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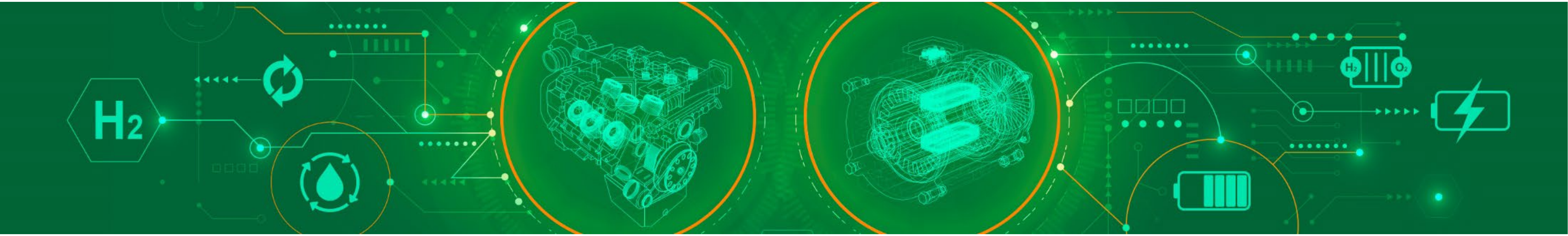
Fuel composition correction for Cslip

19 February 2026



CONTENT

- Methane slip equations
- Methane slip calculation example
- Options, pros & cons
- Calculation examples for options
- Calculation of methane emissions from measured THC
- Attachments
  - Equations
  - Fuel compositions

METHANE SLIP EQUATIONS

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1. IMO EQUATION

ANNEX 5

DRAFT MEPC RESOLUTION

GUIDELINES FOR TEST-BED AND ONBOARD MEASUREMENTS OF METHANE (CH_4) AND/OR NITROUS OXIDE (N_2O) EMISSIONS FROM MARINE DIESEL ENGINES

MEPC 83/WP.10
Annex 5, page 7

5.12.6 Calculation of the specific emission	Calculate CH_4 (g/kg fuel and g/kWh), N_2O (g/kg fuel and g/kWh) and $C_{slip\text{-}CH4}$ (% of the mass of the methane containing fuel used by the engine) for each load point where emissions are measured. $C_{fgas} = q_{mgas}$ /fuel flow $C_{slip\text{-}CH4} = (q_{mCH4}$ /fuel flow$)\cdot 100$ (1) Calculate the average weighed emissions $C_{fgas} = \sum\_i{=}1...n\ (q_{mgas} \cdot W_{Fi})$ / sum_i=1..n $(q_{fuel,i} \cdot W_{Fi})$ With $q_{fuel,i}$ being the fuel flow at each mode point. $C_{slip\text{-}CH4} = \sum\_i{=}1...n\ (q_{mCH4} \cdot W_{Fi})$ / 10 / sum_i=1..n $(q_{fuel,i} \cdot W_{Fi})$ q_{mgas} (g/h): see section 5.12.5.2 of the NTC 2008, equation 18a Fuel flow (kg/h) as measured.

Fuel composition effect in current calculation method

- Methane emission and exhaust hydrocarbon composition are dependent on fuel gas composition.
- As certification emission data is used in the actual value calculation, emission values should be representative of typical gas composition. There are high variations depending on source, and composition cannot be pre-defined.
- Average methane content in LNG composition examples of ISO 23306 is 92.2 mol-%, and inert gases like N_2 or CO_2 are practically non-existent.
- Certification test done on pure methane would result significantly higher value than expected. A significant share of longer hydrocarbons, hydrogen or inert components (in natural gas from pipeline) would affect the result considerably.
- Current calculation equation is affected by the gas quality in two ways: q_{mCH4} is changed depending on CH_4 share in fuel gas but also the fuel flow is affected by the fuel gas heating value (LHV). For example:
  - Longer hydrocarbons have higher LHV, and fuel containing 90 mol-% methane and 10% ethane should result 83% of the Cslip of test done on 100% methane.
  - Gas containing 90 mol-% methane and 10% N_2 would have lower LHV than 100% methane. Measurement on such gas would result higher fuel consumption and therefore lower Cslip-%, even though expected emission would be the same
- Details and calculation examples in the following pages.

METHANE SLIP EQUATIONS

2. PROPOSED EQUATION

Assumption

- Methane emission mass flow is directly proportional to fuel methane mass flow.

By using the following formula no correction equations are needed.

$$C_{slip-CH4} = \frac{q_{mCH4}}{fuel\ methane\ flow} \times 100 \quad (2)$$

Possible solution

- If Cslip-% would be calculated by dividing methane mass flow with fuel methane mass flow, it would not be affected by the gas composition.
- **In addition, one of the following steps is required**:
  - To take into account the in-use methane content, operators would need to record the methane content of the LNG, and multiply the share of methane instead of LNG mass with the Cslip to calculate the absolute CH_4 mass during the reporting period. (option 2 shown later)
  - As a simplified approach, a corrected $C_{slip\text{-}CH4}$ could be calculated by correcting the result to reference gas composition by the equations shown in later pages. Average from ISO 23306 examples could be used as a reference. Same value would then be used for all LNG used during the reporting period. (option 3)
- Details and calculation examples in the following pages.

METHANE SLIP CALCULATION EXAMPLES*

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Gas composition	name / no	REF 100% CH4	90 mol-% methane + 10 mol-% varying component					
	name	100% CH4	C2H6	C3H8	C4H10	H2	N2	CO2
Gas composition	no	1	2	3	4	5	6	7
Engine output	kW	3000	3000	3000	3000	3000	3000	3000
Engine efficiency	%	47	47	47	47	47	47	47
Required fuel heat flow	kJ/s	6383	6383	6383	6383	6383	6383	6383
Fuel methane, CH4, mol fraction	mol-%	100.00	90.00	90.00	90.00	90.00	90.00	90.00
Fuel ethane, C2H6, mol fraction	mol-%	0.00	10.00	0.00	0.00	0.00	0.00	0.00
Fuel propane, C3H8, mol fraction	mol-%	0.00	0.00	10.00	0.00	0.00	0.00	0.00
Fuel butane, C4H10, mol fraction	mol-%	0.00	0.00	0.00	10.00	0.00	0.00	0.00
Fuel hydrogen, H2, mol fraction	mol-%	0.00	0.00	0.00	0.00	10.00	0.00	0.00
Fuel nitrogen, N2, mol fraction	mol-%	0.00	0.00	0.00	0.00	0.00	10.00	0.00
Fuel carbon dioxide, CO2, mol fraction	mol-%	0.00	0.00	0.00	0.00	0.00	0.00	10.00
SUM, all	mol-%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Fuel methane, CH4, mass fraction	w-%	100.0	82.8	76.6	71.3	98.6	83.7	76.6
Fuel methane, CH4, energy fraction	energy-%	100.0	83.5	77.9	73.1	96.8	100.0	100.0
Fuel methane mass flow, CH4	kg/h	459	383	357	335	444	459	459
Fuel mass flow, total	kg/h	459	463	467	470	450	548	599
Fuel lower heating value (LHV), average	MJ/kg	50.1	49.7	49.2	48.9	51.1	41.9	38.4
Methane emissions, expected	g/kWh	1.5	1.3	1.2	1.1	1.5	1.5	1.5
Methane emissions, expected mass flow	g/h	4587	3830	3575	3354	4438	4587	4587
Methane emission mass flow per consumed methane mass flow	**CH4 slip %**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Methane slip Cslip-CH4, IMO formula	**Cslip-CH4 %**	**1.00**	**0.83**	**0.77**	**0.71**	**0.99**	**0.84**	**0.77**

← Proposed equation (2)

← IMO equation (1)

- Methane slip per consumed methane is not sensitive to the fuel composition.
- Methane slip per consumed fuel is sensitive to the fuel composition.
- Methane emission mass flow is directly proportional to the fuel methane energy share, see equation (3)**.
- Fuel mass flow is inversely proportional to the fuel mass-based lower heating value, see equation (4)**.
- Methane slip per consumed fuel i.e. IMO equation is directly proportional to the fuel methane weight share, see equation (5)**.

* The following assumptions applied:
- Methane emission mass flow is directly proportional to the fuel methane mass flow.
- Engine efficiency is constant with varying fuel composition.

** Equation available in attachments.

OPTIONS

Option 1 – as is

- How
  - Certification & onboard: acc. to IMO equation (1) without any corrections
- Pros and cons
  - Pro: No effort needed to introduce new calculation approach
  - Cons: Certified methane slip is highly dependent on the fuel gas composition used in the certification test.
  - Cons: The calculated onboard methane emissions deviate from the actual methane emissions. The magnitude of the deviation depends on the difference between the onboard and the certification gas composition and may be significant.

Option 2 – proposed equation

- How
  - Certification: Methane slip calculation by consumed methane mass flow, see equation (2)
  - Onboard: Report and calculate emission with the consumed methane instead of the consumed fuel mass flow, see equation (2).
- Pros and cons
  - Pro: Correct result in certification test and onboard without any fuel composition corrections.
  - Pro: No reference gas definition is needed.
  - Cons: Reporting of methane consumption (requires bunker notes to include fuel composition) onboard require additional efforts.

OPTIONS

Option 3

- How
  - Certification: Methane slip corrected to the reference gas composition acc. to equation (5).
  - Onboard: To apply the consumed fuel mass flow acc. to IMO equation (1).
- Pros and cons
  - Pro: Certified methane slip value is not sensitive to the gas composition used in the certification test.
  - Pro: Recording of onboard gas composition and methane consumption is not needed.
  - Cons: The reference gas composition needs to be defined.
  - Cons: The calculated onboard methane emissions deviate from the actual methane emissions. The magnitude of the deviation depends on the difference between the onboard and the reference gas composition and may be significant.

Option 4

- To allow the freedom to select between options 2 and 3. This could be considered as a temporary solution until the record of onboard methane consumption can be expected to be always available.

See the calculation examples for the options 1, 2 and 3 in the following slides.

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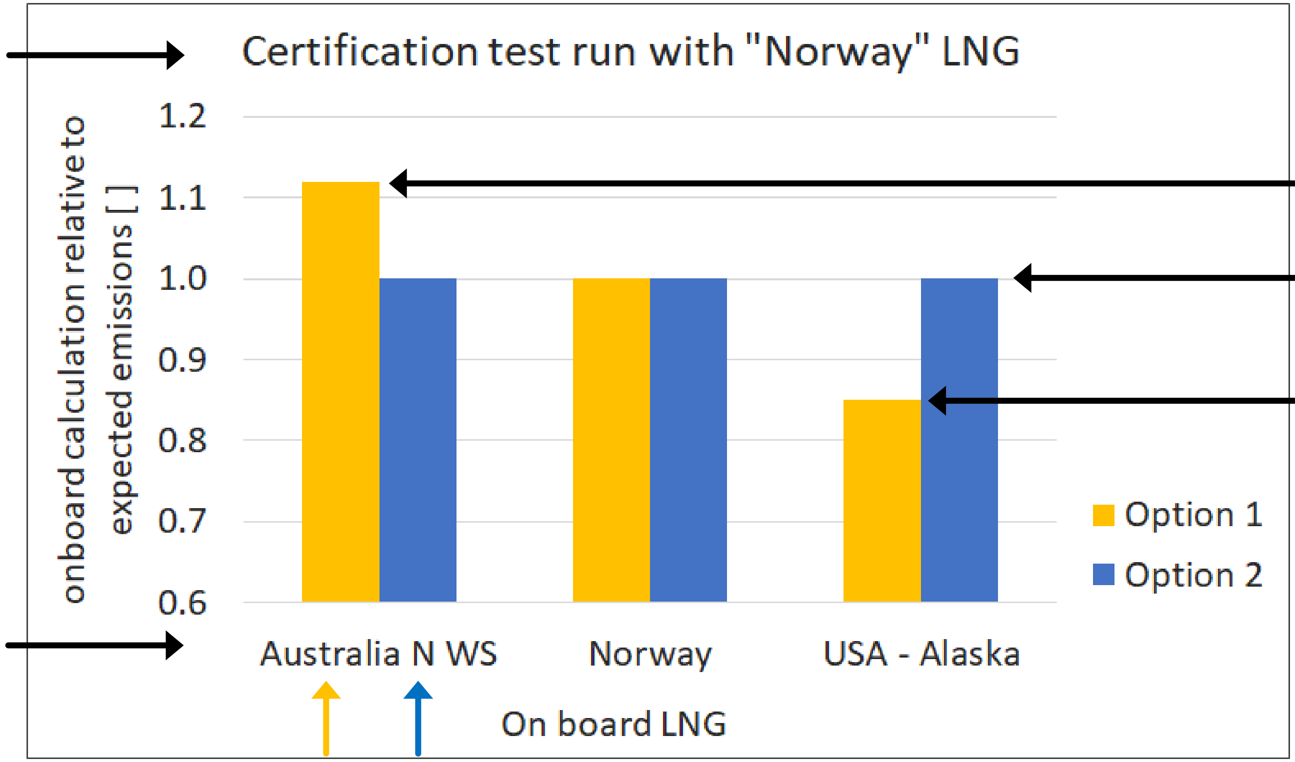
OPTIONS – CALCULATION EXAMPLES

Certification test is run with “Norway” LNG composition



Examples are given for 3 different LNG compositions: “Australia N WS”, “USA – Alaska”, “Norway” (see attachments)

Examples are given for option 1 and option 2

>1 onboard methane emission are **overestimated**

= 1 onboard methane emission calculation **equals to** the expected methane emissions

<1 onboard methane emissions are **underestimated**

Calculations by option 1 deviates from the expected emissions unless the onboard fuel corresponds to the fuel used in the certification test.
Calculations by option 2 equal always to expected emissions.

OPTIONS – CALCULATION EXAMPLES

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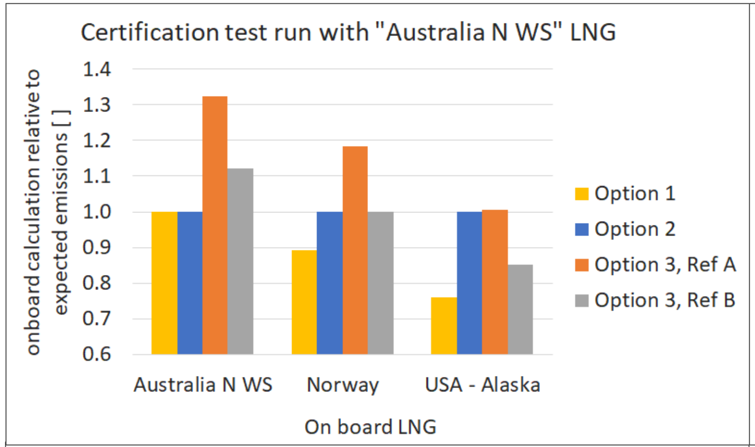
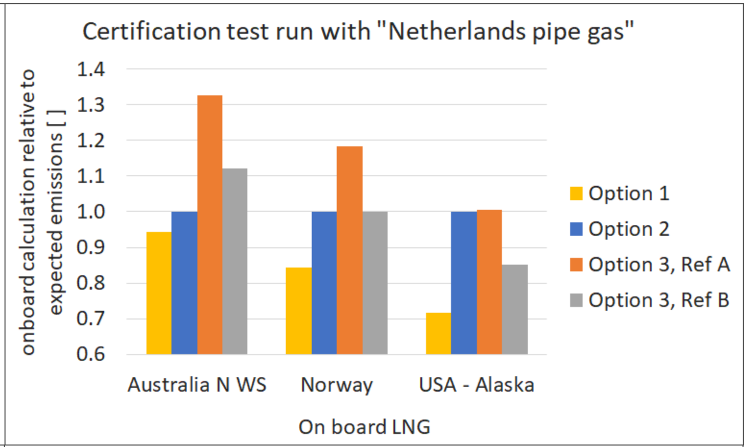
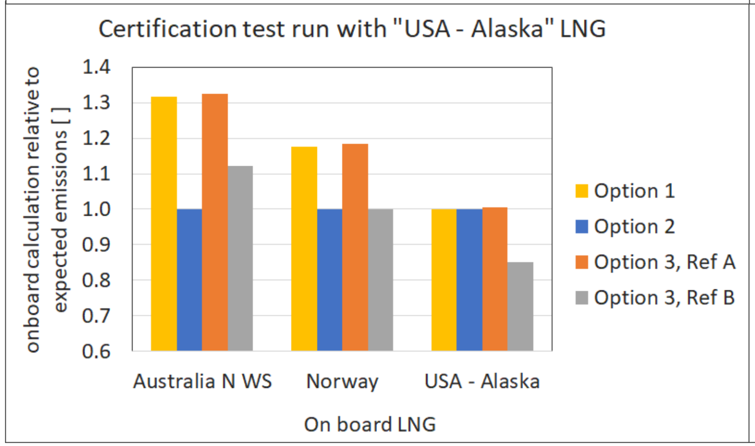
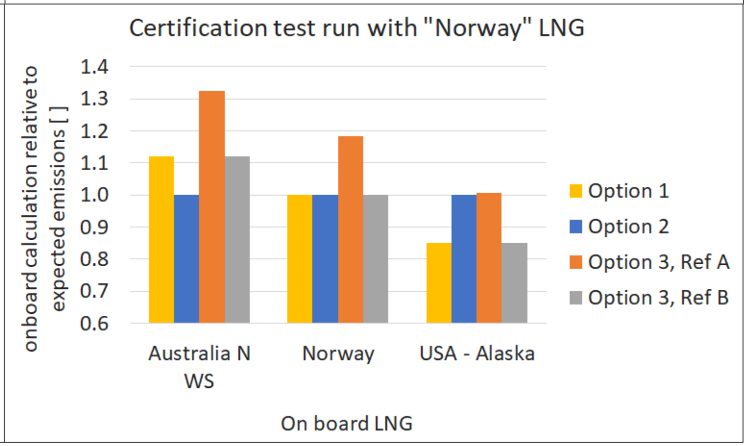
DEVIATION OF ONBOARD CALCULATION FROM THE EXPECTED EMISSIONS









Calculation examples

- Available for 4 different certification gas compositions.
- Examples calculated for options: 1, 2 and 3.
- The calculations for option 3 are given for two reference gas compositions: Ref A and Ref B.

Notes

- The deviation between calculated emissions and expected emissions can be tens of percentage depending on the calculation approach.
- Option 1: deviations sensitive to certification gas
- Options 2 and 3: deviations **not** sensitive to certification gas
- Options 1 and 3: deviations sensitive to onboard fuel
- Option 2: deviations **not** sensitive to onboard fuel
- Option 3: deviations sensitive to reference gas composition, Ref A (pure methane) demonstrating the worst case of over-estimation

LNG examples: “Australia N WS”, “USA – Alaska”, “Norway” are according to ISO 23306:2020 E. “Norway” composition is very close to Ref B.

Reference gas compositions for option 3: Ref A = 100% methane, Ref B = average of all 22 LNG examples given in ISO 23306:2020 E

Pipe gas example: “Netherlands pipe gas” is an example from the past and does not refer to any specific standard.

The gas compositions are available in the attachments.

ATTACHMENTS

EQUATIONS 1/1

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1. Methane slip calculation, acc. to 5.12.6, Annex 5, MEPC 83/WP.10

- $C_{slip-CH4} = \frac{q_{mCH4}}{fuel\ flow} \times 100$ *(1)*

2. Methane slip calculation, proposal

Assumption: Methane emission mass flow is directly proportional to fuel methane mass flow.

- $C_{slip-CH4} = \frac{q_{mCH4}}{fuel\ methane\ flow} \times 100$ *(2)*

3. Correction equation for methane emission mass flow

Assumptions:

- Methane emissions are directly proportional to consumed methane.
- Engine efficiency is constant with varying fuel composition.

$$q_{mCH4C} = q_{mCH4} \times \frac{LHV_{act}}{LHV_{ref}} \times \frac{X_{CH4ref}}{X_{CH4act}} \quad (3)$$

4. Correction equation for fuel mass flow

Assumptions: Engine efficiency is constant with varying fuel composition.

$$q_{fuelC,i} = q_{fuelact,i} \times \frac{LHV_{act}}{LHV_{ref}} \quad (4)$$

5. Correction equation for methane slip by combining (3) and (4)

$$C_{slip-CH4,C} = \frac{q_{mCH4C}}{q_{fuelC,i}} \times 100 = \frac{q_{mCH4} \times \frac{LHV_{act}}{LHV_{ref}} \times \frac{X_{CH4ref}}{X_{CH4act}}}{q_{fuelact,i} \times \frac{LHV_{act}}{LHV_{ref}}} \times 100$$

$$= \frac{q_{mCH4}}{q_{fuelact,i}} \times 100 \times \frac{X_{CH4ref}}{X_{CH4act}} = C_{slip-CH4} \times \frac{X_{CH4ref}}{X_{CH4act}} \quad (5)$$

Definitions:

- $C_{slip-CH4} = methane\ slip\ acc.\ to\ IMO\ equation\ [\%]$
- $q_{mCH4} = measured\ methane\ emission\ mass\ flow\ \left[\frac{kg}{h}\right]$
- $C_{slip-CH4} = methane\ slip\ per\ consumed\ methane\ [\%]$
- $q_{mCH4C} = methane\ emission\ mass\ flow\ corrected\ to\ the\ reference\ fuel\ \left[\frac{kg}{h}\right]$
- $LHV_{act} = lower\ heating\ value\ of\ the\ test\ fuel\ \left[\frac{MJ}{kg}\right]$
- $LHV_{ref} = lower\ heating\ value\ of\ the\ reference\ fuel\ \left[\frac{MJ}{kg}\right]$
- $X_{CH4ref} = mass\ fraction\ of\ methane\ in\ the\ reference\ fuel\ [w-\%]$
- $X_{CH4act} = mass\ fraction\ of\ methane\ in\ the\ test\ fuel\ [w-\%]$
- $q_{fuelC,i} = fuel\ mass\ flow\ corrected\ to\ the\ reference\ fuel\ \left[\frac{kg}{h}\right]$
- $q_{fuelact,i} = measured\ fuel\ mass\ flow\ \left[\frac{kg}{h}\right] = fuel\ flow$
- $C_{slip-CH4,C} = methane\ slip\ corrected\ to\ the\ reference\ fuel\ [\%]$

FUEL COMPOSITIONS USED IN EXAMPLES

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Case	name	REF A 100% CH4	Examples of LNG compositions acc. to ISO 23306:2020 E				Pipe gas, example
			Australia N WS	Norway	USA - Alaska	REF B avg (all 22 examples)	Netherlands
Fuel methane, CH4	mol-%	100.00	87.33	92.03	99.71	92.19	82.31
Fuel ethane, C2H6	mol-%	0.00	8.33	5.75	0.09	5.70	2.90
Fuel propane, C3H8	mol-%	0.00	3.33	1.31	0.03	1.40	0.43
Fuel butane, C4H10	mol-%	0.00	0.97	0.45	0.01	0.52	0.21
Fuel hydrogen, H2	mol-%	0.00	0.00	0.00	0.00	0.00	0.00
Fuel nitrogen, N2	mol-%	0.00	0.04	0.46	0.17	0.20	13.03
Fuel carbon dioxide, CO2	mol-%	0.00	0.00	0.00	0.00	0.00	1.12
SUM, all	mol-%	100.00	100.00	100.00	100.01	100.00	100.00
Fuel methane, CH4	w-%	100.0	75.5	84.5	99.4	84.6	71.2
Fuel methane, CH4	energy-%	100.0	76.7	85.9	99.7	85.7	92.2

LNG examples: “Australia N WS”, “USA – Alaska”, “Norway” are according to ISO 23306:2020 E. “Norway” composition is very close to Ref B.

Reference gas compositions: Ref A = 100% methane, Ref B = average of all 22 LNG examples given in ISO 23306:2020 E

Pipe gas example: “Netherlands pipe gas” does not refer to any specific standard. This is an example from the past.

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