CIPM MRA
Comparison reports

BIPM.QM-K2.b (E+E 2026)

Carbon dioxide in nitrogen

KEY COMPARISON

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Report of the comparison BIPM.QM-K2.b, on Carbon Dioxide in nitrogen at ambient levels, with E+E Elektronik (2026)

Final Report

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Abstract

As part of the ongoing key comparison BIPM.QM-K2.b, a comparison has been performed on the amount fraction of carbon dioxide (CO_2) in nitrogen, in gaseous reference materials value assigned by the Designated Institute of Austria E+E Elektronik (E+E), with the Key Comparison Reference Value based on measurements performed with the comparison reference facility maintained at the Bureau International des Poids et Mesures Headquarters (BIPM). Three standards were used for this comparison, which cover a CO_2 amount fraction range of 350 µmol mol^{-1} to 800 µmol mol^{-1}.

Contents

1 Purpose and scope

The on-going Key Comparison BIPM.QM-K2 was launched in October 2024. The aim of BIPM.QM-K2 is the evaluation of participants' capabilities to accurately produce and/or value assign gas standards of CO_2 in air (part a) and in nitrogen (part b), at amount fractions covering a range between 350 µmol mol^{-1} and 800 µmol mol^{-1}.

The comparison is run as a series of bilateral comparisons between each participant and the BIPM. The facility maintained by the BIPM (the so called the PVT−CO_2 facility) provides the Key Comparison Reference Value (KCRV) in each case and quantifies CO_2 amount fractions in air or nitrogen samples via measurements of the pressure and temperature of the sample and of the CO_2 extracted from the samples by cryogenic trapping. The PVT−CO_2 facility performance has been validated during the Pilot Study CCQM-P225 [1], and described in detail in a publication [2].

E+E took part in BIPM.QM-K2.b, meaning that the matrix of the gaseous reference materials sent for the comparison was nitrogen.

2 Participants and coordinator

BIPM.QM-K2.b is an ongoing key comparison coordinated by the BIPM HQ (abbreviated to BIPM in the rest of this report), which is structured as an ongoing series of bilateral comparisons. A full version of the protocol and the associated forms is available online at https://www.bipm.org/en/gas-metrology/ozone/bipm.qm-k2.

The results of the comparison with E+E Elektronik (E+E, Austria) are reported here. This is the second participation of E+E in BIPM.QM-K2.b, after a first comparison published in 2025 [3].

3 Measurand, quantities and units

The measurand was the amount fraction of carbon dioxide in nitrogen, with measurement results being expressed in mol mol^{-1} (or one of its multiples mmol mol^{-1}, µmol mol^{-1} or nmol mol^{-1}).

4 Measurements schedule

The BIPM.QM-K2.b protocol comprises three measurement periods: one conducted at the BIPM, and two by the participant—one before and one after the BIPM measurement. The measurements reported here were carried out at E+E in March and May 2026, and at the BIPM in April 2026.

5 Standards and values submitted by E+E

The mixtures were to be prepared and/or analysed by the participant using their usual procedure, with constraints on the nominal CO_2 amount fraction and on the matrix composition, as detailed in sections 5.1. The approach used by the participant for value assignment of their standards is described in section 5.3, and section 5.4 summarises the values reported by participants and their uncertainties.

5.1 Nominal CO_2 amount fractions

The participant was required to provide a standard at one or all of the nominal amount fractions summarized in Table 1. E+E provided three standards, one for each nominal value. Values reported by E+E were in accordance with the acceptable range defined in the protocol.

Table 1: Nominal amount fractions and acceptable ranges of standards to be submitted for measurement at the BIPM

Standard Submitted	CO_2 amount fraction nominal value ($\mu mol\ mol^{-1}$)	CO_2 amount fraction acceptable range ($\mu mol\ mol^{-1}$)
1	380	350 to 430
2	480	430 to 530
3	800	530 to 800

5.2 Matrix composition for standards prepared in nitrogen

Binary mixtures of CO_2 in nitrogen were requested to be prepared following the requirements of ISO 6142-1 and ISO 19229 for preparation of gravimetric standards and purity respectively. A matrix composition table was asked with each cylinder submitted. In particular, attention was to be paid to nitrous oxide amount fractions, that were to be reported and should be below 10 $nmol\ mol^{-1}$ and reported with a maximum standard uncertainty of 5 $nmol\ mol^{-1}$.

E+E reported that the mixtures were prepared by another laboratory with ISO 17034 accreditation. They reported that mixtures did not contain N_2O according to the information provided by the manufacturer.

5.3 Mixtures preparation

The participant was asked to prepare and/or value assign their standards using their usual approaches. E+E reported that the mixtures were prepared by another laboratory with ISO 17034 accreditation.

5.4 Mixtures certification and/or verification

The participant was asked to verify or to value assign their standards using their usual approaches. E+E reported that the values of the CO_2 amount fraction in their mixtures were assigned by them using an SI traceable method based on a dynamic volumetric principle. A full description of the method and the metrological traceability of the reported values was provided by E+E in the Information Sheet annexed to this report (see Annex 1 – Participant reports). After the first comparison performed in 2025 [3], the laboratory investigated their calibration procedure and found non-linearities in the smallest piston of their system (volume of 137.17 mm^3) when operated with 1.2 or 2.4 strokes per minute. They modified the calibration procedure to include a two-step mixing procedure to operate all positions of the piston in an optimized range with proven linearity. A first mixture with a CO_2 amount fraction in nitrogen of about

8000 µmol mol^{-1} to 10000 µmol mol^{-1} was targeted, and consequently further reduced to the desired range in a second step.

A second verification period was allocated in the protocol, after measurements were performed at the BIPM. E+E reported that the same procedure for the value assignment was followed in May 2026. Comparing the measurements from March and May 2026 showed a maximum Normalized Error (E_n) value of 0.32, which was interpreted as demonstrating the consistency of both measurement results within the specified measurement uncertainties.

5.5 CO_2 amount fraction and uncertainties reported by participants.

Values submitted by E+E for their three standards are reported in Table 2, with the expanded uncertainties and coverage factor. The standards were tracked with their cylinder ID (unique identifier graved on a cylinder), which is also indicated in the table.

Table 2: Cylinder ID, CO_2 amount fraction ($x_p(CO_2)$), expanded uncertainties ($U(x_p(CO_2))$) and coverage factor reported by E+E.

Standard #	Cylinder ID	$x_p(CO_2)$	$U(x_p(CO_2))$	k
		µmol/mol	µmol/mol	
1	D925796	399.90	3.18	2
2	6954	501.40	3.83	2
3	33744	694.66	4.64	2

A full description of the calculations and the uncertainty budget was provided by E+E in the Information Sheet annexed to this report (see Annex 1 – Participant reports).

6 Measurements at the BIPM

6.1 Preparation and quality control of the BIPM comparison facility

Before starting the analysis of mixtures, it was ensured that all necessary calibrations of the measuring instruments (pressure gauges and temperature sensors) were performed within the appropriate period and that all quality controls were realised within one month prior to the measurements. In particular, the volume ratio between the vessels used to handle the CO_2 gas and the sample from which it is extracted was monitored carefully and observed to be stable within the uncertainties.

The BIPM makes use of a minimum of two quality control mixtures of CO_2 in dry air or nitrogen which are regularly analysed with the facility to check its stability. To demonstrate the stability of the system since the last BIPM.QM-K2 comparison report [4], measurements performed on the QC mixture #3 are displayed on Figure 1. The period covers measurements between October 2024 and July 2026. Figure 2 shows measurements performed in the QC mixture #4, between March and July 2026. Both graphs show stable and reproducible measurements, with a standard deviation of 0.04 µmol mol^{-1} over two years for QC#3 and over 5 months for QC#4, comparable with the typical repeatability of the facility.

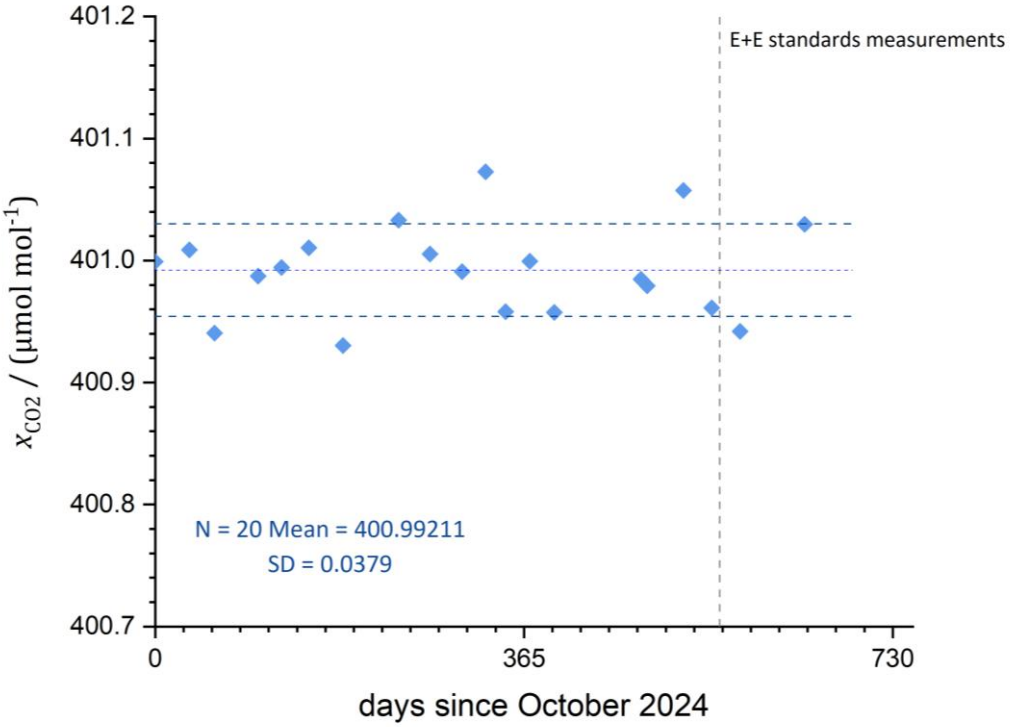

Figure 1: amount fraction of CO_2 in air, as measured by the BIPM PVT-CO_2 facility in the quality control mixture #3 since October 2024.

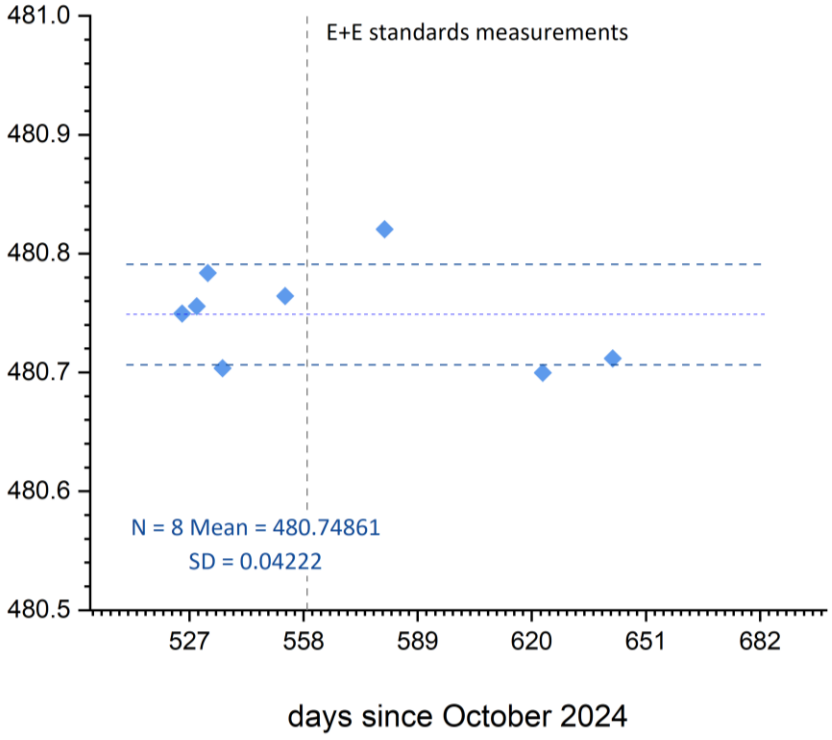

Figure 2: amount fraction of CO_2 in air, as measured by the BIPM PVT-CO_2 facility in the quality control mixture #4 during the weeks prior and after the comparison measurements.

6.2 Preparation and connection of the cylinders

After receipt by the BIPM, all cylinders were allowed to equilibrate at laboratory temperature for at least 24 hours. All cylinders were then rolled for at least 1 hour to ensure homogeneity of the mixture before being transferred to the PVT−CO_2 laboratory. Cylinders were sequentially connected to the PVT−CO_2 system through a cylinder connector appropriate to the cylinder valve and a pressure reducer common to all cylinders.

6.3 Analysis of mixtures

The PVT−CO_2 system samples 6 L of gas for each analysis. The first amount of gas sampled was used for conditioning of the measurement system and not as a measurement result. Standards were then sampled in successive series of $n \geq 3$ separate measurements. The final value and uncertainty were calculated based on all n measurements, taking the mean value and the standard deviation of the mean for the repeatability component of the uncertainty.

6.4 Measurement results

The results of measurements performed with the PVT−CO_2 facility are summarised in Table 3. The number of measurements per series is indicated for information, as well as the value of the standard deviation of the mean, for which values lay between 0.007 µmol mol^{-1} and 0.011 µmol mol^{-1}, showing good repeatability of the system. The combined standard uncertainty is similar to that obtained during the validation study, with the same uncertainty budget being applied.

Table 3: cylinder reference (ID), amount fraction of CO_2 measured by the BIPM ($x_R(CO_2)$), associated standard uncertainty ($u(x_R(CO_2))$), standard deviation of the mean (σ), number of repeats (n).

Standard #	Cylinder ID	$x_R(CO_2)$	$u(x_R(CO_2)$	σ	n
		µmol/mol	µmol/mol	µmol/mol	
1	D925796	400.013	0.097	0.008	3
2	6954	501.411	0.121	0.011	3
3	33744	695.052	0.165	0.007	3

7 Key comparison reference value and uncertainty

There is one reference value for each mixture sent by the participant, defined by the results of measurements performed at the BIPM $x_R(CO_2)$, displayed in Table 3, with their standard uncertainties $u(x_R(CO_2)$.

The uncertainty budget for the PVT−CO_2 facility is described in [2]. It can be summarized in one equation expressing the standard uncertainty as a function of the CO_2 amount fraction x as follows:

$$u(x) = \sqrt{(u_1 x)^2 + u_2^2 + \sigma^2}\ \text{µmol mol}^{-1} \quad (1)$$

Where $u_1 = 2.35\times10^{-4}$ is the relative part of the uncertainty, $u_2 = 0.023$ µmol mol^{-1} is the combination of the uncertainties on the additive corrections without the repeatability, and σ is the standard deviation of the mean over the repeated measurements, which takes the values displayed in Table 3.

8 Degrees of equivalence

There are three degrees of equivalence defined in this comparison, one for each standard, defined as:

$$D = x_P - x_{KCRV} \quad (2)$$

Where $x_P = x_P(CO_2)$ is the measurement results of the participants, and $x_{KCRV} = x_R(CO_2)$ is the KCRV for the same standard as defined in section 7. Its associated standard uncertainty is:

$$u(D) = \sqrt{u(x_P)^2 + u(x_{KCRV})^2} \quad (3)$$

where $u(x_P) = u(x_P(CO_2))$ and $u(x_{KCRV}) = u(x_R(CO_2))$ are the measurement uncertainties of the participant and of the BIPM respectively for the same standard.

The values are reported in Table 4 and plotted in Figure 3.

Table 4: Degrees of equivalence of E+E at the three CO_2 amount fractions in nitrogen measured in this comparison

Standard #	x_P / (µmol mol^{-1})	$u(x_P)$ / (µmol mol^{-1})	x_{KCRV} / (µmol mol^{-1})	u_{KCRV} / (µmol mol^{-1})	D / µmol mol^{-1})	$U(D)$ / (µmol mol^{-1})
1	399.90	1.59	400.01	0.10	-0.11	3.19
2	501.40	1.92	501.41	0.12	-0.01	3.84
3	694.66	2.32	695.05	0.17	-0.39	4.65

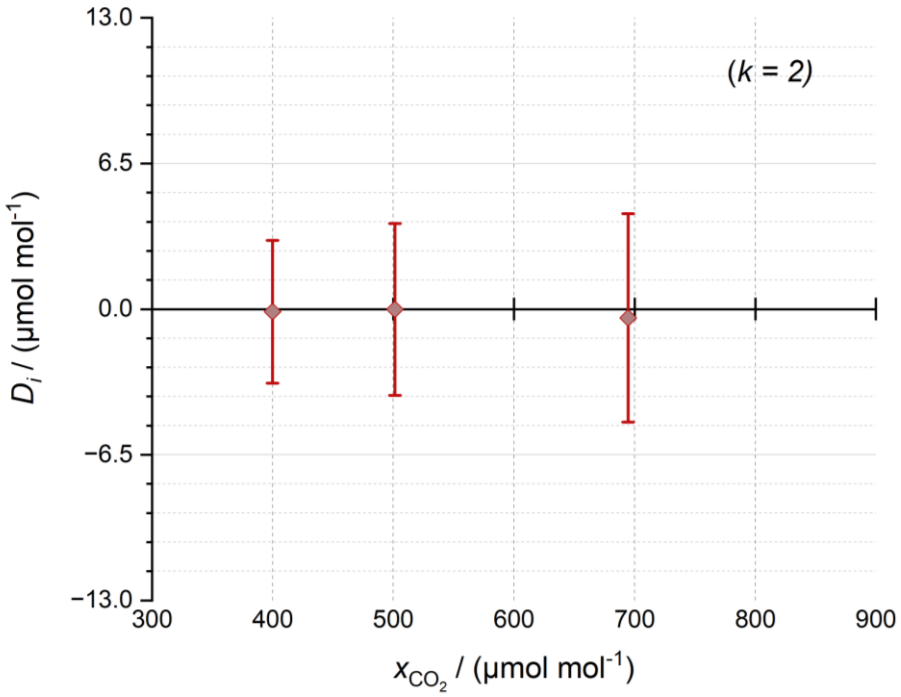

Figure 3: Graph of equivalence

The results show very good agreement between E+E and the BIPM PVT-CO_2 facility for all three standards, covering a range of CO_2 amount fraction in nitrogen between 350 µmol mol^{-1} and 800 µmol mol^{-1}.

9 History of comparisons with E+E

Results of the previous comparison performed with E+E are displayed in Figure 4 together with the results of this comparison.

Figure 4 shows that the agreement between E+E and the BIPM has improved significantly between 2025 and 2026.

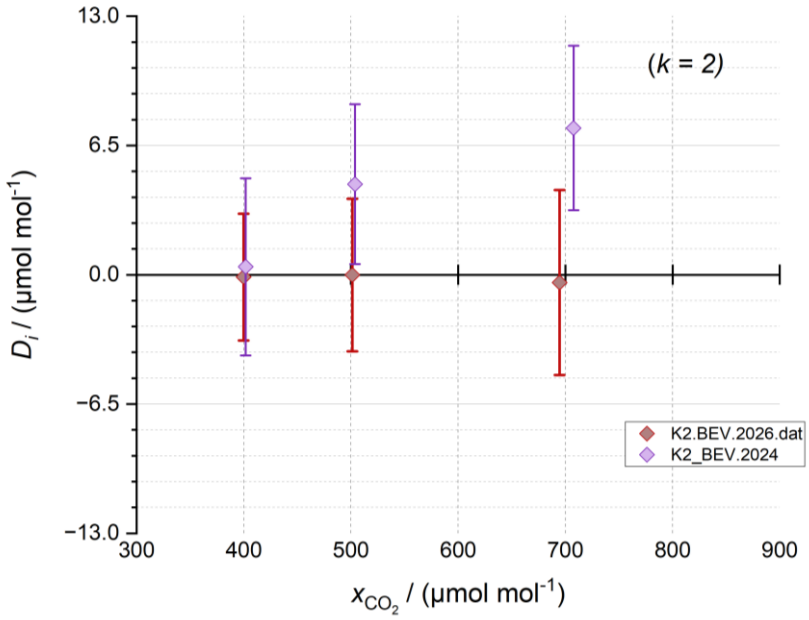

Figure 4: results of previous comparisons with E+E

10 Conclusion

For the second time since the launch of the ongoing key comparison BIPM.QM-K2, a comparison has been performed between the CO_2 amount fractions measurement capabilities of E+E Elektronik, Designated Institute of Austria, and the common reference standard of the key comparison, maintained by the BIPM. Tthree mixtures of CO_2 in nitrogen were sent by the participant for this comparison, allowing a comparison of measured values over a CO_2 amount fraction range of 350 µmol mol^{-1} to 800 µmol mol^{-1}. Degrees of equivalence of this comparison indicated good agreement over this range.

11 Annex 1 – Participant reports

Two reports are displayed entirely in the following pages (PDF version only): the result form (Excel Spreadsheet) and the Information Sheet. Both were completed by the participant.

12 References

[1] Viallon J., Choteau T., Moussay P., Wielgosz R., Veen A.v.d., Bi Z., Crotwell A., Hall B., Webber E.M. and Hill− Pearce R., 2023, Final report of CCQM-P225a and b, international comparison on carbon dioxide in air and nitrogen at ambient levels (350 µmol/mol to 800 µmol/mol), *Metrologia*, **60**, 08029, 10.1088/0026-1394/60/1A/08029

[2] Viallon J., Meyer C., Moussay P., Schmidt J., Maxwell S., Arrhen F. and Wielgosz R.I., 2023, A high accuracy reference facility for ongoing comparisons of CO2 in air standards, *Metrologia*, **60**, 065014, 10.1088/1681-7575/ad0abe

[3] Viallon J., Moussay P., Wielgosz R. and Pachinger D., 2025, Report of the comparison BIPM.QM-K2.b, on carbon dioxide in nitrogen at ambient levels,

with E+ E Elektronik (2025), *Metrologia*, **62**, 08022, 10.1088/0026-1394/62/1A/08022

[4] Viallon J., Moussay P., Wielgosz R. and Valkova M. BIPM 2026 Report of the comparison BIPM.QM-K2.b, on carbon dioxide in nitrogen at ambient levels, with SMU (2025) *CIPM MRA Comparison reports* **08001** (Sevres, 05/01/2026, 10.59161/OHVC2544)

Result Form for the comparison

BIPM.QM-K2.a and b, Carbon Dioxide in air (a) or nitrogen (b)

Participating institute information	
Institute	**BEV/E+E (Designated Institute E+E Eletkronik GesmbH)**
Address	**Langwiesen 7, 4609 Engerwitzdorf, Austria , Europe**
Contact	**Dr. Dietmar Pachinger**
Email	dietmar.pachinger@epluse.com
Telephone	**+43 7235 605-755**

Comparison part (a/b)	**b**

Transfer Standards (cylinders) Information		
Number of standards	3	

Standard #	ID (Serial Number)		Date of preparation	Pressure	(unit)
1	D925796		2026-03-05	15	MPa
2	6954		2026-03-05	15	MPa
3	33744		2026-03-05	15	MPa

Content of the form

This result form is to be completed by participants in BIPM.QM-K2

Please complete the cells according to their format:

	A numerical value is expected
***	*Text is expected*

After completion of the appropriate section of this report, please send to Joële Viallon by email (jviallon@bipm.org)

Additional pages can be added if there is not enough space to report information

Cylinders Composition

CO_2 amount fraction

Complete the highlighted cells below with the value of the amount fraction of carbon dioxide assigned in each cylinder, expressed in µmol/mol,
the associated expanded uncertainty and its coverage factor *k*

Standard #	Cylinder ID	x_{CO2}	$U(x_{CO2})$	*k*
		µmol/mol	µmol/mol	
1	D925796	399.90	3.18	2
2	6954	501.40	3.83	2
3	33744	694.66	4.64	2

N_2O amount fraction

Complete the highlighted cells below with the value of the amount fraction of nitrous oxide measured in each cylinder, expressed in nmol/mol,
the associated expanded uncertainty and its coverage factor *k*

Standard #	Cylinder ID	x_{N2O}	$U(x_{N2O})$	*k*
		nmol/mol	nmol/mol	
1	D925796	none		
2	6954	none		
3	33744	none		

BIPM.QM-K2.a (CO_2 in air) - Matrix Gas

Complete the cells below with the composition of the matrix gas
Indicate the amount fractions of the three major compounds
Compounds at trace levels may be indicated as well in the columns (other)
Indicate the unit in the cells (unit)

Compound	N_2	O_2	Ar	Other	Other	Other
Standard #	(unit)	(unit)	(unit)	(unit)	(unit)	(unit)
1						
2						
3						