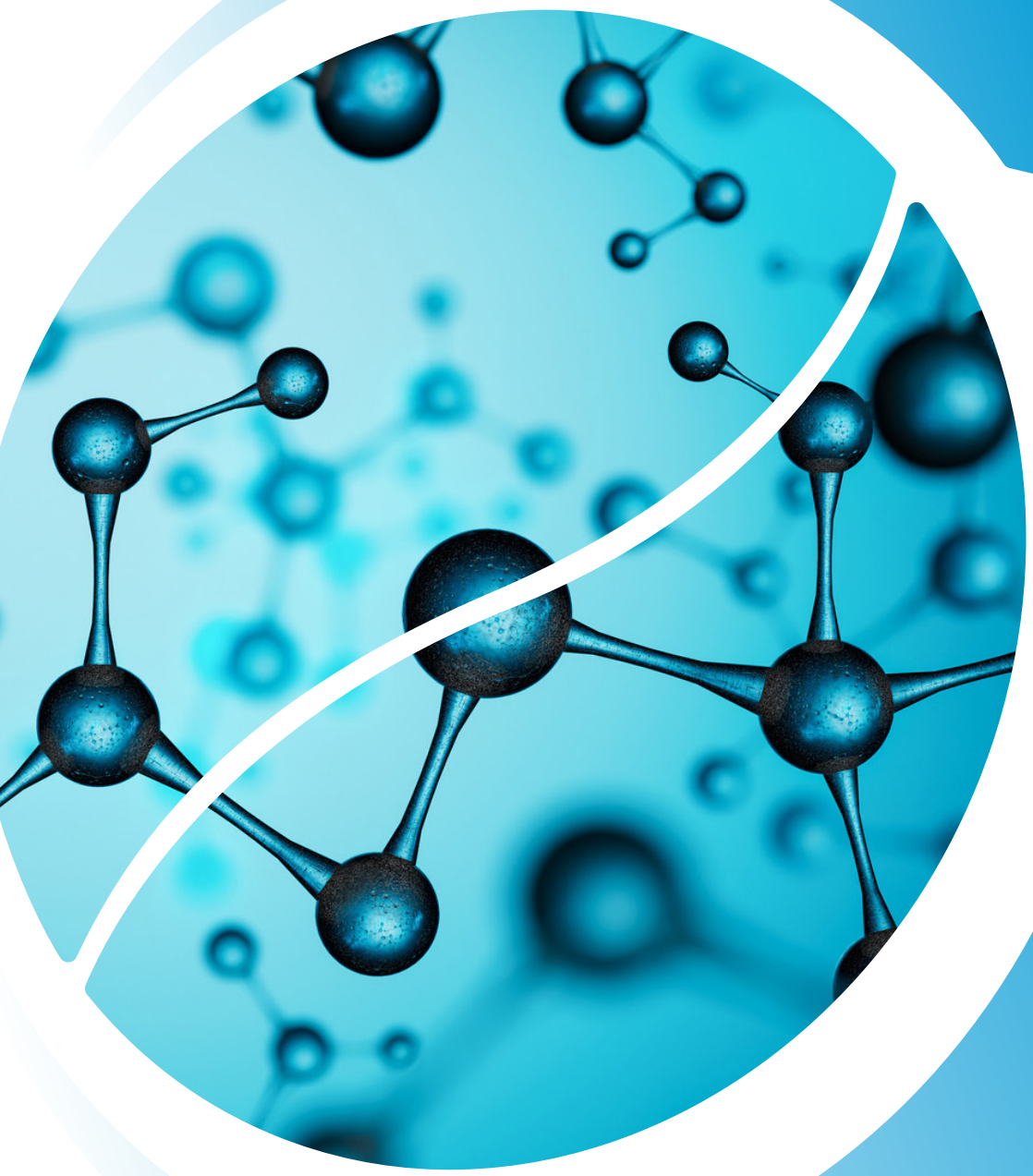
Metrology: The sixth pillar for the European Advanced Materials Act

A Strategic Position Paper by EURAMET and the European Metrology Network for Advanced Manufacturing

Version 1.0 (05/2026)



ADVANCED MANUFACTURING

Authorship and Imprint

This document was developed by the EURAMET e.V. European Metrology Network (EMN) for Advanced Manufacturing.

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We gratefully acknowledge Dietrich Imkamp (Zeiss IQS, Germany) for his valuable contribution to this work.

The authors thankfully recognise the support of the Metrology Partnership project 'Strengthening Communication and Impact for European Metrology with European Metrology Networks' (24CIC01, Comms4Net) for contributing to the event report of the 'Metrology for Advanced Materials - Open consultation event' (21 November 2025) that fed into this paper. The project has received funding from the European Partnership on Metrology, co-financed by the European Union Horizon Europe Research and Innovation Programme and from the Participating States.

EURAMET e.V. and the European Metrology Network (EMN) for Advanced Manufacturing extend their sincere thanks to the speakers of the 2025 open stakeholder consultation events on ‘Critical Materials’, ‘Clean Energy Materials’, ‘Materials for Future Electronics’, and ‘Materials for a Digital World’.

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Official language

The English language version of this document is the definitive version.

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ISBN 978-3-911942-07-2

Image on cover page: istockphoto.com/Brankospejs
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1. Executive Summary

Advanced materials are recognised as essential to ensuring **Europe's technological sovereignty**, industrial competitiveness, and capacity for innovation relative to other global economic powers. However, the transition from laboratory breakthroughs to industrial high-volume manufacturing is frequently stalled by lack of confidence on upscaling innovations to high quality production.

Metrology – the science of measurement – provides the essential infrastructure needed to bridge this gap. It provides **reproducible, traceable, and standardised measurement and test methods** that allow industry to invest and scale new technologies with certainty, accelerating the successful translation of innovation into market adoption.

This position paper outlines how Europe's metrology ecosystem – coordinated through the European Association of National Metrology Institutes (EURAMET) – can act as a strategic enabler for the proposed European Advanced Materials Act. By aligning measurement science with policy priorities, Europe can accelerate the lab to fab transition, reduce risk for industry, and ensure that new materials innovations reach the market rapidly, safely, and competitively.

By strengthening Europe's metrology ecosystem and integrating measurement science into policy frameworks such as the Advanced Materials Act, the European Union can accelerate innovation, support industrial leadership, and ensure that "Made in Europe" remains synonymous with quality, reliability, and trust in global markets.

2. Introduction: The Foundation of Trust in Innovation

2.1. The Advanced Materials Act in the Context of European Industrial Policy

With the Communication "Advanced Materials for Industrial Leadership" dated on 27 February 2024, the European Commission paved the way for a comprehensive strategy aimed at keeping Europe at the forefront of material technologies. Advanced materials are defined as those intentionally designed and engineered to exhibit innovative properties and functionalities. They are crucial building blocks for the Union's economic security and belong to the ten critical technology areas for EU economic security.

The planned Advanced Materials Act (AMA), acting as a key component of the "Competitiveness Compass," aims to create a coherent legal framework to support the design, development, and deployment of these materials. The initiative builds on five strategic pillars:

1. European Research and Innovation (R&I) as a launchpad for the green and digital transformation.
2. Faster transition from the laboratory to the factory (lab to fab).
3. Increasing capital investment and access to financing.
4. Fostering the production and use of advanced materials.
5. A comprehensive governance framework involving the Technology Council for Advanced Materials.

Metrology, however, is not a mere subcategory of these pillars. It forms the necessary technological basis – a "sixth pillar" – that makes all other areas actionable by providing trust in data, standards, and regulatory compliance.

2.2. The Science of Confidence

Metrology is the science of measurement and its application. With a specific emphasis on measurement data quality, it underpins all domains of science, technology, and innovation, serving as a key enabler for a modern, healthy society and competitive business landscape. While often taken for granted, modern society could not function without the precision and trust provided by metrology.

2.3. Metrology in Daily Life

Metrology affects every aspect of modern societies:

- **Advanced manufacturing**: It enables high quality and safe products, **increased productivity and innovation**, and compatibility across complex supply chains.
- **Digital Economy:** It provides the nanosecond precision necessary for **GPS, telecommunications**, and secure financial transactions.
- **Environment:** It enables the precise monitoring of air and water quality and tracks **climate change variables** with decadal stability.
- **Health:** It ensures the safety of medications through accurate dosages and underpins diagnostic tools like **X-rays and MRI scans.**
- **Trade:** It guarantees that consumers receive the exact amount of food or fuel they pay for, maintaining **market trust.**

2.4. EURAMET and the EMNs: Europe's Measurement Backbone

EURAMET is the Regional Metrology Organisation for Europe, coordinating the cooperation of National Metrology Institutes (NMI) and Designated Institutes (DIs) in Europe in research, traceability of measurements to the International System of Units (SI), international recognition of national measurement standards and related Calibration and Measurement Capabilities (CMC). Through Knowledge Transfer and other cooperation among its members EURAMET facilitates the development of the national metrology infrastructures.

To align measurement science services and research with specific industrial needs, EURAMET established **European Metrology Networks (EMNs)**. The **EMN for Advanced Manufacturing** acts as the single point of contact for stakeholders, coordinating research to solve challenges across 13 key industry sectors, including aerospace, mobility, and life sciences.

The EMN for Advanced Manufacturing recently ran **two large stakeholder workshops with more than 300 participants**, to identify needs and priorities to support the Advanced Materials sector. These open stakeholder consultation events covered the topics of **'Critical Materials'**, **'Clean Energy Materials'**, **'Materials for Future Electronics'**, and **'Materials for a Digital World'**.

Across all areas, the need to remove barriers to accelerate innovation was highlighted. In particular, the need to provide confidence at each stage of the innovation process requires that stakeholders agree on metrics and can reproducibly measure and evaluate according to these metrics. These **require widely agreed best practice in measurement, test and evaluation** that is often not available for innovative advanced materials.

Therefore, we suggest that the Advanced Materials Act should foster a reliable and reproducible measurement infrastructure for advanced materials to enable faster innovation. The benefit would be higher confidence to upscale, invest in and adopt advanced materials, where measurement data is trusted and test and evaluation methods are available across the supply chain, from early-stage research and development (R&D) to global trade and regulation.

3. Objective 1: Increasing EU R&I Capacities and Advanced Material Uptake

3.1. Bridging the Lab to Fab Infrastructure Gap

The current materials innovation process is a complex chain requiring **virtual screening, exploration in the lab**, and finally, device evaluation. Metrology must be integrated early in the Research and Innovation (R&I) process to avoid a situation where the manufacturing process is ready, but the tools to validate it are not.

3.2. The Power of 'Operando' and Dynamic Measurements

A major outcome of the November 2025 Advanced Materials open consultation was the consensus on the **importance of *operando* and dynamic measurements, and the need for further development of hybrid metrology**. Traditional static measurements are insufficient for advanced materials that function in non-equilibrium states, such as batteries during charge cycles or catalysts under high pressure.

- **Battery Evolution:** Metrology turns engineering anecdotes into **certified performance**.
- **Frontier Measurements:** There is a critical need for measurements that span from the **nanoscale to the very large dimensions**, and from ultra-fast events to long-term changes, with the ability to measure several measurands simultaneously (e.g. electrical, mechanical, chemical).
- **Hybrid Metrology:** Validation of multimethod measurement approaches are critical for analysis of increasing complex advanced materials.

3.3. RECOMMENDATION 1

In response to the identified bottlenecks in upscaling the advanced materials innovation (Sections 3.1 and 3.2), we recommend that the European Commission should establish a **'Metrology Readiness Level' (MRL)** framework for all Horizon Europe projects (TRL 3-6) involving advanced materials. This would mandate that researchers use existing or develop new reproducible and validated measurement protocols as part of their innovation cycle. This will make best use of R&D investment by reducing duplication and providing confidence to innovate faster, helping transfer discovery into commercialisation and uptake of advanced materials.

Case Study: Metrology driving battery innovation in Europe

Europe's battery sector faces strong global competition, making faster innovation and industrial uptake of advanced materials essential. A key barrier has been the gap between laboratory discoveries and scalable manufacturing.

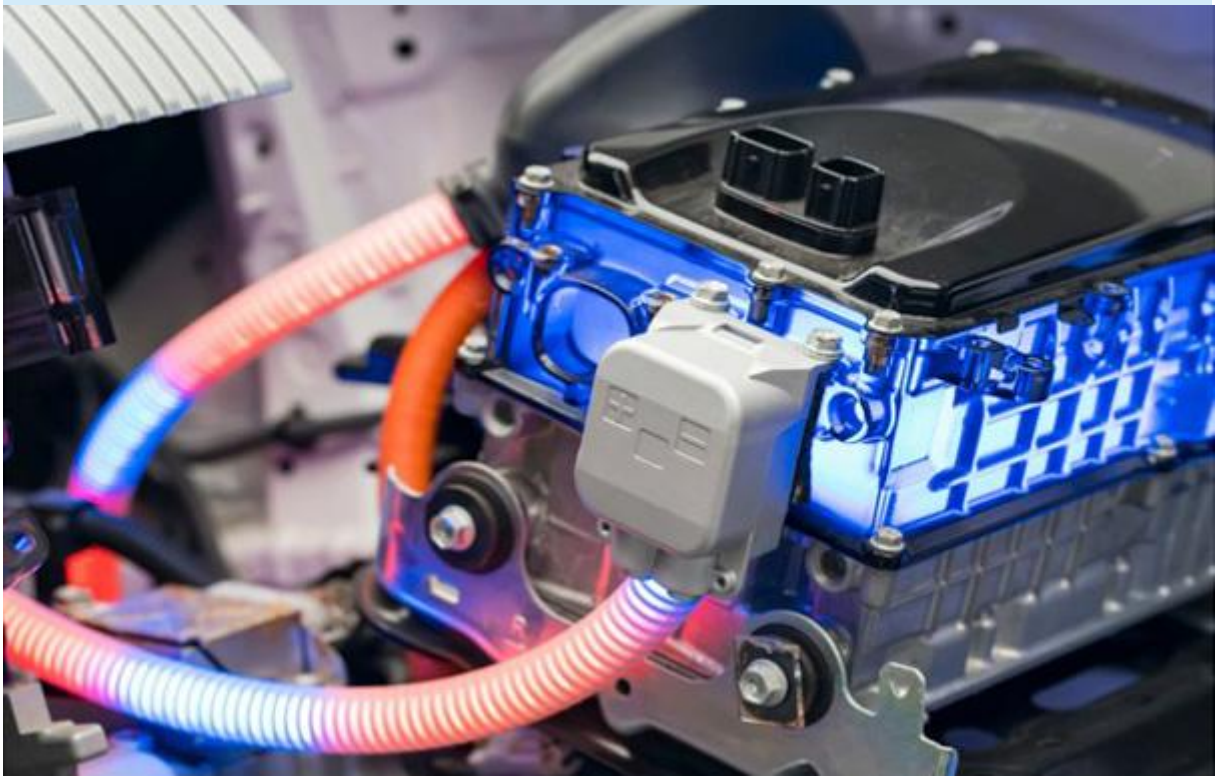
Traditional battery characterisation methods rely heavily on ex-situ analysis, requiring disassembly of cells. This alters internal chemistry, limiting the reliability and reproducibility of results. Therefore, industry faces difficulties in validating new materials, scaling processes, and ensuring consistent product quality.

The Metrology Partnership project Operando metrology for energy storage materials (21GRD01, OpMetBat) addressed this by introducing trustworthy operando metrology, enabling real-time observation of battery processes during operation using a combination of x-ray and impedance techniques.

A key output was the development of the first good practice guide for operando measurements, enabling consistent and reproducible results across laboratories, accelerating material validation and industry adoption.

The follow-on project Hybrid metrology for sustainable and low-carbon footprint battery materials (24GRD09, HyMetBat) is expanding the scope to next-generation battery chemistries, developing a hybrid metrology platform that integrates multiple simultaneous measurements and quantifying impurities in recycled battery materials to access impact on performance.

These projects are bridging the lab to fab gap with reliable data that increase confidence in advanced materials, accelerate uptake and supports battery innovation in Europe.



Objective 2: Strengthening EU Industrial Leadership

3.4. Innovation and industrialisation

There is an urgent need to accelerate the translation of research results into industrial applications to strengthen Europe's technological leadership. Faster pathways from academia to manufacturing are essential to unlock the full value of advanced materials and close the innovation gap. This requires targeted support for scaling, validation, and standardisation. At the same time, empowering SMEs across Europe is critical, as they play a key role in bringing innovative materials to market. Improved access to infrastructure, finance, and metrological capabilities will enable SMEs to compete, innovate, and grow within resilient European value chains.

The 2025 Advanced Materials open consultation identified technical specific challenges for critical EU industries, in semiconductors and clean energy, as well as the overarching challenge of circularity, repurposing and recycling, which are described below.

3.5. Semiconductor Sovereignty

The future of semiconductors relies on adoption of advanced materials and complex 3D structures with sub-nanometer precision. Strengthening European industrial leadership in electronics requires mastering **extreme scaling**. As the industry moves from FinFET (Fin field-effect transistors) to **Gate-all-around (GAA) FETs** and eventually **2D-CFETs** (2D semiconductor-based complementary field-effect transistors), the channel thickness must be controlled at sub-nanometer scales. Alongside miniaturisation, advanced packaging such as 2.5D and 3D chiplet architectures are developing, with particular importance for AI chips. The EU Chips Act also recognises the strength and potential of European leadership in compound semiconductor materials for power electronics, photonics, and telecommunications where innovation is driven by advances in material quality, heterogeneous integration, and packaging.

- **The 1 nm Challenge:** For future devices, there is a crucial need to control thickness, uniformity, and interfaces at **1 nm or less, often in a 3D structure with multiple layers and different materials**.
- **Contamination Control:** In a manufacturing environment, 'metallic contamination' is a constant risk. Metrology must achieve detection limits at the 10^{10} atoms/cm^2 level to ensure the quality of next-generation electronics.
- **Incorporating New Materials:** The adoption of new materials such as 2D semiconductors, high-k dielectrics, and wide bandgap semiconductors requires innovations in metrology for wafer-scale quality control, interface engineering, and process development.

3.6. Clean Energy Leadership: The 'Metric that Matters'

Europe aims to lead in the **Net-Zero transition**. Progress in storage and conversion technologies depends on moving from 'qualitative' to 'quantitative comparison'.

- **Photovoltaics (PV):** Moving from 20 % to 35 % efficiency through **perovskite-silicon tandem cells** could generate enough additional energy to power entire countries. Metrology is required to identify the precise reasons for efficiency losses.
- **Hydrogen:** Reliable metrics for **catalyst performance** are essential to lower the cost of green hydrogen to 1-2 euros per kilogram by 2030.
- **Power electronics** are critical to reduce energy losses in smart grid, electric vehicles, and renewable energy. Metrology is needed for quality control of materials and reliability evaluation of devices.
- **Batteries:** There is a lack of accurate measurement of battery state of health at the cell/device level required to extend usable life and for recycling/reuse.

3.7. Metrology as the ‘Eye’ of the Circular Economy

Circularity is a core priority of the Advanced Materials Act. Without precise measurement of **material purity and degradation**, a truly circular value chain is impossible. Currently there are tools available for measuring the individual materials before they are processed into a product. But it remains very challenging to verify materials properties and origin (e.g. recycled or not) once they are processed and incorporated into components and products.

- **Metrology for Repair and Repurpose:** Methods and technologies are needed to develop to measure material properties after a long service life to decide whether a component can be repaired, reused or must be recycled. Materials at end-of-life are inherently more complex than virgin materials due to chemical and physical heterogeneity, contamination across lifecycle stages, and multiple degradation pathways. As a result, existing measurement protocols for virgin materials are often unsuitable.
- **Zero Waste, Zero Time Loss:** Metrology is the key to moving towards **‘zero waste and zero time loss’** in production. By detecting process drifts in real-time and providing ‘First Time Right’ manufacturing, metrology significantly improves **industrial efficiency** and reduces the material footprint (less rework and in-line corrective action related environmental footprint, production time and costs).
- **Metrology to enable regulation:** Validated test and measurement methods are needed to ensure compliance and enforcement of circular economy regulations.

3.8. Supporting Start-ups and SMEs

EURAMET represents an existing pan-European landscape of measurement facilities and technology infrastructures. These world-class facilities are made available to start-ups and SMEs (small and medium-sized enterprises) that lack the internal capacity to test and validate their high-tech innovations, effectively lowering the barrier to market entry.

3.9. RECOMMENDATION 2

To strengthen industrial leadership in production, we recommend that the European Commission should fund the creation of a **SME Metrology Voucher Scheme**. These would provide SMEs with vouchers to access high-end characterisation tools and measurement expertise across the EU to accelerate their innovation cycles and lower barriers to market entry of advanced materials. A service framework agreement with registered metrology expertise service providers would need to be established to help deliver the scheme. This would make best use of existing metrology infrastructure investments and amplify access to innovative EU companies.

Case Study: Nano-metrology enabling advanced materials industrial leadership in Europe

Advanced materials are at the heart of Europe's industrial competitiveness, underpinning breakthroughs in semiconductors, clean energy, and high-value manufacturing. However, their successful industrial uptake depends on the ability to precisely measure, control, and scale nanoscale properties. Nano-metrology projects demonstrate how advanced measurement capabilities are essential to translating materials innovation into industrial leadership.

The EMPIR project Memristive devices as quantum standard for nanometrology (20FUN06, MEMQuD) addressed the "1-nm challenge" in semiconductor manufacturing, where performance depends on controlling materials at the atomic scale. By developing quantum-based resistance standards using memristive materials, MEMQuD enables ultra-precise, self-calibrating measurements directly onchip. This supports the reliable integration of advanced materials into next-generation electronics, opening pathways for AI and neuromorphic computing.

In parallel, the project High throughput metrology for nanowire energy harvesting devices (19ENG05, NanoWires) focused on nanostructured materials for energy applications. They developed highthroughput metrology tools that allow accurate characterisation of nanowire arrays used in solar cells and energy harvesters. This ensures consistent material performance across millions of structures, improving yield and accelerating the industrial deployment of advanced materials for renewable energy.

The project Improved traceability chain of nanoparticle size measurements (17NRM04, nPSize) tackled a key barrier in scaling nanoparticle-based materials by providing traceable methods for particle size and concentration measurement. These capabilities reduce time-to-market for advanced material formulations and have already driven significant industrial impact, including a reported 75% increase in sales for one partner. Standardisation through ISO is taken forward based on this project results, further supporting widespread adoption across sectors.

4. Objective 3: Fostering Materials Innovations and Upscaling with Digital Tools

4.1. Integrated Computational Materials Engineering (ICME)

Multiple industries already make use of digital tools to accelerate their development and innovation cycles. The ability of evaluating how materials will perform virtually before significant capital expenditure is a main driver. This impact of digital transition often relies on integrated computational materials engineering (**ICME)**, which uses multiscale modelling to understand material behaviour at various scales (e.g. lattice defects, grain boundaries, dislocations). The SI Reference Point already provides a digital authoritative resource providing machine readable and human accessible information about the International System of Units (SI). However, for advanced materials, additional metrology capabilities are needed.

- **FAIR Principles:** Materials data must be **Findable, Accessible, Interoperable, and Reusable** with appropriate quality information**.**
- **Quality metrics for materials data** should be developed to ensure that modelling and big data approaches are not biased by a large volume of poor-quality measurement data. This is particularly challenging for advanced materials where materials properties can depend on the measurement method used and on the sample preparation for testing.
- **Uncertainty in Modelling:** A major priority identified in the consultation is the need for **standardised handling of experimental uncertainty** to validate predictive models.

4.2. The Digital Product Passport (DPP)

The **Digital Product Passport (DPP)** is an initiative by the European Commission aimed at enhancing product transparency and sustainability. It serves as a **digital document** containing comprehensive information about a product throughout its lifecycle, including a unique product identifier, compliance documentation, and details on substances of concern. They can also be used to support a circular economy by tracking materials throughout its lifecycle.

- **Traceable Data:** For the DPP to be trustworthy, every data point regarding chemical composition, safety or structural integrity must be reproducible which requires strong metrological validation through international intercomparisons and traceability to the **International System of Units (SI)**.
- **Machine Actionability:** EURAMET is developing the **Digital-SI (D-SI)** and **Digital Calibration Certificates (DCCs)** to ensure that the DPP is machine-readable and actionable for automated recycling systems.

4.3. Artificial Intelligence (AI) and Machine Learning (ML) in Metrology

- AI and ML are required to fill data gaps in materials databases and predict properties after long-term aging. This is already being used in industry and for example being used for quality assessment of batteries. However, this often relies on proprietary training data that does not necessarily translate to other applications or industries. The stakeholders consulted identified the need that these ‘black box’ methods should be validated using **trusted reference data sets** provided by metrology institutes.
- Future compute technologies based on non-von Neuman paradigms also attract growing interest to tackle the unsustainable energy consumption of traditional AI. Developing and scaling these technologies depends on the choice of underlying material platform and progress is constrained by the lack of appropriate metrology and standardised methods for comparing and increasing performance.

4.4. RECOMMENDATION 3

To empower digital tools to drive materials innovation and industrial upscaling, it is recommended to deploy a **Unified Digital Framework** based on Digital-SI (D-SI) and Digital Calibration Certificates (DCCs) standards, providing the essential technical basis for a machine-actionable Digital Product Passport (DPP). By enforcing FAIR principles and using traceable metrics to validate AI and Integrated Computational Materials Engineering (ICME) simulations, the framework would provide a standardised approach to measurement uncertainty in digital twins. This ensures that AI-driven discoveries are based on high-quality, traceable data, accelerating the commercial adoption of sustainable materials within the EU. Targeted training programmes would ensure that European researchers and industry professionals are proficient in using digital metrological tools and traceable data standards

5. Objective 4: Speeding up the Standardisation Process

5.1. The Standardisation Bottleneck

The development of a documentary standard currently takes several years, even when best practice and scientific understanding is already established. This delay is also reflected in EU´s standardisation strategy. For emerging technologies, significant scientific work is needed before experts can agree on international standards. In a fast-moving global market, this is a significant barrier to innovation and adoption of advanced materials due to lack of confidence. Metrology provides that confidence at each step of the innovation cycle.

5.2. Pre-Normative Research as a Catalyst

EURAMET's coordinated approach to **pre-normative research** can drastically shorten this timeline. Metrology institutes provide a **neutral scientific ground** where industry and regulators can agree on best practice guides that serve as interim standards to provide confidence to advance science, invest, upscale manufacture and trade.

5.3. A Proactive Approach

By aligning metrology with early-stage R&D (research and development), we can provide industry with a competitive advantage, giving them access to validated protocols years before international standards are finalised.

5.4. RECOMMENDATION 4

Implement a **'Fast-Track Standardisation'** mechanism. Under this mechanism, metrologically validated measurement protocols would be automatically recognised as **early drafts of metrology technical specifications** to accelerate the development of ISO Technical Specifications (TS) for EU public procurement, which is in line with the ISO strategy, for EU public procurement, bypassing years of committee deliberation, and allowing companies to have confidence to innovate and invest before full international standards are made public. Funding support to participating in pre-standards R&D and standards development work will be needed to implement this recommendation.

6. Metrology supporting implementation of EU Regulation

Coordinated Regulatory Support: EURAMET's metrology community, including National Metrology Institutes, European Metrology Networks, Technical Committees and collaborative research, provides the technical basis to help **national and EU regulators form and implement rules** that are scientifically sound and industrially achievable.

Metrology is fundamental not only for the development but also to facilitate enforcement of regulation. However, several bottlenecks currently hinder the effective implementation of EU rules.

6.1. Key Metrological Challenges in Regulation:

- **Difficult Testing Requirements:** Regulatory requirements are often set without considering if they are practically testable on a factory floor. Metrology can work with end users to implement realistic test protocols and provide the required training for implementation.
- **Vague Standards:** Standards that are not sufficiently specific allow the use of multiple methods that, even if cross-validated, can provide different results. Metrology interlaboratory comparisons can validate which methods are reproducible and should be a requirement before standards are written.
- **Lack of Certified Reference Materials (CRMs):** There is a persistent shortage of suitable CRMs needed for legal compliance and quality control. Targeted efforts to develop priority CRMs across nations can be facilitated by existing metrology networks.
- **Insufficient Risk Assessment Data:** Rigorous scientific risk assessments often suffer from a lack of reliable, traceable data. Engaging with metrology laboratories is key to establish the required traceability to the International System of units.
- **Limits of Detection:** Legislation sometimes specifies limits that are extremely close to the current physical limits of detection, making enforcement unreliable. Close interaction between regulators and metrology laboratories is needed to inform what is achievable and further develop metrology capabilities ahead of regulatory need.
- **Uncertainty Impact:** There is often a lack of understanding among policymakers regarding how **measurement uncertainty** impacts the setting of technical limits and the assessment of compliance. Reduced measurement uncertainty allows for more confident compliance with thresholds, and consequently allows tighter thresholds / tolerances in the future.
- **Prescriptive standards**: prescriptive standards that mandate use of specific materials are known to hinder introduction of new innovative materials in existing markets. A shift towards "performance-based standards" would address this challenge.

7. Economic Impact and Strategic Sovereignty

Investing in metrology is highly efficient. Evaluations of EU funding programs (EMRP/EMPIR) show a Return on Investment (ROI) of 4:1, with metrological research inducing an estimated 1.6 billion euros in economic turnover from new or improved products.

This economic effect is not limited to large industrial actors. SMEs are strongly embedded in metrology partnership projects through several routes, including as beneficiaries, collaborators and stakeholders. Across the call years 2014–2025 of EMRP, EMPIR and the European Metrology Partnership, 307 SME participations were recorded as beneficiaries or collaborators, while total SME involvement rises to 1,348 when they are included as stakeholders of a project (see figure 1).

Figure *1* **Total involvement of SMEs in metrology partnership projects.** SMEs are strongly embedded in Europe's metrology research landscape through participation as beneficiaries, collaborators, and stakeholders. Data collection for the 2023–2025 call years is ongoing, so the lower values should not be interpreted as a confirmed decline in SME engagement.

Metrology therefore functions not only as a research infrastructure, but as an industrial competitiveness tool. It helps companies develop, validate and commercialise new products, while also providing the common technical language needed for standards, certification and cross-border market access.

In nanotechnology alone – a market that could reach globally $3 trillion US Dollars – robust standards are a prerequisite for European market share. To avoid fragmentation in global markets, European metrology must lead international synchronization efforts (e.g., through the BIPM, VAMAS and international standardisation bodies). Establishing traceable and universally accepted measurement protocols ensures that European advanced materials can be traded and integrated into global value chains without costly re-testing or technical friction.

8. Conclusion: Metrology for a Stronger EU

The success of the **Advanced Materials Act** is inseparable from the strength of Europe's measurement infrastructure. Metrology is not a static cost; it is a **strategic investment** that accelerates innovation, ensures sustainability, and guarantees that 'Made in Europe' remains a global hallmark of quality and trust.

This paper summarises key findings from a series of stakeholder consultation events for Advanced Materials in key areas of Critical Materials, Materials for Clean Energy, Materials for Future Electronics and Materials for Digital Transformation.

We identify four key recommendations to support innovation, adoption and competitiveness of EU's Advanced Materials.

- **Introduce a Metrology Readiness Level (MRL) Framework:** Require EU projects developing advanced materials to incorporate validated and reproducible measurement protocols early in their R&D cycle. This would reduce duplication, improve reliability, and accelerate commercial uptake.
- **Create a SME Metrology Voucher Scheme:** Provide SMEs with vouchers to access high-end measurement facilities and expertise across the EU. This would lower innovation barriers, make better use of existing metrology infrastructure, and support faster market entry for advanced materials.
- **Deploy a Unified Digital Metrology Framework** based on Digital-SI (D-SI) and Digital Calibration Certificates (DCCs). This provides the technical foundation for a machine-actionable Digital Product Passport (DPP) and ensures that AI-driven discoveries are based on high-quality, traceable data. By standardising the handling of measurement uncertainty in digital twins, this initiative accelerates the commercial adoption of sustainable and high-performance materials. Targeted training programmes would ensure that European researchers and professionals are proficient in using these digital metrological tools.
- **Implement a Fast-Track Standardisation Pathway:** Allow metrologically validated measurement protocols to be rapidly recognised as early drafts of metrology technical specifications for EU procurement, enabling earlier industry confidence and investment. Support for pre-standardisation research and standards development will be required.

EURAMET and the EMNs are committed to being the **gateway to Europe's integrated metrology community**. By pooling resources across 39 countries, fragmentation is avoided that hinders tackling global competitors and a scientific foundation for the next decade of European industrial leadership is provided.

The joint research projects mentioned under chapter 3.3 and 4.6 are either part of the European Metrology Programme for Innovation and Research (EMPIR) or the European Partnership on Metrology.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

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