# Strategy 2026-2036

## Consultative Committee for Mass and Related Quantities (CCM)

Version 1.6

August 2026

# Contents

## 1. EXECUTIVE SUMMARY

The document was prepared in 2026 by the Consultative Committee on Mass and Related Quantities (CCM) Working Group on Strategy and MRA Coordination (WGS). Its intended audience are mainly the CCM, NMI Directors, CGPM delegates and the CIPM. The strategy was approved by the CCM by correspondence in August 2026 and will be periodically updated.

The strategy document presents an overview of major scientific, economic and social challenges which can be addressed by measurements of mass and related quantities for challenges identified by the CIPM Strategy 2030+ in response to evolving needs in metrology. The revision of the SI in May 2019 enables realizing the unit of mass and some related quantities directly from fundamental constants. Measurements directly traceable to the SI, dynamic measurements and measurements with a wider range and under wider condition are the main topics for the next decade.

The CCM set three strategic aims for the 2026-2036 period. The strategy foresees contributions to progressing measurement science across all technical areas covered by the CCM. To support global comparability of measurements, managing the transition from an internationally coordinated kilogram dissemination to the use of individual sovereign realizations remains the main focus. The CCM will continue to implement the CIPM-MRA by efficiently organizing key comparisons and coordinating RMO key and supplementary comparisons. The CCM aims to facilitate stakeholder engagement and knowledge transfer by continuing the organization of workshops and webinars and to seek extended collaborations with other Consultative Committees and involvement of external bodies.

The CCM oversees the work programme of the BIPM mass laboratories. The BIPM supports the implementation of the CCM strategy by organizing the comparisons of realizations of the kilogram as well as artefact-based kilogram standard, disseminating the kilogram using an internally coordinated value and providing knowledge transfer of the realization and the dissemination of the kilogram.

## 2. EVOLVING NEEDS FOR METROLOGY

The Consultive Committee for Mass and Related Quantities covers a very diverse range of measurements which include: Mass, Vacuum, Barometry, High Pressure, Force, Torque, Hardness, Liquid Flow, Gas Flow, Solid Density, Liquid Density, Volume of Liquid, Hydrometry, Liquid Refractive Index, Surface Tension, Viscosity, Gravimetry.

The technologies applied to the measurements in these areas vary greatly, as do the scientific and industrial areas which rely on these measurements. Adding the diversity of mass related measurement area to the fact that the measurement of dynamic quantities is becoming increasingly important in a number of these areas (force, torque and pressure for example) means that the scope for end-user benefit can potentially be very wide and a strategy to maximize the impact will need to focus on areas where the benefits can be most effectively exploited. To this end, a Task Group on Dynamic Quantities was formed in 2025 to discuss dynamic measurements across fields.

The revision of the SI and the associated redefinition of the kilogram in May 2019 represented a step change in the way the SI unit of mass is defined, maintained and disseminated at NMI level. More widely, the redefinition of the kilogram enables new methods of traceability to fundamental constants. These will initially be developed at NMI level but, within a few years, will lead to measurements at the point of need, providing improved accuracy and reliability by direct realization of the SI.

For clarity the major activities and strategy of the CCM are discussed based on how they relate to the seven "grand challenges" identified by the CIPM.

## 2.1. Metrology for global challenges

**Global environment**

The assessment of the extent of long-term climate change and the dependable measurement of short-term trends depends on the reliability and equivalence of sensor measurements. For mass related quantities, major requirement in this area is pressure measurement. The traceability chain for the calibration of sensors and instruments in these areas can be very long and use of the revised definition of the kilogram, together with the implementation of new technologies such as optical cavity pressure sensors, will enable the reduction of the traceability chain length and provide an improvement in the reliability and uncertainty of environmental measurements. The density of water also needs to be measured accurately and repeatably to assess salinity (a key marker for changes in ocean current patterns) and pollution. Metrological traceability and the degree of equivalence of liquid and gas density measurements at high pressures are also required for oceanographic applications but also in compression processes (to increase combustion efficiency and therefore energy efficiency). Robust field sensors which provide direct traceability to the SI based on, for example, resonant and optical measurement methods should be investigated. The measurement of small samples of plastics is key to understanding oceanographic trends and pollution and the further development of suitable density measurement techniques, such as density gradient columns, for characterising these will be important.

Terrestrial gravimetry plays an increasingly important role in monitoring environmental processes, including those linked to climate change, by detecting mass redistribution, for example due to glacier melting, groundwater depletion etc. Demonstration of the equivalence of gravity measurements using different instruments by establishing and maintaining a long-term geodetic reference system is of key importance for climate monitoring and Earth observation systems. The need for better monitoring of critical parameters such as ocean level, demands an improved accuracy of the global reference system down to the mm level. Gravimetry, which allows for monitoring mass variations related to climate change in all Earth layers (cryosphere, hydrosphere, geosphere and atmosphere), is a geodetic technique essential for the definition of this reference system. The recent emergence of gravity sensors based on quantum technologies offers new perspectives in Earth monitoring, thanks to their intrinsic properties: better stability, SI traceability, improved operability, ability to perform continuous measurements. They will allow to extend the spatial and temporal scales of gravity observations, which serve as inputs for a multitude of applications in geosciences.

Lighter, longer-lasting materials and coatings make a major contribution to the reduction of resources. Hardness measurement technology is a particularly simple and fast method of testing these materials and specifying changes in the materials.

For environmental monitoring of particulates, true SI traceability is achieved by remote laboratory-based gravimetric measurements. These are therefore not real-time measurements and since they are based on aggregated particulate accumulation over a period of time, do not give a true reflection of peak values or temporal variations. Technology such as that used in the Kibble balance could be employed to produce micro-mass sensors which would enable in the field real-time monitoring of environmental particulates and could also provide true SI traceability for instruments such as particle counters. Mass and pressure measurements also provide the SI traceability basis for gas standards which are in turn used to calibrate environmental monitoring equipment. Improvements in the measurement of small masses will in turn improve the gravimetric preparation of trace reference gas mixture. Beside this, the on-site production of reference materials with high flexibility in composition based on flow measurement is another issue. This is driven by needs to investigate, for example, the dynamic response characteristic of chromatograph equipment or to react in a fast way to end-user demand.

**Health**

The measurement of mass and related quantities plays a critical part in the diagnosis and treatment of a range of clinical conditions and in research into and production and delivery of drugs, pharmaceutical products and medical implants.

True SI traceability for diagnostic measurements of blood pressure, intraocular pressure and for continuous cardiac output instruments needs to be developed in order to improve the reliability and comparability of these measurements as the basis of diagnoses.

The development of micro- and nano- force, mass, torque, flow and surface tension measurement technologies, including multi-component measurements, will be important for pharmaceutical research and production and for personalised medicines and medical devices. High accuracy surface tension and density measurements will be crucial in improving production processes and assessing the quality of medical implants and prosthetics, particularly those produced by additive manufacturing and where coating processes are used. The establishment of metrological traceability and degree of equivalence for shear viscosity and surface tension measurements are of the crucial importance for characterizing the flow of such substances, such as the great majority of medical drugs used in infusion/perfusion). Density measurement will also be important in charactering micro-plastics which constitute a significant risk to health. The development of next-generation density gradient columns, able to identify and measure much smaller samples, will be key to this.

In both the above areas new measurement technologies are being or have been developed and the key is applying the technologies to specific measurands and to achieving acceptance by the end-user medical communities. The latter is an area where collaboration between CCs, device manufacturers and clinical researchers will be important.

### Food and water

High-pressure processing for food preservation uses pressure rather than heat to effect pasteurization and is becoming more common. This underpins a new requirement for accurate and traceable ultra-high-pressure measurements and sensors. Density, surface tension and shear force measurements are key to food (and drink) processing, which uses large amounts of energy, and product characterisation and are often manual and off-line. With a drive towards digitization new, on-line, automated measurement techniques will need to be developed. Similarly, the measurement of and standards for the refractive index of liquids are required to meet the demands from the food industry such as calibrating sugar content using the Brix scale.

### Energy

Density and viscosity are key parameters for the evaluation of energy-related materials such as oil, biofuels and gas. Various measurements under a wide range of conditions are needed in the energy chain from production to end-use. Current density tables are based on old data and known to be relatively inaccurate. Implementing new measurement techniques, for example density based on the density of a silicon sphere or related to the velocity of sound, will enhance accuracy and reliability for density measurements needed in this area and also enable the accurate measurement of properties under wide pressure and temperature ranges to enhance improvement of thermal efficiency in industrial processes such as heat pump system using alternative refrigerants. Improved in-line flow, density and pressure measurements are also required for new energy areas such as hydrogen production, distribution and consumption. With the establishment of a hydrogen-based energy supply, more new synthetic fuels will appear on the market, and this will lead to new requirements for fluid flow to maintain the traceability chains to the SI units. Due to higher diversity of fluid characteristics, the sensors' behaviour dependency on fluid properties will have a higher impact on the overall achievable uncertainty. Therefore, intensified research work on modelling of sensor behaviour will be necessary to compensate this impact.

Alternative carbon neutral energy sources like wind and tidal energy require the development of dynamic measurement capability in the areas of force and torque and an extension of the range of traceable torque measurements. Real-time dynamic torque measurements are also key to the development of efficient drivetrains for electric vehicles. In all these areas the development and use of digital twins to model and review the infrastructure is key to optimising performance and undertaking predictive maintenance. Given the continuing use of nuclear energy remote self-calibrating sensors for pressure, mass and density measurements, in harsh environments, will improve monitoring and safety.

### Advanced Manufacturing

Advanced manufacturing process control and inspection requires a range of mass related measurements. The dynamic nature of the manufacturing processes and the trend towards miniaturisation presents challenges and opportunities for the measurement of mass and related quantities. In particular sensors based on Kibble balance technology will allow direct traceability to the SI for a number of process-based measurements. These sensors will be self-calibrating so are suitable for embedding in process measurements, for use in harsh environments and where dynamic real-time mass and force measurements are required. Advanced manufacturing needs a control of the acting forces and moments in the machine which will lead to an increase in the need for multicomponent force and torque calibration for the sensors used.

For the characterization of manufactured components, in particular those produced by additive manufacturing, a range of new measurement techniques needs to be developed. Density determination by gas pyknometry, traceable to the density of pure silicon, can be used to (non-destructively) assess the integrity and surface and bulk porosity of components. New hardness test methods for in-process evaluation or for product acceptance also need to be developed. The development of real time density and micro-flow sensors to look at feedstock and melt pool characteristics respectively, will improve the quality and reproducibility of additively manufactured components. Improved, in-process measurements of surface tension and wetting will be needed to optimise additive manufacturing and coating processes.

## 2.2. New technologies spawning new metrologies

**Digital transformation and AI**

Digital transformation is something that impacts all aspects of metrology and a coordinated response across all CIPM Consultative Committees is required. Similarly, digital transformation in metrology needs to be integrated with the wider digitization of society and should, to a large extent, to be driven by the requirements of the end users in the individual technical areas.

End-to-end digitalization of measurement processes at NMI level will improve the efficiency and confidence with which calibrations can be provided to end users. The revision of the SI and the redefinition of the kilogram will help to facilitate this with the adoption of “digital ready” instrumentation such as the Kibble balance.

The provision of digital certificates (e.g. digital calibration certificates DCC, digital certificates of conformity D-CoC) for end-users is already being implemented in the area of mass and related quantities, at present mainly driven by instrument manufacturers rather than end-users. Nevertheless, the production, use and interoperability of DCCs and D-CoCs needs to be developed by NMIs to stay ahead of need and to support industry implementation of digital supply chains. User requirements for the dynamic calibration of sensors and instruments will additionally increase the amount and complexity of data which needs to be reported.

The implementation of digital twins for calibration instruments and artefacts will increase knowledge of performance, stability and response to external variables. This will allow optimisation of performance and will inform the need for and periodicity of recalibration. Digital twins will also be useful in the modelling the operation of interaction of sub-systems within complex instruments such as the Kibble balance aiding development and optimising performance.

**System metrology**

The measurement of mass and related quantities is key to a wide range of in-process monitoring requirements from charactering the performance of wind farms to monitoring complex manufacturing processes. Due to the wide range of measurement quantities and instrument types covered by mass related quantities, the design and implementation of metrology systems is key to the effective characterisation and optimising of these processes. In production processes issue such as establishing traceability and estimating uncertainty for measurements, sensor integration, data fusion and validation and measurement system design are critical to the quality of overall metrology system and CCM members have a key role to play in establishing and disseminating good practice.

**Quantum technologies**

The redefinition of the kilogram in terms of a fixed value for the Planck constant opens the possibility for a wide range of quantum-based measurements within the scope of mass and related quantities. Kibble and micro-Kibble instruments could provide mass, force and torque measurements traceable to the SI at point of need. Similarly, optical cavity and trapped atom sensors could be used to cover the entire pressure range from high pressure to ultra-high vacuum giving direct SI traceability. Such instruments will also allow measurements to be made in a dynamic mode whereas traditional instruments such as mass comparators and pressure balances are predominantly designed to provide traceability for static measurements.

## 2.3. NEW METROLOGICAL DEVELOPMENTS TO ADDRESS NEW CHALLENGES

**Human-computer interactions**

Within the scope of CCM, the development and characterization of haptic sensors, mapping of interfacial pressure and accurate measurement of micro-flow are all areas of critical need with regard to developing and optimizing the operation of human-computer interfaces. In most cases novel sensor technology and means of traceable calibration will need to be developed and this will rely heavily on the application of quantum technologies discussed elsewhere in this strategy document.

**Metrology for space and in space**

A number of measurement techniques have been developed by CCM members which are key to current and future requirements for space flight and in-space research. Centre of gravity determinations for satellites and space-based research (Laser Interferometer Space Antenna (LISA)), where measurements beyond the state of the art were required, have been undertaken. Also for LISA, gravimetric techniques for the determination of the magnetic properties of extremely low permeability materials have been improved to deliver the accuracy necessary. As part of research into the development of next-generation Kibble balance, extremely sensitive methods to measure the outgassing of a range of materials have been developed. The determination of mass in a weightless environment will pose fundamental measurement problems and the development of an inertial based Kibble balance instrument of this application can be considered. The characterization of new advanced materials, and their performance in vacuum conditions, will require traceable measurements of and potentially new techniques of the determination of mass, pressure force and hardness.

**Metrological self-traceability and shortened metrological traceability chains**

The implementation of quantum-based sensors discussed elsewhere would be a significant step towards providing SI traceability at point of need and therefore improving the reliability and uncertainty of measurements made by end-users. However, care needs to be taken in the implementation and validation of such measurements, and this will be a key role for NMIs in the future. The development of an infrastructure to validate measurement made by quantum-based instruments will be critical as it will need to demonstrate SI traceability but also validate instrument function in terms of determining a measurand which will usually be different from the SI traceable units (a Kibble balance is traceable to electrical units but delivers a measurement of mass, for example). Remote calibration to check the performance of quantum-based instruments will be critical in the ongoing maintenance of global equivalence for the measurement of mass and related quantities.

## 2.4. Key scientific challenges in metrology

**Opportunities arising from the revised definitions for the SI base units**

Following the revision of the SI, the primary realization of a unit is now theoretically possible anywhere in the world. This presents opportunities within the CCM for the development of instruments which can realize the SI at the point of need for quantities such as mass, force, pressure and torque. Kibble balance technology can be deployed, in a simplified form, to develop end-user instruments which can realize SI traceable mass, force and torque measurements in the lab or on the shop floor. Devices could also be produced to generate SI traceable forces and torques which could be used to calibrate secondary sensors. The operational principle of the Kibble balance means that it can also be used to measure and generate dynamic forces and torques, and it can be calibrated remotely allowing it to be embedded for in-process measurement and designed for use in harsh or inaccessible environments. Quantum-based pressure sensors have similar benefits allowing SI traceable measurement at point of need and being more flexible in application than current pressure standards.

## 2.5. Dynamic measurements

**Enabling traceability in dynamic measurement of mechanical quantities**

Historically, measurement systems and sensors have been calibrated statically while their use is often in dynamic mode. For the last years several research projects have addressed this issue and there are many candidates for dynamic standards under development. As mentioned above, dynamic metrology is critical in many applications, from health to advanced manufacturing. Still, there is no traceability chain available in dynamic metrology.

There are currently no internationally accepted primary standards for dynamic measurement. These need to be developed and the revision of the SI in 2019 provides additional opportunities for primary realizations in several areas, for example Kibble balance technologies for dynamic force and torque, and Rayleigh scattering and absorption spectroscopy for gas pressure. As well as new sensors for dynamic measurement, standard methodologies for dynamic calibration need to be established and modelling and uncertainty calculations need to be developed.

# 3. Vision and mission

**CCM Vision**

A world in which all measurements of mass and related quantities are traceable at the required level of accuracy to meet the needs of society.

**CCM Mission**

To promote the global comparability of mass and related quantities measurement standards and capabilities, enabling Member States and Associates to make and use measurements with confidence.

# 4. Strategy

To implement the CCM's vision and mission, the CCM strategy has three main aims:

- **Progressing the state of the art** for issues identified by NMIs/DIs and the BIPM, by providing leadership and coordination and encouraging the organization of joint research projects.
- **Promoting global measurement comparability** by making comparisons more accessible and quicker, increasing the scope to cover emerging measurement areas and technologies, using a risk-based approach for deciding comparison scope and CMC review exercises and supporting the work of the BIPM. A particular focus is to ensure world-wide equivalence of the dissemination of the mass unit following the redefinition of the kilogram.
- **Improving stakeholder engagement** by organizing workshops and webinars and encouraging collaboration inside and outside the CCM community.

# 5. Activities to support the strategy

The CCM and BIPM activities are aligned to meet the CCM strategy.

## 5.1. Progressing measurement science

Most of the research and development for the advancement of metrology of mass and related quantities is carried out by individual NMIs and DIs together with, and coordinated by, the RMOs. The CCM has a guiding and coordinating role by defining measurement challenges for NMIs/DIs through CCM strategy and the work plans of the CCM Working Groups and Task Groups. Measurement science is progressed through the execution of pilot studies to investigate new methods or measurement areas and workshops focusing on new measurement challenges and technologies (see also 5.3).

The developments in mass and related quantities focus on activities for improving and standardizing measurement of high importance to stakeholders and research projects related to scientific, economic and social grand challenges. The following summarizes such activities in the CCM technical Working Groups.

Density and Viscosity The revision of the SI and the redefinition of the kilogram have led to a significant reduction in the uncertainty of the density measurement of silicon spheres, which often provides traceability for other density measurements. The improvement of optical interferometers for measuring the volume of spheres has led to a considerable reduction in the uncertainty of the reference standards. Relative uncertainties of up to $1.4 \times 10^{-6}$ were confirmed in the completed key comparison for measuring the density of silicon spheres. This will also be reflected in the future development of many comparison measurements based on silicon density standards. Some new key comparisons are planned for liquid density, hydrometer, viscosity and refractive index of liquids. The key comparison for refractive index of liquids includes a recently developed method of optical interferometry. Supplying traceable standard liquids being ensured reliability by this comparison is expected. The demonstration of equivalence for surface tension measurements made using disparate measurement techniques is necessary, for example, to improve production processes and density measurements at high pressure are important for oceanographic monitoring and for biofuel characterisation.

Fluid Flow There is now a backbone of key comparisons established which covers the range of industrial needs in mass flow rate from mg/min to tonnes/s. Within this the main conventional fluids like water, hydrocarbons, air, nitrogen, and natural gas are involved. Currently, several NMIs/DIs are involved in research projects to establish new calibration capabilities related to hydrogen as a central energy carrier in the decarbonized industry. This will result in new CMCs for this area to support the needs in hydrogen production, transport and consumption. For the key comparisons, a set of commercially available transfer meters have been identified to ease the effort of preparing and performing similar comparisons in future. For air speed measurements, comparability was significantly enhanced by introducing non-intrusive optical sensors (LDV) and the equivalence of national realizations for fluid speed was demonstrated at a new lower level of uncertainty. In the field of volume of liquids, especially micro-pipette measurements, but not limited to standard capacity measures as presented in OIML R 120, the activities to address standardization and liaisons with ISO TC28 and TC48 as well as OIML TC8 were established.

Force and Torque The established key comparisons cover the force range from 10 N to 20 MN and the torque range from 100 N·m to 100 kN·m and an extension to lower ranges down to 1 N·m has been decided and will result from CCM.T-K3. The force and torque transfer standards are improved in the past years, but the long-term stability is the limiting factor to verify lowest uncertainties of $\leq$ 0.002%. Pilot studies are performed to cover, for example, lower force ranges down to 1 µN. In lower force and torque ranges there is the need for the development of suitable primary standards and transfer standards, but it is expected that, based on the new SI, this range can be improved by Kibble balances or other non-gravitational methods. Dynamic investigations of force and torque sensors are at the research level and are topics for future pilot studies.

Gravimetry Key comparisons of absolute gravimeters are essential not only for geosciences but also for the realization of the kilogram using the Kibble balance, which requires knowledge of gravity acceleration with a relative standard uncertainty below $5 \times 10^{-9}$. The Key Comparison Reference Value is currently determined mainly by classical absolute gravimeters based on laser interferometry. Absolute gravimeters employing cold-atom sensors have recently made significant progress, with the best instruments reaching the standard uncertainty of the classical absolute gravimeters (2.2 μGal = $2.2 \times 10^{-8}$ m/s$^2$). The latest recently developed absolute quantum gravimeters demonstrate long-term reproducibility at the level of 2 μGal, although systematic biases remain a challenge. The growing number of absolute gravimeters with cold-atom sensors are expected to participate in all levels of comparisons. Strengthened cooperation with the geodetic community within the establishment of International Terrestrial Gravity Reference System and Frame (ITGRS/ITGRF), following the CCM – IAG Strategy for Metrology in Absolute Gravimetry, will be crucial for improving the accessibility of comparisons and calibration of gravimeters (including relative gravimeters) thus for ensuring traceable gravity measurements worldwide. Furthermore, the development of instruments and measurement standards for measuring the second derivatives of the gravity potential is also important.

Hardness Hardness is an ordinal quantity measurement, or a measurement where the result is dependent on the test method used. There are no other independent measurements that can be made to obtain the same hardness result. While the test method procedures specified by Standards Development Organizations, such as ISO and ASTM, are adequate for industrial applications, they allow test parameters to vary within ranges of values. To maintain equivalent hardness national standards between nations, more specific test method definitions are required with single-value test parameters. Consequently, one ongoing effort of the WGH is to develop specific definitions for use by NMIs to reduce global measurement differences at the highest level. As these definitions are developed and approved by the Working Group members, key comparisons are then initiated to determine measurement equivalency among nations and to confirm that the definitions have reduced measurement differences between NMIs.

Mass For Mass metrology the revision of the SI and the redefinition of the kilogram represent a major step change in the way the SI unit of mass is defined and also in the way it will be realised and disseminated. The development of the realization experiments reached a level of uncertainty and equivalence which was acceptable to allow the redefinition of the unit of mass in 2019 and significant progress has been made to improve the number and reliability of the experiments and the degree of equivalence. Biennial comparisons of realizations have been undertaken, and these allow NMIs with experiments to validate their evolving levels of uncertainty and equivalence and also form the basis of the consensus value of the kilogram, currently used to disseminate the SI unit of mass. In addition to the primary realization experiments NMIs are also applying Kibble balance and XRCD technology towards the goal of a distributed SI system. Results of the XRCD experiment have been used to establish direct SI traceability for nanoscale dimensional standards and Kibble and micro-Kibble balances are being developed which will provide direct SI traceability for mass, force and torque measurements for end-users for a wide range of applications from dynamic monitoring in production process to developing the next generation of personalised medicines.

Pressure and Vacuum The revision of the SI has promoted changes to the realization and dissemination of pressure. New measurement techniques that quantify molecular number density of a gas can be used to realize the Pascal directly from the Boltzmann constant and temperature and

have been shown to be as accurate or better than existing pressure standards. These methods rely on quantum-based measurements and molecular interactions to determine the density of molecules. Many NMIs are developing new standards utilising these methods and the first international comparisons are underway. At higher pressures, determination using mass standards retains a lower uncertainty and these standards will remain. In the future, ensuring fundamental standards agree irrespective of the method used to obtain SI traceability will be the task.
Establishing gas pressure standards and providing measurement capabilities up to 100 MPa to support new hydrogen-based technologies and applications are new challenges. Comparisons of 100 MPa gas pressure standards are underway to support new measurement capabilities. In the field of vacuum pressure, collaboration with ISO TC 112 enabled the development and release of new ionisation vacuum gauge technology into the industrial community.

Dynamic metrology To focus on this and to develop a common global view, the CCM has established a Task Group for dynamic measurements whose main focus are to define the requirements for primary standards in the area, not based on the technologies used but on generic requirements that can be applied in several areas, to develop a vocabulary for dynamic metrology to be included in the VIM later and to collaborate with the RMOs and through them with the stakeholders.

The CCM will continue to provide a global forum to exchange information about the state of the art and best practice by organizing workshops and selected technical presentations at the time of CCM meetings. The focus of these events will evolve from an emphasis on topics in mass metrology to examine other quantities greatly influenced by the kilogram redefinition and to topics connected to the grand challenges.

The CCM will actively promote collaboration among CCM Working Groups and participate in cross-disciplinary projects with other Consultative Committees especially in responding to evolving needs in metrology.

## 5.2. PROMOTING GLOBAL COMPARABILITY

The CCM will continue to manage the practical realization and dissemination of the kilogram in the transition period from an internationally coordinated maintenance and dissemination to individual sovereign realizations. The CCM will produce additional/revised guidance as necessary.

The CCM will continue to closely work with RMOs in the context of the CIPM MRA to efficiently plan, execute and monitor key and supplementary comparisons. The CCM will investigate more efficient, timely and robust comparison schemes such as star-type comparisons in the force and torque domain, co-sharing piloting responsibilities, etc. This will help overcome challenges such as finding pilots for comparisons, staff resourcing/continuity at pilot laboratories and failure of transfer standards. The CCM will keep under review the existing arrangements for 'how far the light shines' statements on the results from comparisons. The strategy for comparisons will also be kept under review. It will end up in best practise guidance to ensure knowledge transfer and to support improvement in the delivery of proficiency testing under Global Accreditation Cooperation Incorporated (Global ACI).

To support and simplify the process of CMC review, specific guidance on criteria for a risk-based approach in each mass related quantity will be established by the relevant CCM Working Group. The

CCM will continue to work with the RMOs and NMIs on ensuring consistency in the presentation of CMC entries following the recommendations of the CIPM MRA review.

The CCM will support the introduction of the SI digital framework in mass related metrology, working with BIPM and other consultative committees. That includes digitalization of services such as the use of digital calibration certificates, making comparison data machine-readable and actionable, and providing support for NMIs/Dis in implementing digital ways of working.

The CCM will continue to support the BIPM in organizing the comparison of realizations of the kilogram and in disseminating the kilogram using a Consensus Value during the transition to the use of individual sovereign realizations.

## 5.3. Improving stakeholder involvement

The CCM will continue to provide workshops and initiate webinars, both at CCM and CCM WG levels, to facilitate stakeholder engagement and enable knowledge transfer to and from the stakeholder communities.

The CCM aims to achieve a greater involvement of external bodies by inviting their representatives for a talk at CCM meetings or strategic discussions of the CCM Working Groups. This aim can be more easily achieved by the increasing use of videoconference meetings.

The CCM will encourage WGs to include in meeting agenda, points on feedback about individual interaction with stakeholder groups of interest to the wider community, for example, WG on Force and Torque, WG on Hardness and WG on Fluid Flow about the ISO technical committee activities. The CCM also will encourage the direct relationships, e.g. via liaisons, with relevant ISO TCs, Global ACI and OIML, and non-governmental metrology-related organisations like IMEKO.

The CCM will also seek contributions from other Consultative Committees as well as key manufacturing and supply industries, accreditation organizations and universities. The CCM will create an appropriate structure to communicate and provide input into any CIPM sector specific structure or other Consultative Committees that would benefit from CCM engagement.

In support of smaller NMIs/DIs, the CCM together with RMOs will increase knowledge transfer activities closely linked to the BIPM Capacity Building & Knowledge Transfer Programme.

## 5.4. Work program of the BIPM laboratories

The work programme of the BIPM Laboratories is closely aligned to the work of the CCM[1].

As the custodian of the international prototype of the kilogram, the former definition of the kg, and as the pilot laboratory for the key comparisons of realization experiments, the BIPM has special responsibility for dissemination of the mass unit. Until satisfactory agreement between independent realizations has been reached, internationally coordinated dissemination through the Consensus

[1] Details are available on https://www.bipm.org/en/work-programme

Value approach is being used during Phase 2 of the kilogram dissemination, which came into force in February 2021[2]. The BIPM reference mass standards serve as a "flywheel" to link successive KCs of the kilogram realizations and to maintain the Consensus Value during the Phase 2.

The main activities in the mass area are:

- Organization and coordination of periodic key comparisons of primary realizations of the kilogram CCM.M-K8 and of secondary mass standards,
- Contribution to the calculation of the Consensus Value of the kilogram after each CCM.M-K8 comparison during the Phase 2 of the dissemination,
- Maintenance of an ensemble of reference mass standards as a means of providing traceability for BIPM kilogram calibrations and as reference to link successive CCM.M-K8 comparisons,
- Refinement and maintenance of the established BIPM Kibble balance and development of the compact apparatus for realizing the kilogram, participation in the CCM.M-K8,
- Calibration of Pt-Ir and stainless steel kilogram mass standards for member states,
- Implementation of digital calibration certificates,
- Providing knowledge transfer in the fields of the realization (Kibble balance) and dissemination of the kilogram,
- Collaboration with CCM-WGM and NMIs in order to avoid duplication of effort.

[2] Details are available on the CCM detailed note on the dissemination process after the redefinition of the kilogram, https://www.bipm.org/documents/20126/28432674/working-document-ID-11291/cf8f685d-fc3d-1883-9a42-0678a2c34453

# ANNEX

## 1. GENERAL INFORMATION

CC Name: Consultative Committee for Mass and Related Quantities

Date established: 1980

CC President: Ms Georgette Macdonald

CC Executive Secretary: Dr Hao FANG

Number of CC Members: 27 (plus 5 Observers)

Periodicity between Meetings and date of last/next Meeting: 2-3 years (1981...2023, 2025, 2027)

Working Groups:

| WG | Technical area covered |
|---|---|
| WGDV | Working Group on Density and Viscosity |
| WGFF | Working Group on Fluid Flow |
| WGFT | Working Group on Force and Torque |
| WGG | Working Group on Gravimetry |
| WGH | Working Group on Hardness |
| WGM | Working Group on Mass |
| WGPV | Working Group on Pressure and Vacuum |
| WGS | Working Group on Strategy and MRA Coordination |

| | |
|---|---|
| TGPfD-kg | Task Group on the Phases for the Dissemination of the kilogram following redefinition |
| TGDM | Task Group on Dynamic Measurements |

## 2. LIST OF KEY AND SUPPLEMENTARY COMPARISONS

The key and supplementary comparisons organized by the CCM and the RMOs are listed on the KCDB. The Final Reports of the comparisons as well as those of the Pilot Studies are also available on the CCM web site. The following table lists the ongoing and future CCM KCs.

| Comparison | Description | Repeat cycle | Start date | How far does the light shine |
|---|---|---|---|---|
| Density and viscosity | | | | |
| CCM.D-K3 | Density of stainless steel weight | 10-15 | 2024 | Mass range 20 g to 1 kg |
| CCM.D-K5 | Liquid density measurement by oscillation-type density meter | 10-15 | 2019 | 7 kg/m³ to 9 kg/m³ |
| CCM.D-K6 | Refractive index of liquid | 10-15 | 2026 | 1.3 to 1.7 |
| CCM.D-K1.2023 | Density of silicon sphere | 10-15 | 2023 | Mass 1 kg |
| CCM.V-K5 | Comparison of kinematic viscosity measurements of newtonian liquids | 12 | 2025 | 5 mm²/s to 150000 mm²/s |
| CCM.V-K4 | Measurement of viscosity standard liquids in a wide temperature range | 12 | 2018 | 10 °C to 100 °C |
| Fluid flow | | | | |
| CCM.FF-K1.2022 | Water flow | 10 | 2022 | 0.1 µL/min to 10 µL/min |
| CCM.FF-K2.2021 | Hydrocarbon liquid flow | 10 | 2021 | 1 m³/h to 10³ m³/h |

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| CCM.FF-K3 | Air speed | 10 | 2025 | 0.5 m/s to 40 m/s |
| CCM.FF-K4 | Liquid volume | 10 | 2025 | $10^{-4}$ L to 20 L |
| CCM.FF-K5.2021 | High pressure gas flow | 10 | 2021 | 25 $m^3$/h to 1600 $m^3$/h |
| CCM.FF-K6 | Low pressure gas flow | 10 | 2027 | $10^{-4}$ $m^3$/h to $10^3$ $m^3$/h |
| Force and torque | | | | |
| CCM.F-K23 | Force measurements at 200 N and 500 N | 15-20 | 2019 | 10 N to 1 kN |
| CCM.F-K1 | Force measurements at 5 kN and 10 kN | 15-20 | 2021 | 1 kN to 20 kN |
| CCM.F-K2 | Force measurements at 50 kN and 100 kN | 15-20 | 2027 | 20 kN to 200 kN |
| CCM.F-K3 | Force measurements at 500 kN and 1 MN | 15-20 | 2030 | 200 kN to 1 MN |
| CCM.F-K4 | Force measurements at 2 MN and 4 MN | 15-20 | 2024 | 1 MN to 20 MN |
| CCM.T-K3 | Torque measurements at 20 N·m and 50 N·m | 15-20 | 2024 | 1 N·m to 100 N·m |
| CCM.T-K1 | Torque measurements at 500 N·m and 1 kN·m | 15-20 | 2025 | 100 N·m to 5 kN·m |
| CCM.T-K2 | Torque measurements at 10 kN·m and 20 kN·m | 15-20 | 2028 | 5 kN·m to 100 kN·m |
| Gravimetry | | | | |
| CCM.G-K2.2023 | Gravity acceleration | 6 | 2023 | 9.75 m/$s^2$ to 9.85 m/$s^2$ |
| CCM.G-K2.2029 | Gravity acceleration | 6 | 2029 | 9.75 m/$s^2$ to 9.85 m/$s^2$ |
| Hardness | | | | |
| CCM.H-K3 | Rockwell C scale (HRC) | 10 | 2025 | 20 HRC, 30 HRC, 45 HRC, 60 HRC and 64/65 HRC |
| CCM.H-K4 | Rockwell cone indenter | 10 | 2026 | Geometry of the indenter |
| CCM.H-K5 | Leeb hardness (HLD, HLG) | 10 | 2026 | |
| CCM.H-K6 | Brinell hardness (HBW) | 10 | 2027 | <u>HBW hardness levels</u> 250, 350, 450 <u>HBW scales</u> HBW1/30, HBW2.5/187.5, HBW5/750, HBW10/3000 proposal |
| Mass | | | | |
| CCM.M-K4.2026 | 1 kilogram stainless steel | 10 | 2026 | 1 kg |
| CCM.M-K2.2024 | (Sub-)multiples of the kilogram | 10 | 2026 | 1 mg to 10 kg |
| CCM.M-K8.2027 | Kilogram realizations at 1 kg | 3-4 | 2027 | 1 kg realization |
| CCM.M-P1 | Determination of Centre of Mass | - | 2026 | CofG up to 10 kg |
| CCM.M-P2 | Determination of Magnetic Susceptibility | - | 2026 | 0 to 10 |
| Pressure and vacuum | | | | |
| CCM.P-K3 | IG, range $3\cdot10^{-9}$ Pa … $9\cdot10^{-5}$ Pa | 15 | 2027 | Pressure range $10^{-9}$ Pa ... $10^{-4}$ Pa |
| | Leaks against atmosphere (ATL), $2\cdot10^{-9}$ mol/s | 15 | 2027 | Molar flow (leak) rate $10^{-10}$ mol/s … $10^{-7}$ mol/s |
| CCM.P-K4.2019 | CDG/RSG (P-K4), 1 Pa to 10 kPa | 15 | 2019 | Pressure range 1 Pa ... $10^4$ Pa |

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|---|---|---|---|---|
| CCM.P-K13 | Pressure balance, hydraulic pressure | 15 | 2027 | Pressure range $10^6$ Pa … $10^8$ Pa gauge |
| CCM.P-K16 | Pressure balance, absolute mode, 25 kPa to 350 kPa | 15 | 2020 | Pressure range $10^5$ Pa … $10^6$ Pa absolute |
| CCM.P-K17 | Pressure balance, gauge mode, 25 kPa to 350 kPa | 15 | 2020 | Pressure range $10^5$ Pa … $10^6$ Pa gauge |
| CCM.P-K18 | Pressure balance, gauge mode, 0.7 MPa to 7 MPa | 15 | 2020 | Pressure range $10^6$ Pa … $10^7$ Pa gauge |
| CCM.P-S1 | Pressure measuring device, gas gauge mode, 10 MPa to 100 MPa | 9 | 2024 | Pressure range 10 MPa … 100 Mpa gauge |

## 3. SUMMARY OF WORK ACCOMPLISHED

The key actions accomplished by the CCM have been the following since 2022.

**Strategy and action plans:** updating the CCM Strategy 2022-2032 in 2024, undertaking a major revision and establishing the Strategy 2026-2036 in 2026; defining and following-up of annual CCM action plans; creating the Task Group on Dynamic Measurements in 2025

**Meetings:** holding the 19th CCM and the 20th CCM meetings and its WG meetings, as well as two technical workshops on new developments in mass and related quantities, comparisons and digitalization during the CCM meetings

**Realization and dissemination of the redefinition of the kilogram**

- issuing the CCM recommendation to address lack of agreement in the realization experiments
- development of a road map to address the CCM recommendation
- completion of the 2rd and 3rd key comparisons of realizations of the kilogram CCM.M-K8
- significant improvement in agreement of the 3rd comparison results
- calculation of the 2rd and 3rd Consensus Value of the kilogram and writing related note and detailed report for each Consensus Value
- elaboration of a guide to the Consensus Value of the kilogram
- initiating work towards a potential move to mass dissemination from individual realizations

**Guidance documents**: producing or updating guidance documents for CMC submission and review by the WGFT, WGM and WGPV; producing a note for comparisons of absolute gravimeters by the WGG

**KCs and CMCs**: completion of a large number of CCM and RMO comparisons and CMC reviews

The main achievements of the CCM technical WGs are summarized as follows.

- <u>Density and Viscosity</u> Key comparisons covering possible CMCs for a variety of density measurements mainly based on silicon density standards, liquid density and also for viscosity measurements under wide viscosity and temperature ranges have been implemented. The first key comparison of the solid density of mass standards and the density of liquids by an oscillation-type density meter are underway. Refractive index of liquid was newly added in the CCM service category in 2016, and the work toward implementing key comparison is underway in liaison with the CCPR. Key comparisons on density of liquids and hydrometer have also been agreed.

- Fluid Flow As the quantity of fluid in flow measurement is always compared indirectly via the indication of flow sensors, the performance of the sensors depending on time and on fluid properties is essential for the correct evaluation of comparison results, the related uncertainties, and statements on equivalence between different realizations of units. The development and publication of statistically based criteria to judge the impact of the transfer standard characteristics on the outcome of comparisons was done in 2016. With this, there are now criteria and tools available to evaluate the applicability of transfer standards a priori to a comparison. Parallel to this, WGFF clarified essential terms and released a guide on the declaration of uncertainties in CMCs and calibration reports. For time efficiency in the review of CMC claims, all reports of comparisons now provide a final chapter explicitly stating the success for each participant with respects to its published CMCs. Together with a review protocol for CMCs under WGFF, the consistency of CMC claims among all RMOs will be achieved.
- Force and Torque Key comparisons in force and torque are regularly performed with selected force and torque transfer devices and defined measurement procedures. The transfer standards have improved in recent years, but the stability is still the main influence to be considered in the key comparison evaluation. To consider the drift effect of the sensors, the star type formation has conventionally been used, resulting in a lot of work for the pilots and long durations of the comparisons. To reduce the duration and the workload for the pilot in comparison CCM.F-K23, instead of circulating the transfer standards from the pilot, each participant sent their own transfer standards to the pilot. This did result in a shortened timescale for the exercise but with the disadvantage that uncertainties associated with transducer drift (in some cases the major contribution) were harder to assess.
- Gravimetry Key comparisons CCM.G-K2.2017 and CCM.G-K2-2023, together with the linked regional comparisons EURAMET.M.G-K3 and EURAMET.M.G-K2-2023 have been completed and the results have been published in the BIPM KCDB. The number of published CMCs has more than doubled and now reaches 15 entries, covering both measurement and calibration of absolute gravimeters. As a result, the contribution of absolute "*g*" measurements covered by CMCs to Kibble balance experiments has been significantly improved, leading to a reduction of the relative expanded uncertainty from $8.0\times10^{-9}$ to $4.4\times10^{-9}$.
- Hardness In 2021, improved new definitions for the Rockwell hardness 15N, 30N and 45N scales were developed and approved for use by NMIs. In addition, an improved revision of the Rockwell HRC scale definition was also approved. A key comparison of the Rockwell HRC scale is now underway, with plans moving forward for key comparisons of the Rockwell 15N, 30N and 45N scales. In recent years, two Pilot Studies for the Geometrical Measurement of the Rockwell Diamond Indenter and for Leeb Hardness Measurement were conducted. Both Pilot Studies demonstrated problematic comparison issues that need to be addressed before conducting key comparisons of these measurements.
- Mass Progress on developing the XRCD and Kibble balance realization experiments continues, either to reduce uncertainties or to make the measurements more reliable and easier to perform. Three key comparisons of realization experiments have been completed in 2019, 2021 and 2024 the results of which have been used to determine the 2026 consensus value for the kilogram. The results of the latest key comparison showed much improved agreement between experiments and if this agreement continues, we will be in a position to move to Phase 3 of the kilogram dissemination (from individual realization experiments) after the next key comparison in 2027. Work is underway at a number of NMIs using Kibble

balance technology to develop instruments aimed at the end-user community. Key comparisons of artefact mass standards of one kilogram and at a range of other nominal values are scheduled to start in 2026 and will be repeated on a regular basis to ensure continued global equivalence of measurements. Pilot studies for centre of mass and magnetic susceptibility have also been agreed.

- Pressure and Vacuum Several NMIs have picked up the new fundamental method of realising the Pascal by measuring gas density via refractive index. Others improved the method of absorption spectroscopy to determine gas density and pressure. So, there is a general trend towards optical methods for pressure and vacuum standards. The Working Group for Pressure and Vacuum served as an advisory committee for several research projects developing a novel, highly stable ionisation vacuum gauges suitable as transfer and reference gauges, and new optical methods for the realization and dissemination of the pressure scale. The first digital certificates have been issued in this community. The list of key comparisons has been revised to adequately address the changing demands in pressure calibrations as well as the new measurement capabilities of NMIs' standards. An analysis of best units-under-calibrations (UUCs) was performed and a list of best UUCs provided, which should facilitate a realistic evaluation of NMIs' CMCs in the field of pressure and vacuum. A task group was established, and the first work was performed to establish an objective and efficient risk-oriented process for the evaluation of new CMC submissions.

## 4. Document revision schedule

1 year for exceptions
2 years for updating numbers and dates
4 years for general revision

| Document | Type of revision | Date of revision |
|---|---|---|
| CCM Strategy 2022-2032, Version1.8 | 4-year general revision | March 2022 |
| Version 2.0 | 2-year update (annex 1 and 2) | July 2024 |
| CCM Strategy 2026-2036, Version1.6 | 4-year general revision | August 2026 |