CCQM STRATEGY DOCUMENT 2030+

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EXECUTIVE SUMMARY

The document sets out the strategy to be followed by the Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology (CCQM) to 2034 and beyond to deliver its mission of advancing the global comparability of chemical and biological measurement standards and capabilities, and thereby enabling Member States and Associates to make measurements with confidence. In so doing, measurement science will also be progressed, and stakeholder engagement strengthened. In developing its strategy, the CCQM expert groups have identified nine key sectors that are expected to influence and drive the development on National Metrology Institutes' (NMI) and Designated Institutes' (DI) services to 2034 and beyond and impact CCQM activities for achieving global comparability of chemical and biological measurements. Scientific, economic and social challenges which can be tackled through metrology at the CCQM level are described for the following sectors: Environment and Climate; Healthcare and Life Sciences; Food safety, trade and authenticity; Energy; Legal Metrology; Fundamental metrology and support of the SI; Forensic Sciences and Anti-doping; Advanced Manufacturing; Biotechnology and Drug Discovery. The document provides a limited revision to the strategy document published in 2021, based on major developments in the period 2021-2025.

The CCQM has set seven strategic aims to be progressed, notably: to contribute to the resolution of global challenges; to promote the uptake of metrologically traceable chemical and biological measurements; to progress the state of the art of chemical and biological measurement science; to improve efficiency and efficacy of the global system of comparisons for chemical and biological measurement standards it conducts; to continue the evolution of Calibration and Measurement Capabilities (CMCs) to meet stakeholders needs; to support the development of capabilities at NMIs and DIs with emerging activities; to maintain organizational vitality, regularly review and, if required, update the CCQM structure for it to be able to undertake its mission.

The strategy foresees contributions to progressing the state of the art in measurement science across all nine technical science areas covered by the Committee including Organic, Inorganic, Gas, Isotope Ratio, Surface, Electrochemical, Protein, Nucleic Acid and Cell analysis areas. Thirty-four activities have been identified where progress is expected, ranging from support for the emerging areas of 'omics', development of new particulate standards, isotope ratio and microplastic standards, to the development of reference measurement systems for biomarkers, surface chemical composition for semiconductor and quantum devices, RNA quantification, food authentication, and cell counting as examples.

A more structured approach to stakeholder engagement is foreseen in the new strategy and considered as a key tool in promoting the activities and impact of the CCQM and of the Chemical and Biological Metrology community in general. The use of task groups is key to the strategy and has already been successfully exploited in the 2021-2024 period in both engaging with outside stakeholders, and to address emerging requirements in CCQM, across sectors and CCs, such as set out in the CIPM 2030+ strategy. This allows the CCQM to rapidly address emerging new areas such as pandemic response and the application of artificial intelligence (AI) to address metrology issues. Extension of the CCQM Liaison Membership, to better represent the expanded technical coverage of the committee, remain a longer term goal.

A core capability/comparison strategy will be continued with the aim of not increasing overall resources required for comparisons for the 71 institutes worldwide maintaining over 6500 CMCs in the chemistry/biology field. The rapid development of AI and moves towards digitalization of reference data to support accurate measurements will be the focus of the Task Group on Data Digitalization, which is expected to increase the efficiency of CCQM and CIPM MRA processes.

Strong interaction will be maintained between the CCQM and RMOs, with continued coordination of linked, satellite and supplementary comparisons, and increased focus on capacity building and knowledge transfer.

The implementation of the strategy is supported by the BIPM Chemistry Department providing the CCQM Executive Secretary Role, coordination of comparisons in technical areas prioritized by the CCQM, laboratory-based knowledge transfer programmes for National Metrology Institutes with emerging metrology systems, the JCTLM database and support for engagement with stakeholder communities.

Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology: Strategy Document (2030+)

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1. INTRODUCTION

The CCQM was established by the International Committee of Weights and Measures (CIPM) to bring together the world's experts in metrology in chemistry and biology. Created in 1993, it is one of the ten Consultative Committees of the CIPM, and the only one working solely in the domain of chemistry and biology. To cover the different technical disciplines within its sphere of activity, the CCQM currently maintains nine technical subject working groups, a Strategy Planning WG, a Working Group on Key Comparisons and CMCs, and an ad-hoc WG on the mole, and is supported by a scientific and technical programme at the BIPM. It also establishes Task Groups at the CCQM or WG level to progress

well defined actions through coordinated activities between NMIs and stakeholders. The membership of the CCQM is constituted of 43 institutes worldwide (either as members, observers or liaisons), with over 70 institutes and over 600 scientists participating on a regular basis in the activities of its working groups. The CCQM work programme has resulted in the execution of just over 540 inter-laboratory comparison exercises since its creation, with on-average 18 new comparisons initiated each year. The CCQM activities together with those of the RMOs, support over 6500 calibration and measurement capabilities in chemistry and biology from over 70 institutes worldwide. The activities of the CCQM have also contributed to the establishment of the Joint Committee for Traceability in Laboratory Medicine (JCTLM), and to which NMI and DIs active in CCQM continue to participate.

The document provides a limited revision to the strategy document published in 2021, based on major developments between 2021 and 2025, and covers the period to beyond the year 2034. The 2021-2030 strategy document was drafted by the Strategic Planning WG of the CCQM, chaired by the CCQM President, following approval of the vision and mission statements and strategic aims for the 2021-2030 period by the CCQM in 2020. Plans for detailed activities developed within each of the technical subject working groups covered by the CCQM, following consultation in 2020 with National Metrology Institutes and Designated Institutes active in these groups, have been updated where necessary. The plans are summarized in this document and detailed technical subject strategies available for consultation. The 2030+ CCQM Strategic Plan builds upon and replaces the previously published 2021-2030 and 2017-2026 CCQM Strategy documents. The document will be submitted to the 31st meeting of the CCQM for approval.

2. SCIENTIFIC, ECONOMIC AND SOCIAL CHALLENGES

Reliable chemical and biological measurements are essential for meeting the scientific, economic and sustainability challenges faced by our societies today. Nine key sectors have been identified within the technical subject areas covered by the CCQM, that are expected to influence and drive the development of NMI and DI services within the period 2021-2030 and impact the CCQM strategy for achieving global comparability of chemical and biological measurements. Examples of each sector's reliance of chemical and biological measurements and standards is given below, with more complete descriptions provided in each of the technical subject strategy documents referenced in Annex 3.

a) Environment and Climate

Policies and programmes to protect and restore the environment and biodiversity and provide coordinated action in response to climate change will require: enhanced measurements systems for monitoring, source apportionment and emission control of greenhouse gases, aerosols and air quality pollutants; primary measurements systems and metrological services to characterize seawater CRMs for the variables of the seawater CO_2 system; reliable measurements of persistent organic pollutants, endocrine disruptor compounds, antibiotics, Per- and polyfluoroalkyl substances (PFAS) and other pollutants, regulated and emerging ones, or their indicators, in air, water, wastewater, soils and sediments. Biofilms and microplastics and the circular economy in general represent a growing challenge requiring a multidisciplinary approach.

b) Healthcare and Life Sciences

Policies and programmes to advance healthcare will require: reference methods, reference materials and services for in vitro diagnostic tests and companion kits to meet regulatory requirements for metrological traceability and consistency of measurement results from different manufacturers; reliable and rapidly deployable reference measurement systems for infectious diseases; reliable measurements for in vitro diagnostics of non-communicable diseases; reliable measurements for regenerative medicine and gene therapy; a measurement infrastructure for the next generation of clinical biomarkers (e.g. breath analysis) for screening and diagnosis. Furthermore, the upcoming

multi-omics approaches (proteomics, metabolomics, genomics, transcriptomics..) will require novel approaches for standardisation and calibration.

c) Food and feed (human and animal)

Programmes and policies to ensure security/trade of safe and authentic food/feed will require: reliable measurements for regulated contaminants and residues, nutritional and anti-nutritional content parameters (such as elements, vitamins, lectins, tannins and phyto-oestrogens), food processing and migration contaminants (particularly those emerging with the transition towards a circular economy, such as biological contaminants from alternative protein sources [such as insects, micro/macroalgae, fungi] and drug metabolites) in food, elemental speciation, microplastics and nanoparticles; reliable measurements, standards and databases for food authenticity/provenance determinations; verification of mandatory fortification levels with staple foodstuffs; reliable and comparable measurement systems for food allergens, toxins and pathogens; reliable molecular, chemical and electrochemical methods for food/feed quality; reliable measurement methods and materials for the identification and quantification of GMO content in food/feed stuffs, precision bred organisms and new genome technologies.

d) Energy

Policies and programmes to develop, provide and trade current and future energy sources will require: globally maintained measurement infrastructure for natural gas composition; appropriate measurements systems for composition of biomethane, LNG and LPG, to facilitate diversification in the supply of energy gases; standards and databases for low carbon fuel authenticity/provenance determinations; a global measurement infrastructure for hydrogen purity to move towards a hydrogen economy; enhanced measurements of conductivity of feed water in steam turbines and in biofuels; enhanced measurement systems for the performance of alkaline-ion batteries and fuel cells; reliable surface chemical analysis of battery and fuel cell electrodes, supercapacitor and graphene materials, and photo-voltaic devices; reliable measurements of heavy metals and sulfur contaminants in fuel.

e) Forensic Sciences and Anti-doping

The areas of forensic sciences and anti-doping will require: reference materials for the identification of novel designer drugs; reference materials and methods for identification and quantification of prohibited substances and their metabolites; reference materials, methods and databases to authenticate provenance of commodities such as timber, food, animal and plant products; reliable measurements for nuclear forensics and the points of origin of nuclear materials and events. New sampling approaches will require reliable measurements for techniques such as dried blood spot testing.

f) Advanced Manufacturing

Requirements in advanced manufacturing will include: enhanced measurements systems for high purity gases for advanced manufacturing including semiconductor and organic electronic components; reliable measurements from electrochemical sensors and chemical surface analysis in miniaturized devices; reliable chemical analysis for nanotechnology development; reliable compositional measurements of alloys, organic thin films, oxides and other materials.

g) Biotechnology and Drug Discovery

Future developments in biotechnology and process control will require: reliable measures of cell parameters including viable cell concentration, volume and wet cell weight, supporting oligonucleotide and therapeutic protein (such as insulin, monoclonal antibody, enzyme replacement therapy, clotting factor) production including product characterisation; reliable measurements for cell authentication; reliable measurements to characterize advanced cell and gene therapy treatments (such as CAR-T or induced pluripotent stem cells) to ensure their quality, safety and potency.

h) Legal metrology

Implementation of statutory requirements for measuring instruments and methods will require: availability of metrologically traceable standards including those for automotive emissions from

traditional and emerging transport fuels and non-exhaust emissions, consumer products, and breath alcohol and interfering substance testing.

i) Fundamental Metrology and the SI

Analytical methods for chemical measurements require reliable calibration with metrological traceability to calibrations solutions and pure substance reference materials of known purity and isotopic composition. Characterization of chemical sensors and bio-sensing technologies requires a metrological traceability framework. Comprehensive underpinning of metrological traceability will require: reliable databases of reference data for chemical and biological measurement; availability of high accuracy chemical and biological measurement services that underpin the realization of SI units; developments in measurement methods and comparisons that can be used to meet global requirements for reference materials.

Sector/ Technology	CCQM OAWG	CCQM PAWG	CCQM NAWG	CCQM CAWG	CCQM SAWG	CCQM EAWG	CCQM IAWG	CCQM IRWG	CCQM GAWG	CCQM Task Groups (2025)
Environment & Climate	POPs, PFAS Contaminants Microplastics Water/Soil		Microbial contaminants	Microbial contaminants	Nanoparticles	Seawater pH and salinity	Heavy Metal Contaminants Emerging Contaminants Speciation Water/Soil Particles	GHGs	GHGs Air Quality Emissions Particles	CCQM Task Group on Nano- and Microplastics Measurements and Standards (CCQM-TG-NMMS)
Health & Life Sciences	Diagnostic biomarkers Anti-doping Forensics	Diagnostic biomarkers Therapeutics	Diagnostic biomarkers Therapeutics	Diagnostic biomarkers	Imaging diagnostics	Diagnostic biomarkers	Diagnostic biomarkers	Diagnostic biomarkers Anti-doping Forensics	Breath diagnostics	Joint Committee for Traceability in Laboratory Medicine (JCTLM) CCQM Task Group on Infectious Disease Diagnostics and Metrology for Pandemic Preparedness (CCQM-TG-PANDEMIC)
Food Safety	Toxins Contaminants Residues	Allergens novel foods	GMO-Foods Pathogens	Pathogens	Packaging Nanoplastics		Heavy metal Contaminants Speciation Particles	Food authentication	Safe and sustainable packaging	CCQM Task Group on Food Measurement (CCQM-TG-FOOD)
Safe water	Contaminants			Pathogens			Heavy metal Contaminants Speciation Particles			
Energy						Batteries Fuel Cells	Fuel Contaminants		Natural Gas LPG/LNG Hydrogen Biofuels	CCQM Task Group on Metrology for Li-ion batteries (CCQM-TG-LI-ION)
Advanced Manufacturing		Advanced Therapy Development	Biotechnology Advanced Therapy Development	Biotechnology Advanced Therapy Development	Nanotech Semiconductors		Nanotech Elements		Trace Gases	CCQM TG on Gene Delivery Systems (CCQM-TG-GDS)
Digital Transformation		AI in diagnostics and enginneering biology	AI for engineering biology	Digital Pathology and AI for engineering biology				Isotope Ratio Scale defining RMs Database	GHG Scales Database & Management	CCQM Task Group on Data Digitalization (CCQM-TG-DD)
Systems Metrology		Multi-omics approaches								
Quantum based technologies					Quantum Devices					CCQM-SAWG Task Group on Chemical Metrology for 2D materials

Figure 1: Mapping of sectors, identified by the CIPM study on evolving needs for metrology, and summary of measurement needs being addressed by CCQM technical subject WGs, CCQM Task Groups and the JCTLM.

The CIPM published its 2030+ strategy in May 2025, identifying metrology requirements within 5 grand challenge areas as well as four new technology area that are expected to spawn new metrologies. There is strong overlap between these areas and the nine sectors considered in the CCQM strategy, and Figure 1 summarizes the topics that will be covered by the CCQM technical subject working groups and current CCQM Task Group plans. Additional Task Groups at the CCQM Working Group level complement those of the CC (See section 5.3).

The CCQM is seeking to capitalize on the recent rapid advances in Artificial Intelligence Systems, in addition to the drive for the digitalization of data and has established a Task Group on data digitalization to focus on both these topics. Consideration is being given to the accessibility and availability of chemical and biological reference data, as well as the role of metrology in the provision of trusted data for machine learning algorithms that are used by AI. The JCTLM database, isotope ratio scale defining reference material database and Greenhouse Gas Standard databases are initial areas of focus, as well as future support for sensor networks and distributed measurements.

3. VISION AND MISSION

The CCQM's vision: A world in which all chemical and biological measurements are made at the required level of accuracy to meet the needs of society.

The mission of the CCQM is: To advance global comparability of chemical and biological measurement standards and capabilities, enabling Member states and Associates to make measurements with confidence.

The responsibilities of the CCQM are:

a. to demonstrate the global comparability of chemical and biological measurements, promoting traceability to the SI, and where traceability to the SI is not yet feasible, to other internationally agreed references;

b. to advise the CIPM on matters related to chemical and biological measurements including guiding international activities related to the definition and realization of the mole and advising on the BIPM scientific programme;

c. to reach out to new and established stakeholders to promote the international measurement system and prioritize needs;

d. to progress the state of the art of chemical and biological measurement science and act as a forum for the exchange of information about measurement research, technical programmes and service delivery;

e. to contribute to the implementation and maintenance of the CIPM MRA with respect to chemical and biological measurements.

4. STRATEGIC AIMS FOR 2030+

In line with the CCQM's vision and mission, the aims of the 2030+strategy are:

To contribute to the resolution of global challenges such as climate change and environmental monitoring, energy supply, food safety, healthcare including infectious disease pandemics, by

identifying and prioritizing critical measurement issues and developing studies to compare relevant measurement methods and standards.

To promote the uptake of metrologically traceable chemical and biological measurements, through workshops and roundtable discussions with key stakeholder organizations, to facilitate interaction, liaison and cooperative agreements, and receive stakeholder advice on priorities to feed into CCQM work programmes.

To progress the state of the art of chemical and biological measurement science, by investigating new and evolving technologies, measurement methods and standards and coordinating programmes to assess them.

To improve efficiency and efficacy of the global system of comparisons for chemical and biological measurement standards conducted by the CCQM, by continuing the development of strategies for a manageable number of comparisons to cover core capabilities.

To continue the evolution of CMCs to meet stakeholders needs, incorporating the use of broad claim CMCs where applicable to cover a broader range of services and considering options to present these in a way that meets stakeholder needs and encourages greater engagement with the CMC database.

To support the development of capabilities at NMIs and DIs with emerging activities, by promoting a close working relationship with RMOs including mentoring and support for NMIs and DIs preparing to coordinate comparisons for the first time and promoting knowledge transfer activities including workshops, as well as secondments to other NMIs, DIs and the BIPM.

To maintain organizational vitality, regularly review and, if required, update the CCQM structure for it to be able to undertake its mission and best respond to the evolution of global measurement needs, by prioritizing where new areas or issues should be addressed within the structure and evolving working group remits as required.

5. ACTIVITIES TO SUPPORT THE STRATEGY

Implementation of the strategic aims of the CCQM will be achieved through the sub-structures and tools available to the Committee, notably:

a) The CCQM plenary, to set strategic objectives, oversee activities, establish working groups and liaisons, and initiate new activities;

b) The CCQM technical subject working groups, to develop and implement work programmes in each of their technical subject areas following the CCQM strategic aims;

c) The CCQM Strategic Planning Working Group, to harmonise and align activities between WGs and prepare documents for review and approval of the CCQM;

d) The CCQM Key Comparison and CMC Quality working group, to work with the RMOs in maintaining a coordinated and harmonized system for inter-regional CMC review, with guidelines developed in collaboration with the CCQM technical subject working groups;

e) Support from the BIPM Headquarters, and principally the BIPM Chemistry Department, to implement CCQM strategic aims and CCQM and WG activities;

f) Task groups established at the Committee and WG levels to initiate and complete specific tasks, including those requiring engagement with stakeholders, between WGs and with other Committees;

g) Workshops and webinars providing knowledge transfer opportunities between Metrology Institutes and to and from stakeholder communities;

h) Appointment of vice-Chairs for WGs, with documentation of strategy and procedures, to enable effective succession planning.

5.1. PROGRESSING MEASUREMENT SCIENCE

Measurement science is progressed through the activities of the CCQM technical subject working groups and notably through the execution of pilot studies to investigate new methods or measurements areas, workshops and webinars focusing on new measurements challenges, and focus and task groups to define and execute new areas of work.

Activities that will be undertaken within the period 2021-2034 and lead to advances in measurement science are:

1. Supporting greenhouse gas reference material development for isotope ratios
This will support the development of a robust infrastructure for gas phase reference materials for isotope ratios of carbon dioxide for source apportionment, meeting the demand for new standards with the advent of commercial optical spectroscopy for isotope ratio monitoring starting with the CCQM-P204 study.

2. Developing greenhouse gas scale science with traceability to the SI
This will develop protocols to maintain consistency between independently held sets of primary carbon dioxide in air gas reference materials at the 0.02 µmol mol^{-1} level, providing fit-for-purpose standards for GHG monitoring and emissions authentication.

3. Supporting standards development for diversification of the energy gas supply
This will support progress in analytical methods and reference materials to support the quality infrastructure for hydrogen purity (building on CCQM-K164) and for other energy gases.

4. Extending particle metrology
This will improve methods and uncertainties attainable when measuring particle mass, size and number concentration measurements and the characterisation of regulated components, building on initial comparison studies.

5. Supporting reactive gas standard development for air quality monitoring
This will support reference material and spectroscopic analytical method development for the characterization of reactive gases such as nitrogen dioxide, hydrogen chloride and ammonia, building on information gained from comparative measurements.

6. Advancing spectroscopy for absolute gas mole fraction measurement
An initiative to support NMIs developing optical methods based on invariant spectroscopic properties of molecules and atoms to measure amount fraction and isotopic abundance of gas mixtures with quantifiable systematic and statistical uncertainties required for SI traceability.

7. Advancing analytical methods for high purity metal characterization
This will support improvement in methods for the determinations of nonmetallic impurities in high-purity metals, based on studies of several nonmetallic elements, building on CCQM-P149 results, and the fundamentals of SI traceability for inorganic measurands.

8. Supporting development of analytical methods for nanoparticle metrology
This will support development of single particle (sp)ICP-MS methods as well as novel techniques such as A4F for measurement of the mean size, size distribution, and number concentration of a population of metal-containing nanoparticles suspended in a liquid, building upon results from CCQM-P194 (Number concentration of colloidal nanoparticles in liquid suspension).

9. Supporting development of element-based quantitation of biomolecules
This will support the development of reliable measurement methods of biomolecules, such as proteins, peptides, nucleotides, DNA, and RNA with element-based measurement methods, building on results of CCQM-P156 (Element-based quantification and purity analysis of a dNMP standard

solution) and CCQM-P191 (Determination of the amount content of a purity-assessed recombinant protein in an aqueous calibration solution).

10. Supporting development of small sample and spatially resolved metrology

This initiative will support institutes in developing their capabilities for laser ablation ICP-MS, to provide high quality chemical composition data that is spatially resolved.

11. Supporting methods and standards development for elemental speciation

This initiative will support the wider application of species-specific IDMS as well as fit-for-purpose methods, building on studies of tributyl tin in seawater and inorganic arsenic in rice flour.

12. Supporting method development for SI traceability of isotope ratios measurements

This will extend the application of the full gravimetric isotope mixture model (FGIM) for absolute SI traceable isotope ratio determinations, starting with a focus on Cu isotope amount ratios.

13. Supporting metrological traceability development for solid state isotope ratio measurements

This will support the establishment of methods for SI traceability for solid state measurement techniques, such as laser ablation for isotope ratio measurements.

14. Supporting the development of pH scales to complex matrices

This will support the development of pH scales to different non-aqueous solvents, solvent-water mixtures, and high ionic strength matrices such as seawater.

15. Extending conductivity and impedance spectroscopy to more challenging conditions

This will support the extension of conductivity measurements and impedance spectroscopy to challenging matrices including pure water, seawater at high pressures, biofuels and Li-ion batteries.

16. Supporting the extension of coulometry as a reference method

This will support the extension of coulometric methods to bases, reductants and complexing agents (EDTA), and its use in determining antioxidant capacity in complex matrices.

17. Supporting the extension of SI traceable measurements for surface chemical composition

This will support the development of SI traceable measurements of chemical composition of layers of up to 1 µm thickness, chemical mapping of surfaces with lateral scale length of less than 1 mm, and chemical measurements of nanostructured and highly porous materials. The chemical measurement of 2-dimensional materials such as graphene, increasingly used in technological applications, will be developed.

18. Supporting advanced organic purity assignment method development

This will support the development of validated methods for purity assessment of organic molecules, including those with larger molar masses, lacking UV-chromophores and salt materials.

19. Supporting protocol development for reference material commutability studies

This will support the development of best practices in commutability studies required for CRMs used in a calibration hierarchy for clinical diagnostics.

20. Supporting the development of Reference Data as an emergent measurement service

This will initiate the use of well-documented, open source and machine-readable formats for data submitted for comparison results, supporting digitalization activities.

21. Supporting the application of Quantitative Nuclear Magnetic Resonance Spectroscopy (qNMR)

This will support metrological applications of qNMR to more complex molecules and evolving areas of application such as quantitative NMR for ^{19}F, ^{31}P and ^{13}C as alternative nuclei, and quantum mechanical approaches for data handling.

22. Supporting the application High resolution mass spectrometry (HRMS) and double isotope dilution mass spectrometry in CRM characterization

This will support the assessment of general quantitative performance of HRMS hyphenated techniques for organic and clinical analytes and CRM value assignment.

23. Supporting the development of Compound Independent Calibration (CIC)

This will support activities to develop CIC, based on hyphenated Inductively Coupled Plasma Mass Spectrometry (ICP-MS), measuring elemental species, for pure organic or standard solution value assignment with either inorganic element or other organic reference material calibrators.

24. Supporting development of methods for microplastic contaminant quantification

This will support development of methods and reference materials for microplastic characterization and quantification across a range of matrices.

25. Supporting reference measurement system development for protein biomarkers

This will support the development of reference materials and methods for high priority clinical biomarkers as well as antigens and antibodies for infectious disease diagnostics.

26. Supporting reference measurement system development for SI traceable measurement of nucleic acids

This will support the development of methods to improve DNA/RNA quantification and purity evaluation and their use in calibration hierarchies for the future of nucleic acid measurement, including infectious disease detection.

27. Supporting reference material development for food origin authentication

This will support the development of reference measurement methods and materials for food authentication, including organic components, mitochondrial DNA sequence analysis, and next generation and Sanger sequencing, and digital PCR techniques.

28. Supporting reference method development for genes, gene expression and epigenetics studies

This will support the characterization of candidate reference methods for measuring actionable genetic, epigenetic and transcriptomic changes.

29. Supporting reference method development for microbial quantification

This will develop reference methods for DNA/RNA copy number quantification studies for microbial identification and concentration determinations in industrial and environmental applications and infectious disease diagnosis and management.

30. Supporting reference method development for counting of cells in suspension

This will support the development of reference methods for cell counting, including flow cytometry, for cells in suspension, building on CCQM-P217 (Enumeration of fixed peripheral blood mononuclear cells in suspension), CCQM-P205 (Enumeration of membrane intact E. coli) and CCQM-P222 (Polystyrene (um) particle number concentration measurement for blood cell counting).

31. Supporting reference method development for counting of cells adhered to surfaces

This will support reference material development for the counting and characterization of adhered cells building on CCQM-P123 (Number and geometric property of cells adhered to a solid substrate) and CCQM P-197 (Proliferative mesenchymal stromal cell number per unit area).

32. Supporting method development for cell viability and functional measurement

This will support the development of reference methods and materials to measure cell viability by cell membrane disruption and metabolic methods alongside defined biological activities by quantification of specific cell bound targets (i.e. intracellular cytokines).

33. Supporting method development to practically implement the newly defined 'mole'

This will support various initiatives seeking to develop approaches to directly quantify chemical or biological entities through enumeration, providing SI traceability for measurements that can be readily related to the mole.

34. Supporting method development for (multi-) omics approaches

This will support the development of reference materials and methods for the standardization and calibration of omics approaches such as proteomics, metabolomics, genomics and transcriptomics in personalized medicine.

5.2. IMPROVING STAKEHOLDER INVOLVEMENT

Assuring appropriate stakeholder interaction has been identified as a key route for CCQM to promote the uptake of metrologically traceable chemical and biological measurements. This is envisaged to be achieved through workshops and roundtable discussions with key stakeholder organizations, which will facilitate interaction, liaison and cooperative agreements, and permit stakeholder advice on priorities to be received and to feed into CCQM work programmes. The mechanisms available to the CCQM for stakeholder interaction include:

a) Granting of CCQM liaison status to organizations that participate within the plenary meeting;
b) Workshops and webinars either at the CCQM or WG level;
c) Expert laboratory participation within CCQM pilot studies;
d) Signature of the CIPM MRA and participation within CCQM key comparisons;
e) Participation in CCQM WG Task groups when task completion requires stakeholder involvement;
f) Liaisons established with stakeholder organizations maintained by the BIPM Headquarters.

In many instances, stakeholder engagement is assured directly at the national level through the NMI or DI. However, where strategic interaction and communication with an entire measurement community, including promotion of interaction at national levels, is required, further action from the CCQM can be justified.

A CCQM Task Group on Stakeholder Engagement delivered its report in 2022 (CCQM/2022-03), and actions to be undertaken by the CCQM to further stakeholder engagement and achieve its strategic aims are:

a) To undertake a review and document the obligations and privileges for Liaison Members of CCQM and identify additional international candidate organizations whose involvement would be beneficial to the mission of the CCQM;
b) To maintain workshops and webinars, both at CCQM and CCQM WG levels, to facilitate stakeholder engagement and enable knowledge transfer to and from stakeholder communities, based on a mid- and longer-term plan for stakeholder engagement identified by the committee. Recent examples have included both the CCQM webinar series on ‘Reliable measurements in response to the Covid-19 pandemic’, and the CCQM GAWG virtual workshop on Accurate Surface Ozone Measurement.
c) To continue expert laboratory participation in CCQM pilot studies as a method of gaining expert knowledge for the CCQM and engaging additional stakeholder communities;
d) To keep under consideration opportunities for other international organizations providing chemical and biological measurement standards to participate in the CIPM MRA;
e) To utilize Task Groups at the CCQM and WG level to engage with stakeholders in delivering the mission of the CCQM. Recent examples include the establishment of the CCQM GAWG Task Group on Ozone Cross Section Change Implementation;
f) To encourage WGs to include agenda points in meetings on feedback on individual NMI interaction with stakeholder groups of interest to the wider community, for example related to ISO technical committee activities;
g) To establish appropriate structures (liaisons, focus groups or task groups) to maintain communication and input into any CIPM Sector specific structures or other Consultative Committees that have an overlap or would benefit with CCQM engagement;
h) To identify organizations and committees where it would be beneficial for the BIPM Secretariat to establish liaisons to facilitate the implementation of the CCQM mission.

5.3. THE USE OF TASK GROUPS

The CCQM foresees the continued use of task groups to address its strategy in both engaging with outside stakeholders, and to address emerging requirements in CCQM, across sectors and CCs, such as set out in the CIPM 2030+ strategy.

Examples of CCQM and CCQM WG task groups active in 2025 and their engagement with stakeholders and expected outputs are:

- CCQM Task Group on Infectious Disease Diagnostics and Metrology for Pandemic Preparedness (CCQM-TG-PANDEMIC) – working with health care professional and industry to promote and demonstrate NMI capabilities for rapid deployment of standards and controls in the event on a new pandemic;
- CCQM Task Group on Food Measurement (CCQM-TG-FOOD) – working with food testing laboratories and other CCs to define a 2030+ strategy for metrology in support of safe food;
- CCQM Task Group on Data Digitalization (CCQM-TG-DD) – working with CIPM MD FORUM and experts from the digital and AI field to allow measurement standard service information handling to benefit from machine and AI readability;
- CCQM Task Group on Nano- and Microplastics Measurements and Standards (CCQM-TG-NMMS) – working with stakeholders to determine key measurands an comparison for this emerging field;
- CCQM Task Group on Metrology for Li-ion batteries (CCQM-TG-LI-ION) – working with other CCs and industry to determine comparisons that can facilitate battery reuse;
- CCQM Task Group on Gene Delivery Systems (CCQM-TG-GDS) – working with biotechnology industry to standardize measurements for gene delivery systems;
- CCQM EAWG Task Group on Metrological traceability for seawater pH and pHT values (CCQM-EAWG-TG-SEAWATER) – working with the marine monitoring community to provide standards for the future;
- Joint CCQM-IAWG/SAWG Task Group on Particle Metrology (CCQM-IAWG-SAWG-TG-PARTICLE) - CCL WG-N to leverage knowledge and identify opportunities for cooperation between (nano)dimensional, chemical and biological activities with respect to particle metrology;
- CCQM-GAWG Task Group on Aerosol Metrology (CCQM-GAWG-TG-AEROSOL) – working with stakeholders to develop a metrology infrastructure for particle number concentration, particle mass concentration, particle size distribution, black carbon mass concentration and particle surface area;
- CCQM-GAWG Task Group on Ozone Cross-Section Change Management – working with environment agencies, scientists and manufacturers to implement more accurate ozone measurements worldwide;
- CCQM-GAWG Task Group on GHG Scale Comparisons (CCQM-GAWG-TG-GHG) – working with WMO and atmospheric scientists to make standards more accessible;
- CCQM-IRWG/GAWG Task Group on Carbon Dioxide and Methane Stable Isotope Ratio Measurements (CCQM-GAWG-IRWG-TG-ISOTOP)- working with IAEA and WMO and the research community to improve the robustness of the world's systems for isotope ratio measurements;
- CCQM-OAWG Task Group on Clinical/Toxicology Sector (CCQM-OAWG-TG-CLIN/TOXSEC) working with IFCC and IVD industry to prioritize clinical measurand for standardizations and comparisons;
- CCQM-ah-WG-Mole Task Group on Terms, Quantities and Units for Bioanalytical Measurement (CCQM-TG-TQUB) - working with stakeholders in biological science to harmonise key units and quantities that are commonly used in bioanalysis;

- CCQM-IAWG Task Group on CMC Claims – an intra-IAWG task group striving to provide updated guidance, online tools, and training to assist NMIs and DIs with making and evaluating CMC claims, especially broad-scope claims.

5.4. PROMOTING GLOBAL COMPARABILITY

The CCQM activities over its first 30 years of existence have done much to promote the uptake of metrological traceability within chemical and biological analytical measurements and laboratories. Within the same time period, there has been growth both in the number of NMIs/DIs providing chemical and biological reference materials and measurement services as well as a broadening of the technical fields in which these services are offered. Seventy-one institutes now have a total of over 6500 CMCs registered in the BIPM key comparison database. The challenge for the CCQM is to maintain a system able to demonstrate the equivalence of chemical and biological measurements standards and capabilities at the required level of quality assurance with a manageable level of comparisons. A second challenge is to ensure that submitted CMCs meet stakeholder needs, and that the resources required for CMC maintenance and review also remain at manageable levels. A third emerging challenge is to ensure the machine readability of CMC data and its integration into a digitalized world.

The CCQM strategy for maintaining comparisons at manageable levels is to develop and maintain models for core capabilities and comparisons, where one or a combination of comparison exercises can demonstrate capabilities across a broader area of capabilities than the single analyte and matrix studied in the comparison. These are supplemented by specialized comparisons, where particular focus is on a globally important or challenging analyte/measurand. The strategy has been implemented within the WGs with the most mature programmes, with newer WGs developing their measurement programmes with this concept already in mind. As a result, the total number of comparison exercises run each year, is foreseen to remain at or below 18 comparisons per year for the period to 2030+. This is consistent with the number targeted in the previous CCQM 2021-2030 strategy, and the number of comparisons that were registered in the period 2021-2024.

Maintaining resources for processing CMCs at manageable levels is to be achieved through use of the web based tools of CMC submission and review now available in KCDB2.0, and the development of models for the formatting and required evidence for Broad Scope CMCs. The CCQM strategy has been to encourage the development of broad claim CMC models within all technical areas covered by the Committee, and available for NMIs to implement if they wish. The 2017 to 2021 period has seen the total number of Chem-Bio CMCs increasing from 6227 to 6346, a rise of 119 over 4 years, and in 2025 the number is 6535, a further rise of 189 since 2021. As the adoption of broad scope CMC claims is voluntary, and driven by individual national stakeholder requirements, the future evolution of CMCs will be determined by national decisions on implementation of the broad claim option. The CCQM, through its Key Comparison WG, maintains an active CMC re-review cycle and in 2025 completed review of all CMCs that were from 2010 or older. The CCQM is currently considering alternative strategies for assuring CMC review as well as the impact of AI and digitalization on CMC format and processes for CMC review.

The CCQM was instrumental in the development of the JCTLM Database of Reference Materials, Methods and Services for Laboratory Medicine. The database is maintained by the BIPM and the vast majority of entries for CRMs are from NMIs/DIs. In the field of Laboratory Medicine, matrix CRMs are required to exhibit the property of commutability (showing the same behaviour as human test samples within the kits to which they are applied), as well as meeting requirements of specific documentary standards. The JCTLM database remains the only sector specific database of NMI

measurement capabilities maintained by the BIPM. A strategic consideration for the CCQM is to ensure that the process of the CIPM MRA and the JCTLM are well aligned.

The CCQM will keep under review the need for further initiatives for sector specific databases, or sector specific applications derived from a machine readable KCDB2.0 to meet stakeholder needs on globally comparable reference measurements. A potential case study would be an initiative to address the traceability exception that exists within the CIPM MRA for isotope ratio measurement standards for delta scale measurements. A database of reference materials with supporting data meeting FAIR principles, providing a global database of reference points for global scales, would be one approach to meet requirements.

5.5. INTERACTION WITH RMO ACTIVITIES

Effective and efficient interaction between CCQM and RMOs is achieved through:
a) RMO representation at the CCQM Plenary meeting;
b) RMO Metrology in Chemistry TC Chair membership of the CCQM Strategic Planning WG;
c) CCQM technical subject WGs maintaining standing agenda points within their meetings for RMO comparisons and other activities;
d) the CCQM KCWG with representatives from RMOs, CCQM technical subject WGs and the BIPM Headquarters.

As comparisons within CCQM are not normally limited by the availability of a transfer standard (as is often the case in Metrology in Physics) regional key comparisons linked to CCQM ones are less frequent in the Chemistry/Biology measurement space. However, notable exceptions are in the field of gas metrology as well as ethanol in water in organic analysis, where exactly the same measurand needs to be measured on a global level, and in the former case where the cost of preparation of multiple transfer standards limits participant numbers. In these cases, RMO linked key comparisons are foreseen to continue.

RMOs have an active programme in supplementary comparisons to meet comparison needs of their members wishing to demonstrate new or maintained measurement capabilities. To best use resources and avoid unnecessary duplication of efforts, NMIs from other regions can be invited to participate in an RMO's comparisons, and this is facilitated by discussion within CCQM technical subject WGs. This is particularly relevant where RMOs are co-ordinating comparisons of relevance to developing institutes that may not be occurring at the CCQM level.

Capacity building and knowledge transfer (CBKT) programmes originated and are maintained within the RMOs to enable countries and laboratories with emerging metrology systems in chemistry and biology to participate fully in the CIPM MRA processes and comparisons. Since 2016, the regional CBKT programmes have been augmented with activities of the BIPM Headquarters, including the BIPM Chemistry Department running CBKT laboratory projects for laboratories developing organic calibrators and gas standards for food safety and air quality monitoring, with these projects being extend to summer schools for qNMR with related on-line knowledge transfer modules. The expected continued growth in numbers of laboratories and countries with emerging metrology systems wishing to develop and demonstrate compatibility of their chemical and biological measurement standards and capabilities will require these projects to continue. Online meetings on the CCQM Working Groups have permitted a much larger number of scientists from around the world to participate in their meetings, including those wishing to develop their capabilities. The CCQM OAWG and GAWG have reacted by establishing task groups on knowledge transfer to meet this need. The CCQM would also encourage additional NMIs to become coordinators of comparison exercises, with plans for

laboratories experienced in comparison coordination partnering and mentoring laboratories wishing to coordinate a CCQM comparison for the first time.

RMOs are also establishing research programmes, which include or result in pilot studies on new technical areas, with EURAMET and the EMPIR/EMP programmes being a notable example. RMO research activities are also reported within CCQM technical subject WGs, and this provides a process for regional pilot studies to be elevated to CCQM level, where there is sufficient interest from other regions of the world. EURAMET has established metrology networks to link to stakeholders in various sectors, and CCQM encourages feedback on stakeholder needs to its plenary and WG meetings.

5.6. WORK PROGRAMME OF THE BIPM LABORATORIES

The implementation of the CCQM strategy is supported by the BIPM Chemistry Department providing the CCQM Executive Secretary Role, coordination of comparisons in technical areas prioritized by the CCQM, laboratory-based knowledge transfer programmes for National Metrology Institutes with emerging metrology systems, the JCTLM database, and support for CCQM Task Groups and organization of workshops and support for engagement with stakeholder communities.

BIPM laboratory activities enable a long-term commitment to comparison coordination, which is best adapted to periodic comparisons and allowing close monitoring of performance. The CCQM WG strategy plans, for the Gas, Isotope Ratio, Organic, Protein and Nucleic Acid Analysis WGs, foresee BIPM coordinated CCQM comparisons of:

a) NMI/DI core capabilities for primary reference materials and calibrators for small organic molecules
b) NMI/DI core capabilities for primary reference materials and calibrators for peptides and proteins
c) NMI/DI core capabilities for primary reference materials and calibrators for DNA and RNA
d) NMI/DI primary calibrators/capabilities for prioritized green-house gases and air quality gases
e) NMI/DI calibrators/reference capabilities for the traceability of $\delta^{13}C$ and $\delta^{18}O$ measurements

The laboratory-based capacity building and knowledge transfer laboratory activities initiated at the BIPM in 2016 in the fields of Metrology for Safe Food and Feed and Clean Air, supporting KT activities in the RMOs, have had good uptake. The future strategy sees the expansion of these to cover Pesticides and Veterinary Drugs relevant to residues in Food, Dynamic standards for Air Quality Gases, and Pure peptides for Laboratory Medicine. The visiting scientist placement programme will be reinforced with on-line eLearning modules, as well as summer schools, increasing the possibility of participation in the next period, and support the increased interest in CCQM activities from NMIs with emerging metrology systems.

The implementation of machine-readable databases with data following FAIR principles and the application of AI, will be addressed by the BIPM, in the first instance, with the JCTLM database and investigation of the application of AI for entry submission and review. Activities will be extended to the GHG Scales database as well as a database for international standards for isotopic ratio measurements This builds on previous database projects and the development and publication of reference data for qNMR internal standards, which are maintained. In addition, the opportunities offered by using AI to facilitate management and accessibility of reference data will be pursued, starting with the JCTLM database.

The CIPM strategy for 2030+ foresees the establishment of interdisciplinary fora for discussion of identified challenges and development of international metrology actions to support them. The sectors that have initially been identified by the CIPM are: Environment; Health and Life Sciences;

Food and Water Safety; Energy; Advanced Manufacturing; as well a new technologies that will lead to New Metrology. The fora and CIPM sector Task Groups will require support from the BIPM Headquarters and notably the Chemistry Department, with a considerable number of themes having strong technical overlap with the CCQM.

A detailed strategy for the BIPM activities, together with short terms and longer-term actions is described in Annex 4.

ANNEXES

ANNEX 1: GENERAL INFORMATION

CC Name: **CCQM**
Date Established: **1993**
Number of Members: **25 members; 12 Observers; 6 Liaisons**
Number of Working Groups: **12**
Number of Participants at last meeting: **110 at plenary (590 in WGs)**
Number of Institutes participating in CCQM and CCQM WGs: **76**
Periodicity between Meetings: **1 year**
Date of last meeting: **10-11 April 2025**
CC President: **Dr Sang-Ryoul Park, KRISS**
Number of KCs organized (from 1999 up to and including 2025): **251 Key comparisons**
Number of Pilot studies organized (from 1999 up to and including 2025): **160 stand-alone pilot studies**
Number of CMCs published in KCDB supported by CC body activities (As of July 2025): **6535**

ANNEX 2: LIST OF PLANNED KEY AND SUPPLEMENTARY COMPARISONS AND PILOT STUDIES

Comparisons that are planned with a formal start date can be found on the BIPM website at the address below and are updated by the CCQM on a 6-monthly basis.
https://www.bipm.org/documents/20126/41532304/Planned+Future+CCQM+Comparisons/e8683f8f-0dd4-8d79-3e9c-e3eae0b806a4 Individual WG strategy documents contains further information of plans for future comparisons, and this data has been summarized in the table below.
A summary of registered comparisons that are active or completed is available at https://www.bipm.org/documents/20126/48101949/CCQM_KCs_PSs.xlsx/eaf57589-7beb-52d0-60c6-ca8e21481c03 , and has been used to summarize the 2021-2024 period in the table below.

CCQM Working group	Estimated number* (in 2021) of Key comparisons in 2021-2024	Estimated number* (in 2021) of (standalone) Pilot Studies in 2021-2024	Number of Key comparisons registered in 2021-2024	Number of (standalone) Pilot Studies registered in 2021-2024
Gas Analysis Working Group (GAWG)	**10**	**1**	**12**	**3**
Organic Analysis Working Group (OAWG)	**10**	**1**	**7**	**0**
Inorganic Analysis Working Group (IAWG)	**11**	**2**	**11**	**2**
Electrochemical Analysis WG (EAWG)	**7**	**1**	**11**	**2**
Surface Analysis Working Group (SAWG)	**5**	**4**	**1**	**2**
Isotope Ratio Working Group (SAWG)	**3**	**2**	**2**	**0**
Nucleic acid Analysis Working Group (NAWG)	**2**	**3**	**4**	**4**
Protein Analysis WG (PAWG)	**4**	**2**	**3**	**2**
Cell Analysis Working Group (CAWG)	**1**	**2**	**0**	**3**
Estimated and completed average number of CCQM comparisons per year (based on 2021-2024 data)	**13**	**5**	**13**	**5**

Table Annex 2: Number of key comparisons and stand-alone pilot studies that were foreseen and run during the period 2021-2024 by each of the current CCQM WGs, and estimates of the average number of new comparison that will be run each year to 2034+.

ANNEX 3: REFERENCES TO INDIVIDUAL TECHNICAL SUBJECT AREA STRATEGIES FOR 2021-2030+

Description	Link
CCQM CAWG Strategy Document 2030 +	https://www.bipm.org/documents/20126/41532413/CCQM+Strategy/31283069-94f4-f2c7-bbfc-7d652c9b3de8
CCQM IRWG Strategy Document 2021-2030	https://www.bipm.org/documents/20126/57465585/CCQM-IRWG+Strategy+document+2021-2030.pdf/41d93edc-c543-8ed4-883b-26e97ac93867
CCQM GAWG Strategy Document 2030 +	https://www.bipm.org/documents/20126/57465561/CCQM-GAWG+Strategy+document+2021-2030.pdf/868de3d5-f89e-3eaf-a3da-b0bb7b9c985f
CCQM OAWG Strategy Document 2030 +	https://www.bipm.org/documents/20126/57465491/CCQM-OAWG+Strategy+document+2021-2030.pdf/786d14ba-829d-9c77-7481-19529759e19a
CCQM EAWG Strategy Document 2030 +	https://www.bipm.org/documents/20126/57465543/CCQM-EAWG+Strategy+document+2021-2030.pdf/5ca7b44b-9962-8f51-9615-0fcbc3743f05
CCQM PAWG Strategy Document 2030 +	https://www.bipm.org/documents/20126/57465501/CCQM-PAWG+Strategy+document+2021-2030.pdf/a3159c77-5198-7432-474c-33e84d891d08
CCQM IAWG Strategy Document 2021-2030	https://www.bipm.org/documents/20126/57465575/CCQM-IAWG+Strategy+document+2021-2030.pdf/56c8a480-f539-0ea2-b486-7c0fee0e0c1c
CCQM SAWG Strategy Document 2030 +	https://www.bipm.org/documents/20126/57465515/CCQM-SAWG+Strategy+document+2021-2030.pdf/a0778065-5ab3-8a4f-f8a2-45a2d11a6e2e
CCQM NAWG Strategy Document 2030+	https://www.bipm.org/documents/20126/2071059/CCQM-NAWG%20Strategy%20document%202021-2030.pdf/77097cb9-1089-643c-fa29-5fc3232badd1

ANNEX 4: WORK PROGRAMME OF THE BIPM LABORATORIES 2034+

The implementation of the CCQM strategy is supported by the BIPM Chemistry Department providing the CCQM Executive Secretary Role, coordination of comparisons in technical areas prioritized by the CCQM, laboratory-based knowledge transfer programmes for National Metrology Institutes with emerging metrology systems, the JCTLM database and support for engagement with stakeholder communities.

Key outputs from the work programme of the BIPM Chemistry laboratories in support of the CCQM and participating NMIs and DIs in the 2020-2023 programme included:

- 22 comparison exercises coordinated by the BIPM with 313 NMI participations covering NMI standards/ reference capabilities for Greenhouse Gases; Isotope ratios; Air Quality Gases; Organics; Proteins/Peptides; and SARS-CoV-2 antibody quantification;
- 12 peer reviewed publications supported by 10 seconded visiting scientists, including papers on reference methods for Greenhouse Gases and isotope ratios; monoclonal antibody quantification; virus-like particles; organic material purity; protein/peptide clinical analytes;
- Launching online knowledge transfer programmes on organic purity measurements with over 100 subscribed participants;
- Launching online knowledge transfer programmes on Application of FTIR for gas standard analysis as part of Metrology for Clean Air programme;
- Measurement guidelines for 4 mycotoxin pure materials and solutions and reference data for an additional internal standard for qNMR;
- Launch of a new version of the JCTLM database for IVD reference material, methods and services;
- Organization and hosting of the BIPM-WMO workshop on Metrology for Climate action;
- Organization of the workshop on workshop on Accurate ozone measurements and development and publication of guidelines for a global change of ozone cross section value;
- Organization and hosting of over 150 online meeting to support and progress CCQM activities.

Interaction between the BIPM laboratory and NMIs has been particularly strengthened by strong uptake of visiting scientist placements in the BIPM Chemistry Department. Visiting scientist number were reduced from 16 to 10 in the 2020-2023 period, due to travel restrictions during the covid pandemic, but are expected to rise back to previous levels in the next period.

The future CCQM strategic plan relies on a range of comparisons underpinning a broad range of NMI capabilities through core capability comparisons in addition to specific analyte-matrix comparisons which are required when uncertainties are challenging and critical to the application of the capability. In consequence, CCQM comparisons include both;
a) core comparisons which underpin fundamental and a broad range of capabilities following a model and periodicity determined by the concerned CCQM WG;
b) specialised comparisons which can have regular repeat periodicities to closely monitor long term performance of capabilities;

BIPM laboratory activities enable a long-term commitment to comparison coordination, which is best adapted to periodic comparisons and allowing close monitoring of performance. The CCQM WG strategy documents, for the Gas, Isotope Ratio, Organic and Protein Analysis WGs, foresee BIPM coordinated CCQM comparisons of
a) NMI/DI core capabilities for primary reference materials and calibrators for small organic molecules
b) NMI/DI core capabilities for primary reference materials and calibrators for peptides and proteins

c) NMI/DI primary calibrators/capabilities for prioritized green-house gases and air quality gases
d) NMI/DI calibrators/reference capabilities for traceability of $\delta^{13}C$ and $\delta^{18}O$ measurements
e) NMI/DI core capabilities for primary reference materials and calibrators for DNA and RNA

The BIPM comparison coordination activities provide substantial support to the specific working groups for whom they have been prioritized. The relative level of support provided is demonstrated in Figure 1 of Annex 3, where the resources of individual institutes to comparison coordination of CCQM GAWG comparisons is depicted. Similar levels of support are provided for the CCQM Organic WG, Protein WG and Isotope Ratio WG.

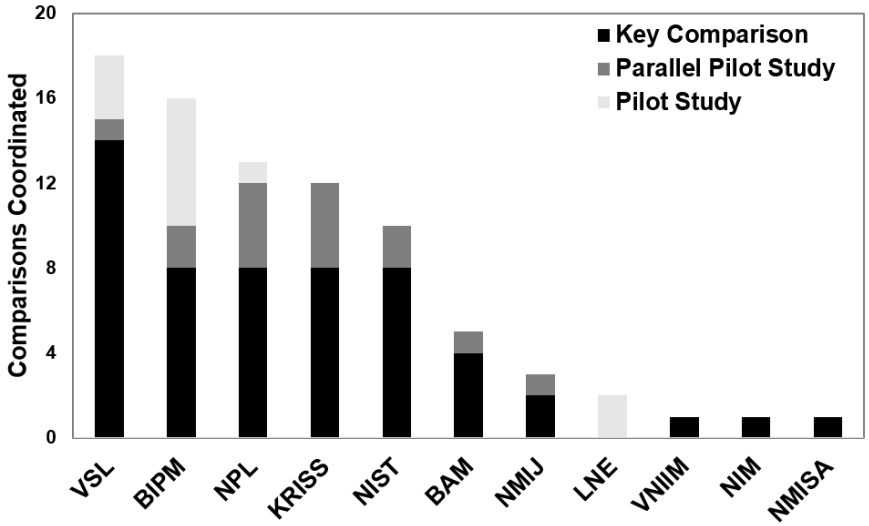

Figure 1 Annex 3 Bar chart from CCQM GAWG strategy document showing previous coordinators of CCQM GAWG key comparisons, pilot studies and parallel pilot studies.

The BIPM also offers comparisons run as a series of bilaterals, with BIPM.QM-K1 being the long-standing example for Ozone standard Photometers, BIPM.QM-K2 on CO_2 in air and nitrogen standards (launched in 2024), BIPM.QM-K6 on nitrogen dioxide in nitrogen standards and BIPM.QM-P5 on carbon dioxide in air scale standards (to be launched in 2025 and 2026) and comparisons in planning for Isotope ratios in CO_2 (pure and in air matrix). The benefits for NMIs/DIs of this series of comparisons is the fast turnaround time and ability to monitor for potential biases over time against an independent stable reference. These facilities also serve as the basis for future Knowledge Transfer programmes.

The laboratory-based capacity building and knowledge transfer laboratory activities initiated at the BIPM in 2016 in the fields of Metrology for Safe Food and Feed and Clean Air, supporting KT activities in the RMOs, have had good uptake. The future strategy sees the expansion of these to cover Pesticides and Veterinary Drugs relevant to residues in Food, Dynamic standards for Air Quality Gases, Peptide and protein standards for Laboratory Medicine, Isotope ratio standards and measurements, and qNMR for organic purity determination. The programme is being reinforced with on-line eLearning modules and summer schools increasing the possibility of participation in the next period.

Implementation of machine-readable databases with data following FAIR principles, will be addressed in the first instance with a database for CO_2 scale comparisons in support of the CCQM GAWG Task group on GHG Scale comparisons. This builds on previous database projects, such as the JCTLM, and the development and publication of reference data for qNMR internal standards, which are maintained.

The CIPM evolving needs in metrology study for 2030+ foresees the establishment of interdisciplinary fora for discussion of identified challenges and development of international metrology actions to support them. The sectors that have initially been identified by the CIPM are: Climate change and Environment; Health and Life Sciences; Food Safety; Energy; Advanced Manufacturing; Digital Transformation; and 'New' Metrology. The fora will require support from the BIPM Headquarters and notably the Chemistry Department, with a considerable number of themes having strong technical overlap with the CCQM.
A more detailed description of BIPM Chemistry Laboratory activities in support of the CCQM mission to beyond 2030 is described in the following table.

Strategic objectives	**Current plans (2026-2027)**	**Long-term goals (2028+)**
To support the CCQM strategy in demonstrating and improving equivalence and facilitating the establishment of national reference measurement capabilities and services for: - **small molecule organics**, at performance levels required to support reference measurement systems for laboratory medicine, food safety and trade in primary produce, forensics, environmental analysis and pharma. - **peptides and proteins**, at performance levels required to support reference measurement systems for laboratory medicine, health care and bioengineering sectors. - **DNA and RNA**, at performance levels required to support reference measurement systems for nucleic acid testing associated with human/animal disease, foods and environmental analysis.	Coordintaing CCQM comparisons on calibration standards for: – monitored therapeutic drugs (Cyclosporin A and Digitoxin) – small molecule organics (Pesticides and Veterinary drugs) – diagnostic peptide biomarkers (PTH(1-84)) – mycotoxin food contaminants (OTA). Providing reference data on heteronuclear internal standards for qNMR, supporting NMI measurement services. Providing on-site and on-line knowledge transfer courses and studies for NMIs establishing: – qNMR for purity evaluation – Mycotoxin in food – Pesticide and Veterinary Drug Residue in Food.	To support the CCQM 2030+ strategy through provision of: - Comparisons for both high and low molar mass DNA and RNA markers covering NMI calibrators for clinical testing (infectious disease, cancer and hereditary genetic disease marker measurement), food analysis, environmental monitoring and biotechnology. - Comparisons for both high and low molar mass peptide and proteins with and without modifications covering NMI reference materials for clinical testing, food allergens, and bioengineering - Comparisons for both high and low polarity small molecule organics covering NMI standards and measurement services for food and environmental contaminants, and clinical testing. - Knowledge transfer activities with online eLearning and practical onsite activities, covering qNMR analysis of pure material, calibration solution production, peptide and protein standard value assignment for NMIs establishing or expanding their national chemical and biochemical measurement

		infrastructure. - Investigation of accuracy of Digitial Reference Materials for use in qNMR and extension to Internal Standard Reference Materials
To support the CCQM strategy in demonstrating and improving equivalence and facilitating the establishment of national measurement standards and services for: – **greenhouse gases**, at performance levels required to support national energy and environmental priorities; – **major air quality gases**, at performance levels required to support national health and environmental priorities	Coordinating CCQM and BIPM on-going comparisons of standards for: – methane and carbon dioxide in air, with uncertainties congruent with global and urban monitoring requirements. – isotope ratios of carbon dioxide with uncertainties congruent with scale definitions and emission source apportionment – surface ozone and nitrogen dioxide for accurate air quality monitoring. Maintaining and disseminating primary reference gas for NMIs to realize highest accuracy stable carbon isotope measurements and services Providing on-line knowledge transfer courses for NMIs establishing: – Air quality standards – Reactive gas standards and FTIR facilities – Isotope ratio standards for carbon and oxygen.	To support the CCQM 2030+ strategy through: – On demand comparisons for CO_2, CH_4, N_2O, NO_2 and O_3 gas standards to support NMI measurement services and addressing global energy and environmental priorities – On demand comparisons and primary reference gas for carbon isotope ratio measurement to enable NMI measurement service equivalence for energy transition and fuel standards – Knowledge transfer activities with online eLearning and practical onsite activities, covering gas standard calibration, spectroscopic purity analysis, isotope ratio measurement, dynamic gas standards for NMIs establishing or expanding their national gas standard systems. To support programmes to mentor NMI scientists coordinating gas standard comparisons for the first time.
To promote and develop the use of SI traceable standards and measurements with inter-governmental and other stakeholders for use in chemical and biochemical analysis.	Supporting CCQM task groups in: – Developing metrology strategies for food safety – Digitalization – Coordinating a global change in ozone reference measurements; – Developing an extended global greenhouse gas measurement system	To increase participation in the CIPM MRA and uptake of NMI measurement services by International Organizations with laboratory networks active in chemical and biochemical measurement. To support CCQM task groups in interfacing with and providing technical solutions to global

	– Micro and nano-plastic measurement Upgrading the JCTLM Database with web-based nomination and review functionality and visibility to Large Language Models (LLMs) for greater uptake of reference measurement systems in clinical diagnosis Developing a Greenhouse Gas measurement and meta data database following FAIR principles enabling greater uptake of NMI standards	stakeholder communities To investigate the use of AI in the submission and review process of the JCTLM Database; to move to real time review and approval of Reference Material, Methods and Servis for IVD industry To expand the GHG Scale database to cover all standards produced by NMIs for accurate environmental monitoring To establish an international isotope scale database as a unique reference for global isotope measurements To support sectoral and cross committee efforts in promoting and developing the use of the SI, notably in the health, environmental, food safety and advanced manufacturing sectors.

Table 1 Annex 3 BIPM support of the CCQM Strategic plan 2030+.

ANNEX 5: SUMMARY OF WORK ACCOMPLISHED AGAINST STRATEGIC GOALS (2021-2024)

Summaries of work accomplished in the 2017-2024 period in each of the technical subject CCQM working groups is described within their individual strategy documents. A number of highlights and CCQM achievements are described here against the strategic goals of the CCQM.

1) Contributions to the resolution of global challenges such as climate change and environmental monitoring, energy supply, food safety, healthcare including infectious disease pandemics, by identifying and prioritizing critical measurement issues and developing studies to compare relevant measurement methods and standards.

Accomplishments:

- Three CCQM Seminars and One International Workshop on pandemic preparedness during 2020-2021 which led to CCQM Roadmap to Metrology Readiness for Infectious Disease Pandemic Response, 2022, a CCQM TG and its recommendations and completion for the first ‘fire-drill’ exercises demonstrating rapid deployment nucleic acid (2024/2025) and protein (2025) capabilities of the metrology community to detect infectious diseases. The Roadmap and its underlying metrological recommendations are currently being incorporated within the 100d Mission to respond to future pandemic threats.

- WMO-BIPM workshop in climate action in 2022 and 1st CIPM Sectorial Task Group on Environment Stakeholder meeting at the BIPM in 2024. Contributions by the CCQM to identify the role of metrology in climate and to respond to the recommendations.
- Completed cross-working group comparisons to show equivalence of measurement results for particle number concentration measurements among several techniques. Additional work and comparisons are likely in the next few years, with several measurands beyond just number concentration.
- Technical preconditions for the traceability of ocean pH_T measurements used to monitor ocean acidification have been realized in the European metrology project "SapHTis". In response to those achievements CCQM has established a TG on the traceability of seawater pH and pH_T measurements to implement respective measurements into CIPM-MRA framework and foster its uptake by the oceanographic community.
- Key comparisons relevant to environmental monitoring of seawater have been completed to demonstrate reliability of the underlying chemical measurements, including elements and tributyl tin in seawater (CCQM-K155) and anions in seawater (CCQM-K161).
- Development and demonstration of equivalency of advanced metrology for elemental speciation for food safety continues to be pursued, with completion of studies regarding toxic and essential elements in bovine liver powder (CCQM-K145), species of arsenic in rice flour (CCQM-K158), and arsenic speciation in seafood (CCQM-P215). Additional work in this area is planned.
- Key comparisons for the value assignment of organic, high-purity veterinary drug calibrators and their corresponding salts (CCQM K148b and K179), as well as calibration solutions for pesticides (CCQM K78b), play a vital role for the provision of SI traceable calibrators applied in food safety and environmental monitoring of toxic contaminants. These efforts align with the World Health Organization's One Health concept, as these contaminants are recognized as threats to both biodiversity and human health.

2) Promotion of the uptake of metrologically traceable chemical and biological measurements, through workshops and roundtable discussions with key stakeholder organizations, to facilitate interaction, liaison and cooperative agreements, and receive stakeholder advice on priorities to feed into CCQM work programmes.

Accomplishments:

- CCQM workshop on particle metrology (virtual meeting hosted by the BIPM, 2022) which resulted in establishing new CCQM task groups on particle metrology for aerosols, liquid suspensions, and solid matrices, working with the stakeholder community to address emerging requirements.
- CCQM Workshop report on "Metrology for viral vectors as molecular tools", published as Campbell et al. *Biologics* 2024, *4*(2), 187-201. Conference Report: Standards and Metrology for Viral Vectors as Molecular Tools - Outcomes from a CCQM workshop, which has led to the creation of a new CCQM gene delivery systems TG (2025).
- The outcomes of the CCQM workshop on "Protein structure and activity" and follow-up questionnaire will be used to devise PAWG's strategy in this area.

3) Progression in the state of the art of chemical and biological measurement science, by investigating new and evolving technologies, measurement methods and standards and coordinating programmes to assess them.

Accomplishments:

- The IAWG has performed considerable work further developing single-particle (sp)ICP-MS as a relatively new technique for measuring size, size distribution, and number concentration of particles suspended in liquids. Working with the SAWG, equivalency of measurement results for number concentration with several more established techniques has been demonstrated.
- Pilot study CCQM-P248 "quantitative analysis of metal alloy films" established traceable methods to measure the relative composition of platinum-nickel alloys and benchmarked the capabilities of new analytical methods including atom probe tomography, which has the potential to simultaneously measure chemical composition and structure on the sub-nanometre scale.
- Implementation of a new SI-traceable value and uncertainty for ozone cross-section at 253.65 nm (air), for global surface ozone measurements.
- The GAWG has also conducted pilot studies in emerging areas such as CCQM-P204 which assessed the level of compatibility of laboratories' measurement capabilities to value assign isotope ratios in samples of pure CO_2 gas, expressed as isotope delta values relative to the relevant international scale: δ^{13}(C)VPDB and δ^{18}(O)VPDB-CO_2 for atmospheric source apportionment. A pilot study (CCQM-P229) on absolute line intensities of selected $^{12}C^{16}O$ transitions was the first of its kind and involves distinct primary measurements of amount fraction based on linear absorption spectroscopy. CCQM-P172 assessed the level of comparability of laboratories' spectroscopic methods for trace gas quantification using nitric acid as a model system, chosen due to its presence in NO_2 gas standards as an impurity. The results, provide evidence to support reproducibility of the same FTIR methods (referenced to HITRAN data) employed in different laboratories for the measurement of HNO_3 amount fractions in the 100 to 1000 nmol mol^{-1} range.
- IDMS and NMR workshops held in 2023 & 2024 will lead to Track D studies and advances in the Organic Analysis and Standards area.

4) Improvements in the efficiency and efficacy of the global system of comparisons for chemical and biological measurement standards conducted by the CCQM, by continuing the development of strategies for a manageable number of comparisons to cover core capabilities.

Accomplishments:

- A Decision Tree has been developed and deployed in the IAWG to improve the efficiency of KCRV and DoE value estimation, mitigating some of the long working group discussions on these topics and enabling key comparisons to be completed more quickly.
- CCQM Workshop on Digital and FAIR Chemical and Biological Reference Data and Certificates: Challenges and Opportunities, held in 2024 , to plan how digitalization and AI can be applied to Chem-Bio reference measurements and CMCs.

5) Evolution of CMCs to meet stakeholders needs, incorporating the use of broad claim CMCs where applicable to cover a broader range of services and considering options to present these in a way that meets stakeholder needs and encourages greater engagement with the CMC database.

Accomplishments:

- Implementation of broad claim CMCs to reduce the number of entries in the KCDB. The GAWG has established principles for when a key comparison is archived and no longer available to support CMCs. A gap analysis has been performed to refine the strategic plan for key comparisons to ensure sufficient evidence to maintain capabilities.

6) Support for the development of capabilities at NMIs and DIs with emerging activities, by promoting a close working relationship with RMOs including mentoring and support for NMIs and DIs preparing to coordinate comparisons for the first time and promoting knowledge transfer activities including workshops, as well as secondments to other NMIs, DIs and the BIPM.

Accomplishments:

- Established OAWG TG-KT (2024) that will lead to structured activities 2025-2030 to support developing NMIs along with RMO activities.
- CCQM-K154 series of comparisons on mycotoxin calibrations solutions (aflatoxin B1, deoxynivalenol, patulin) coordinated by the BIPM, supporting NMI capabilities for producing and value assigning mycotoxin calibrants, which provide the basis for accurate and traceable measurements in the food analysis sector.
- qNMR summer school held at BIPM Headquarters for NMI scientists developing this method for organic primary reference material value assignment.
- eLearning modules developed and launched by the BIPM Headquarters on: qNMR for organic standards; FTIR analysis for gas standards; Stable isotope measurements; Non Structure-Related Impurity Content in Organic Pure Materials.

7) Maintaining organizational vitality, regularly review and, if required, update the CCQM structure for it to be able to undertake its mission and best respond to the evolution of global measurement needs, by prioritizing where new areas or issues should be addressed within the structure and evolving working group remits as required.

Accomplishments:

- Establishment of task groups at CCQM and WG level to deliver outputs and CCQM strategy.
- The *mise en pratique* for the definition of the mole was reviewed and a new, updated version was published in 2025 reflecting recent developments in the understanding of concepts and technological development related to realization.

ANNEX 6: EXAMPLES OF IMPACT OF CCQM ACTIVITIES (2017-2024)

Seventeen case studies of the impact of CCQM activities from the 2017-2024 period are provided within the technical subject CCQM Working Group strategy documents.

Case Study N°	Description	Document describing case study
1	Primary Methods and Standards for Organic Measurements: qNMR internal standards and related techniques	OAWG strategy document
2	Perfluorinated alkyl substances (PFAS) – A persistent Global environmental issue	OAWG strategy document
3	Organic contaminants in food (mycotoxins, pesticides and veterinary drug residues) (updated from "Mycotoxins in Foodstuffs"	OAWG strategy document
4	Measurement Services Supported by OAWG Key Comparisons on Clinically Relevant Small Molecule Organic Biomarkers	OAWG strategy document
5	GMOs in Food	NAWG strategy document
6	Support for equivalence of pH CRMs	EAWG strategy document
7	pH of seawater	EAWG strategy document
8	Conductivity in the pure water range	EAWG strategy document
9	Roadmap for purity determination (high-purity elements and inorganic compounds)	IAWG strategy document
10	Copper calibration solutions (CCQM-K143/P-181)	IAWG strategy document
11	Counting nanoparticles	IAWG strategy document
12	Toxic and essential elements in bovine liver	IAWG strategy document
13	A new measurement infrastructure for underpinning atmospheric observations of key greenhouse gases to meet global net zero initiatives	GAWG strategy document
14	Global implementation of a new reference value for more accurate measurements of ground-level ozone towards cleaner air	GAWG strategy document
15	Underpinning hydrogen fuel quality to support the transition towards cleaner energy	GAWG strategy document
16	Absolute SI quantification of DNA	NAWG strategy document
17	Towards SI traceable RNA measurement	NAWG strategy document
18	Progress towards underpinning protein quantification in biological matrices (CCQM K177 and CCQM K186)	PAWG strategy document
19	Underpinning an international metrology hierarchy for parathyroid hormone (PTH) together with WHO (CCQM-K115.d)	PAWG strategy document

20	Response to COVID-19 pandemic: quantification and structure analysis of an antibody (CCQM-P216)	CCQM PAWG
21	Measuring ultrathin hafnium oxide for faster computers	SAWG strategy document

ANNEX 7: DOCUMENT REVISION SCHEDULE

Document name; type of revisions; date

Document Reference	Type of revision	Date
Version 0.3	Draft by SPWG sent to CCQM for comment	02/04/2021
Version 1.0	Updated by SPWG based on CCQM comments	21/06/2021
Version 2.1	1st set of draft changes for 2030+ strategy	06/03/2025
Version 2.2	Additional modifications following WG Chair input	28/07/2025
Version 2.3	Modification following NAWG strategy publication and NMI feedback on BIPM Strategic Plan	12/11/2025
Version 2.4	Incorporation of CCQM WG Chair comments	28/11/2025
Version 2.5	Incorporation of CCQM submitted comments	02/04/2026