}$$

where:

V_{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_{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_{EG} = 0 (no gas is consumed),
- E_{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_{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).

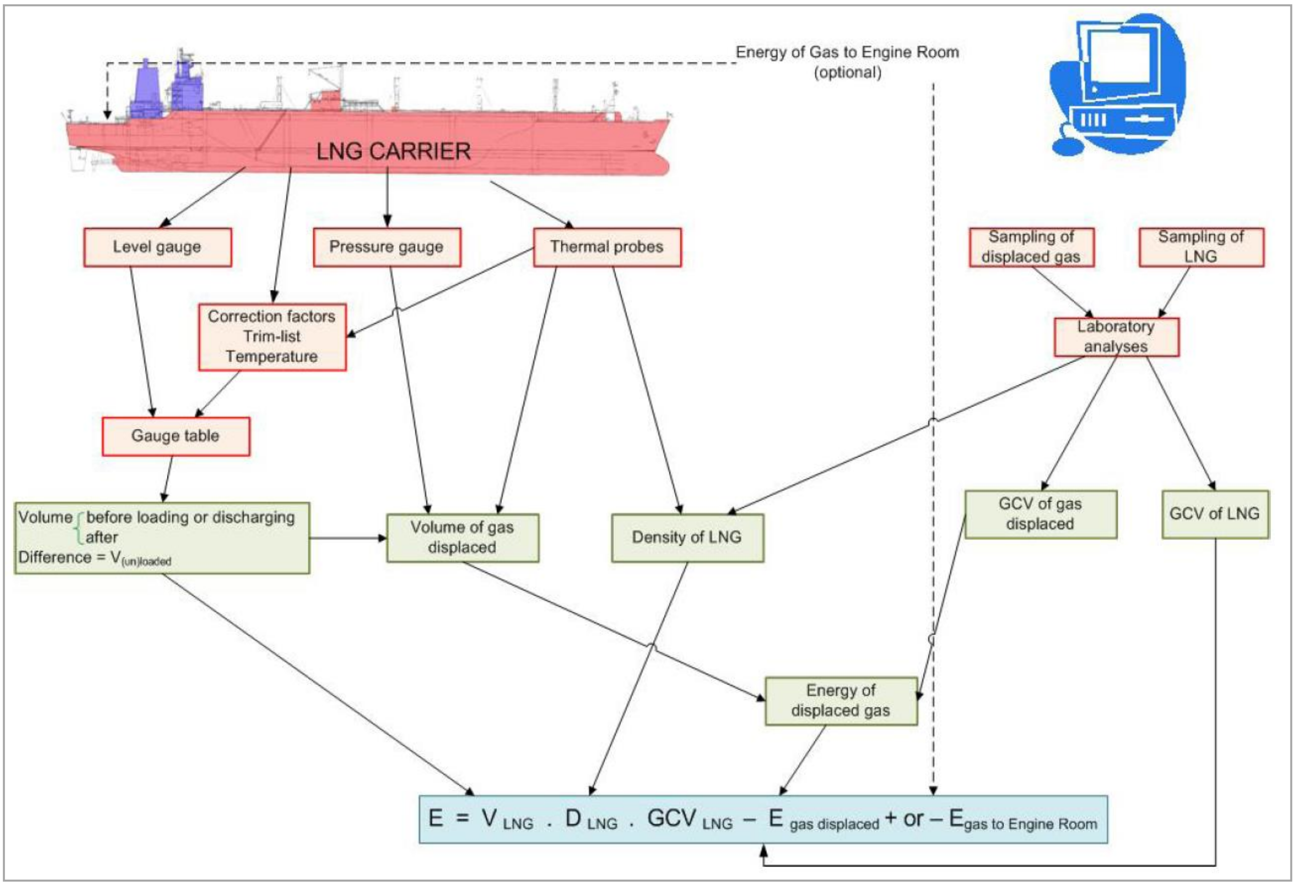


Figure 2 : Determining the transferred energy (using cargo measurement data)
Source: LNG Custody Transfer Handbook, 6th edition, GIIGNL, 2021

2. Calculating the transferred energy

2.1 Calculating the gross transferred energy

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

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

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

2.1.1 Calculating the transferred LNG volume V_{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 ρ_{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[1]; **the temperature of the LNG is taken in °C with 1 decimal place**.

Elengy uses the revised Klosek-McKinley (KMK) method[2] 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:

Methane (CH_4)	> 60 % mol.
Iso and normal butanes ($iC_4 + nC_4$)	< 4 % mol.
Iso and normal pentanes ($iC_5 + nC_5$)	< 2 % mol.
Nitrogen (N_2)	< 4 % mol.
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:

$$\rho_{LNG} = \frac{M_{LNG}}{\upsilon_{LNG}}$$

where:

ρ_{LNG} : density of LNG in kg.m^{-3}

$M_{LNG} = \sum x_i \cdot M_i$: 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.

with:

M_i : molar mass of component i according to table 1 of ISO 6976-2016 (cf. appendix 2 of this note)

x_i : molar fraction of component i

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

$$\mathcal{V}_{LNG} = \sum x_i . \mathcal{V}_i - \left[K_1 + (K_2 - K_1) \cdot \left(\frac{x_{N_2}}{0,0425} \right) \right] \cdot x_{CH_4}$$

with:

$\mathcal{V}_i$: molar volume of component i at LNG temperature

K_1, K_2 : correction factors

and $\mathcal{V}_{mol} = \sum x_i . \mathcal{V}_i$

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_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 $\mathcal{V}_{mol}$.**

- **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:

$$H_{LNG} = \sum_{i=1}^{N} \left[\left(x_i \cdot \frac{M_i}{M_{LNG}} \right) \cdot \hat{H}_i^{\circ}(t_1) \right]$$

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

$\hat{H}_i^{o}(t_1)$: 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:

$$\hat{H}_i^o(t_1) = \frac{\overline{H_i^o(t_1)}}{M_i}$$ (see data in appendix 2 of this note)

❖ **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_{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) $\mathbf{E_{NG}}$ is based on the following terms:

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

$$\mathbf{E_{NG} = V_{NG} \, . \, H_{NG}}$$

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 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.

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

where:

$\mathbf{V_{NG}}$: 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 $\mathbf{V_{NG}}$ 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:

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

where:

$\tilde{H}_i^\circ[t_1, V(t_2, P_2)]$: ideal gross heating value (on a volumetric basis) of component i

$\overline{H_i^\circ}(t_1)$: ideal gross heating value (on a molar basis) of component i

R : molar constant of the gases being equal to 8,314 462 1 $J.mol^{-1}.K^{-1}$

$\mathbf{T_2 = (t_2 + 273.15)}$: absolute temperature in K, with $\mathbf{t_2}$ in °C

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

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

where $\mathbf{x_i}$ 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:

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

where:

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

$\mathbf{Z_{mel}}$: compressibility factor of the return gas equal to $1 - \left[\sum_{i=1}^{N} \left(x_i \sqrt{b_i} \right) \right]^2$

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 6976-2016. **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:

$$\mathbf{E_{EG} = 0}$$

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

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:

$$\mathbf{H_{EG} = H_{NG}}$$

where $\mathbf{H_{EG}}$ is the gross heating value of the gas consumed by the carrier's engine and $\mathbf{H_{NG}}$ 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:

$$\mathbf{E_{EG} = 0.001\ E_{LNG}}$$

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:

$$\mathbf{E_{EG} = H_{EG}\ .\ m_{EG}}$$

where:

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

$\mathbf{m_{EG}}$: 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_{NG} : gross heating value (on a <u>mass</u> basis) of NG in $MJ.kg^{-1}$ at $T_{reference\ combustion}$ = 0 °C,

H_i : gross heating value (on a <u>mass</u> basis) of component i in $MJ.kg^{-1}$ at $T_{reference\ combution}$ = 0 °C, equal to the gross heating value (on a <u>molar</u> basis) of the component i divided by its molar mass Mi (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 m³** using the following equation:

$$E_{EG} = H_{EG} \cdot V_{EG}$$

where:

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

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

<u>2.3.1 Determining the gross heating value of the gas consumed by the LNG carrier's engine H_{EG}</u>

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

<u>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}</u>

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

$$V_{EG} = \frac{Z_{ref}}{Z_{NG}} \cdot \frac{T_{ref}}{T_{NG}} \cdot \frac{P_{NG}}{P_{ref}} \cdot V_{EGactual}$$

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:

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

- cargo reloading:

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

❖ **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_{LNG} : volume of transferred LNG, expressed in m^3 to 3 decimal places,

ρ_{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_{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_{LNG} : gross heating value (on a <u>mass</u> 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_{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_{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_{LNG} is applied.
If no gas is consumed at carrier's engine, E_{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 ($T_{reference\ combustion}$) = 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. 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 :

$$\mathbf{V_{Gas} = V_{LNG}} \times \mathbf{Expansion\ factor}$$

where :

V_{LNG} : volume of LNG given by cargo tank gassing-up tables, expressed in m^3_{GNL}

Expansion Factor : from the LNG composition and temperature measured in the terminal tank (usually between 569 and 576), expressed in $m^3(n)/m^3_{LNG}$

The gassing-up energy is given by :

$$\mathbf{E_{Gassing\text{-}up} = V_{Gas}} \times \mathbf{H}_{vol.\ LNG}$$

where :

$E_{Gassing\text{-}up}$: energy for gassing-up, expressed in kWh/m^3(n)

V_{Gas} : gas volume expressed in reference pressure and temperature conditions (0°C ; 1,01325 bar) and expressed in m^3(n).

$H_{vol.\ LNG}$: 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)

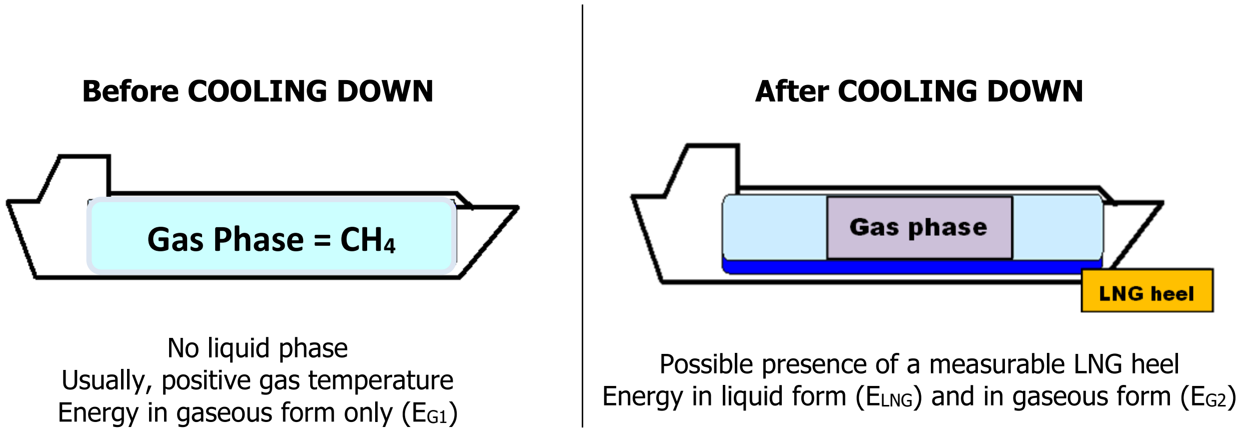


Figure 3 : Cool down operation

The net Cool Down energy $\mathbf{E_{CD}}$ 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 :

ρ_{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

$$E_{G2} = (V_{vessel} - V_{LNG2}) \times \left(\frac{273{,}15}{273{,}15 + t_2}\right) \times \frac{P_2}{1{,}01325} \times H_{vol.LNG}$$

$$E_{G1} = V_{vessel} \times \left(\frac{273{,}15}{273{,}15 + t_1}\right) \times \frac{P_1}{1{,}01325} \times H_{vol.\ CH4}$$

where :

V_{vessel} : 100% capacity of vessel's tanks

V_{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

$H_{vol.\ GNL}$: 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.

$H_{vol.\ CH4}$: 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) :**

$$\mathbf{E_{NG} = V_{NG} \times H_{NG}}$$

where :

V_{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 m^3 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_{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:

$$\mathbf{H_{EG} = H_{LNG}}$$

where **H_{EG}** is the gross heating value of the gas consumed by the carrier's engine and **H_{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:

$$\mathbf{E_{EG} = 0.001\ E_{LNG}}$$

B) <u>mass</u> 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:

$$\mathbf{E_{EG} = H_{EG} \cdot m_{EG}}$$

where:

$H_{EG} = H_{LNG}$:gross heating value (on a <u>mass</u> basis) of the LNG in $MJ.kg^{-1}$

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

C) volume flowmeter at carrier's engine; the energy of the 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:

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

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

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.

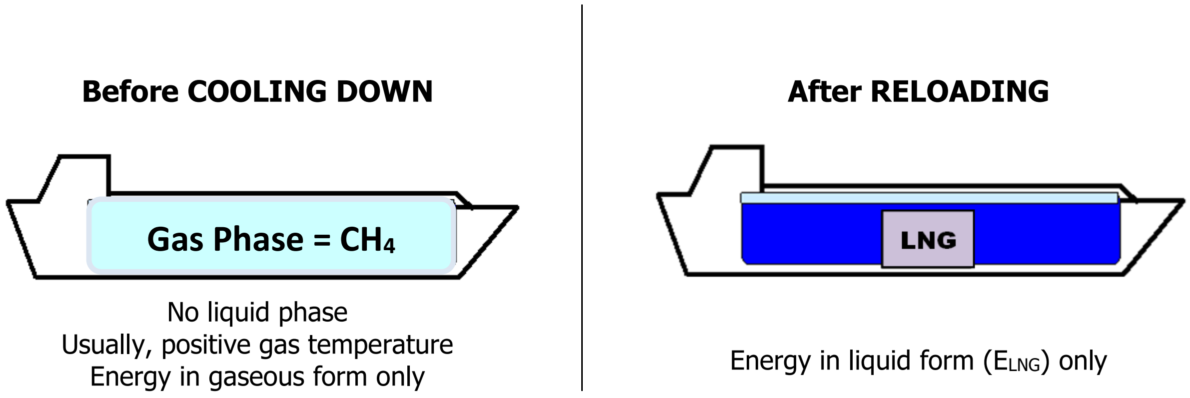


Figure 4 : Cooling down operation with reloading

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.

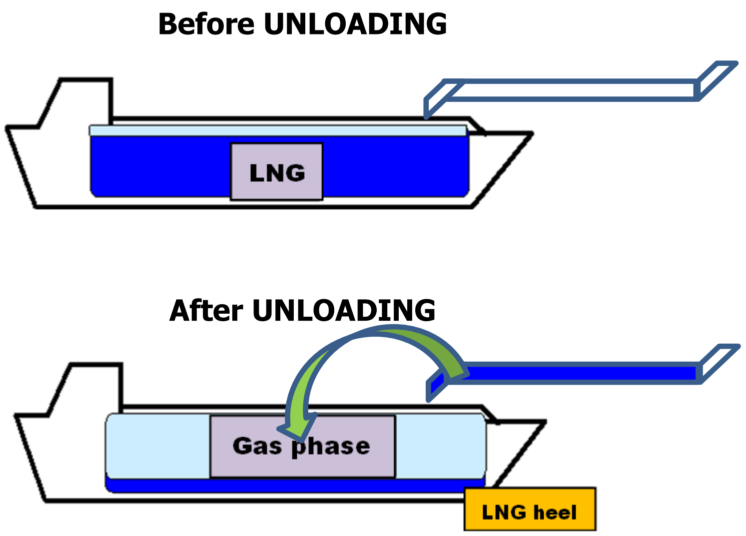
Only gas phase pressure and temperature before cooling down are recorded and taken into account for the calculation of return gas energy (**E_{NG}**).

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



During the opening custody transfer, cargo lines are empty.

During the closing custody transfer, cargo lines are full.

After the closing custody tranfer, LNG into cargo lines (V_{Lines}) is transferred into the cargo tanks.

Figure 5 : Transfer during unloading operation

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 :

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

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

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

where :

$$E_{Lines} = V_{Lines} \times \rho_{GNL} \times H_{GNL}$$

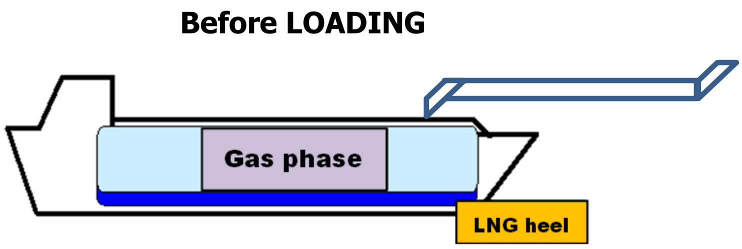
E_{LNG} : the gross transferred energy

E_{Lines} : energy contained in cargo lines

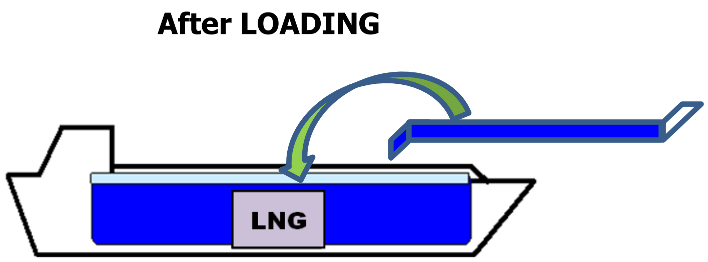
E_{NG} : return gas energy

E_{EG} : energy consumed by the LNG carrier’s engine

5.2 Loading case



During the opening custody transfer, cargo lines are empty.



During the closing custody transfer, cargo lines are full.

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

Figure 6 : Transfer during loading operation

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 « **E** » is then :

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

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

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

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

Whatever the type of transfer (unloading or loading), the volume of LNG contained in the cargo lines (**V_{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 m^3 to (3) three decimal places
Volume of LNG after transfer	: in m^3 to (3) three decimal places
Volume of LNG from cargo lines	: in m^3 to nearest m^3 (no decimal places)
Volume of gross transferred LNG	: in m^3 to (3) three decimal places
Volume of net 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
Methane number[4]	: 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)

[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 ($\mathcal{V}_i$)

Component	Molar volume*, $L.mol^{-1}$							Molar mass**, $kg.kmol^{-1}$
	118 K	116 K	114 K	112 K	110 K	108 K	106 K	
CH_4	0.038817	0.038536	0.038262	0.037995	0.037735	0.037481	0.037234	16.04246
C_2H_6	0.048356	0.048184	0.048014	0.047845	0.047678	0.047512	0.047348	30.06904
C_3H_8	0.062939	0.062756	0.062574	0.062392	0.062212	0.062033	0.061855	44.09562
iC_4H_{10}	0.078844	0.078640	0.078438	0.078236	0.078035	0.077836	0.077637	58.12220
nC_4H_{10}	0.077344	0.077150	0.076957	0.076765	0.076574	0.076384	0.076194	58.12220
iso + neo-C_5H_{12}	0.092251	0.092032	0.091814	0.091596	0.091379	0.091163	0.090948	72.14878
$C6^+$ + n-C_5H_{12}	0.092095	0.091884	0.091673	0.091462	0.091252	0.091042	0.090833	72.14878
N_2 (+ CO_2)	0.050885	0.049179	0.047602	0.046231	0.045031	0.043963	0.043002	28.0134

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

VOLUME CORRECTION FACTOR - $K_1 \times 10^{-3}$

Molecular weight of mixture $g.mol^{-1}$	Volume reduction, $L.mol^{-1}$						
	105 K	110 K	115 K	120 K	125 K	130 K	135 K
16	-0.007	-0.008	-0.009	-0.010	-0.013	-0.015	-0.017
17	0.165	0.180	0.220	0.250	0.295	0.345	0.400
18	0.340	0.375	0.440	0.500	0.590	0.700	0.825
19	0.475	0.535	0.610	0.695	0.795	0.920	1.060
20	0.635	0.725	0.810	0.920	1.035	1.200	1.390
21	0.735	0.835	0.945	1.055	1.210	1.370	1.590
22	0.840	0.950	1.065	1.205	1.385	1.555	1.800
23	0.920	1.055	1.180	1.330	1.525	1.715	1.950
24	1.045	1.155	1.280	1.450	1.640	1.860	2.105
25	1.120	1.245	1.380	1.550	1.750	1.990	2.272

Source: NBS - Technical note 1030, December 1980

VOLUME CORRECTION FACTOR - $K_2 \times 10^{-3}$

Molecular weight of mixture	Volume reduction, $L.mol^{-1}$						
	105 K	**110 K**	**115 K**	**120 K**	**125 K**	**130 K**	**135 K**
16	-0.010	-0.015	-0.024	-0.032	-0.043	-0.058	-0.075
17	0.240	0.320	0.410	0.600	0.710	0.950	1.300
18	0.420	0.590	0.720	0.910	1.130	1.460	2.000
19	0.610	0.770	0.950	1.230	1.480	1.920	2.400
20	0.750	0.920	1.150	1.430	1.730	2.200	2.600
21	0.910	1.070	1.220	1.630	1.980	2.420	3.000
22	1.050	1.220	1.300	1.850	2.230	2.680	3.400
23	1.190	1.370	1.450	2.080	2.480	3.000	3.770
24	1.330	1.520	1.650	2.300	2.750	3.320	3.990
25	1.450	1.710	2.000	2.450	2.900	3.520	4.230

Source: NBS - Technical note 1030, December 1980

APPENDIX 2 – Data from standard ISO 6976-2016

Component	Molar mass ($kg.kmol^{-1}$) M_i	Gross heating value on a molar basis ($kJ.mol^{-1}$) $H_i^\circ(t_1)$ @ 0°C	Gross heating value on a volumetric basis ($MJ.m^3$) $\widetilde{H}_i^\circ(t_1; V(t_2, p_2))$ @ 0/0°C	Summation factor $\sqrt{bi}$ @ 0°C
Methane	16.04246	892.92	39.838	0.04886
Ethane	30.06904	1564.35	69.79	0.0997
Propane	44.09562	2224.03	99.23	0.1465
n-Butane	58.12220	2883.35	128.64	0.2022
2-Methyl propane	58.12220	2874.21	128.23	0.1885
n-Pentane	72.14878	3542.91	158.07	0.2586
2-Methyl butane	72.14878	3536.01	157.76	0.2458
2,2-Methylpropane	72.14878	3521.75	157.12	0.2245
C_{6+}	86.17536	4203.24	187.53	0.3319
Nitrogen	28.0134	0	0	0.0214
Carbon dioxide	44.0095	0	0	0.0821