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## Publishable Summary for 19NET01 AdvManuNet

### Support for a European Metrology Network on advanced manufacturing

#### Overview

Advanced manufacturing has been identified by the European Commission (EC) as one of six Key Enabling Technologies (KETs) with applications across multiple industries. Several previous EMRP and EMPIR research projects have partly addressed the metrological needs for advanced manufacturing. However, a high-level coordination of the metrology community is currently absent, and this has limited the impact of metrological developments in advanced manufacturing. This project aims to strengthen the European position in advanced manufacturing by accelerating the development and uptake of innovative metrology, by focusing on the needs of advanced manufacturing and optimising stakeholder interaction with the metrology community.

#### Need

The KETs identified by the EC are a group of six technologies: advanced manufacturing, advanced materials, life-science technologies, micro/nano-electronics and photonics, artificial intelligence, security and connectivity. They have applications in multiple industries and help tackle societal challenges. A concept for manufacturing for 2030 states that “Manufacturing, with its approximately 20 industrial sectors, is the backbone of the European economy.” and that “Manufacturing 2030 reflects a time scale in which a fundamental change – initiated by research activities and technical innovations – can be reached.” This project and the European Metrology Network (EMN) for Advanced Manufacturing aim to directly address the above-mentioned topics.

Recent innovative developments in advanced materials that result in new material properties are often due to the addition of nanomaterials. Despite being advanced themselves, these materials can require advanced manufacturing processes to be able to realise new or substantially improved products, and in turn these advanced manufacturing processes need to be supported by new metrology approaches for quality control. For example, the development of additive manufacturing technologies offers a new and ‘improved’ class of applications in advanced manufacturing, which itself also creates challenges for the metrological characterisation of parts produced and the integration of additively manufactured components into established manufacturing chains. This is particularly important within the framework of flexible manufacturing infrastructures, as described in concepts such as Industry 4.0, the Industrial Internet of Things (IIoT) and digitalisation. Within the EMRP and EMPIR several preceding projects have addressed such challenges, which required expertise from different EURAMET TCs. However, the results of neither these nor H2020 research projects have been systematically analysed with respect to their potential for impact on advanced manufacturing and its related KETs, advanced materials and nanotechnology. Without the collation of the results and the systematic analysis of such research projects, the uptake of relevant results, knowledge sharing between stakeholders and therefore overall impact is significantly hindered.

According to EC statistics, 2.1 million enterprises were classified as “manufacturing” in the EU in 2015 with nearly 30 million employees. In addition to industrial companies, different organisations at the national and European levels have a focus on manufacturing topics. Within EURAMET, several Technical Committees (TCs) have a strong relation to advanced manufacturing topics, but to date there is no single point of contact (SPOC) for advanced manufacturing as a whole and the related KETs. Furthermore, EURAMET TCs have developed different roadmaps describing specific metrology challenges, but not a joint one for metrology in advanced manufacturing and its related KETs. There is a need to develop a roadmap that considers the available expertise, facilities and research capabilities for advanced manufacturing. It should also include input from stakeholder communities such as the European Factories of the Future Research Association (EFFRA), the European Association of the Machine Tool Industry and related Manufacturing Technologies. A gap analysis between this roadmap and those for future metrology requirements is also needed. This gap analysis will facilitate the future planning of research, training and service provision in metrology for advanced manufacturing across Europe.

## Objectives

The overall aim of this network project is to accelerate the implementation of the future EMN for Advanced Manufacturing. The specific objectives are:

1. To establish regular, constructive dialogue and liaison between the project and stakeholders in advanced manufacturing, as well as overlapping areas in advanced materials and nanotechnology. The project will foster new and existing collaborations including those with relevant societies and standardisation bodies.
2. To develop a Strategic Research Agenda (SRA) and roadmaps for advanced manufacturing metrology using the feedback from stakeholders in Objective 1. The SRA will identify gaps in current metrological capabilities and take into account existing networks and roadmaps.
3. To set up a knowledge-sharing programme for advanced manufacturing stakeholders using the feedback from stakeholders in Objective 1, in order to promote the dissemination and uptake of results, including those from previous, relevant EMRP and EMPiR projects. This will take into account existing training programmes and include a range of regularly hosted activities, e.g. exchange of researchers, industry focussed events and training courses.
4. To develop a web-based platform for advanced manufacturing stakeholders using the feedback from stakeholders in Objective 1. The platform will include easy access to European metrology capabilities and links to other relevant European and international networks, as well as a service desk. It will be developed in a manner that allows it to be maintained by a future EMN.
5. To develop a plan for a joint and sustainable European metrology infrastructure for advanced manufacturing via a European Metrology Network. The plan will be completed within 12 months of the start of the project and will (i) use coordination and smart specialisation of capabilities (ii) align with other running initiatives and projects, (iii) promote the development of emerging member states, and (iv) consider how to extend collaboration to third countries.

## Results

*Objective 1. Establish stakeholder dialogue in advanced manufacturing, as well as overlapping areas.*

Stakeholder dialogue in advanced manufacturing was initiated and undertaken. These activities included a definition of advanced manufacturing that capitalised on the CIRPedia definition of manufacturing and specialised it to advanced manufacturing, taking into account information from other references. The proposed definition is supported by explanations given as additional notes.

A list of keywords used for structuring advanced manufacturing topics was also generated and will be used for the development of the web-based platform (Objective 4). Thirteen relevant KISs (Key Industrial Sectors) were identified with the purpose of establishing the boundaries of the future EMN for Advanced Manufacturing in its activities, remit and stakeholder engagement. The KIS have been useful also for identifying areas where the EMN activities can be widened, and to identify possible EMN stakeholder advisory committee members, chosen one per KIS. The 13 KISs are [2]: metrology equipment and service; machine tools & robotics; digitalised and integrated manufacturing systems; advanced materials & processing; energy generation, transmission & storage; nano- & microelectronics; nano- & microtechnology; optics and photonics, land & sea-based mobility; aerospace; complex infrastructure & civil engineering; life science technology; defense & security. These 13 KIS were chosen based on the EC list of 20 industry sectors analysed by the project regarding potential metrology demand and with stakeholder input.

In addition to the KISs, Cross-Cutting Topics (CTTs) were identified. They mirror the subsequent phases in the product lifecycle. They are (i) Intelligent product design, (ii) Advanced materials, (iii) Smart manufacturing and assembly, (iv) Quality control and testing, (v) Digitalisation and vertical metrology integration, (vi) Standardisation, (vii), Health & safety, environment & sustainability (viii) Knowledge-transfer and accessibility. Together with the KISs, these CTT's constitute the coordinates for localising activities within Advanced Manufacturing. The CTT classification emerged in the preparation of the Strategic Research Agenda (see Objective 2).

An EMN stakeholder council (SC) has been established with high-level representatives from European companies of the different KIS such as Zeiss, Renishaw, Siemens, Vestas, BASF, ST Microelectronics,

Rolls-Royce and organisations, such as DTU, CERN and BfR. The EMN stakeholder advisory committee is providing advice for the work of the EMN for Advanced Manufacturing.

The project and EMN are also engaging stakeholders with the first issue of a newsletter for informing stakeholders and the public about the activities of the project and of the new EMN Advanced Manufacturing (distributed in May 2023).

Further to this, the structure of a questionnaire open to the public was prepared. The goal of the questionnaire is to provide a way for stakeholders to feedback to the project and the EMN on metrological needs in Advanced Manufacturing. The questionnaire will be made available on the EMN website and set out in a way suitable for input to the Strategic Research Agenda, so it can contribute to its maintenance over time.

*Objective 2. Develop an SRA and roadmaps for advanced manufacturing metrology.*

The main activity so far has concentrated on the production of a first draft of the SRA. An early version of draft content for the SRA was presented and made available via the EMN's webpage hosted by EURAMET at the end of 2022 in advance of the European Partnership for Metrology Call 2023 on Metrology for Industry. This early publication was achieved following an agreed revision to the project plan accelerating all underpinning activities with support from EMN delegates, the EMN SC (see Objective 1) and stakeholders.

The content and structure of the 1<sup>st</sup> draft of the SRA has since been further developed and major revisions made based on feedback obtained from stakeholder engagement activities. These revisions have improved the SRA content with clear descriptive text for cross cutting topics and new subheadings to provide a clear themed substructure within each CCT (see Objective 1). Furthermore, KIS specific inputs (see Objective 1) have now been transposed into the more broadly applicable CCT structure with the guidance of the EMN SC members. This has focussed the document on the highest priority metrology themes and condensed the SRA document to a more easily digestible length for readers, which is in response to early feedback from EMN delegates, SC members, and EURAMET.

In addition to ongoing stakeholder engagement to support SRA development via planned workshop events in the next 12 months, the status of the SRA was presented at the 23<sup>rd</sup> euspen conference in Copenhagen, June 2023. Work in the coming period will finalise the content of the SRA ready for publication in 2024.

*Objective 3. Set up a knowledge-sharing programme for advanced manufacturing stakeholders.*

Key sources of information on research results in the field of advanced manufacturing (including EMPIR/EMPIR projects, H2020 projects, highly ranked scientific journals e.g. The Int. J. of Advanced Manufacturing Technology, CIRP Annals Manufacturing Technology and Precision Engineering and the euspen knowledgebase) have been analysed to provide the groundwork for a knowledge base on advanced manufacturing research results. This knowledge base will eventually be integrated into a web-based platform for advanced manufacturing stakeholders (Objective 4).

A list of current metrology needs in the field of advanced manufacturing has been identified by the project (as part of Objective 2). These results have been made accessible to the stakeholder community (<https://www.euramet.org/european-metrology-networks/advanced-manufacturing/strategic-research-agenda>) as a single point of information as part of the web-based platform for advanced manufacturing stakeholders (Objective 4) and are intended to provide easy access and up-to-date overviews on the state-of-the-art for advanced manufacturing stakeholders.

Moreover, the project's knowledge sharing programme will allow stakeholders in advanced manufacturing to find information more easily about existing metrology training programmes that are of interest to them, as well as allow them to propose topics for the development of new and future metrology training courses. The interaction between metrology institutes and stakeholders will be further fostered by a series of industry focused events by NMI/DI researchers (<https://www.euramet.org/european-metrology-networks/advanced-manufacturing/events>). Knowledge exchange between NMI/DI researchers and industry is particularly important for advanced manufacturing as it will promote a mutual understanding between experts working in industry and metrology institutes, thus supporting the uptake of metrology research results by industry. This network project will also incorporate in its knowledge-sharing programme: a long-term communication and training strategy for target stakeholder groups in advanced manufacturing, that includes workshops, newsletters, questionnaires, and training materials. The identification of these key stakeholder groups was done using the 13 KISs identified in Objective 1.

*Objective 4. Develop a web-based platform for advanced manufacturing stakeholders.*

Web-based platforms of existing/active and no-longer active initiatives and associations have been analysed regarding their (i) funding programme types, (ii) funding periods, (iii) funding budgets and (iv) sustainability of the platforms. This analysis is part of the project's first steps in developing a web-based platform for advanced manufacturing stakeholders. The web-based platform will be hosted on the website of the EMN for Advanced Manufacturing. The web-based platform will bring together, for the first time, a comprehensive list of information regarding existing metrology capabilities offered by EURAMET NMIs and DIs in advanced manufacturing.

So far, the content and design for the web-based platform is under development. The content and design include links to other relevant European and international networks, to improve sharing of information between stakeholders and prevent duplication of work. In addition, the web-based platform will contain a service desk that can be used by stakeholders as a specialised single point of contact (SPOC) for questions related to metrology issues in advanced manufacturing. It is intended that the service desk will answer basic stakeholder questions more quickly than complex issues (e.g. those that may require consultation with multiple experts) and reply within a defined and reasonable response time.

*Objective 5. Develop a plan for a European metrology infrastructure for advanced manufacturing via an EMN.*

A proposal for the EMN for Advanced Manufacturing was developed based on the supporting information available from (i) the stakeholder dialogue (Objective 1), (ii) the gap analysis and SRA (Objective 2), (iii) a comprehensive list of information regarding existing metrology capabilities (Objective 3) and (iv) a systematic analysis of different areas addressed in the underpinning EMN planning activities (completed as part of this objective). The analysis included coordination and smart specialisation capabilities, other running initiatives and projects, emerging member states, and third countries.

The draft EMN proposal was harmonised with EURAMET TCs and other EURAMET EMNs in order to identify collaborative links. Then the finalised proposal for the EMN for Advanced Manufacturing was submitted to EURAMET for the consideration of the EURAMET General Assembly in June 2021. The EURAMET General Assembly approved the EMN for Advanced Manufacturing [New EMN for Advanced Manufacturing - News - EURAMET](#) and the EMN held its 1<sup>st</sup> Annual General Meeting in October 2021 [EMN Advanced Manufacturing Annual General Meeting 2021 - Event Details – EURAMET](#) and its 2<sup>nd</sup> Annual General Meeting in October 2022.

## Impact

The impact of this network project can be measured by the outreach activities it has completed in order to inform advanced manufacturing stakeholders and metrology communities of the project and the EMN for Advanced Manufacturing. So far this has included presentations by members of the consortium to European (EURAMET TCs), national (DIN) and international (ISO) standardisation committees such as ISO TC 213 Dimensional and geometrical product specifications and verification, EURAMET TC-T (Thermometry), TC-TF (Time and Frequency), TC-L (Length), TC-IM (Interdisciplinary Metrology), BIPM and CIPM Consultative Committee for Length (CCL), CIRP (the International Academy for Production Engineering), VDI/VDE GMA Society for Measurement and Automation Technology, NA 062-08-17-02 UA Test methods and DIN NA 062-08-17 AA Nanotechnology.

The aim of the project's outreach activities is to increase the visibility of the project and the EMN for Advanced Manufacturing to potential stakeholders in the wider advanced manufacturing landscape. So far, these dissemination activities have included a poster presentation and conference proceedings article at the 20th International Conference of the European Society for Precision Engineering and Nanotechnology, Euspen 2020 held online in June 2020. This has been followed by contributions to Euspen 2021, CIM2021, 3DMC 2021, Euspen 2022, UMTIK 2022, 3DMC 2022, CIM2023, Euspen 2023 (both oral presentations and posters, and conference proceedings articles). A complementary article detailing the project and aimed at the dimensional and temperature metrology stakeholders in industry was also published in the trade magazine "Precision" in December 2020. This article provided a general outline of this project and the outlook for the future EMN for Advanced Manufacturing. The recent progress of the project and the EMN for Advanced Manufacturing has been described in a newsletter sent to registered subscribers on the EMN for Advanced Manufacturing website <https://www.euramet.org/european-metrology-networks/advanced-manufacturing>.

The project has also engaged with stakeholders via workshops and training events:

- First workshop Metrology for Advanced Manufacturing was held at the Euspen 2021 virtual conference on June 7, 2021.
- A second workshop was held at the 3DMC conference in Aachen, Germany 2022.
- A training event for emerging countries including EU13 and candidate countries was held in Belgrade, Serbia on May 16 and 17, 2023.
- Another workshop/training event, The Future of Advanced Manufacturing, was held at the Euspen 2023 conference in Copenhagen, Denmark on June 12, 2023.

Further to this, a peer reviewed article on the project was published in Measurement Science and Technology, which described the project's aims, the definition of advanced manufacturing, the key industrial sectors and a literature review of the metrology gaps existing for advanced manufacturing. The progress of the strategic research agenda was also published in the Conference Proceedings for the Euspen 2023 conference.

In the longer term, this project and the EMN for Advanced Manufacturing will establish relationships and liaisons with existing National and European organisations that are active in advanced manufacturing thus promoting interaction between them and the metrology community. Given that metrology capabilities and knowledge are currently distributed across a number of European NMIs and DIs, the development of a web-based platform as a single point of contact will be beneficial for stakeholders from industry and other European organisations. In the long term, such smart specialisation of European NMI research, facilities and services will allow future metrology demands from KET advanced manufacturing and its related KETs to be sustainably addressed by the planned EMN on advanced manufacturing. Furthermore, the project will create a knowledge sharing programme, so stakeholders have improved access to metrological capabilities and facilities.

The project and EMN on Advanced Manufacturing will also stimulate the development of international standardisation activities focussed on the use of reliable measurement results and their measurement uncertainties as a basis for decisions in the manufacturing infrastructure of the Factories of the Future. This project and the EMN on Advanced Manufacturing will provide input regarding metrology issues in the future development of European Directives, such as the Machinery Directive 2006/42/EC, that has to be revised due to the emergence of new digital technologies such as Artificial Intelligence and the IoT.

### List of publications

1. H. Bosse, et. al., AdvManuNet: a networking project on metrology for advanced manufacturing, in Proceedings of euspen's 20<sup>th</sup> International Conference & Exhibition, June 2020, <https://www.euspen.eu/knowledge-base/ICE20374.pdf>
2. Przyklenk, A. et al. New European Metrology Network for advanced manufacturing, Measurement Science Technology, <https://doi.org/10.1088/1361-6501/ac0d25>
3. Przyklenk, A. et al. AdvManuNet: Support for a European Metrology Network for Advanced Manufacturing, in Proceedings of euspen's 21<sup>st</sup> International Conference & Exhibition, June 2021, <https://www.euspen.eu/knowledge-base/ICE21292.pdf>
4. H. Bosse, et. al., Progress of the European Metrology Network for Advanced Manufacturing, in Proceedings of euspen's 22<sup>nd</sup> International Conference & Exhibition, June 2022, <https://www.euspen.eu/knowledge-base/ICE22299.pdf>
5. D. O'Connor, et. al., European Metrology Network (EMN) for Advanced Manufacturing – Development of the Strategic Research Agenda (SRA), in Proceedings of euspen's 23<sup>rd</sup> International Conference & Exhibition, June 2022, <https://www.euspen.eu/knowledge-base/ICE23297.pdf>

This list is also available here: <https://www.euramet.org/repository/research-publications-repository-link/>

Project start date and duration:		01 June 2020, 48 months
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