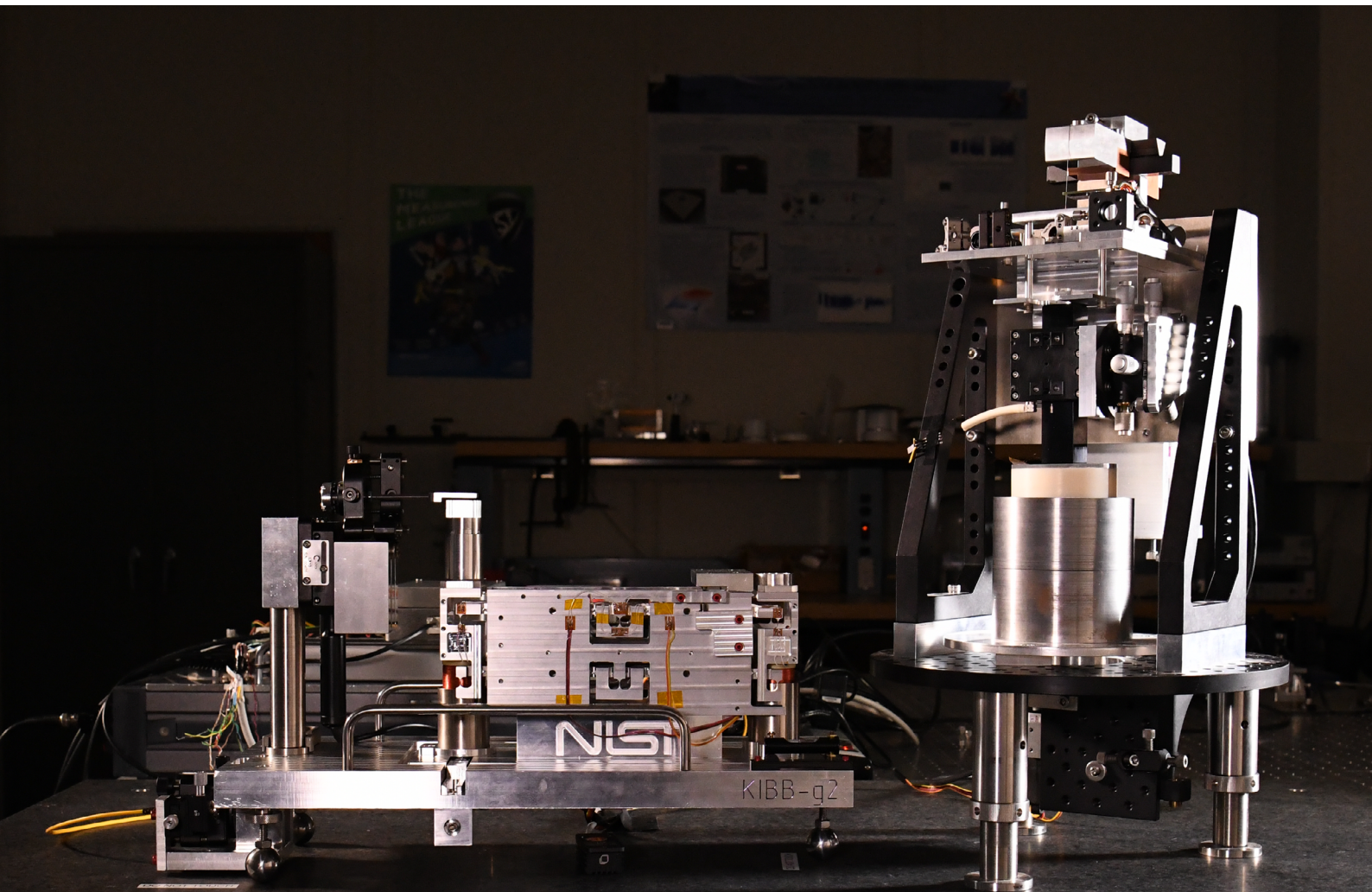




UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Bureau
International des
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Mesures



Deployment and Knowledge Transfer of Tabletop Kibble Balance Technology for SI-Traceable Mass Realization

NIST has developed a series of tabletop Kibble balances to enable advanced mass metrology capability beyond the NMI

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The Challenge

Mass measurements are essential to many commercial transactions, pharmaceutical production, the healthcare industry, and many transportation and advanced manufacturing sectors. These industries rely on accurate mass measurements to ensure their internal measurements and processes are consistent and reliable. As with many national metrology institutes (NMIs) with mature metrology programs, the National Institute of Standards and Technology (NIST) in the US offers highly accurate, SI-traceable mass standard calibration services. These are also linked to the NIST-4 Kibble Balance, which provides a direct (and very accurate) realization of the kilogram through the Planck constant (h). While these mass standards can serve as primary standards in a metrological traceability chain, the calibration services and dissemination methods required to support them can be relatively costly and time-consuming to deliver.

For many industries, government entities, and local and regional authorities within the US, extreme accuracy in mass measurements may not be required. This situation is similar in many developing economies, where their industries and metrology institutes may only require a “fit-for-purpose” mass realization for many of their metrology-based activities and services. However, maintaining metrological traceability is key to mass measurement comparability across the nation’s technical sectors and for fair and equitable global trade.

The Solution

NIST has developed a series of tabletop Kibble balances designed to operate in general laboratory environments, which are less expensive to deploy and more robust over time.¹ The initial design was intended to achieve mass measurements at the gram level with uncertainties on the order of parts per million.² The next-generation tabletop Kibble balances are developed with comparable accuracy but greater robustness and larger range, while remaining consistent with standard precision balance specifications (e.g., Class 3 in ASTM E617) (see **Figure 1**). Further, an international comparison demonstrating good agreement among three different tabletop Kibble balances (with different designs) over a range of masses (1 mg to 10 g) has just been completed by NIST, PTB, and the Technische Universität Ilmenau in Germany.³

¹ NIST. Mass Revolution: Kibble Balances for All <https://www.nist.gov/news-events/news/2023/03/mass-revolution-kibble-balances-all>

² Chao, L et al. 2020 Metrologia 57 035014. DOI 10.1088/1681-7575/ab507d

³ Johannes Konrad et al 2026 Metrologia 63 045002. DOI 10.1088/1681-7575/ae890c

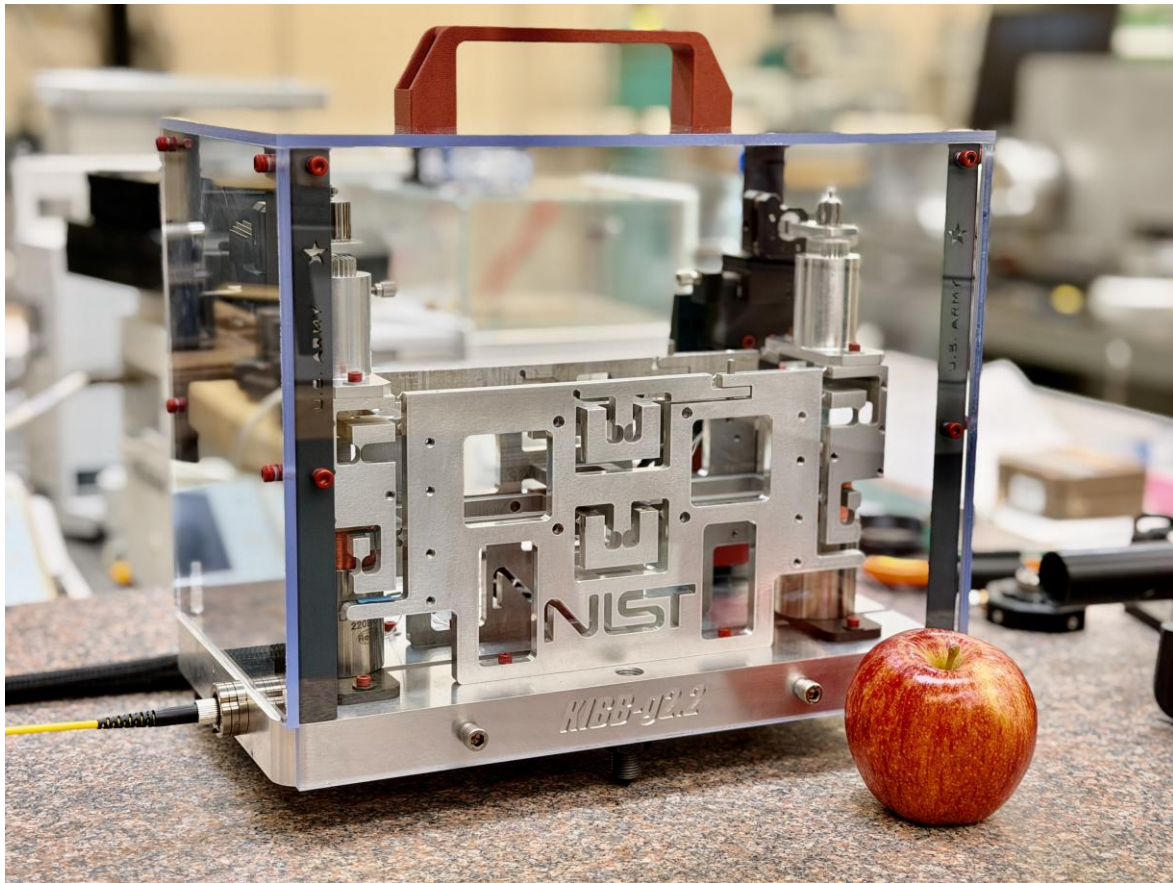


Figure 1. Mechanics of KIBB-g2.2 housed inside an antistatic draft shield. The test mass is on the left side, and a tare mass is on the right side. Reproduced with permission.

As part of a strategic effort to facilitate international cooperation and build global metrology capacity, NIST is also collaborating with other NMIs (CENAM and KEBS) to refine the tabletop Kibble balance as a scalable, transferable primary standard. Through a series of on-site laboratory activities at NIST and corresponding NMI site visits, the tabletop balance will be refined, participate in experimental campaigns, and co-develop documentation and best practices for replication and deployment. Both NMIs provide practical experience operating metrology infrastructure in resource-constrained, field-relevant environments, offering valuable insights into system robustness, usability, and adaptability for broader deployment within each of the nation's industry sectors. KEBS is also leading many mass metrology training efforts and can be considered a regional hub, uniquely positioned to extend the impact of this collaboration beyond Kenya to neighboring NMIs within AFRIMETS.



Figure 2. Staff from both CENAM and NIST are standing next to the Mexican and US versions of KIBB-g2.3, both housed inside antistatic draft shields.

A Quantifiable Impact

As a result of this capacity-building and knowledge-transfer activity, CENAM and KEBS will soon be able to directly realize mass via a primary mass standard, such as a tabletop Kibble balance, and other mass measurements traceable to the Planck constant (h). The deployment of the tabletop Kibble balance at CENAM (see Figure 2) is anticipated to make Mexico the first country to serve as an early adopter of Kibble technology, enabling a parallel mass metrological traceability chain. Once feasibility is established, CENAM will begin replacing conventional mass comparators, which generally have a lifespan of 10 years, with tabletop Kibble balances.

Mexico is motivated to improve its mass measurement capability to directly support its economic development through industrial growth and technological progress, while adhering to global standards and leveraging enhanced metrological capabilities. For example, it is estimated that Mexico's manufacturing exports amount to roughly USD 500 billion annually. A rejection rate of just 0.1 % due to poor mass measurements and a lack of metrological traceability in critical sectors can result in annual losses, rework, and penalties reaching hundreds of millions of dollars.

A further motivation is the streamlining of the mass metrological traceability chain that the Centro Nacional de Metrologia (CENAM) maintains for a wide range of Mexican industries. It is estimated that CENAM provides mass traceability to a network of 180 to 200 accredited laboratories, which entails direct calibration fees and high-security logistic costs of up to USD 4.8 million annually. In turn, these accredited laboratories perform over 150 000 calibration services for the industry each year. Factoring in direct service costs and hidden expenses such as production downtime, the industry spends between USD 130 and 170 million annually just to maintain this metrological infrastructure. If these laboratories and key industrial nodes can

directly realize mass *in situ* using tabletop Kibble balances, the high costs associated with physical logistics and downtime would disappear, generating structural savings of USD 65 to 90 million annually for the Mexican industry.

A key impact for NIST is the opportunity to validate and field-test emerging Kibble balance designs in real-world conditions, enabling well-informed, practical refinements in future designs. Collaboration with both CENAM and KEBS introduces environmental, infrastructural, and operational conditions that differ significantly from controlled laboratory settings, enabling NIST to identify system sensitivities, improve robustness, and refine alignment and diagnostic procedures. This feedback loop is critical for transforming precision instruments into scalable technologies suitable for widespread adoption.

The impact on the US and global industry is both direct and long-term. Reliable, globally consistent mass traceability underpins advanced manufacturing, pharmaceuticals, semiconductor fabrication, and precision engineering sectors. By enabling developing economies, NMIs, and DIs worldwide to realize mass directly from the SI, the metrological intervention reduces the dependence on artifact-based metrological traceability chains and enhances confidence in international measurements that affect trade, calibration services, and supply chains. The main benefit of this technology is that direct mass realization can be achieved with the same level of accuracy (as a primary standard), while significantly reducing the metrological traceability chain and minimizing the potential for increased uncertainty, including bias, associated with the traditional calibration process of using sequential mass standards. In the future, this would enable many industries and other stakeholders reliant on accurate mass measurements (e.g., within the commercial sector) to have direct access to accurate mass realization capability.

This work also advances cutting-edge instrumentation to improve the reliability and metrological traceability of many industrial sectors (including advanced manufacturing). It also reinforces and integrates quantum-based metrology of Kibble balance technology from a laboratory experiment to a deployable, globally adopted primary standard. Lastly, this tabletop Kibble balance technology will encourage equal participation across all levels of the economy, ultimately ensuring worldwide uniformity in metrology practice.

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