Bureau International des Poids et Mesures

Consultative Committee for Mass and related quantities

CCM WG Strategy 14.01.2013 (updated 01.03.2013)

Strategy 2013-2023
Consultative Committee for Mass and related quantities (CCM)

The audience for this strategy is mainly the CCM, the NMI Directors, the government representatives, the BIPM director and the CIPM.
This strategy reflects the present structure of the CCM. Major changes in this structure are expected at the next CCM meeting.

0 Management summary

The CCM has 11 Working Groups and two Task Groups (the number of Working Groups was reduced from 14 to 11 at the 14th CCM meeting in February 2013, further simplification will follow). 47 Key Comparisons were completed during the time from 1999 to 2012. 25 are in progress and 24 planned. The total number of Calibration and Measurement Capabilities is 2785.

The agreed repeat frequency at the CCM level is generally 10 years. The CCM seems to have a sufficient number of KCs to cover the declared CMCs.

The strategy presents the status of activities and achievements of each Working Group as well as future vision of the landscape and consequent requirements and measurement challenges. The possible redefinition of the kilogram will dominate the scene for the next few years, involving new challenges and commitments. The role of the BIPM will be mainly driven by this issue. Most of the other activities traditionally covered by the CCM will continue largely unchanged. Legal metrology and accreditation bodies, as well as mechanical industry, will continue to be important stakeholders. Dynamic measurement of quantities derived from mass, like torque and pressure, is becoming an important topic.

The CCM want to strongly simplify its structure and increase its efficiency.

Finally a summary of resources needed for piloting CCM Key Comparisons is given. The CIPM MRA is a big cost factor for the NMIs but the benefits for global trade are probably higher (a detailed cost benefit analysis was not performed up to now within the CCM).

1 General information on the CCM

1.1 Administrative information

Date Established: 1980
President: Philippe Richard, METAS since October 19, 2012 (previous President: Mitsuru Tanaka, NMIJ, from October 2001 to June 2012)
Number of Members: 23 (+ 4 observers)[1]
Number of Participants at last meeting (2013): 33 (+ 3 observers, 10 guests and 5 BIPM staff members)
Periodicity between Meetings: 1 to 3 years (2013, 2011, 2010, 2008, 2007, 2005…)
Date of last/next meeting: 14th meeting in February 2013 / 15th meeting planned for 2015

1.2 Working Groups

The CCM has established the following 14 Working Groups (WG), and already reduced this number to 11 in 2013:

- WG on the Avogadro Constant (WGAC), closed in 2013.
- WG on Calibration and Measurement Capabilities (WGCMC), closed in 2013
- WG on Density (WGD)
- WG on Force (WGF)
- WG on Fluid Flow (WGFF)
- WG on Gravimetry (WGG)
- WG on Hardness (WGH)
- WG on High Pressure (WGHP)
- WG on Low Pressure (WGLP)
- WG on Mass Standards (WGM), renamed into WG on dissemination of the kilogram (WGD-kg) in 2013
- WG on Strategy (WGS)
- WG on the Changes to the SI kilogram (WGSI-kg), renamed into WG on realization of the kilogram (WGR-kg) in 2013
- WG on Viscosity (WGV)
- Chairs of CCM WGs, WG Key Comparison, closed in 2013

On the proposal of the CCM President, the 14th CCM meeting decided in February 2013 the simplification of the CMC structure of WGs.
From 14 WGs the total number of WGs was reduced in a first phase to 11 (more than 20 % of reduction). Further simplification will come in future phases.

A table with detailed information on each WG and the recent changes is given in Appendix 1.

The CCM WGM established two Task Groups (TG):
Task Group 1 on "Mass metrology under vacuum for a *mise en pratique*";
Task Group 2 on "Uncertainty components due to traceability to the international prototype of the kilogram".
A table with detailed information on the TGs is given in Appendix 2.

1.3 Key Comparisons

Number of Key Comparisons (KCs) organized (from 1999 up to and including 2012): 47 completed, 25 in progress and 24 planned.
Number of Pilot studies organized (from 1999 up to and including 2012): Total: 6; 3 (WGG), 1 (WGH), 1 (WGM), 1 (WGFF)
Number of CMCs published in KCDB supported by CC body activities (up to and including 2012):

[1] http://www.bipm.org/utils/en/pdf/directory.pdf

Total CMCs[2]: 2785
(WGM: 751, WGD: 201, WGHP + WGLP: 482, WGF: 248, WGV: 392, WGH: 125, WGG: 4, WGFF: 582)

The reader should be aware that the significance of the total number of CMC entries and KCs is limited.

A table with detailed KCs information is given in Appendix 4.

1.4 Common issues across all CCM WGs

- Expand stakeholders awareness of BIPM efforts and the KCDB. Presently, public knowledge of the work and results of the CCM, including the use of KCDB is too limited.
- Web meetings. Increase participation in WGs by smaller economies by using web meetings or video conference.
- Review and redesign of service categories. In some measurement areas, the existing structure of service categories should be improved (e.g. combine categories for mass flow and volume flow to decrease the number of CMC entries). Service categories should be added to accommodate new calibration capabilities in the area of dynamic (non-steady state) measurements (see results of the BIPM Dynamic Measurements Workshop of November, 2012).
- KC efficiency. The mean time for completion of a CCM KC is >5 years. For the pilot laboratory, the labour is >100 man-days and equipment and transport costs are > Euro 25,000. This cost demonstrably decreases when KCs are repeated, especially as we learn which transfer standards offer the best performance. Further efficiency can be gained by developing validated data reduction spreadsheets and protocol and report templates.
- KC funding. Many measurands are having difficulty finding NMIs to volunteer as pilots. Generally, the larger NMIs are repeatedly serving as pilots because small NMIs cannot afford the cost. Some KCs have successfully shared shipping costs. Mechanisms for cost sharing to better distribute the cost of transfer standard equipment should be considered, perhaps via a general fund administered by the BIPM.
- Directives for technical work. The approach to be followed during review of documents, *mise en pratique*, KCs and CMCs should be documented with structured, consequent actions. The procedures for receiving comments and communicating responses should be clear. WGs should consider using the BIPM discussion forum[3] for more transparent communication.
- Example uncertainty analysis. The best available uncertainty analysis and recommended papers for various types of reference standards can be validated by WG review and shared with the community as a resource to labs developing new standards. The will also be useful to technical assessors during accreditation.

2 Terms of reference

Present activities concern matters related to the comparisons of mass standards with the international prototype of the kilogram, considerations affecting the definition and realization of the unit of mass, establishment of international equivalence between national laboratories for mass and a number of related quantities (density, pressure, force, fluid flow, viscosity, hardness, gravitational acceleration) and advice to the CIPM on these matters.

The terms of reference of all CCM WGs and TGs are available on the BIPM web site. They are regularly reviewed at CCM meeting.

[2] http://www.bipm.org/utils/common/pdf/KCDB_CMCs.pdf
[3] http://www.bipm.org/jforum/forums/list.page

3 Baseline
(status of activities and achievements up to and including 2012)

The number of *completed KCs* (first number) and *KCs in progress* (second number) below is related to the period 1999-2012. The number of CMCs is the status at the end of 2012. A table with detailed KCs information is given in Appendix 4. The agreed repeat frequency at the CCM level is generally 10 years (15 years for WGF).
The CCM seems to have a sufficient number of KCs to cover the declared CMCs. The CIPM MRA is a big cost factor for the NMIs but the benefits for global trade are probably higher (a detailed cost benefit analysis was not performed up to now within the CCM).

3.1 Avogadro constant (KCs: -, CMCs: -)

The Working Group on the Avogadro Constant (WGAC) promotes the international efforts for the determination of the Avogadro constant by the X-ray-Crystal-Density method (XRCD method) in view of a redefinition of the mass unit kilogram in terms of a fundamental constant.

- In 2005 the Avogadro constant was determined with relative uncertainty 3×10^{-7} using natural silicon.
- In 2011 the Avogadro constant was determined with relative uncertainty 3×10^{-8} using isotopically enriched silicon.
- In September 2012 the EMRP Joint Research Project kNOW “Realisation of the awaited definition of the kilogram - resolving the discrepancies” started for 3 years programme. In this project, most of the institutes working on the XRCD method cooperate with the European watt balance projects. One aim of the project is to reach a relative uncertainty of the Avogadro constant of 1.5×10^{-8}.

3.2 Density (KCs: 1 *completed* / 3 *in progress*, CMCs: 201)

The major achievements created through the technical discussions and research works are:

- recommended table for the density of water between 0 °C and 40 °C based on recent experimental reports[4];
- new CIPM formulation for the density of air[5];
- clarifying roles of the CIPM and IAPWS[6] formulations for the density of water[7];

As a result of these achievements, most of the NMIs are now using a silicon sphere as their density standard instead of the liquid density standard based on the density of water.
Because water is still important for most calibration work, redetermination of its density was reported by PTB and discussed to improve the precision of the liquid density reference for the use in density calibration, volume determination of mass standard artefacts, and general volumetry.

3.3 Force and Torque (KCs: 8 *completed* / 6 *in progress*, CMCs: 248)

The technical discussions were related to force standards and focused on the improvement in the stability and reproducibility of force transducers, torque measurement standards.
The discussion on the repeat frequency of KCs has shown that KCs will never cover all ranges. But many CMC entries are supported by other measurements or results of special investigations or knowledge and by supplementary comparisons.

3.4 Fluid Flow (KCs: 10 *completed* / 5 *in progress*, CMCs: 582)

The WGFF covers liquid flow (i.e. water, hydrocarbon liquid, cryogenic nitrogen), gas flow (air, nitrogen, natural gas, etc.), liquid volume (from microliters to thousands of litres), and the speed of fluids (air speed and water speed).

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[4] Metrologia Vol. 38, 2001, pp. 301–309
[5] Metrologia Vol. 45, 2008, pp. 149–155
[6] International Association for the Properties of Water and Steam
[7] Metrologia Vol. 46, 2009, pp. 196–198

In the past decade, international cooperation in the field of high pressure gas flow (natural gas) has had a large commercial impact. Harmonization of the calibration results for valuable fluids avoids buyers and sellers using particular labs for economic gain (previously, meter owners used labs that were known to produce high or low results to improve their profit).
A global update of CMCs is underway. The WGFF completed a *Guideline on CMC Uncertainty and Calibration Report Uncertainty*. The guideline will lead to consistent understanding of how to quantify and include device under test uncertainty. We hope to reduce the number of CMCs by combining mass flow and volume flow into a single CMC entry.

Specific issues related to fluid flow which may concern the BIPM-ILAC MoU: Some commercial water flow laboratories are accredited with lower uncertainty than the NMI of the host country. This has happened because flow facilities are traceable to mass and time and commercial laboratories with sufficient resources can reduce uncertainties related to so-called dynamic uncertainty components (those related to flow diversion to a collection tank, steadiness of flow, etc.) to lower values than the NMI. This has led to scepticism about the accreditation validity. A similar situation may exist in the future for other derived quantities (e.g. pressure). The WGFF is a valuable forum for addressing this issue: the WGFF has encouraged the commercial labs to publish results of their proficiency tests, informed accreditors to scrutinize the uncertainty analysis and proficiency tests of these labs more carefully, and provided materials on dynamic uncertainty components to labs and accreditors. Proficiency tests published to date support the commercial labs' claims, but unfortunately they are compared to NMIs with significantly larger uncertainty. A better solution would be comparisons between the commercial labs that claim the smallest uncertainties.

3.5 Gravimetry (KCs: 1 *completed* / 1 *in progress*, CMCs: 4)

From simple estimations of the offsets between the participating gravimeters in 1980s the WGG in collaboration with geodetic community developed the advanced procedures for the organization of International Comparison of Absolute gravimeters (ICAGs) and evaluation of the results of comparisons in conformity with the MRA rules.
The results of investigations of different kinds of the sources of systematic uncertainties, as well as different procedures and documents related to the organization of ICAGs are permanently under discussion. The interest of absolute gravimeter users in the determination of metrological characteristics of absolute gravimeter and insufficient traditional metrological service in absolute gravimetry are other issues.
Currently declared uncertainties of CMCs in the field of the measurement of gravity (free fall) acceleration is bigger than the uncertainties of majority of the absolute gravimeters in use as it is demonstrated in ICAGs. In addition, there are only four NMIs and DIs with declared CMCs. This forces the users of absolute gravimeters to determine the metrological characteristics of their instruments participating in comparisons instead of their calibrations in NMIs and DIs. The specificity of situation in absolute gravimetry is that 90% of more than one hundred absolute gravimeters in use are fabricated by the same company. These gravimeters are not calibrated by the producer.
For the first time in 2009 the KC of absolute gravimeters was organized in the frame of VIII-th ICAG consisted of simultaneous KC and Pilot Study parts with the participation of a new type of absolute gravimeter based on cold atom interferometry.
The collaboration with IAG is important in the view of their task to establish a new global system of absolute gravity reference stations
After the closure in 2010 of ICAGs at BIPM the WGG was responsible to find a suitable gravimetric site for ICAG-2013 and for future ICAGs. The specific document "Guide to evaluation of the sites for AG comparisons" was developed in 2012 and the procedure of the call for proposal of the sites for the comparisons after 2017 is under development.

3.6 Hardness (KCs: 3 *completed* / 2 *in progress*, CMCs: 125)

The WGH deals with hardness standards and promotes the international cooperation among NMIs, DIs, RMO members and international organization like ISO, ASTM, OIML, VAMAS and others, for improving traceability and standardization in the field. The most important activities and goals are the following:

- International primary definition of the Rockwell C hardness scale,
- Organization of Key comparisons on the most used hardness scales (Vickers, Brinell and Rockwell C) and on other under development (Martens, Leeb, Shore),

Organization of a Pilot Study on the geometrical characterization of diamond Rockwell indenters.

3.7 Pressure (high and low) (KCs: 11 *completed* / 5 *in progress*, CMCs: 482)

From May 2nd to May 5th 2011, the 5th CCM Pressure International Conference took place. This time it was the first conference joining efforts to make a one full pressure and vacuum global Conference with the IMEKO TC16 4th Conference.
It was agreed that the organization of comparisons between 1 kPa and 100 kPa would be jointly agreed upon with the WGLP according to the interests of the groups and the primary and the transfer standards involved.
Leak rate comparison was initiated to enable CMC entries in this field. No new technology except new pressure balances suitable for vacuum. Close cooperation with ISO TC 112 (vacuum technology).

3.8 Mass standards (KCs: 5 *completed* / 3 *in progress*, CMCs: 751)

The WGM deals with mass standards calibration and other issues related to mass standards (like material, magnetic properties, stability, cleaning, sorption effects...). The covered mass range is from 1 mg to 10'000 kg.
With a national prototype of the kilogram calibrated against the IPK in 38 countries, the present dissemination of the mass scale is highly decentralised. The dissemination is very robust despite the unknown stability of the IPK.
Most of the scientific work and discussion took place in both TGs. The major issues are closely related to the preparation work towards the new definition of the kilogram. The TG members are working hard on cleaning methods of mass standards, on the study of new materials for mass standards, on mass comparisons under vacuum and on uncertainty related to the traceability to the IPK. Transfer from vacuum to atmosphere
The new definition of the kilogram is stimulating a lot of scientific work related to the future *mise en pratique* of the definition. Many scientific papers were published during the last ten years and this trend became even stronger recently.

3.9 Viscosity (KCs: 3 *completed* / 3 *in progress*, CMCs: 392)

The WGV deals with methods for the absolute measurement of viscosity, for the calibration of viscometers and related issues like reference liquids in a broad viscosity and temperature range. The covered viscosity range is from 1 mm²/s to 1000000 mm²/s, the covered temperature range is from -40 °C to +150 °C.
The technical discussions were related to:

- Viscosity, temperature and pressure range to be covered,
- Reduction of the number of CMC entries,
- Absolute measurement of viscosity at intermediate viscosities,
- Use of viscometers other than glass capillaries.

4 Stakeholders / end users (who they are and their level of involvement)

Looking at the broad scope of the CCM, its work will remain of significant importance for a large variety of different stakeholders, be it “external” ones, such as industry, legal metrology bodies, research institutes, standardization bodies, or “internal” ones, i.e. the various organizations and institutes being directly involved in metrology issues.

4.1 Identification of general stakeholders

The following stakeholders are considered to be important, regardless of any specific CCM working group.

a) The “metrology community” itself
- The committees of the meter convention: CIPM, CGPM, BIPM, CCM itself and other CCs, (Example: work on Avogadro / watt balance in the frame of the redefinition of the kilogram),
- NMIs.

b) Stakeholders from outside the “metrology community”
b1) Industry
- Industry from different economic sectors such as process control (sensors), transportation, energy measurement, safety, health, environment, automotive, aeronautic, petrochemical, aviation, …
- Manufacturers to control their production or rendering calibration services, also those manufacturers that have global manufacturing and calibration facilities requiring uniform application of accreditation requirements and equivalence between the measurements made in NMIs.
- Accredited calibration laboratories using standards with traceability to NMIs.

b2) Legal metrology: OIML, verification offices, inspection services, …

b3) Standards and conformance bodies (conformity assessement bodies).

b4) Research field: Universities, research institutes / facilities, academic foundations, …

4.2 Identification of specific stakeholders

In the following, some specific stakeholders are identified that are related to some CCM working groups.

Density:
Traditional users of density standards are the liquor and alcohol industries, where hydrometers (covered by CCM.D-K4) have been calibrated for legal metrology and taxation at each country. However, more precise, automatized and conventional instruments, such as vibrating-tube densimeters, have started to be used in those industries. This stimulated a new calibration service using density standard liquids (covered by CCM.D-K2). Silicon density standards (covered by CCM.D-K1) are now used by most of the NMIs as density standards for calibrating the density of solid, liquids, and even gases. In the 201 CMCs on density, many of them are for the density and volume of stainless steel weights. This is the reason why CCM.D-K3 is necessary for the mass standard.

Force and Torque:
- Producers of force and torque equipment and transfer standards,
- Users of force and torque.

Fluid flow:
Flow measurements are critical to nearly every economic sector: transportation, energy, safety, manufacturing, etc. Petroleum, natural gas, and alternative fuel providers are notably important stake holders. A few specific examples are: air speed measurements for wind turbines, the quantity of fuel dispensed to vehicles, and the flow of gases used in manufacturing semiconductors. All sectors are connected to WGFF activities via RMO flow technical committees, NMIs, instrument manufacturers, and commercial calibration laboratories.

Gravimetry:
The end users of confident and traceable absolute gravity measurements are the NMIs (for watt-balance experiments, for the calibration of absolute gravimeters and sometimes for in-the-field measurements, DIs, ,IUGG, IAG, geodetic, geophysics, geological and other services for the engineering geology, hydrology, for the geological exploration, for the monitoring of mineral reserves including the hydrocarbons and water, for the support (calibrations) of international, national and local gravimetry networks.

Hardness:
- Producers of hardness equipment and reference standards,
- Users of hardness testers.

Pressure:
- Gauge manufacturers,
- Industries: semiconductor, coating, photovoltaic, lightning, metallurgical, chemical, pharmaceutical, food, automotive, aerospace, process, petrochemical, aviation,
- Research facilities: high-energy accelerators, synchrotrons, fusion, and surface science.
- Secondary calibration laboratories and instruments manufacturing companies.

Mass standards:
Weighing instrument manufacturers, manufacturers of weights.

Viscosity:
- End-users who need characterization of materials (fuel, oil, lubricant, paint, furnish, food),
- A direct contact between users/stakeholders and the WGV does not exist up to now. There are more personal contacts between members of the WGV and standardization bodies and calibration labs,
- The NMI level is restricted to Newtonian liquids measured by glass capillaries and serves for basic calibrations,
- The users are often focused on non-Newtonian liquids and are measuring using rotational viscometers.

5 Future Scan (2013-2023)

5.1 General issues

The possible redefinition of the kilogram will dominate the scene for the next few years, involving new challenges and commitments. These are described under 5.2.8. Nonetheless, most of the activities traditionally covered by the CCM will continue largely unchanged, as they will be only marginally affected by the redefinition. This is especially true for derived units. Legal metrology and accreditation bodies, as well as mechanical industry, will continue to be important stakeholders. In this respect, dynamic measurement of quantities derived from mass, like torque and pressure, is becoming an important topic.

5.2 Sector specific

5.2.1 Avogadro

The WGAC helps to improve and confirm all measurements of the XRCD method in order to
- determine the Avogadro constant and – after the redefinition of the mass unit –realize the new kilogram with a relative uncertainty of 1×10^{-8} or better and
- monitor the stability of the international prototype of the kilogram.

Additionally the WGAC
- helps NMIs to realize the new kilogram by the XRCD method
- organizes international research comparisons and
- participates to the mass unit dissemination.

5.2.2 Density

A new key comparison (CCM.D-K5) to compare the absolute volume measurements by optical interferometry was proposed, as a few NMIs (NIM, NMIA, NMIJ, and PTB) already possess the capability for it. A new key comparison for the vibrating-tube densitometer (CCM.D-K6) was also proposed by some of the members, but starting those new KCs have not yet been agreed in the WGD.
The strategic planning to serve industry and society has been discussed at its meetings on the following subjects:

- density measurements under high pressures and high temperatures (*pρT* properties) for energy saving and environment technology
- refractive index of liquids for food industry and agriculture
- liquid density standard for the volume measurement of a spherical resonator used for the determination of the Boltzmann constant
- density measurements of various biotechnology materials;

The *pρT* properties of fluids are of importance for energy savings and energy transportations, especially for heat pump technologies using refrigerants. The standards for the refractive index of liquids are necessary especially for calibrating sugar content of the Brix scale. As the density of liquid is closely related to the refractive index of liquids, and a few NMIs already possess such a calibration services, planning a new key comparison for the refractive index was discussed in the WGD.

5.2.3 Force and Torque

- No big changes, but some new metrological challenges for big forces up to 50 MN and in the very high torque range (2 MNm up to 16 MNm) are expected due to new power generators (wind energy, improvement of turbines) and better control of ship propulsion, etc.

As future subjects, the working group will consider small force measurement, multi-component force measurement, and comparisons under consideration of parasitical components and dynamic force metrology. In the field of torque it is planned to continue the torque KCs in the range below 500 N•m, especially for the torque steps of 20 N•m and 50 N•m.

5.2.4 Fluid Flow

- The WGFF is focused on comparisons and relies on Pilot labs to perform R&D to improve the stability of transfer standards.
- Existing comparisons are likely to be repeated on an approximately 10 year cycle. Some comparisons will occur on a shorter cycle because they are simpler and cheaper to perform or because there is an economic justification (e.g. natural gas or liquid volume [petroleum]). Improvements in our understanding of transfer standards means that water flow and hydrocarbon liquid flow comparisons could be combined into a single comparison in the future (we are trying this on a voluntary basis in a current hydrocarbon liquid KC).
- New comparisons will arise as NMIs fulfil their customer's measurement needs.
- Some possibilities are:
    - Cryogenic flows (to support liquefied natural gas transactions).
    - Micro-flows, both gas and liquid (for manufacturing and medical applications).
    - Dynamic or transient flows (for gaseous vehicle re-fueling, better process control).

5.2.5 Gravimetry

Taking into account the growing needs for absolute and relative gravimetry in geodesy, geophysics, geology, for the exploration industry, for gravimetric support of navigation systems on moving platforms, for Global Navigation Satellite Systems, for establishment of a new International System of Fundamental Absolute Gravity Stations and the growing number of Absolute Gravimeters worldwide, including those based on new technologies (cold atom gravimetry), it can be anticipated that the needs for comparisons and calibrations will increase. The required uncertainty in absolute gravity measurements will be at the level from one to a few microgals. Smaller uncertainties than those currently declared in the CMCs of NMIs and DIs in the field of absolute gravimetry are already required for calibration of absolute gravimeters. This also will require realization of the corresponding R&D projects aimed at improving the existing absolute gravimeters and investigating sources of systematic uncertainties.

5.2.6 Hardness

Hardness fields in which it is foreseen to have further activities to improve the measurement traceability through development of primary definitions and organization of KCs and pilot Studies are the following:

- Instrumented indentation test,
- nano-indentations,
- dynamic hardness,
- portable hardness testers,
- hardness of elastomers,
- Martens hardness,
- Leeb hardness.

It is already decided to carry on:

- Activity in the development of international primary definitions for Brinell, Vickers and Rockwell scales (about 2 years each – activity already started in 2011 – end of activity on 2015),

KCs in different hardness scales (HRB, HRN, HBW, HSD, HL) (2013 – 2020).

5.2.7 Pressure (high and low)

High and low pressure:

- Optically based standards for pressure
- Dynamic pressures measurements.

High pressure:

- Uncertainty reduction to about 1 ppm near 7 MPa for a new definition of kelvin,
- Replacement of primary mercury manometers by alternative standards – special pressure balances, oil manometers or optical standards,
- Low differential pressures with high accuracy and low line pressure,
- Standards for industrial high pressure technologies (above 1 GPa).

Low pressure:

- Leak reference and transfer standards,
- Standards for outgassing, outgassing reference probes, special materials with low outgassing rate
- Standards for partial pressure measurements.

5.2.8 Mass standards

In connection with a possible redefinition and agreement of the *mise en pratique* for the definition of the kilogram, the following activities would be necessary:

- Realisation and dissemination of the redefined kilogram based on appropriate primary methods and primary mass standards to be developed, improved and adequately maintained, both at the BIPM and at NMIs,
- Role of the BIPM (see also section 6.5) to be defined and practically implemented to guarantee the continuity, traceability, accuracy and acceptance of mass measurements worldwide (ensemble of appropriate mass standards, including ^{28}Si and natural Si spheres, organisation of key comparisons for primary methods, continuation and improvement of BIPM watt balance),
- New realizations of the kilogram, alternative to watt balance and XRCD routes, thus based on different ideas,
- Further, independent, watt balances,
- Further independent XRCD experiments,
- Develop commercial instruments for the realization of the kilogram,
- Clarification of the relationship between CCM (even CIPM) and CODATA,
- Establishment of criteria for accepting new experiments as plausible realizations,
- Establish experiments for the direct realization for small masses,
- Continue the classical KCs for the dissemination of the kilogram.

5.2.9 Viscosity

- Implementing measurements under pressure
- Implementing non-Newtonian liquids
- Implementing viscometers other than glass capillaries
- Implementation of industrial measuring devices into CMCs.

6 Rationale for various activities (2013-2023)

6.1 Overview

Research and development activities, measurement services and key comparisons under the scope of the CCM are driven by international needs for metrology in spheres of activity including industry, science, health, society and the environment. Examples of these needs are given below that will require metrological developments during the next decade.
The CCM has a sufficient set of comparisons that covers the current scope of the CCM's activities (see section 7). The light shines wide enough to cover most of the CMCs. There is a small room for improvement in defining the right set of KCs for each field (see section 7). It is anticipated that this set will be only slightly expanded with time to complement new measurement capabilities.

6.1.1 Avogadro

All activities of the WGAC are driven by the aim to define and realize the mass unit kilogram by a fundamental constant, thus

- improving the mass unit kilogram,
- insuring the stability of the new kilogram and
- acting as a method that is completely independent of the watt balance approach.

This includes a measurement of the instability of the international prototype of the kilogram before the redefinition.

6.1.2 Density

- More accurate and precise $p\rho T$ properties of refrigerants are needed in IEA (International Energy Agency) for efficiency improvement of heat pump systems. Development of a new ozone-depletion free and low GWP (Global Warming Potential) fluid is an urgent task for environment. Standards for the thermodynamic properties of those fluids are needed for developing their equation of state (EOS).
- Producers of instruments measuring the refractive index of liquids are now requiring a traceable standard liquid. Supplying the refractive index standard liquids, which are similar to the density standard liquids, would introduce a good impact for food industry and agriculture.

6.1.3 Force and Torque

Efficient and sustainable energy production (e.g. wind energy as renewable energy source) and protection of the environment (e.g. more efficiency and less pollution of engines)

6.1.4 Fluid Flow

- Resolving differences in air speed key comparisons
- Effort to combine liquids comparisons (liquid flow with different liquids), with the same transfer standard.

Some flow CMCs registered in the MRA KCDB are not yet covered by key comparisons.

6.1.5 Gravimetry

- Organize sufficient calibration service in absolute gravimeters (more calibration than participation to a KC)
- Decrease uncertainty (CMCs)
- Request from customers at the same level as the standard in NMIs
- Increase number of CMCs entries (more participants)

6.1.6 Hardness

All activities are devoted to improve traceability and equivalency among NMIs as requested by stakeholders.

6.1.7 Pressure

Research and development activities are required in the fields of:

- Low differential pressure with high accuracy and low line pressure (10 to 120 kPa absolute mode)
- High hydraulic pressures (above 1 GPa),
- Dynamic pressures (in all modes and ranges, starting with relative hydraulic pressure in medium pressure, 100 MPa).
- Nano pressures.
- Industrial processes in non-equilibrium environments (e.g. CD/DVD metallization),
- Absolute pressure standards up to 7 MPa with relative standard uncertainties of $1 \cdot 10^{-6}$ are required in the frame of the new definition of the temperature unit kelvin in terms of the Boltzmann constant,
- Requirements relating to the refrigerant greenhouse, specifications of tightness of refrigerant equipment and refrigerants' limit leak detection, improved leak testing of nuclear power stations and nuclear waste storage containers,
- Fusion experiments, high energy research facilities, innovative industrial processes such as e.g. semiconductors, coatings, displays production or EUV-lithography have very strict requirements for vacuum properties, i.e. very low outgassing,
- Measurements of partial pressure performed in industry using residual gas analysers (RGAs) are very important to control many kinds of processes (e.g. physical and chemical vapour deposition),
- High pressure technologies such as high pressure processing of food, innovative diesel engineering, autofrettage, hydroforming and isostatic pressing, vessel production for the petrochemical and pharmaceutical industry, manufacturing of water cutting machines and new material fabrication require traceable pressure measurement above 1 GPa,

Some pressure CMCs registered in the MRA KCDB are not yet fully covered by KCs.

6.1.8 Mass standards

- Minimize the (negative) consequences of increased uncertainties in the traceability chain of future mass determinations (after the redefinition of the kg)
  Note: To minimize the (negative) consequences of increased uncertainties in the traceability chain of future mass determinations (after redefinition of the kilogram), it would be sufficient to allow an internationally accepted realization (at the BIPM).
- Do the utmost to ensure continuity, traceability, accuracy and acceptance of mass measurements worldwide, i.e. avoid or at least minimize possible discrepancies between different ("national") realisations for mass metrology
- To increase the number of independent realizations.
- To make a (commercial) realization widely available.

6.1.9 Viscosity

Measure of the pressure dependance of fuels ans of heat transfert liquids.

6.2 Visions

The CCM WG Strategy wants to:

- Simplify and increase the operational efficiency of the CCM,
- Simplify, standardise and accelerate all steps of KCs (from the protocol to the publication of results),
- Use common resource for KCs and streamlining (protocols, data analysis, reporting) at least within each WGs,
- Share validated calculation tools,
- Encourage common views across the CCs to analyse KC data and aim at an improved coordination work across the CCs,
- Review or create directives for the technical work.

6.3 Action plan at the technical level

Strategic actions and management actions decided at the 14th CCM meeting.

6.3.1 Short-term

- Publish written reports from all WGs (before the end of April 2013)
- Revise the membership of all WGs (before the end of April 2013)
- Comment the version 7.1 of the *mise en pratique* of the definition of the kilogram (before the end of April 2013)
- Advise the BIPM on its next Program of Work

6.3.2 Medium-term

- Prepare the final version of the *mise en pratique* of the definition of the kilogram to be approved at the 15th CCM meeting.
- Plan a special edition of Metrologia on the the *mise en pratique* of the definition of the kilogram for 2015
- For the 15th CCM meeting, each member will be asked to prepare a scientific report of activities prior to the meeting.

6.3.3 Long-term

Review the CCM membership.

6.4 Action plan at the management level

The CCM President will strongly simplify the CCM structure according to the CIPM mandate. This simplification means a strong reduction of the number of CCM WGs. A reduction of the number of WGs by a factor of two seems to be attainable.

The first phase concerns obvious organisational changes that should be realized rather quickly without too heavy discussions. This concerns also primarily WGs chaired presently by the CCM President.

1. WG Strategy (WGS includes the present WGS, the WGCMC, the chairpersons meeting and the WG KCs).
Chair: CCM President.
Official start: 20 February 2013 (20 November 2012).

2. WG on the realization of the kilogram (WGR-kg). This new WG includes WGSI-kg and the WGAV). This WG should include all NMIs with primary methods to realize the kilogram. This WG could include TG on AC and WB with separate or join meetings. This WG is responsible of the *mise en pratique*. This WG should consider organizing KC of primary realizations before and after the redefinition.
Note: Before the redefinition, the chair of the CCEM WG kg on electronic kilogram is invited to attend WGR-kg meetings.
After the redefinition the CCEM WG kg on electronic kilogram and WGR-kg could be merged.
Chair: Horst Bettin (PTB)
Official start: 19 February 2013

3. WG on dissemination of the kilogram (WGD-kg). This WG includes WGM, TG1 and TG2). This WG is responsible for all maintenance and dissemination issues (including vacuum and uncertainties).
Chair: Chris Sutton (MSL)
Official start: 19 February 2013

During the seconde phase, we will establish general criteria for the operation of CCM WGs and further simplify the CCM structure. This is planned to be achieved at the end of 2014.

6.5 Role of the BIPM

Considering also the output from the recent workshop on the *mise en pratique* of the definition of the kilogram, the BIPM Mass Department is responsible for:

- The realization through the BIPM watt balance and the dissemination at 1 kg,
- The maintenance of IPK and its copies,
- The establishment, monitoring and use of the *Ensemble of reference mass standards* before and after redefinition as a stable mass reference for dissemination,
- The 1 kg on going KC of primary realizations before and after redefinition.

7 Required Key comparisons and pilot studies 2013-2023 with indicative repeat frequency

The CCM general philosophy when deciding to make a comparison is to be close to industry and to the customer needs.

A short description of the required KCs in each WG is given here. The full list of KCs is presented under section 9 (Appendix 4). Without further indication, the repeat frequency for a KC is 10 years.

7.1 Density

- In general, completed and planned KCs covers almost all of the CMCs on density. No frequent KCs are necessary. A period of 10 to 15 years is considered to be adequate.
- As the gas density measurements will be of importance for energy savings and energy transportations, such a CMC may be covered by a new KC on the *ppT* properties of fluids.
- As the food industry and agriculture need a traceable standard of the refractive index of liquids for sugar content measurements, supplying the refractive index standard liquids, which are similar to the density standard liquids, will be necessary.

7.2 Force and Torque

- In general, for dead-weight force and torque facilities, no frequent KCs are necessary, a period of 15 years is considered to be adequate,
- KCs are especially necessary in the ranges not yet covered by comparisons, e.g. below 100 Nm or above 20 kNm, and comparison of dynamic forces,
- A comparison of 20 Nm and 50 Nm is planned for 2013/14, pilot and details are not yet decided,
- A comparison up to 200 kNm is foreseen without concrete planning yet
- At the moment, there are no results available as a basis for estimating an appropriate repeat frequency of comparisons with non-dead weight machines being involved.

7.3 Fluid Flow

- The second round of 8 fluid flow comparisons will be finished before 2020 and a third round will be planned for start in 2021. The third round may include KCs in cryogenic flow or micro-flows, depending on progress at NMIs in these measurands.
- So far, a 10 year cycle is not a serious burden for the flow community. Lengthening the period could probably be tolerated, but is not recommended. If KCs were not organized by the WGFF, comparisons would continue (informally organized between NMIs as they were before the WGFF was formed in 2000), but they would be poorly organized, selectively documented, etc. (as they were before 2000). Progress in the study of transfer standards and protocols for KCs and the corresponding improvements in proficiency testing for commercial lab accreditation would suffer.

7.4 Gravimetry

CCM.G-K2, ICAG-2017 (pilot study not yet approved as a KC), regional comparison of AGs (EURAMET, APMP) – periodicity of about four years.

7.5 Hardness

- Vickers (every 10 years changing partially the scales) (2015)
- Brinell (every 10 years changing partially the scales) (2014)
- Rockwell C (every 10 years) (2021)
- Rockwell (other scales) (every 10 years) (2015)
- Shore (10 years) (2013)
- Leeb (10 years) (2013).

7.6 Pressure

List of next key comparisons in order of proposed priorities is given below. The priorities and dates are to be specified by the CCM LP and HP WGs. The suggested repetition period is 12 years for LP and 15 years for HP KCs.

7.7 Mass standards (realization and dissemination)

- Organise a comparison with IPK in order to provide direct traceability for all active experiment able to contribute to the value of h within the next few years.
- Organise a pilot study/comparison of future experiments for the realisation of the redefined kg before the redefinition (the CCM recommendation G1 (2010) has to fulfilled with the results of this comparison prior to redefinition).
- On going key comparisons of realisations of the new definition of the kilogram (the first immediately after redefinition, the second after approx. 5 years, further comparisons approx. every 10 years if the results of the previous comparisons are acceptable considering the CCM recommendation G1 (2010),
- Traditional comparisons of mass standards should continue regularly,
- Comparisons below 100 mg (at least once) should be considered.

7.8 Viscosity

The current situation is one key comparison every 6 years, alternating between broad viscosity range at moderate temperatures and moderate viscosities in a broad temperature range.

8 Resource implications for laboratories for piloting comparisons

Summary of resources for piloting CCM KCs:

- Mean value for the total person days per CCM KC (without meetings): 91 person-days.
- Mean cost per CCM KC for equipment purchase: Euro 23 000.-
- Mean cost per CCM KC for transportation cost: Euro 3 600.-
- Mean total per CCM KC: Euro 26 600.-

These values were estimated with the help of data from 21 recent KCs performed in most of the WGs.

The Appendix 3 presents the information above with the help of four different more detailed graphics. The Figure 1 presents the effort (in person-days) by type of activity for 17 different CCM KCs. The biggest effort is related to the design, selection, evaluation and calibration of the transfer standard. In the case of one fluid flow KC the biggest effort was by far the data analysis and report preparation. The Figure 2 presents the direct costs of the pilot laboratory for 12 different KCs. The graphic shows that most of the cost is related to the cost of the transfer standard. The Figure 3 shows the total effort of the pilot laboratory in person-days for 21 different CCM KCs. Finally the Figure 4 presents the total expenditure (equipment purchase and transportation costs) for the pilot laboratory. The fluid flow and force comparisons are the most expensive for the pilot laboratory.

These results indicate that a cost sharing system between the participants could make sense for the CCM KCs.

In addition, the resources required to participate in a key comparison were estimated relative to those required to pilot a comparison. Estimates of participant effort and costs were obtained for 6 of the 21 comparisons used above. This data indicate that the effort in person-days required to participate in a CCM key comparison is between 14 % and 18 % of that required to pilot a comparison. For costs, there is no obvious pattern. For five of the six comparisons, the participant cost is 3 % to 9 % of the cost to the pilot institute but for the sixth comparison, the direct cost to the pilot was zero.

Summary of resources for participating in a CCM KC:

- Mean value for the total person days per CCM KC (without meetings): 13 person-days.
- The mean effort for a participant is about 15 % of the total effort of the pilot laboratory.

9 Summary table of comparisons, dates, required resources and the laboratories already having institutional agreement to pilot particular comparisons

The Appendix 4 presents the available information for past (after the year 2000) and planned CCM KCs.

10 Document Revision Schedule

1 year for exceptions
2 year updating of all lists
4 year major revision with extension of period covered by rolling programme

Versions:
14 January 2013: First version (version 0.7)
01 March 2013: Update (including appendix) after the 14th CCM (version 1.0)

11 Appendix 1: Details of CCM Working Groups

CCM WG	Date es-tablished - stopped	Chair (previous chair)	Institute	Years in post[8]	Number of members (observers)	Participants at the last meeting (members/guests)	Date last meeting	Periodicity (years)
(WGAC)	1995 - 2013	Horst Bettin	PTB	2	5 NMIs + BIPM	15 / 6	June 2012, merged in WGR-kg in 2013	1
(WGCMC)	2005 - 2013	Chris Sutton	MSL	7	24	19	May 2011, merged in WGS in 2013	3
WGD	1981	Kenichi Fujii	NMIJ	10	17 NMIs	16/ 8	February 2013	3
WGF	1981	Rolf Kumme	PTB	6	35	17	March 2011	3
WGFF	2000	John Wright	NIST	2	24	28	June 2012	1
WGG	2003	Leonid Vitushkin	VNIIM	9	20	11	February 2013	1 - 2
WGH	1998	Alessandro Germak	INRIM	14	20	16 / 3	September 2012	1
WGHP	1981	Jorge Torres-Guzman	CENAM	4	19	17 / 4	May 2011	3
WGLP	1981	Karl Jousten	PTB	7	20	22	May 2011	3
WGV	2005	Henning Wolf	PTB	4	21	13	May 2011	3
WGD-kg (WGM)	1981	Chris Sutton (Philippe Richard)	MSL (METAS)	0 (8)	21 (2)	28	February 2013	1 - 3
WGR_kg (WGSI-kg)	2006	Horst Bettin (Philippe Richard)	PTB (METAS)	0 (6)	18	12	February 2013	1 - 2
WGS	2012	Philippe Richard as CCM President	METAS	1	15	13 + RMO TC chairs	February 2013	1 - 2
(Chairs, KCs)	... - 2013	Philippe Richard as CCM President	METAS	1	11	members + RMO TC chairs	May 2011, merged in WGS in 2013	2 - 3

[8] All WG chairpersons (except for the WGS) were appointed or re-appointed by the CCM President with the agreement of the CM members at the 13th CCM meeting in 2011 for four years. According to the document CIPM-D-01, section 6.3, all WG chairs must be reappointed at the latest in 2015.

Working Group on the Avogadro Constant (WGAC)
Working Group on Calibration and Measurement Capabilities (WGCMC)
Working Group on Density (WGD)
Working Group on Force (WGF)
Working Group on Fluid Flow (WGFF)
Working Group on Gravimetry (WGG)
Working Group on Hardness (WGH)
Working Group on High Pressure (WGHP)
Working Group on Low Pressure (WGLP)
Working Group on Viscosity (WGV)
Working Group on Mass Standards (WGM)
Working Group on the Changes to the SI kilogram (WGSI-kg)
Working Group on Strategy (WGS)

12 Appendix 2: Task Groups of the WGM

CCM WG	Date established	Chair	Institute	Years in post	Number of members	Participants at the last meeting (members/guests)	Date last meeting	Periodicity (years)
WGM TG1	2006	Michael Borys	PTB	6	19	19 / 7	May 2011 / February 2013	1
WGM TG2	2006	Lars Nielsen	DFM	6	20	17	May 2011 / February 2013	1 - 3

Task Group 1 on "Mass metrology under vacuum for a *mise en pratique*" (WGM TG1)
Task Group 2 on "Uncertainty components due to traceability to the international prototype of the kilogram" (WGM TG2)

13 Appendix 3: Resources for Key Comparisons

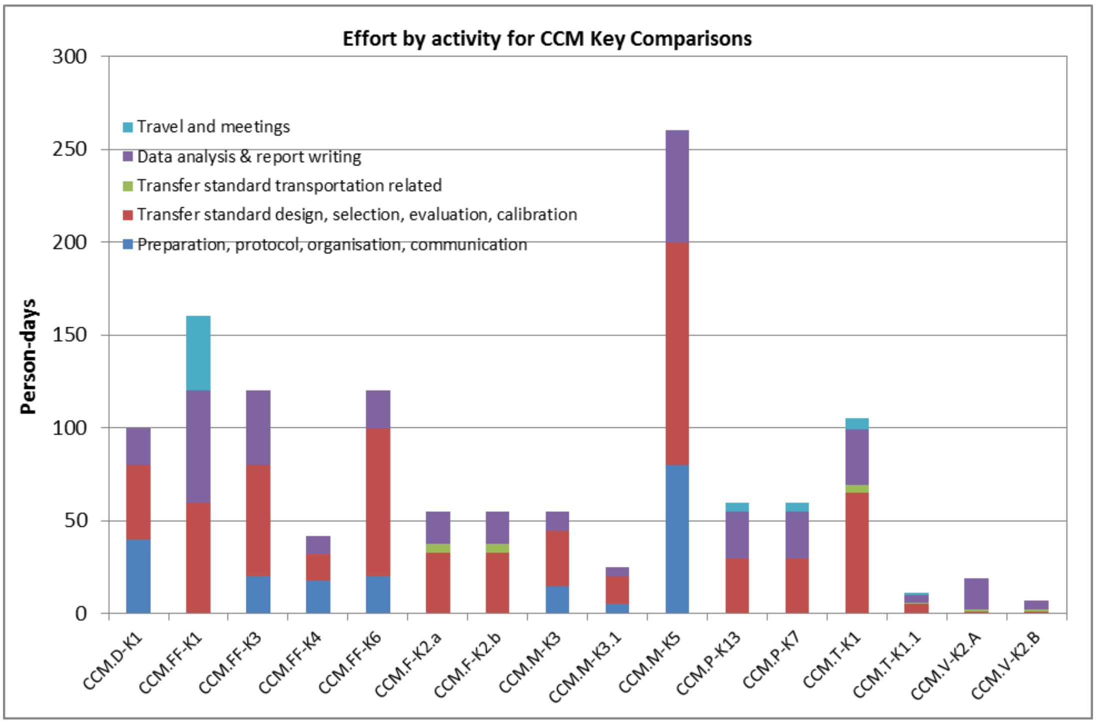

Figure 1: Effort by type of activity for CCM KCs, for the coordination of the pilot lab.

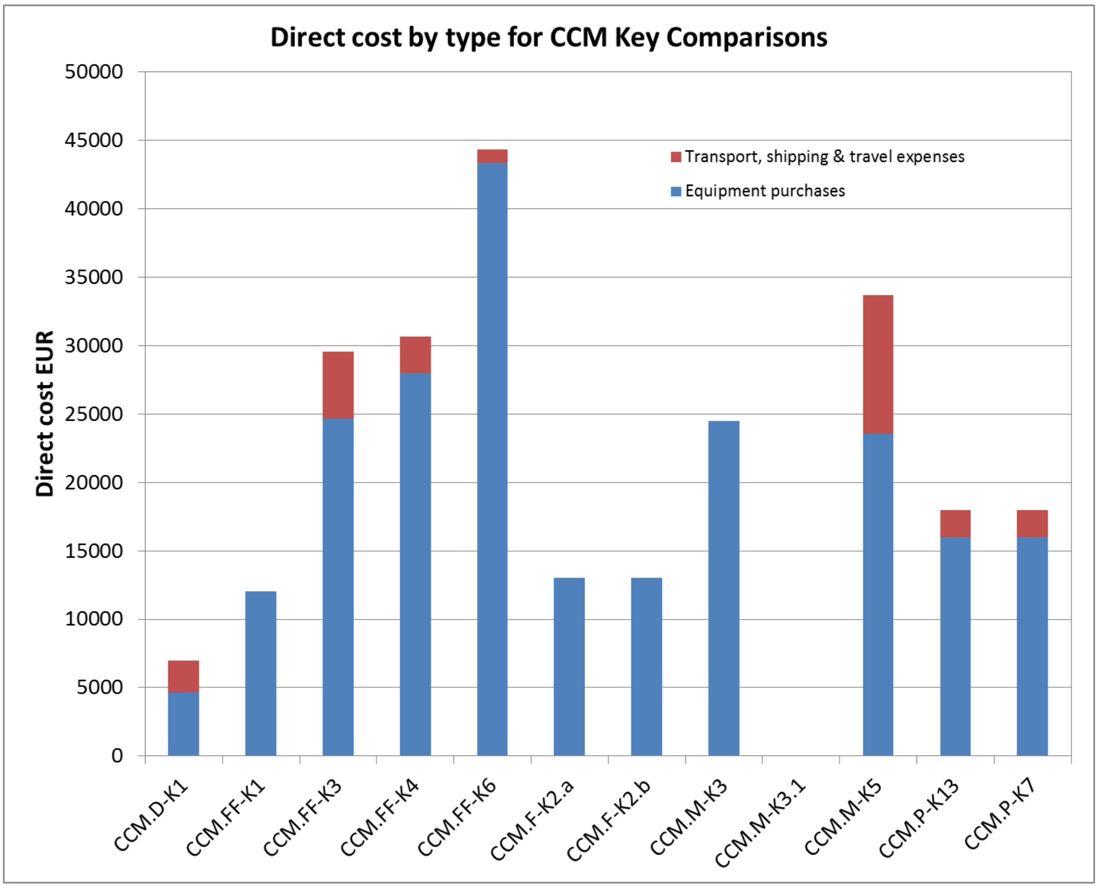

Figure 2: Direct cost of the pilot laboratory by type of KCs

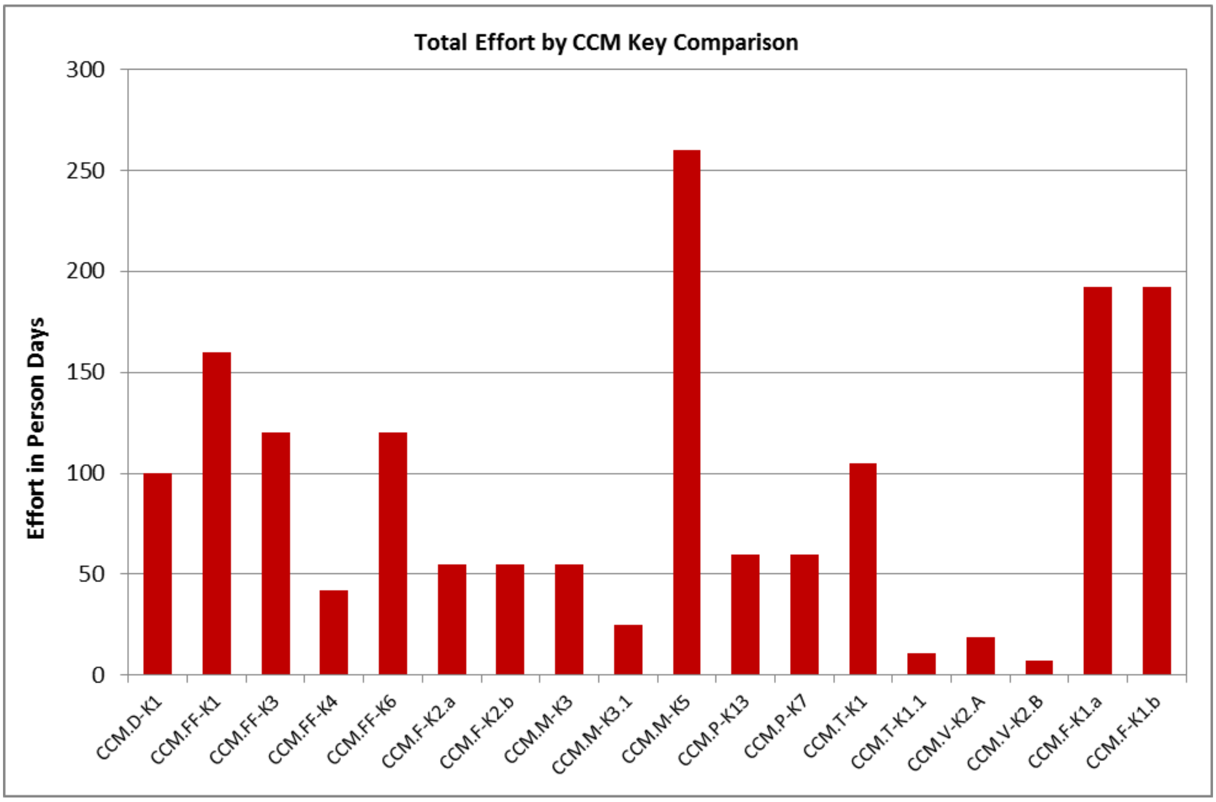

Figure 3: Total effort of the pilot laboratory in man days by type of KCs

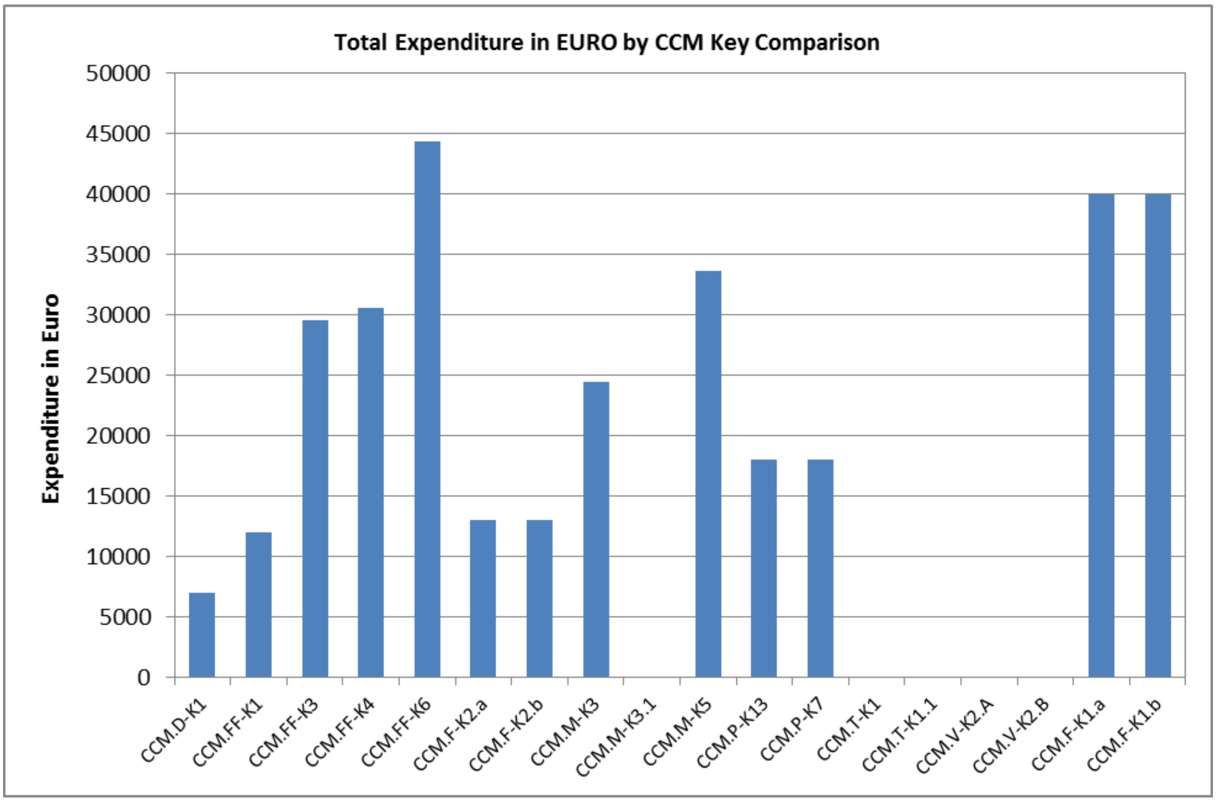

Figure 4: Total expenditure by type of KCs expressed in Euros.

14 Appendix 4: Past (after the year 2000) and planned CCM KCs

See separate document.

15 List of abbreviations

The abbreviations of the working groups are given in Appendix 1 and 2.

AG	Absolute gravimeter
APMP	Asia pacific metrology program
ASTM	American Society for Testing and Materials
BIPM	Bureau international des poids et mesures
CC	Consultative Committee
CD	Compact disk
CCEM	Consultative committee on electricity and magnetism
CCM	Consultative Committee for Mass and related quantities
CGPM	Conférence générale des poids et mesures
CIPM	Comité international de poids et mesures
CMC	Calibration and measurement capabilities
DI	Designated institute
DVD	Digital Versatile Disc
EMRP	European Metrology Research Programme
EOS	Equation of state
EURAMET	European association of metrology institutes
EUV	Extreme ultraviolet
GWP	Global Warming Potential
IEA	International Energy Agency
ICAG	International comparison of absolute gravimeter
IUGG	International Union of Geodesy and Geophysics
IAG	International Association of Geodesy
IAPWS	International Association for the Properties of Water and Steam
ILAC	International Laboratory Accreditation Cooperation¨
IMEKO	International Measurement Confederation
ISO	International Organization for Standardization
IPK	International prototype of the kilogram
KC	Key comparison
KCDB	Key comparison data base
METAS	Federal institute of metrology (Switzerland)
MoU	Memorandum of Understanding
MRA	Mutual recognition arrangement
NIM	National metrology institute of China
NMI	National metrology institute
NMIA	National metrology institute of Australia
NMIJ	National metrology institute of Japan
OIML	Organisation internationale de métrologie légale
PTB	Physikalisch- Technische Bundesanstalt (National metrology institute of Germany)
R&D	Research and development
RGA	Residual gas analyser
RMO	Regional metrology organization
TC	Technical committee
TG	Task group
VAMAS	Versailles Project on Advanced Materials and Standards
WG	Working group
WGD-kg	Working group on dissemination of the kilogram
WGR-kg	Working group on the realization of the kilogram
XRCD	X-ray-Crystal-Density