BS EN 1555-1:2025

BSI Standards Publication

Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE)

Part 1: General

bsi.

National foreword

This British Standard is the UK implementation of EN 1555-1:2025. It supersedes BS EN 1555-1:2021, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PRI/88, Plastics piping systems.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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European foreword

This document (EN 1555-1:2025) has been prepared by Technical Committee CEN/TC 155 "Plastics piping and ducting systems", the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2026, and conflicting national standards shall be withdrawn at the latest by April 2026.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 1555-1:2021.

The main changes are as follows:

— terms and definitions have been distributed over EN 1555-1, EN 1555-2 and EN 1555-3;

— a conversion and normalisation step has been included to the requirement for the CRB;

— EN ISO 1183-3 has been introduced as alternative test method for the compound density;

— recommended stress ranges for the CRB and stress levels for the AFNCT have been added;

— the strip-bend test (ISO 21751) and the crush test (ISO 13955) have been added as alternative to ISO 13954;

— a requirement for the electrofusion compatibility has been added;

— information related to the suitability of PE pipe systems for 100 % hydrogen and its admixtures with natural gas has been added.

System Standards are based on the results of the work being undertaken in ISO/TC 138 "Plastics pipes, fittings and valves for the transport of fluids", which is a Technical Committee of the International Organization for Standardization (ISO).

They are supported by separate standards on test methods to which references are made throughout the System Standard.

The System Standards are consistent with general standards on functional requirements and on recommended practice for installation.

EN 1555 consists of the following parts:

— EN 1555-1, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 1: General* (this document);

— EN 1555-2, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 2: Pipes*;

— EN 1555-3, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 3: Fittings*;

— EN 1555-4, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 4: Valves*;

— EN 1555-5, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 5: Fitness for purpose of the system*;

In addition, the following document provides guidance on the assessment of conformity:

— CEN/TS 1555-7, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) —Part 7: Guidance for assessment of conformity.*

NOTE EN 12007-2 prepared by CEN/TC 234 “Gas infrastructure” deals with the recommended practice for installation of plastics pipes system in accordance with EN 1555 (all parts).

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

Introduction

The EN 1555 series specifies the requirements for a piping system and its components made from polyethylene (PE) compounds, which is intended to be used for the supply of gaseous fuels.

This document covers materials and the general aspects of the plastics piping system.

Requirements and test methods for components of the piping system are specified in EN 1555-2, EN 1555-3 and EN 1555-4.

Characteristics for fitness for purpose of the system are covered in EN 1555-5. CEN/TS 1555-7 gives guidance for assessment of conformity.

Recommended practice for design, handling and installation is given in EN 12007-2.

1 Scope

This document specifies materials and the general aspects of polyethylene (PE) piping systems in the field of the supply of gaseous fuels.

NOTE For the purpose of this document the term gaseous fuels include for example natural gas, methane, butane, propane, hydrogen, manufactured gas, biogas, and mixtures of these gases.

It also specifies the test parameters for the test methods referred to in this document.

In conjunction with EN 1555-2, EN 1555-3, EN 1555-4 and EN 1555-5, this document is applicable to PE pipes, fittings and valves, their joints and, joints with components of PE and other materials intended to be used under the following conditions:

a) a maximum operating pressure, MOP, up to and including 10 bar[1] at a design reference temperature of 20 °C;

b) an operating temperature between −20 °C and 40 °C.

For operating temperatures between 20 °C and 40 °C, derating coefficients are specified in EN 1555-5.

The EN 1555 series covers a range of MOPs and gives requirements concerning colours.

It is the responsibility of the purchaser or specifier to make the appropriate selections from these aspects, taking into account their particular requirements and any relevant national guidance or regulations and installation practices or codes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1555-2:2025, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 2: Pipes*

EN 1555-3, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 3: Fittings*

EN 1555-4, *Plastics piping systems for the supply of gaseous fuels — Polyethylene (PE) — Part 4: Valves*

EN 12099, *Plastics piping systems — Polyethylene piping materials and components — Determination of volatile content*

EN ISO 1133-1, *Plastics — Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics — Part 1: Standard method (ISO 1133-1)*

EN ISO 1167-1, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 1: General method (ISO 1167-1)*

EN ISO 1167-2, *Thermoplastics pipes, fittings and assemblies for the conveyance of fluids — Determination of the resistance to internal pressure — Part 2: Preparation of pipe test pieces (ISO 1167-2)*

EN ISO 1183-1, *Plastics — Methods for determining the density of non-cellular plastics — Part 1: Immersion method, liquid pycnometer method and titration method (ISO 1183-1)*

[1] 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

EN ISO 1183-2, *Plastics — Methods for determining the density of non-cellular plastics — Part 2: Density gradient column method (ISO 1183-2)*

EN ISO 6259-1, *Thermoplastics pipes — Determination of tensile properties — Part 1: General test method (ISO 6259-1)*

EN ISO 6259-3, *Thermoplastics pipes — Determination of tensile properties — Part 3: Polyolefin pipes (ISO 6259-3)*

EN ISO 9080, *Plastics piping and ducting systems — Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation (ISO 9080)*

EN ISO 11357-6, *Plastics — Differential scanning calorimetry (DSC) — Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT) (ISO 11357-6)*

EN ISO 12162, *Thermoplastics materials for pipes and fittings for pressure applications — Classification, designation and design coefficient (ISO 12162)*

EN ISO 13477, *Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Small-scale steady-state test (S4 test) (ISO 13477)*

EN ISO 13478, *Thermoplastics pipes for the conveyance of fluids — Determination of resistance to rapid crack propagation (RCP) — Full-scale test (FST) (ISO 13478)*

EN ISO 13479:2022, *Polyolefin pipes for the conveyance of fluids — Determination of resistance to crack propagation — Test method for slow crack growth on notched pipes (ISO 13479:2022)*

EN ISO 15512, *Plastics — Determination of water content (ISO 15512)*

EN ISO 16871, *Plastics piping and ducting systems — Plastics pipes and fittings — Method for exposure to direct (natural) weathering (ISO 16871)*

ISO 6964, *Polyolefin pipes and fittings — Determination of carbon black content by calcination and pyrolysis — Test method*

ISO 11413:2019, *Plastics pipes and fittings — Preparation of test piece assemblies between a polyethylene (PE) pipe and an electrofusion fitting*

ISO 11414:2009, *Plastics pipes and fittings — Preparation of polyethylene (PE) pipe/pipe or pipe/fitting test piece assemblies by butt fusion*

ISO 13953, *Polyethylene (PE) pipes and fittings — Determination of the tensile strength and failure mode of test pieces from a butt-fused joint*

ISO 13954, *Plastics pipes and fittings — Peel decohesion test for polyethylene (PE) electrofusion assemblies of nominal outside diameter greater than or equal to 90 mm*

ISO 16770, *Plastics — Determination of environmental stress cracking (ESC) of polyethylene — Full-notch creep test (FNCT)*

ISO 18488, *Polyethylene (PE) materials for piping systems — Determination of Strain Hardening Modulus in relation to slow crack growth — Test method*

ISO 18489:2015, *Polyethylene (PE) materials for piping systems — Determination of resistance to slow crack growth under cyclic loading — Cracked Round Bar test method*

ISO 18553, *Method for the assessment of the degree of pigment or carbon black dispersion in polyolefin pipes, fittings and compounds*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1555-2, EN 1555-3 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms related to material characteristics

3.1.1
lower confidence limit of the predicted hydrostatic strength
σ_{LPL}
quantity that represents the 97,5 % lower confidence limit of the predicted hydrostatic strength at temperature θ and time t

Note 1 to entry: It is expressed in megapascals (MPa).

3.1.2
minimum required strength
MRS
value of the *lower confidence limit of the predicted hydrostatic strength* (3.1.1) at 20 °C and 50 years, rounded down to the next smaller value of the R10 series or the R20 series

Note 1 to entry: Only compounds with an MRS of 8 MPa or 10 MPa are specified in this document.

Note 2 to entry: The R10 series and the R20 series conform to ISO 3 [11].

Note 3 to entry: It is expressed in megapascals (MPa).

[SOURCE: EN ISO 12162:2009, 3.3, modified — Note 1 to entry has been removed and replaced with new Notes 1 to 3 to entry.]

3.1.3
design coefficient
C
coefficient with a value greater than 1, which takes into consideration service conditions as well as properties of the components of a piping system other than those represented in the *lower confidence limit of the predicted hydrostatic strength* (3.1.1)

3.1.4
design stress
σ_S
allowable stress for a given application at 20 °C, that is derived from the *minimum required strength, MRS* (3.1.2), by dividing it by the design coefficient, *C* (3.1.3)

Note 1 to entry: This is demonstrated in the following formula:

$$\sigma_S = \frac{MRS}{C}$$

Note 2 to entry: It is expressed in megapascals (MPa).

3.1.5
melt mass-flow rate
MFR
value relating to the viscosity of the molten material at a specified temperature and load

Note 1 to entry: It is expressed in grams per 10 minutes (g/10 min).

3.2 Terms related to service conditions

3.2.1
gaseous fuel
substance that reacts exothermically with oxygen, which is in gaseous state at a temperature of 15 °C and at atmospheric pressure

Note 1 to entry: The energy contained in the fuel is released when it burns.

Note 2 to entry: Typical gaseous fuels are for example natural gas, methane, butane, propane, hydrogen, manufactured gas, biogas, ..., and mixtures of these gases.

Note 3 to entry: Additional information about the suitability of PE pipe systems for hydrogen and its admixtures can be found in Annex B.

3.2.2
maximum operating pressure
MOP
maximum effective pressure of the fluid in the piping system, which is allowed in continuous use

Note 1 to entry: It is expressed in bar. It takes into account the physical and the mechanical characteristics of the components of a piping system. It is calculated using the following formula:

$$MOP = \frac{20 \times MRS}{C \times (SDR - 1)}$$

Note 2 to entry: Research on long-term performance prediction of polyethylene gas distribution systems shows a possible service life of at least 100 years; see References [19], [20] and [21].

3.2.3
design reference temperature
temperature for which the piping system is designed

Note 1 to entry: It is used as the base for further calculation when designing a piping system or parts of a piping system for operating temperatures different from the design reference temperature (see EN 1555-5).

3.2.4
manufactured gas
synthetic gas
gas which has been treated and can contain components that are not typical of natural gas

Note 1 to entry: Manufactured (synthetic) gases can contain substantial amounts of chemical species that are not typical of natural gases or common species found in atypical proportions as in the case of wet and sour gases.

Note 2 to entry: Manufactured gases fall into two distinct categories, as follows:

a) those that are intended as synthetic or substitute natural gases, and that closely match true natural gases in both composition and properties;

b) those that, whether or not intended to replace or enhance natural gas in service, do not closely match natural gases in composition.

Case b) includes gases such as town gas, coke oven gas (undiluted), and LPG/air mixtures. None of which is compositionally similar to a true natural gas (even though, in the latter case, it can be operationally interchangeable with natural gas).

[SOURCE: EN ISO 14532:2017, 2.1.1.4]

3.3 Terms related to joints

3.3.1
butt fusion joint
joint made by heating the planed ends of pipes or spigot end fittings, the surfaces of which are fused together by holding them against a flat heating plate until the polyethylene material reaches fusion temperature, removing the heating plate quickly and pushing the two softened ends against one another

3.3.2
electrofusion joint
joint between a polyethylene electrofusion socket fitting or electrofusion saddle fitting and a pipe or spigot end fitting, made by heating the electrofusion fitting by the Joule effect of the heating element incorporated at their jointing surfaces, causing the material adjacent to them to melt, and the pipe and fitting surfaces to fuse

3.3.3
fusion compatibility
ability of two similar or dissimilar polyethylene compounds to be fused together to form a joint

4 Symbols and abbreviated terms

4.1 Symbols

For the purposes of this document, the following symbols apply.

A	surface area
C	design coefficient
d_n	nominal outside diameter
E	wall thickness (at any point) of a fitting and valve body
e	wall thickness (at any point) around the circumference of a component
e_{min}	minimum wall thickness (at any point)
e_n	nominal wall thickness
$<G_p>$	strain hardening modulus
L	length of a pipe
Δp	difference in partial pressure

p_{c}	critical pressure
$p_{c,full\text{-}scale}$	critical pressure obtained in full-scale test
p_{cS4}	critical pressure obtained in S4-test
P_{coef}	permeation coefficient
Q_{m}	mass flow rate
Q_{V}	permeated volume per time unit
S	pipe series
T_{y}	wall thickness tolerance
t	time
θ	temperature
ρ	density
$\Delta\sigma_{0}$	stress range
σ_{s}	design stress
σ_{LPL}	lower confidence limit of the predicted hydrostatic strength

4.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

AFNCT	accelerated full notch creep test
ANPT	accelerated notched pipe test
CRB	cracked round bar (test)
DN/OD	nominal size
FNCT	full notch creep test
LPL	lower predicted limit
LPG	liquefied petroleum gas
MFR	melt mass-flow rate
MOP	maximum operating pressure
MRS	minimum required strength
NPT	notched pipe test
OIT	oxidation induction time
PE	polyethylene
PLT	point load test
RC	raised crack resistance
RCP	rapid crack propagation
SCG	slow crack growth
SDR	standard dimension ratio
SHT	strain hardening test

5 Material

5.1 Material of the components

The pipes, fittings and valves shall be made of a PE compound conforming to this document.

This document includes materials classified as PE 80 and PE 100.

Another type of PE 100, designated as PE 100-RC with enhanced resistance to SCG, is also included in this document, see Annex A for additional information.

The material described in this document is a compound, which shall be supplied in the form of granules, suitable for the production of pipes conforming to EN 1555-2, fittings conforming to EN 1555-3, or valves conforming to EN 1555-4.

5.2 Compound

5.2.1 Additives and pigments

The compound shall be made by adding to the PE base polymer only those additives and pigments (e.g. carbon black) necessary for the manufacture of pipes, fittings and valves conforming to EN 1555-2, EN 1555-3 and EN 1555-4, as applicable, and for their fusibility, storage and use.

The carbon black used in the production of black compound shall have an average (primary) particle size of 10 nm to 25 nm.

All additives and pigments shall be uniformly dispersed.

5.2.2 Colour

The colour of the compound shall be yellow (PE 80), orange (PE 100 and PE 100-RC) or black (PE 80, PE 100 and PE 100-RC).

5.2.3 Characteristics

5.2.3.1 Characteristics of the compound in the form of granules

The compound in the form of granules used for the manufacture of pipes, fittings and valves shall have characteristics conforming to the requirements given in Table 1.

Table 1 — Characteristics of the compound in the form of granules

Characteristic	Requirement [a]	Test parameters		Test method
		Parameter	Value	
Compound density	≥ 930 kg/m³	Test temperature	23 °C	EN ISO 1183-1 or EN ISO 1183-2 [c]
		Number of test pieces [b]	Shall conform to EN ISO 1183-1 or EN ISO 1183-2 [c]	
Oxidation induction time (OIT) (thermal stability)	≥ 20 min	Test temperature	210 °C [d]	EN ISO 11357-6
		Test atmosphere	Oxygen	
		Sample mass	(15 ± 2) mg	
		Number of test pieces [b]	3	
Melt mass-flow rate (MFR)	(0,20 ≤ MFR ≤ 1,40) g/10 min Maximum deviation of ±20 % of the nominated value [e] [f]	Loading mass	5 kg	EN ISO 1133-1
		Test temperature	190 °C	
		Time	10 min	
		Number of test pieces [b]	Shall conform to EN ISO 1133-1	
Volatile content	≤ 350 mg/kg (equivalent to ≤ 0,035 % by mass)	Number of test pieces [b]	1	EN 12099
Water content [g]	≤ 300 mg/kg (equivalent to ≤ 0,03 % by mass)	Number of test pieces [b]	1	EN ISO 15512
Carbon black content [h]	(2,0 to 2,5) % (mass fraction)	Number of test pieces [b]	Shall conform to ISO 6964 [i]	ISO 6964
Carbon black dispersion [h]	Grade ≤ 3 Rating of appearance A1, A2, A3 or B	Preparation of test pieces	Free [j]	ISO 18553
		Number of test pieces [b]	Shall conform to ISO 18553	
Pigment dispersion [k]	Grade ≤ 3 Rating of appearance A1, A2, A3 or B	Preparation of test pieces	Free [j]	ISO 18553
		Number of test pieces [b]	Shall conform to ISO 18553	
Resistance to SCG for PE 100-RC Strain hardening test (SHT) [l]	$<G_p> \geq 53,0$ MPa	Test temperature	80 °C	ISO 18488
		Thickness	300 µm	
		Test speed	Shall conform to ISO 18488	
		Number of test pieces [b]	Shall conform to ISO 18488	

Characteristic	Requirement [a]	Test parameters		Test method
		Parameter	Value	
Resistance to SCG for PE 100-RC Cracked round bar (CRB) test [l]	≥ 1,5 × 10^6 cycles at an interpolated stress range ($\Delta\sigma_0$) of 12,5 MPa and converted and normalised to a diameter of 14 mm and an initial crack length of 1,40 mm [m]	Test temperature	23 °C	ISO 18489
		Type of test	In air	
		Diameter of test piece	14 mm	
		Reference stress range	12,5 MPa	
		Target initial crack length a_{ini}*	1,50 mm	
		Waveform/ frequency	Sinusoid/10 Hz	
		Number of test pieces [b]	Shall conform to ISO 18489	
Resistance to SCG for PE 100-RC Accelerated FNCT (AFNCT) [l]	≥ 550 h at an interpolated reference tensile stress of 4 MPa [n o] or ≥ 300 h at an interpolated reference tensile stress of 5 MPa [n o]	Test temperature	90 °C	ISO 16770
		Environment	Lauramine oxide [p]	
		Concentration	2 % (mass fraction)	
		Test piece dimension	10 mm square	
		Failure mode [q]	Brittle	
		Number of test pieces [b]	Shall conform to ISO 16770	

NOTE 1 Chemical Abstracts Service (CAS) Registry Number® is a trademark of the American Chemical Society (ACS). This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of the product named. Equivalent products can be used if they can be shown to lead to the same results.

NOTE 2 Arkopal® N100 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of this product.

NOTE 3 Dehyton® PL is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of this product.

NOTE 4 The requirement for CRB of 1,5 × 10^6 cycles is under revision based on the analysis of current round robin performances.

[a] Conformity to these requirements shall be proven by the compound manufacturer.

[b] The number of test pieces given indicates the number required to establish a value for the characteristic described in this table. The number of test pieces required for batch release testing and product verification testing should be listed in the manufacturer's quality plan. Guidance on assessment of conformity can be found in CEN/TS 1555-7.

[c] EN ISO 1183-3 may be used as alternative. In case of dispute, EN ISO 1183-1 or EN ISO 1183-2 shall apply.

[d] Test may be carried out at 200 °C or 220 °C provided that a clear correlation has been established. In case of dispute, the reference temperature shall be 210 °C. The test may be carried out on melt flow extrudate or pellet. In case of dispute, the test shall be carried out on pellet. The sample thickness is free and not in accordance with EN ISO 11357-6.

[e] Nominated value given by the compound manufacturer.

[f] Materials (0,15 ≤ MFR < 0,20) g/10 min may be introduced. In such case 5.3.1 applies. The lowest MFR value resulting from the maximum lower deviation of the nominated value is to be not less than 0,15 g/10 min.

Characteristic	Requirement [a]	Test parameters		Test method
		Parameter	Value	
[g] Volatile or water content shall be measured. In case of dispute, the requirement for water content shall be used, using method B.2 of EN ISO 15512. As an alternative method, ISO 760 [12] may be used. The requirement applies to the compound manufacturer at the stage of manufacturing and to the compound user at the stage of processing (if the water content exceeds the limit, drying is required prior to use). [h] Only for black compounds. [i] In case of dispute, Method A "Electric Tube Furnace" shall be used. [j] In case of dispute, the test pieces shall be prepared by the microtome method. [k] Only for non-black compounds. [l] These tests are only performed on PE 100-RC material. [m] For interpolation, CRB test target stress ranges should be chosen between 11,5 MPa and 13,5 MPa. Target stress ranges of 11,5 MPa, 12,2 MPa, 12,8 MPa and 13,5 MPa are recommended. After the test the stress range is to be converted and normalised to a diameter of 14 mm and an initial crack length of 1,4 mm, in accordance with ISO 18489:2015, Annex A. [n] This requirement correlates to a test in accordance with ISO 16770, with a stress of 4 MPa at 80 °C in nonylphenol ethoxylate with no failure for a period of 8 760 h [22] and may be used as an alternative. Nonylphenol ethoxylate (CAS Registry Number® 9016–45–9) with a trade name of Arkopal® N100 is used for this test with a concentration for testing of 2 % (mass fraction). In case of dispute, the AFNCT applies. [o] AFNCT test stress levels should be chosen close to the nominal stress in order to avoid long testing times. Test stress levels of 3,7 MPa, 3,9 MPa, 4,2 MPa, 4,5 MPa for the 4 MPa reference stress, and 4,7 MPa, 4,9 MPa and 5,2 MPa and 5,5 MPa for the 5 MPa reference stress are recommended. [p] Lauramine oxide (CAS Registry Number® 85408–49–7) is commercially available as Dehyton® PL. The dilution of the lauramine oxide in the product shall be taken into account when calculating the concentration of 2 % (mass fraction). For example, when Dehyton® PL is used, it is already diluted to 30 % (mass fraction). Therefore, 6,67 % (mass fraction) of Dehyton® PL is needed to obtain 2 %(mass fraction) lauramine oxide. [q] Test specimens tested at a tensile stress of ≥ 4 MPa (or ≥ 5 MPa) may be terminated once the minimum failure time of 550 h (or 300 h) has been achieved, in which case there is no failure mode. Test specimens tested at a tensile stress of < 4 MPa (or < 5 MPa) may be terminated once the interpolated failure time of 550 h (at the reference tensile stress of 4 MPa) or 300 h (at the reference tensile stress of 5 MPa) is achieved, taking possible scatter in the actual tensile stress into account.				

5.2.3.2 Characteristics of the compound in the form of pipe

Unless otherwise specified by the applicable test method, the test pieces shall be conditioned at (23 ± 2) °C before testing in accordance with Table 2.

Table 2 — Characteristics of compound in the form of pipe

Characteristic	Requirement [a]	Test parameters		Test method
		Parameter	Value	
Resistance to gas condensate	No failure during the test period of all test pieces	Conditioning period (pipe filled with condensate)	1 500 h in air at 23 °C	EN ISO 1167-1 and EN ISO 1167-2
		End caps	Type A	
		Test temperature	80 °C	
		Orientation	Free	
		Number of test pieces [b]	3	
		Circumferential (hoop) stress	2,0 MPa	
		Pipe dimensions: d_n e_n	 32 mm 3 mm	
		Type of test	Synthetic condensate [c] internal and water external to the test piece ("liquid-in-water")	
		Test period	≥ 20 h	
Resistance to weathering [d e]	The weathered test pieces shall fulfil the requirements of the following characteristics, a), b) and c) below:	Preconditioning (weathering): cumulative radiant exposure	≥ 3,5 GJ/m^2	EN ISO 16871
		Number of test pieces [b]	See below	
a) Decohesion of an electrofusion joint	a) Sample prepared in accordance with ISO 11413:2019, Jointing condition 1: 23 °C; ≤ 33 % brittle failure d_n: 110 mm SDR 11			a) ISO 13954 [f]
b) Hydrostatic strength (1 000 h at 80 °C)	b) Shall conform to EN 1555-2:2025, Table 4 d_n: 32 mm SDR 11 (preferred) or 110 mm SDR 11			b) EN ISO 1167-1 and EN ISO 1167-2
c) Elongation at break	c) Shall conform to EN 1555-2:2025, Table 4 d_n: 32 mm SDR 11 (preferred) or 110 mm SDR 11			c) EN ISO 6259-1 and EN ISO 6259-3
Resistance to rapid crack propagation (RCP) (Critical pressure, p_c)	$p_c \geq 1{,}5$ MOP with $p_c = 3{,}6\, p_{cS4} + 2{,}6$ [g]	Pipe dimension [h]	d_n: 250 mm SDR 11	EN ISO 13477
		Test temperature	0 °C	
		Pressurizing fluid	air	
		Number of test pieces [b]	Shall conform to EN ISO 13477	

Characteristic	Requirement [a]	Test parameters		Test method
		Parameter	Value	
Resistance to SCG for PE 80 and PE 100 Notched pipe test (NPT) [i]	No failure during the test period	Pipe dimension	d_n:110 mm SDR 11	EN ISO 13479
		Test temperature	80 °C	
		Internal test pressure for: PE 80, SDR 11 PE 100, SDR 11	 8,0 bar 9,2 bar	
		Test period	≥ 500 h	
		Type of test	Water internal and water external to the test piece (“water-in-water”)	
		Number of test pieces [b]	Shall conform to EN ISO 13479	
Resistance to SCG for PE 100-RC Accelerated notched pipe test (ANPT) [j]	No failure during the test period	Pipe dimension	d_n: 110 mm SDR 11	EN ISO 13479
		Test temperature	80 °C	
		Internal test pressure for: PE 100-RC, SDR 11	 9,2 bar	
		Test period	≥ 300 h [k]	
		Type of test	Water internal and detergent solution external to the test piece [l] (“water-in-liquid”)	
		Number of test pieces [b]	Shall conform to EN ISO 13479	
Determination of the failure mode in a tensile test on a butt-fusion weld	Test to failure: Ductile – pass Brittle – fail	Pipe dimension	d_n: 110 mm SDR 11	ISO 13953
		Test temperature	23 °C	
		Number of test pieces [b]	Shall conform to ISO 13953	

NOTE 1 Chemical Abstracts Service (CAS) Registry Number® is a trademark of the American Chemical Society (ACS). This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of the product named. Equivalent products can be used if they can be shown to lead to the same results.

NOTE 2 Arkopal® N100 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of this product.

NOTE 3 Dehyton® PL is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of this product.

[a] Conformity to these requirements shall be proven by the compound manufacturer.

[b] The number of test pieces given indicates the number required to establish a value for the characteristic described in this table. The number of test pieces required for batch release testing and product verification testing should be listed in the manufacturer’s quality plan. Guidance on assessment of conformity can be found in CEN/TS 1555-7.

[c] 50 % *n*-decane and 50 % (mass fraction) 1–3-5 trimethylbenzene.

Characteristic	Requirement [a]	Test parameters		Test method
		Parameter	Value	

[d] Only for non-black compounds.

[e] For outdoor storage for one year a cumulative radiant exposure of up to 7 GJ/m^2 is valid based on current measurements. Information on regional levels of UV radiation can be found on web pages of national authorities e.g. meteorological institutes.

[f] Alternatively the strip-bend test according to ISO 21751 [15] or the crush test according to ISO 13955 [14] may be used.

[g] If the requirement is not met or S4 test equipment is not available, then (re)testing by using the full-scale test shall be performed in accordance with EN ISO 13478. In this case: $p_c = p_{c,full-scale}$.

[h] For PE 80 materials, smaller pipe diameters may be used for the RCP test. RCP performance is dependent on wall thickness. Pipe of thickness ≥ 15 mm shall be tested for RCP performance.

[i] This test is not performed on PE 100-RC materials.

[j] The ANPT is specifically for testing PE 100-RC materials.

[k] This requirement correlates to a test on 110 mm diameter SDR 11 PE 100-RC pipe in accordance with EN ISO 13479, at a pressure level of 9,2 bar at 80 °C, water-in-water, with no failure in a test period of 8 760 h, and may be used as an alternative [23][24][25]. In case of dispute, the ANPT applies, see EN ISO 13479:2022, Annex D.

[l] Nonylphenol ethoxylate (CAS Registry Number® 9016–45–9) with a trade name of Arkopal® N100 is used for this test with a concentration for testing using a 2 % (mass fraction) aqueous solution. This detergent will be replaced by lauramine oxide (CAS Registry Number® 85408–49–7), which is commercially available as Dehyton® PL. The requirement for the ANPT using lauramine oxide is under development at the time of publication of this document.

5.3 Fusion compatibility

5.3.1 The compounds conforming to Table 1 shall be fusible. The compound manufacturer shall check that the requirement for the failure mode in a tensile test given in Table 2 is fulfilled for a butt fusion joint. The test sample shall be prepared by using the parameters specified in ISO 11414:2009, Annex A, at an ambient temperature of (23 ± 2) °C, from pipes both manufactured from that compound.

Fusion compatibility shall be demonstrated by the compound manufacturer for each compound of their own product range.

For (0,15 ≤ MFR < 0,20) g/10 min pipe compounds, butt fusion compatibility shall be tested in accordance with ISO 13953 on pipes d_n ≥ 200 mm and e_n > 20 mm instead of the tensile test on d_n 110 mm pipes as specified in Table 2.

For (0,15 ≤ MFR < 0,20) g/10 min pipe compounds, electrofusion compatibility shall be tested using the normal conditions in accordance with EN 1555-5 on pipes d_n ≥ 250 mm, SDR 11, with fittings made from PE 100 or PE 100-RC.

5.3.2 Compounds conforming to Table 1 are considered fusible to each other. If requested, the compound manufacturer shall demonstrate this by checking that the requirement for the failure mode in a tensile test given in Table 2 is fulfilled for a butt fusion joint prepared by using the parameters as specified in ISO 11414:2009, Annex A, at an ambient temperature of (23 ± 2) °C from two pipes manufactured from the compounds from their own range covered by this request.

5.4 Classification and designation

Compounds shall be designated by the type of PE material. The minimum required strength (MRS) shall conform to Table 3 when tested in the form of pipe.

Table 3 — Classification and designation of compounds

Classification by MRS MPa	**Designation**
8	PE 80
10	PE 100
	PE 100-RC

The compound shall be evaluated in accordance with EN ISO 9080 on pipes at least at three temperatures, where the first temperature is 20 °C, and the second temperature is 80 °C, and the third temperature is free between 30 °C and 70 °C, to find the σ_{LPL}. The MRS-value shall be derived from the σ_{LPL} and the compound shall be classified by the compound manufacturer in accordance with EN ISO 12162.

At 80 °C, there shall be no knee detected in the regression curve at a time t < 5 000 h.

The conformity of the designation of the compound to the classification given in Table 3 shall be demonstrated by the compound manufacturer.

Where fittings are manufactured from the same compound as pipes, then the material classification shall be the same as for pipes.

For the classification of a compound intended only for the manufacture of fittings, test pieces in the form of extruded pipe made from the compound shall be used.

5.5 Design coefficient and design stress

The design coefficient, C, for pipes, fittings and valves for the supply of gaseous fuels shall be greater than or equal to 2. The maximum value for the design stress, σ_S, shall be 4,0 MPa for PE 80, and 5,0 MPa for PE 100 and PE 100-RC materials.

Annex A
(informative)

Additional information related to the installation of PE 100-RC systems

A.1 Pipe material

Polyethylene materials have been used for the manufacture of piping systems for gas supply since the 1960s, offering a corrosion resistant system. Since this time, the materials used for these systems have been developed and improved in terms of performance, potential pressure rating, and above all durability and resistance to RCP.

While initial improvements increased the material's pressure resistance (PE 63, PE 80 and PE 100), considerable progress has been made in recent years in increasing the resistance to SCG. [26]

The main technical advantage of PE 100-RC is that it is even more resistant to SCG. PE 100-RC materials for piping systems require a separate number of tests to assess SCG performance. Piping systems made of such a material can be used for alternative trenchless installation methods when more surface damage can be encountered or for installations where excavated soil is used as the embedding material, respecting local regulations. As a result, the durability of the system is potentially increased by using these materials.

The material and product requirements of PE 100-RC compared to the well-known and established PE 100 are identical in each part of the EN 1555 series, with the exception of requirements specified for the resistance to SCG behaviour for the material and the pipe, fitting and valve components, as appropriate. Table A.1 gives a comparison between the performance of PE 100 and PE 100-RC materials related to resistance to slow crack test methods.

Table A.1 — Resistance to SCG for PE 100 and PE 100-RC

PE 100 typical performance	PE 100-RC expected performance	Accelerated test method for PE 100-RC to reduce test time
NPT ≥ 500 h	NPT ≥ 8 760 h	ANPT 80 °C, ≥ 300 h 2 % (mass fraction) solution Arkopal® N100
FNCT ≥ 300 h at 4 MPa stress, 80 °C, 2 % (mass fraction) solution Arkopal® N100	FNCT ≥ 8 760 h at 4 MPa stress, 80 °C, 2 % (mass fraction) solution Arkopal® N100	AFNCT ≥ 550 h at 4 MPa stress [a] ≥ 300 h at 5 MPa stress [a] (Brittle fracture surface required) 90 °C, 2 % (mass fraction) solution Lauramine oxide
SHT $<G_p>$ ≥ 40 MPa [a]	SHT $<G_p>$ ≥ 53 MPa [a]	Not applicable
CRB ≥ 0,9 × 10^6 cycles [a]	CRB ≥ 1,5 × 10^6 cycles [a]	Not applicable

NOTE Arkopal® N100 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by CEN of this product.

[a] Derived from DVGW study, see Reference [22].

The NPT in accordance with EN ISO 13479 simulates scratches on the outside of the pipe, which under pressure and stress would slowly drive the crack through the pipe wall. In this test, the PE 100-RC offers a significantly higher resistance to SCG resistance so that failure time of > 500 h for PE 100 increases to > 8 760 h for PE 100-RC. Such a long test time is not practical. A correlated accelerated method, the accelerated notch pipe test (ANPT) has been developed with the stress cracking media on the outside of the pipe reducing failure time to > 300 h (see EN ISO 13479:2022, Annex D). This has been proven in broader technical studies and is referred to in References [23], [24] and [25].

In the past, a point load test (PLT) to simulate the effect of stone indentation as included in DIN PAS 1075 [17][2] has been performed on 110 mm SDR 11 PE 100-RC materials in Europe. A correlation between the PLT and FNCT has been demonstrated [26]. Instead of the PLT, the combination of the SHT, CRB, ANPT and AFNCT methods for PE 100-RC compounds is referenced in this document.

A.2 Installation conditions

The usual conventional installation method for PE 80 and PE 100 piping systems is often open trench installation with sand bedding around the pipe.

Other non-conventional installation techniques using specialized machinery and trenchless 'No-Dig' techniques can increase the risk of scratches and damage to the pipe in more undefined conditions. Using PE 100-RC material with low notch sensitivity and reduced rates of SCG potentially increases the safety, reliability and lifetime of the pipe system. It is therefore used especially for:

- installation without sand embedding and re-use of the excavated soil in open trenches;
- installation using trenchless installation techniques – replacement of pipeline systems, replacement off the line;
  - horizontal directional drilling (HDD),
  - impact moling,
  - pipe jacking:
    - auger boring,
    - microtunnelling.
- installation using trenchless installation techniques – rehabilitation of pipeline systems, replacement on the line:
  - pipe bursting,
  - pipe removal:
    - pipe eating,
    - pipe extraction.
- rehabilitation of pipeline systems using renovation methods:
  - lining with continuous pipe,

[2] Withdrawn.

— lining with close-fit pipes,

— lining with inserted hoses.

NOTE Terminology from EN ISO 11295.

A selection between PE 100 or PE 100-RC for the pipe system material according to the installation method, soil condition, backfill characteristics, degree of compaction and design coefficients should be determined by agreement with the network owner, the installation company and the manufacturer.

Annex B
(informative)

Additional information related to the suitability of PE pipe systems for 100 % hydrogen and its admixtures with natural gas

B.1 General

Polyethylene pipes have already demonstrated excellent track records as reliable piping material for gaseous fuels transport, with their benefits such as durability (over 50 years lifetime), light weight, corrosion free, excellent chemical resistance, good fusibility, low maintenance and low installation costs.

To prepare for the future and because of the decarbonization policies, the gas industry is looking for alternative gaseous fuels, one being hydrogen, that can be produced from sustainable sources, such as wind energy, through electrolysis. Studies were launched to check the long term exposure of PE pipes to hydrogen and the impact of hydrogen and its admixtures in the natural gas grid.

The injection of hydrogen in natural gas infrastructures demands considerations, which are addressed in the code of practice (e.g. EN 12007-2), with regard to the integrity, safety and performance of the systems facing increasing hydrogen levels, its fluctuation and variation. CEN/TR 17797 provides guidance on how injection of hydrogen into the gas infrastructure can impact processes from the input of gas into the onshore transmission network up to the inlet connection of gas appliances.

B.2 Chemical resistance

Approved polyethylene gas pipes are fully resistant to hydrogen at operating temperatures and pressures within the scope of this document. This is proven by experience, practical tests and laboratory investigations. Therefore, no decrease in lifetime of the PE pipes is expected.

For instance, the Hong Kong & China Gas company uses a gas mixture containing about 50 % hydrogen [27]. Hong Kong started using PE pipes since 1987 and has an extensive pipe network with pipe diameters from 32 mm to 400 mm, operating at pressures up to 4 bar. Also, Hawai'i Gas currently transports up to 15 % hydrogen through their high-density polyethylene gas network [28]. For industrial applications, PE pipes are used to transport coke oven gas and town gas in accordance with CEN/TR 16787, which contain more than 40 % of hydrogen.

Multiple practical tests demonstrated no noticeable degradation when PE pipes were exposed to hydrogen:

— In the Netherlands a field trial of four years was performed where existing PE pipes were exposed to natural gas mixed with hydrogen up to a molar fraction of 20 %. No effect on the PE materials was measured [29][30].

— In Denmark a similar field trial was performed with exposure of continuous pure hydrogen for over four years for PE 80 and ten years for PE 100, on both used pipes taken from a natural gas network and new pipes. Extensive laboratory tests based on international standards indicate no influence on PE 80 or PE 100 natural gas pipes' durability [31][32].

— In Germany up to a volume fraction of 9,9 % hydrogen was mixed with natural gas in the PE piping network of Klanxbüll/Neukirchen [33]. Furthermore, 20 % hydrogen is mixed with natural gas in the Fläming project [34], up to 30 % is mixed in the Öhringen Hydrogen Island [35] and up to 100 % hydrogen is tested in the hydrogen test field of Bitterfeld-Wolfen [36].

— In the UK PE pipes are considered to be suitable for pilots where up to a molar fraction of 20 % hydrogen was mixed with natural gas in the gas network of the Keele University and in the gas network of Winlaton [37]. Also, for the feasibility study to convert the existing natural gas network of Leeds to 100 % hydrogen, PE pipes are considered to be suitable for transporting 100 % hydrogen [38].

— Many more trials are running at the moment of publication of this document. Knowledge and experiences are shared within the alliance of Ready4H2 and identified over 1 million km of distribution pipelines, which include PE piping systems, to be ready for hydrogen [39].

Also, laboratory investigations showed no degradation due to exposure to hydrogen:

— Laboratory samples of PE pipe materials were aged and tested. It was concluded that the aging effect of hydrogen on PE pipe materials is not significant. No degradation by pure hydrogen has been reported. Little or no interaction between hydrogen gas (or any non-polar gas) and polyethylene should be expected. In addition, hydrogen alone does not provide radicals that can cause polymer breakdown [40].

— No effect of hydrogen on the tensile properties was observed when samples taken from PE pipes were tested in a 100 bar hydrogen atmosphere during the tensile test [41].

— Short term (1 000 hours) chemical resistance tests showed no significant differences between PE pipes exposed to air and those exposed to hydrogen [42].

— No statistically significant difference was observed in respect of the specimen weight, dimensions or mechanical properties between the exposed (2 300 hours at 42 bar(g)) and non-exposed PE specimens of a reinforced thermoplastic pipe [43].

— Piping samples were soaked in pure hydrogen for 6 weeks. Electrofusion and squeeze-off testing indicated that hydrogen did not compromise the pipeline’s integrity [44][45].

— No macroscopic differences were found between unexposed PE and PE exposed to H_2 for 6 months [46].

— After long-term aging up to 13 months in hydrogen at various pressures (5 bar or 20 bar) and temperatures below and above the alpha-c transition for PE (20 °C, 50 °C and 80 °C), no deleterious effect was observed on the mechanical properties of PE [47].

PE is classified as having “satisfactory” resistance to hydrogen in ISO/TR 10358 [13], PPI TR-19 [18] and DIN 8075 Supplement 1 [16].

The resistance of PE to hydrogen has led to the position papers of TEPPFA (The European Plastic Pipes and Fittings Association), DVGW (German competence network) and KRV (German Plastics Pipes Association) that PE pipe systems can be considered for use with hydrogen-methane based blends, and with pure hydrogen gases [48][49][50].

B.3 Permeation

Permeation is the phenomenon where a permeant (e.g. methane or hydrogen gas) passes a physical barrier (e.g. a PE pipe wall). It is different from a leak, where no physical barrier exists. Therefore, a leakage rate is much higher than the permeation rate of a gas. Moreover, permeated gas is distributed over the entire surface area of the pipe system, while a leak is concentrated at one location.

The permeation rate (Q_V, permeated volume per time unit, in ml/day) through the physical barrier depends on:

— the permeability or permeation coefficient of the barrier P_{coef}, which is a material property that indicates how easy the permeant passes through the material, in (ml·mm)/(m^2·bar·day). The P_{coef} depends on the temperature T, in K, where a higher temperature will increase the P_{coef};

— the difference in partial pressure Δp, which is the pressure of the gas mixture times the fraction of the gas. This is the driving force for permeation to occur, in bar;

— the surface area of the barrier A, where a larger surface area will increase the permeation rate, in m^2;

— the thickness of the barrier e, where a large wall thickness will decrease the permeation rate, in mm.

The permeation rate for a pipe at a specific temperature can be approximated [51] by:

$$Q_V = \frac{P_{coef} \cdot (d_n - e_m) \cdot \pi \cdot L \cdot \Delta p}{1000 \cdot e_m} = \frac{P_{coef} \cdot (SDR - 1) \cdot \pi \cdot L \cdot \Delta p}{1000}$$

The mass flow rate (Q_m in kg/day) can be calculated using the density of the gas in the preferred conditions (ρ in kg/m^3) using:

$$Q_m = \frac{Q_V \cdot \rho}{1\,000\,000}$$

where, at ISO standard reference conditions [9], the density of hydrogen and methane is:

ρ_{H2}(288,15 K, 101,325 kPa) = 0,085 2 kg/m^3

ρ_{CH4}(288,15 K, 101,325 kPa) = 0,680 kg/m^3

The permeation rate through a pipe is the main contributor to the overall permeation of the PE pipe system. Butt fusion joints have the same material property (P_{coef}) and the same wall thickness (e_m) and can therefore be seen as part of the pipe. Electrofusion socket fittings and electrofusion saddle fittings will increase the wall thickness locally, thus decreasing the permeation rate. For mechanical fittings the material could be virtually impermeable (metal) or have a higher permeation coefficient than PE (e.g. rubber). However, the total surface area of barrier in the joint is much smaller than the surface area of the pipe, therefore giving a negligible contribution to the total permeated volume through a PE pipe system.

Many different permeation coefficients have been measured for hydrogen and methane through various PE pipe grades. Table B.1 and Table B.2 give a range of permeation coefficients for hydrogen and methane. The operating temperature should be taken into account.

NOTE The operating temperature is defined as the average annual temperature profile of the pipe taking into account the internal and external environment. Typically, buried gas supply systems in Europe are operated below 20 °C.

Table B.1 — Typical range of permeation coefficients of PE 80, PE 100 and PE 100-RC for hydrogen

Temperature °C	Range P_{coef} (ml·mm)/(m²·bar·day)	Source
8	55 to 65	[52][53]
14	75 to 85	[52]
20 to 25	108 to 193	[40][52-56]
40	321 to 523	[56][57]

Table B.2 — Typical range of permeation coefficients of PE 80 and PE 100 for methane

Temperature °C	Range P_{coef} (ml·mm)/(m²·bar·day)	Source
8	6 to 9	[53][58]
20 to 25	10 to 37	[40][53][58]
40	98 to 165	[56][57][59]

EXAMPLE A PE pipe system (DN 110, SDR 11) of 1 km long at 20 °C is pressurized with a 10 bar(g) blend of 80 % natural gas (of which 80 % is methane, the rest is nitrogen and minor constituents) and 20 % hydrogen. The absolute pressure of the gas mixture is therefore 11 bar(a), so the partial pressure of the hydrogen is:

$$\Delta p_{H2} = 0{,}2 \cdot 11 = 2{,}2 \text{ bar}$$

and the partial pressure of the methane is:

$$\Delta p_{CH4} = 0{,}8 \cdot 0{,}8 \cdot 11 = 7{,}04 \text{ bar}$$

This pipe system will permeate:

$$Q_{V\_H2} = \frac{(108 \text{ to } 193)\cdot(11-1)\cdot\pi\cdot 1\,000\cdot 2{,}2}{1\,000} = 7\,464 \text{ to } 13\,339 \frac{\text{ml}}{\text{day}} = 7 \text{ to } 13 \text{ litre hydrogen per day}$$

$$Q_{V\_CH4} = \frac{(10 \text{ to } 37)\cdot(11-1)\cdot\pi\cdot 1\,000\cdot 7{,}04}{1\,000} = 2\,212 \text{ to } 8\,183 \frac{\text{ml}}{\text{day}} = 2 \text{ to } 8 \text{ litre methane per day}$$

At 20 °C the density of the gas is slightly lower than at ISO standard reference conditions:

$$\rho_{H2}(293{,}15 \text{ K}, 101{,}325 \text{ kPa}) = 0{,}083\,8 \text{ kg/m}^3$$

$$\rho_{CH4}(293{,}15 \text{ K}, 101{,}325 \text{ kPa}) = 0{,}668 \text{ kg/m}^3$$

This leads to a mass flow rate of:

$$Q_{m\_H2} = \frac{(7\,464 \text{ to } 13\,339) \cdot 0{,}083\,8}{1\,000\,000} = 0{,}000\,626 \text{ to } 0{,}001\,118 \frac{\text{kg}}{\text{day}} = 0{,}6 \text{ to } 1{,}1 \text{ gram hydrogen per day}$$

$$Q_{m\_CH4} = \frac{(2\,212 \text{ to } 8\,183) \cdot 0{,}668}{1\,000\,000} = 0{,}001\,477 \text{ to } 0{,}005\,466 \frac{\text{kg}}{\text{day}} = 1{,}5 \text{ to } 5{,}6 \text{ gram methane per day}$$

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