EMN for Advanced Manufacturing - 1st informational meeting

Virtual Zoom meeting, hosted by INRIM, June 23, 2021, 10:00 – 12:00 CEST

Harald Bosse, PTB
harald.bosse@ptb.de

Acting Chair of EMN for Advanced Manufacturing

Coordinator of 19JNP01 AdvManuNet

Agenda

- 10:00 Welcome address and introduction to the agenda
  A. Balsamo, INRIM: Virtual Host and acting EMN vice-chair
  D. Auerbach: EURAMET Programme Manager
  H. Bosse, PTB: Acting EMN chair
- 10:15 EMN overview: JNP activities, current EMN status, future tasks
  H. Bosse, PTB
- 11:00 Keynote presentation of EMN stakeholder council member
  D. Imkamp, Zeiss
  Metrology for Advanced Manufacturing of the next Decade
- 11:30 Overview of partner organisations of EMN:
  euspen (D. Phillips, ED), EFFRA (Ž. Pazin, ED),
  ManuFuture (M. Gattiglio, HLG), NanoFabNet (S. Friedrichs, AcumenIST)
- 11:45 Discussion
- 12:00 End of meeting

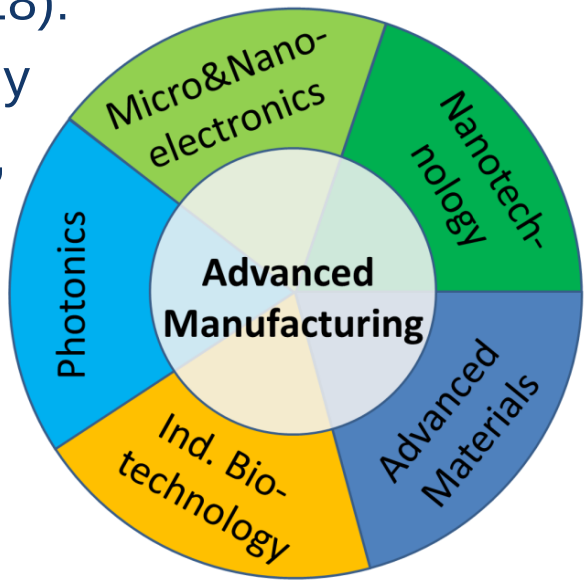
Outline

- Introduction to EMN and JNP (short presentation to EURAMET GA, 8.6.)
- Achievements of JNP: euspen workshop, 7.6.:
  - Introduction to the AdvManuNet project
  - Definition of advanced manufacturing and stakeholder engagement
  - Literature study on advanced manufacturing
  - Analysis of dimensional metrology capabilities and demands in Europe
  - Analysis of established networks and of existing roadmaps
- Current state of EMN and further steps
  - Formalities: MoU, RoP, 1st General Meeting
  - Interaction with partner organisations and stakeholders
  - Working in the 3 sections of the EMN:
    - Stakeholder dialogue
    - Development of strategic research agenda (SRA)
    - Roadmap development & implem.: Metrology for advanced manufacturing
    - Timelines

Advanced Manufacturing

The need for the EMN for Advanced Manufacturing

- **Advanced manufacturing (EC):**
  - one of six Key Enabling Technologies (KETs)
- Applications in multiple industries
  - full exploitation of KETs: creating advanced & sustainable economies
- European Technology Platform **MANU*Future***:
  - Vision 2030 strategy document (HLG, 12/2018):
- Manufacturing: backbone of European economy
- 2014: 2.1 million enterprises, 30 million people, 1 710 B€. However: European manufacturing has been losing ground
- In 2030, European manufacturing will be competitive at global level due to its high-performance and technological level, targeting **zero-defect, zero-delay, zero-surprise and zero-waste production processes**

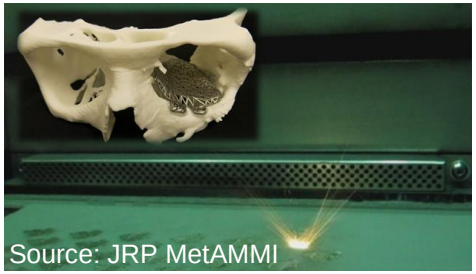


KETs from 2009 (EC)

Metrology demands

Aim: zero-defect, zero-delay, zero-surprise and zero-waste production processes

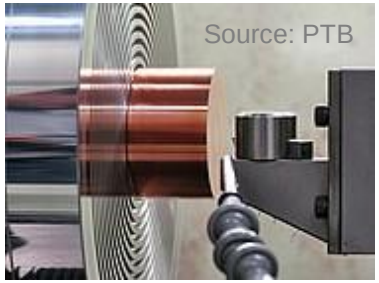
Examples: metrology demands



Example:
Additive Manufacturing:
- in-process metrology
- fast & holistic metrol.

Example:
Machine tools:
- improved control by 5G sensor technology
- sensor integration: metrology data interface

Example:
Lithography tools:
- full simulation of relevant processes
- metrology tools using AI data algorithms

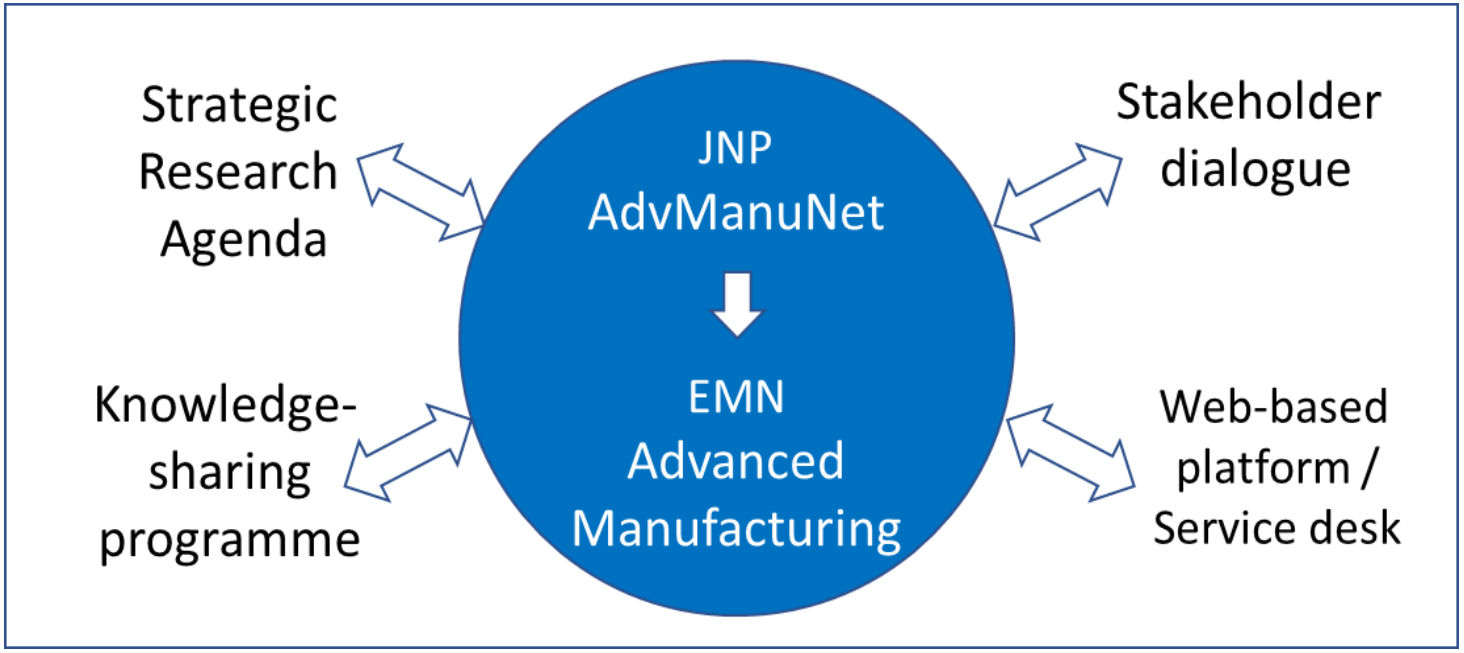


Example:
Machine tools & Additive Manufacturing:
- less scrap via hybrid manufacturing chains (MT & AM)
- reduced energy consumption by advanced machining processes

- **EMN sections:**
  - Advanced Materials
  - Smart Manufacturing Systems
  - Manufactured components and products

Major activities for EMN

JNP: funded project within EMPIR to accelerate process of establishing EMN



EMN: European Metrology Network for Advanced Manufacturing:
- Sustainable network operated by national metrology institutes

JNP consortium

JNP 19NET01 AdvManuNet
4 years, start 6/2020: Project partners

euspen HQ, UK:
Dishi Phillips

NPL, UK:
Daniel O'Connor

BAM, DE:
Alexander Evans

RISE, SE:
Olena Flys

METAS, CH:
Felix Meli

PTB, DE:
Harald Bosse
JNP coordination

CMI, CZ:
Vit Zeleny

GUM, PL:
Dariusz Czułek

- Head of PTB Division Precision Engineering
- TC-L chair: 2015-2019
- CCL delegate of PTB
- euspen president: 2017-2019
- harald.bosse@ptb.de

INRiM, IT:
Alessandro Balsamo

POLITO, IT:
Carlo Stefano Ragusa

TUBITAK UME, TR:
Tanfer Yandayan

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

EMN Scope and achievements so far

Achievements so far:

- 2 paper, 3 accepted conf. submissions, 1 workshop, 1 manuscript under review
- Proposed definition of “Advanced Manufacturing”
- Identified 13 Key Industry Sectors (KIS) relevant for EMN
- Stakeholder council members: EURAMET Research Council; KIS; EU Partnerships
- Defining EMN Scope:

The EMN will address metrology issues along whole manufacturing value chain:

- Design
- **Advanced Materials => Smart Manufacturing Systems => Components & Products**
- Recycling

Involved NMIs/DIs: BAM, CEM, CMI, CNAM, DFM, DTI, INRIM, IPQ, GUM, LNE, METAS, PTB, NPL, RISE, SMD, UME/TUBITAK, VSL, VTT

Main EMN expertise from colleagues in TC-L, TC-T, TC-M (hardness, force, …)
Expertise from other TCs (incl. WG M4D) and EMNs will be integrated whenever needed

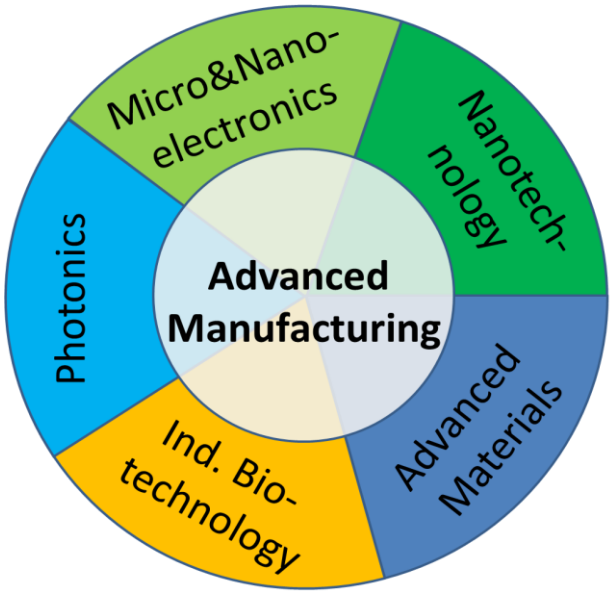
Partnering with:

- EFFRA / European Partnership Made in Europe; - European Technology Platform (ETP) MANU*Future*;- H2020 CSA project NanoFabNet; - euspen; - …

EMN for Advanced Manufacturing

Metrology to support Advanced Manufacturing

TC-involvement:
- TC-L
- TC-T
- TC-IM WG M4D
- TC-M
- TC-PR
- TC-MC
- TC-F



Partner Organisations:
- EFFRA / Made in Europe
- ManuFuture
- euspen
- NanoFabNet
- …

EMN-interaction:
- EMN QT
- EMN MathMet
- EMN PNTG
- EMN SmartNorth

EMN sections:
- Advanced Materials
- Smart Manufacturing Systems
- Manufactured Components and Products

Stakeholders:
- Manufacturing industry
- Industry organisations
- Research institutes
- Universities
- EC, Nat'l governments

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Stakeholder Workshop at euspen conference on June 7, 2021

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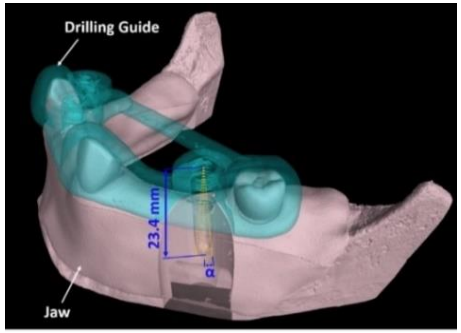
Time	Programme	Presenter
13:00 - 13:10	Welcome	Harald Bosse, PTB, DE
13:10 - 13:30	Introduction to the AdvManuNet project	Harald Bosse, PTB, DE
13:30 - 13:45	Definition of Advanced Manufacturing	Alessandro Balsamo, INRIM, IT
13:45 - 14:05	Stakeholder engagement	Alessandro Balsamo, INRIM, IT
14:05 - 14:20	Literature study on advanced manufacturing	Anita Przyklenk, PTB, DE
14:20 - 14:45	Analysis of dimensional metrology capabilities and demands in Europe	Tanfer Yandayan, TUBITAK/UME, TR
14:45 - 15:00	Scoping engagement with established networks and analysis of existing roadmaps	Daniel O´Connor, NPL, UK
15:00 - 15:15	*Coffee Break*	
15:15 - 16:45	Guided discussion & feedback forum on the SRA	Alexander Evans, BAM, DE Alessandro Balsamo, INRIM, IT Daniel O´Connor, NPL, UK Harald Bosse, PTB, DE
16:45 - 17:00	Wrap up and further steps	Harald Bosse, PTB, DE Anita Przyklenk, PTB, DE
17:00	Close	



Trial of a dental drilling guide produced by additive manufacturing and features measured by means of computed tomography. (Source: JRP MetAMMI)

Ca. 35 participants at Workshop:
- Industry
- Research Institutes & universities
- NMIs

EURAMET

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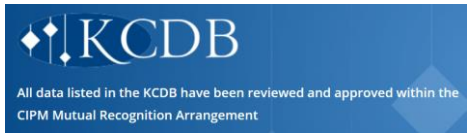
- EURAMET: The European Association of National Metrology Institutes: 38 members (NMI) and 77 associates (DI); one of 6 regional metrology organisations (RMO)

- Our mission is to develop and disseminate an integrated, cost effective and internationally competitive measurement infrastructure for Europe. Always taking into account the needs of industry, business and governments. To enhance benefits of metrology to society is one of the highest priorities for EURAMET and its members.

- Two main tools to achieve these goals are the European Metrology Research Programme (EMRP) and the European Metrology Programme for Innovation and Research (EMPIR) with more than 100 joint research projects so far.

- As important to achieve our goals is the CIPM MRA. The Comité International des Poids et Mesures (CIPM) sponsored the creation of a Mutual Recognition Scheme (CIPM MRA) to underpin and formalise technical competence of its signatory National Metrology Institutes and Designated Institutes.

=> KCDB



EURAMET TCs

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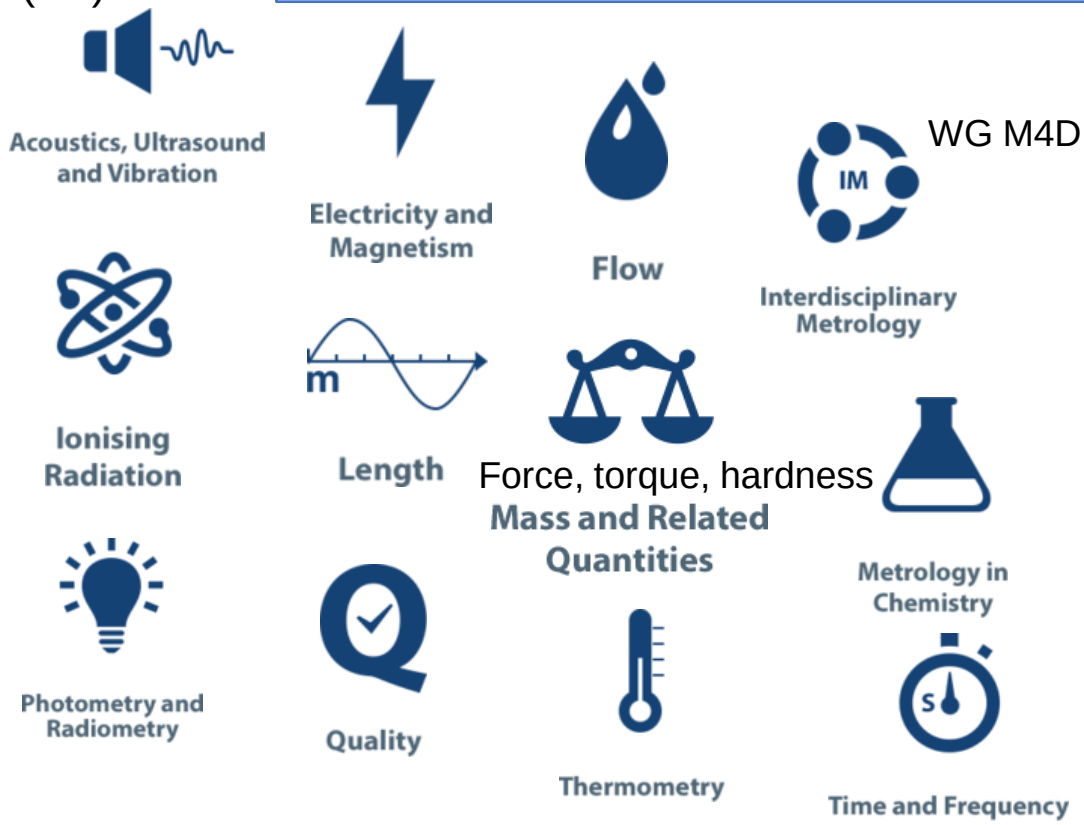
Metrology competence to support **advanced manufacturing** is spread over **several TCs**

EURAMET 12 **Technical Committees** (TC)

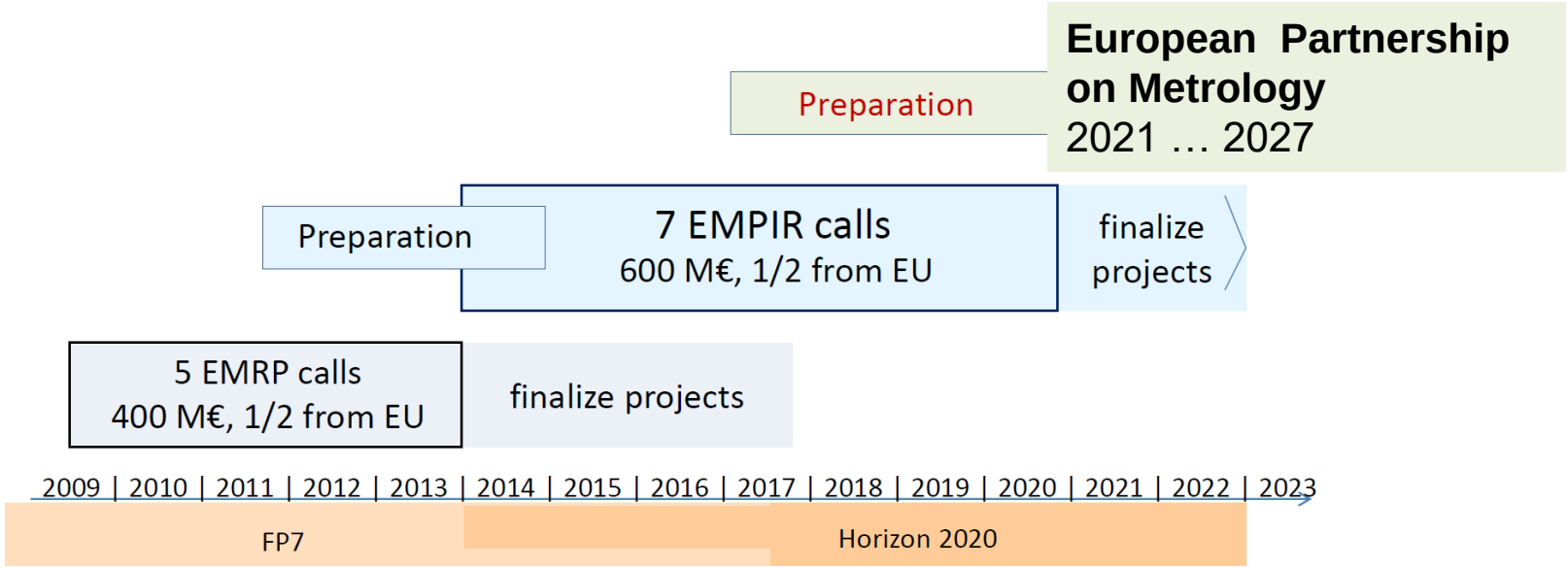
- Acoustics, Ultrasound and Vibration
- Electricity and Magnetism
- Flow
- Interdisciplinary Metrology
- Ionising Radiation
- Length
- Mass and Related Quantities
- Metrology in Chemistry
- Photometry and Radiometry
- Quality
- Thermometry
- Time and Frequency



European metrology research programmes

Implemented by EURAMET; Current programme **EMPIR**; proposed programme: **European Partnership on Metrology**

- Annual calls between 2014 and 2020
- Thematic calls on
  - Fundamental science - **Innovation in industry**
  - Grand challenges - Standardisation
  - SI traceability - Capacity building



Examples of Joint Research Projects (JRP) related to advanced manufacturing

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JRPs in IND Calls 2014&2017 related to advanced manufacturing

Project #	Acronym	Project name (coordinator)
17IND02	SmartCom	Communication and validation of smart data in IoT-networks (PTB)
17IND03	LaVA	Large Volume Metrology Applications (NPL)
17IND04	EMPRESS 2	Enhancing process efficiency through improved temperature meas. 2 (NPL)
17IND05	MicroProbes	Multifunctional ultrafast microprobes for on-the-machine measurements (PTB)
17IND08	AdvanCT	Advanced CT for dimensional and surface measurements in industry (PTB)
17IND12	Met4FoF	Metrology for the Factory of the Future (PTB)
14IND03	Strength-ABLE	Metrology for length-scale engineering of materials (NPL)
14IND07	3D Stack	Metrology for manufacturing 3D stacked integrated circuits (LNE)
14IND09	MetHPM	Metrology for highly-parallel manufacturing (NPL)
14IND12	Innanopart	Metrology for innovative nanoparticles (NPL)
14IND13	PhotInd	Metrology for the photonics industry - optical fibres, waveguides & appl. (MIKES)
14IND14	MNm Torque	Torque measurement in the MN•m range (PTB)

JRPs in HLT & ENG Calls related to adv. manuf.

15HLT09	MetAMMI	Metrology for additively manufactured medical implants (LNE)
19ENG07	Met4Wind	Metrology for enhanced reliability and efficiency of wind energy systems (PTB)

What's next?
European Partnership on Metrology

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- European Partnership on Metrology is currently prepared as next metrology research programme
- Scheduled from 2021 – 2027, in parallel to Horizon Europe
- Similar budget as EMPIR, i.e. 600 M€
- Call for Needs has started in Jan 2021
- Calls 2021 include:
  - Metrology for Green Deal,
  - Metrology Research for Pre- and Co-normative and
  - Research Potential projects
- The outcome of the Call for Needs could serve as a basis for a potential partnership call later in 2021 for joint research projects and is subject to eligibility criteria which may open in the third quarter of 2021

- Future Calls on metrology for industry are planned:
  - How to shape these calls to reflect stakeholders needs?
  - What are the metrology needs identified by stakeholders for further development of advanced manufacturing?
- Stakeholder oriented dialogue organised by EMN

EURAMET

EURAMET'S EUROPEAN METROLOGY NETWORKS

Close collaboration in measurement science with a new sustainable structure

The vision of EURAMET and its members is to ensure Europe has a world-leading metrology capability, based on high-quality scientific research and an effective and inclusive infrastructure, that meets the rapidly advancing needs of end users. EURAMET's European Metrology Networks (EMNs) help realising this aim.

Currently there are seven EMNs: Climate and Ocean Observation, Energy Gases, Mathematics and Statistics, Quantum Technologies, Smart Electricity Grids, Smart Specialisation in Northern Europe, and Traceability in Laboratory Medicine.

The EMNs will analyse the European and global metrology needs and address these needs in a coordinated manner. EMN members will then formulate common metrology strategies including aspects such as research, infrastructure, knowledge transfer and services. The members will be committed to contributing to the EMN, helping to establish sustainable structures that are strategically planned from the outset.

=> EMNs listed above were established in 6/2019

Examples of EMN achievements so far

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- EMN for Climate and Ocean Observation:
  - Stakeholder Needs Report December 2020 (Executive Summary)
  - 3 sections: Atmosphere, Land and Earth Observation, Ocean Observation

CLIMATE AND OCEAN OBSERVATION

- EMN for Energy Gases:
  - Strategic Research Agenda

ENERGY GASES

- EMN for Traceability in Laboratory Medicine:
  - TLM Coronavirus response

TRACE LAB MED

- EMN for Mathematics and Statistics:
  - Joint Workshop on Mathematical & Statistical Methods for Metrology 2021-05-31 to 2021-06-01

General approach:
a) Determine stakeholder needs
b) Develop strategic research agenda (SRA)
c) Develop roadmap for implementation of SRA
  - Input to programme calls; NMI smart special.

Iterative process

- EMN for Quantum Technologies:
  - Roadmaps under develop. in 3 sections: Quantum Clocks & Atomic Sensors, Q-Electronics, Q-Photonics

- EMN for Smart Electricity Grids:
  - Smart Electricity Grids' draft Strategic Research Agenda; Smart Electricity Grids Survey 2021

SMART ELECTRICITY GRIDS

Support for a European Metrology Network on advanced manufacturing

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Support for a European Metrology Network on advanced manufacturing

Short Name: AdvManuNet, Project Number: 19NET01

Solar panel manufacturing

PARTICIPATING EURAMET NMIS AND DIS

- BAM (Germany)
- CMI (Czech Republic)
- GUM (Poland)
- INRIM (Italy)
- METAS (Switzerland)
- NPL (United Kingdom)
- PTB (Germany)
- RISE (Sweden)
- UME (Turkey)

OTHER PARTICIPANTS

EUSPEN - EUROPEAN SOCIETY FOR PRECISION ENGINEERING AND NANOTECHNOLOGY (United Kingdom)
Politecnico di Torino (Italy)

INFORMATION

PROGRAMME
EMPIR

FIELD
Support for Networks

STATUS
in progress

CALL
2019

DURATION
2020-2024

JNP AdvManuNet started in 6/2020

Definition of Advanced Manufacturing

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An authoritative definition of ***Manufacturing*** does exist:

The entirety of interrelated economic, technological, and organizational measures directly connected with the processing/machining of materials, i.e., all functions and activities directly contributing to the making of goods

INRiM, IT:
Alessandro Balsamo

T. Segreto, R. Teti, 2014, ***Manufacturing***. In: The International Academy for Production Engineering (**CIRPedia**), Laperrière L., Reinhart G. (eds) CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-20617-7_6561

The following definition is proposed for ***Advanced Manufacturing***:

Branch of manufacturing that exploits evolving or emerging knowledge, technologies, methods and capabilities to make and/or provide new or substantially enhanced goods or services, or improve production efficiency or productivity, while ensuring environmental and societal sustainability

A. Przyklenk et al., 2021, New Metrology Network for Advanced Manufacturing. In: Meas. Sci. Technol., provisionally accepted

Single sentence definition is complemented with six notes, adding further details

Identified Key Industry Sectors (KIS)

20 industry sectors of EC:
https://ec.europa.eu/growth/sectors_en

- Aeronautics industries
- Automotive industry
- Biotechnology
- Chemicals
- Construction
- Cosmetics
- Defence industries
- Electrical and electronic engineering industries
- Firearms
- Food and drink industry
- Gambling
- Healthcare industries
- Maritime industries
- Mechanical engineering
- Postal services
- Pressure equipment and gas appliances
- Raw materials, metals, minerals and forest-based industries
- Social economy
- Space
- Textiles, Fashion and creative industries
- Tourism
- Toys

Focus on **metrology needs**
for **advanced manufacturing requirements**
in these KIS

13 identified KIS within JNP AdvManuNet:

1) Metrology equipment & service
2) Machine tools & robotics
3) Digitalized and integrated manufacturing systems
4) Energy generation, transmis-sion & storage
5) Advanced materials & processing
6) Nano- & microelectronics
7) Nano- & microtechnology
8) Optics and photonics
9) Land and sea-based mobility
10) Aerospace
11) Complex infrastructure & civil rngineering
12) Life science technology
13) Defence & security

KIS reflected in keynotes of euspen ICE 2021

Topics of ICE keynotes and relation to KIS

Microdevices for oral drug delivery
Anja Boisen, Technical University of Denmark, DK

Offshore blade development research needs
Peter Fuglsang, Siemens Gamesa, DK

Complex data as the new normal in precision engineering: opportunities and challenges
Bianca Maria Colosimo, Politecnico di Milano, IT

New perspectives on applied thermometry
Jonathan Pearce, National Physical Laboratory, UK

Sustainable production enabled by remanufacturing: Production under uncertain product specifications
Gisela Lanza, Inst. Production Science (wbk), KIT, DE

KIS related to keynotes:

2) Machine Tools & Robotics
7) Nano- & Microtechnology
12) Life Science Technology

4) Energy generation, transmission & storage

3) Digitalized and integrated manufacturing systems

1) Metrology Equipment & Service

2) Machine Tools & Robotics
3) Digitalized and integrated manufacturing systems

Analysis of dimensional metrology: Capabilities and demands for Advanced Manuf.

Analysis of EURAMET NMIs based on
- CCL Length Services Classification (DimVIM)
- Recent CIRP publication

Ver. 1 (Jun 2020) **English**

CLASS

Consultative Committee for Length (CCL)
Working Group on the MRA (WG-MRA)
CCL Length Services Classification (DimVIM)

DimVIM : Multilingual CMC classification scheme

CCL Service Category	English Language Approved Terms: Instrument or Artifact	Measurand(s)
1 Radiations of the Mise en Pratique		
1.1 Laser Radiations		
1.1.1	frequency stabilized laser	vacuum wavelength; optical frequency
1.2 Lamp Radiations		
1.2.1	spectral lamp	vacuum wavelength
2 Linear Dimensions		
2.1 Length Instruments		
2.1.1	(laser, length) interferometer (system, optics, refractometer)	error of indicated displacement; wavelength compensation
2.1.2	EDM instrument	error of indicated distance
2.1.3	1-D measuring machine	error of indicated [size; displacement]
2.1.4	height measuring instrument	error of indicated [vertical size; displacement]
2.1.5	1-D displacement [transduscer, actuator] (LVDT, PZT,...)	error of indicated displacement
2.1.6	gauge block comparators	error of indicated displacement
2.1.7	dial-indicator tester	error of indicated displacement
2.2 End Standards		
2.2.1	gauge block	central length; variation in length; thermal expansivity; length difference of gauge block pairs

TUBITAK, UME:
Tanfer Yandayan

CIRP Template v4.0

Contents lists available at SciVerse ScienceDirect

CIRP Annals Manufacturing Technology

Journal homepage: www.elsevier.com/locate/cirp

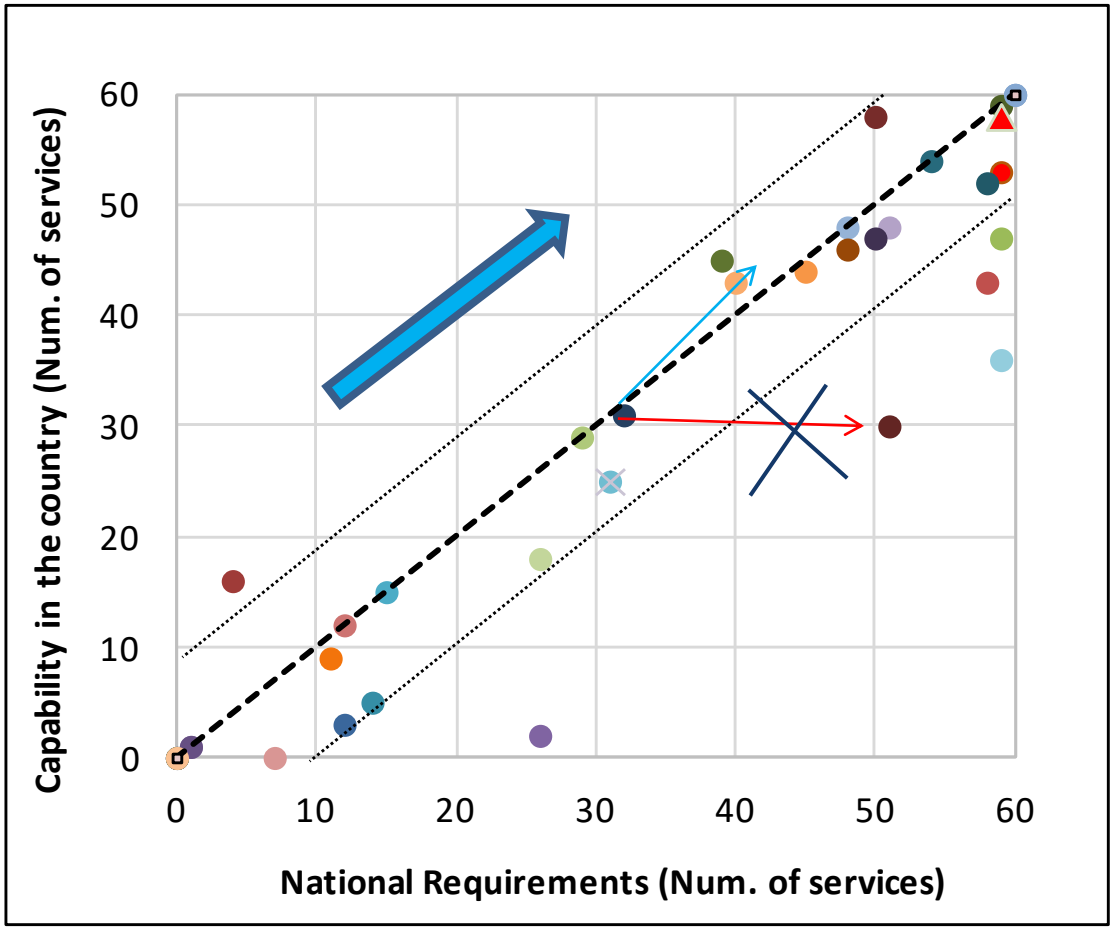
Dimensional artefacts to achieve metrological traceability in advanced manufacturing

S. Carmignato[1] (2), L. De Chiffre[2] (1), H. Bosse[3] (3), R. K. Leach[4] (2), A. Balsamo[5] (1), W. T. Estler[6] (1)

Figure 17. Examples of complex artefacts based on simple geometrical features, for coordinate metrology on CMMs or on machine tools. Left:

Analysis of dimensional metrology: Capabilities and demands for Adv. Manuf.

Questionnaire 1 sent to 38 TC-L contact persons => 33 responses received



JNP AdvManuNet project aims:

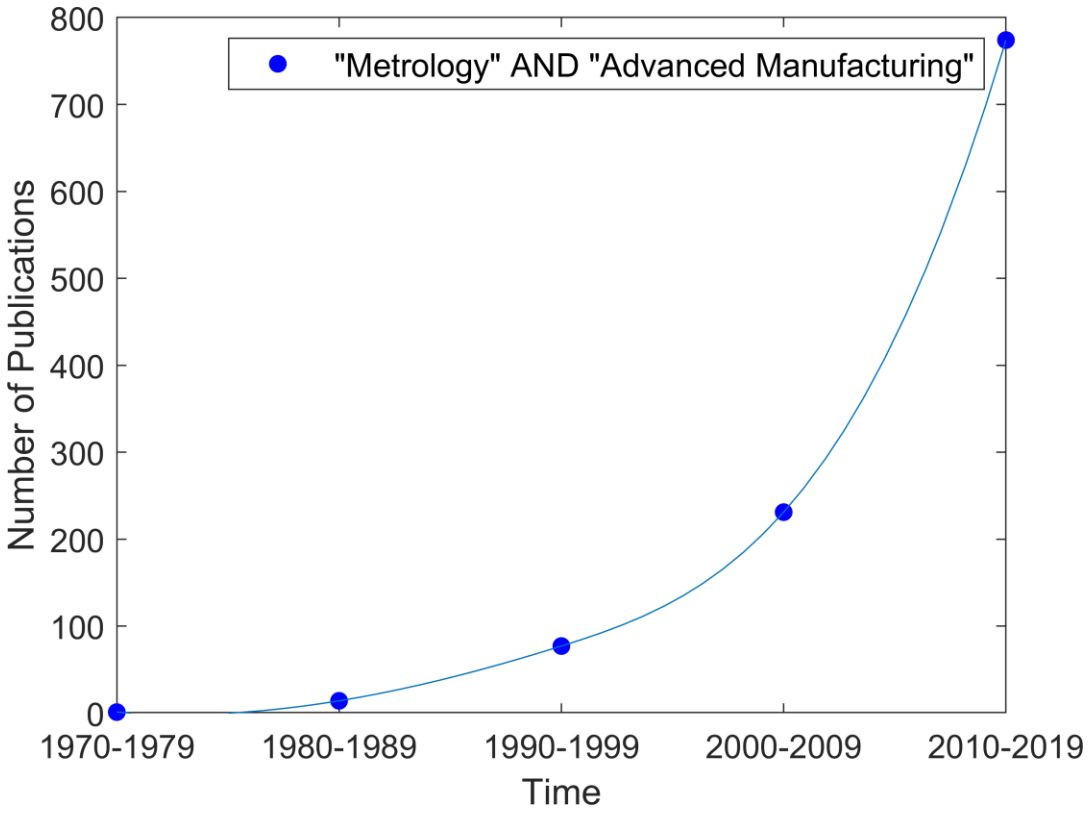
To foster the member states for developing emerging metrology technologies during the grow up

Help to keep them close to the line, indicating that the number of existing calibration capacities corresponds to the number of national requirements.

Questionnaire 2 is on metrology demands related to 13 KIS and industry focus on KIS in countries => valuable input received

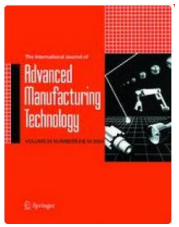
Literature Analysis of Advanced Manufacturing

- search on link.springer.com
- combined search for metrology and advanced manufacturing
- entire content was taken analysed:
  - articles
  - books
  - conference proceedings
  - …
- development of the number of publications over the years between 1970 and 2019

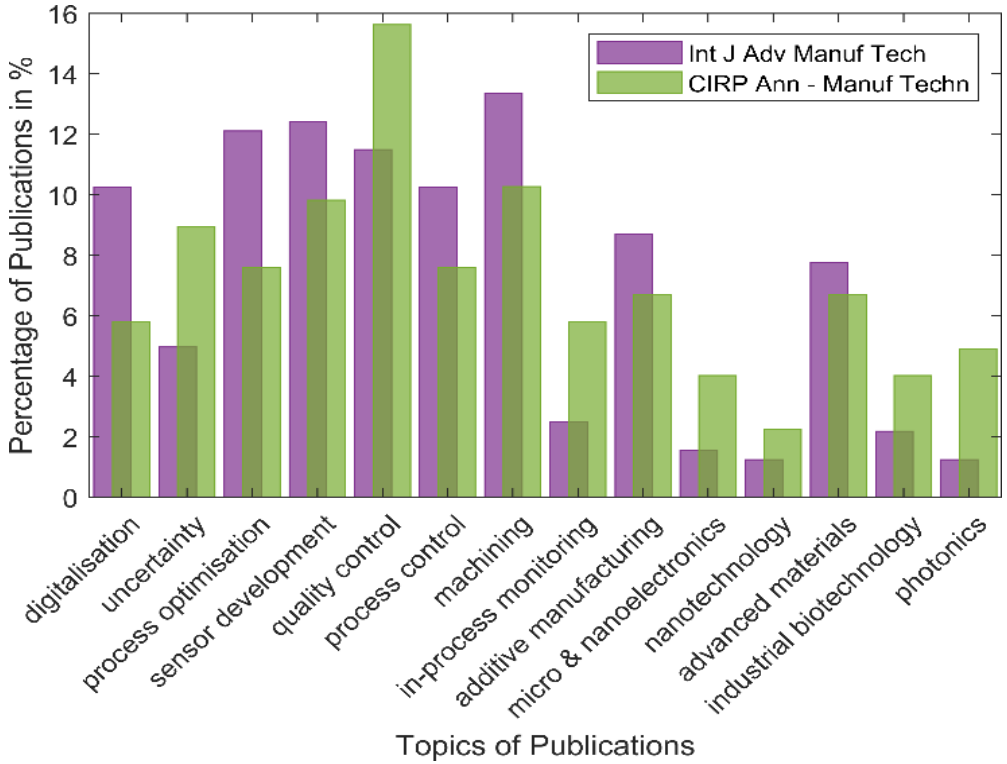


Anita Przyklenk
PTB, DE

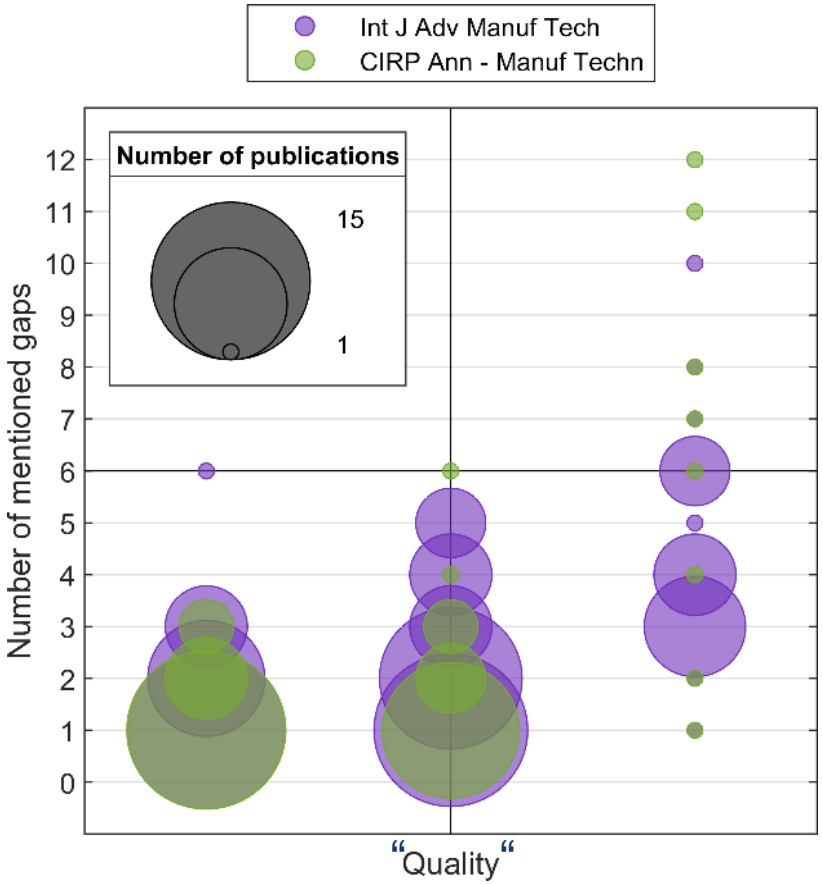
Literature Analysis of Advanced Manuf.



Analysis of published papers in 2 journals in 2019-2020:
- Int J Adv Manuf Tech: 85 publ. found for “Metrology” search
- CIRP Annals: 60 publications found for “Metrology” and “Advanced Manufacturing”

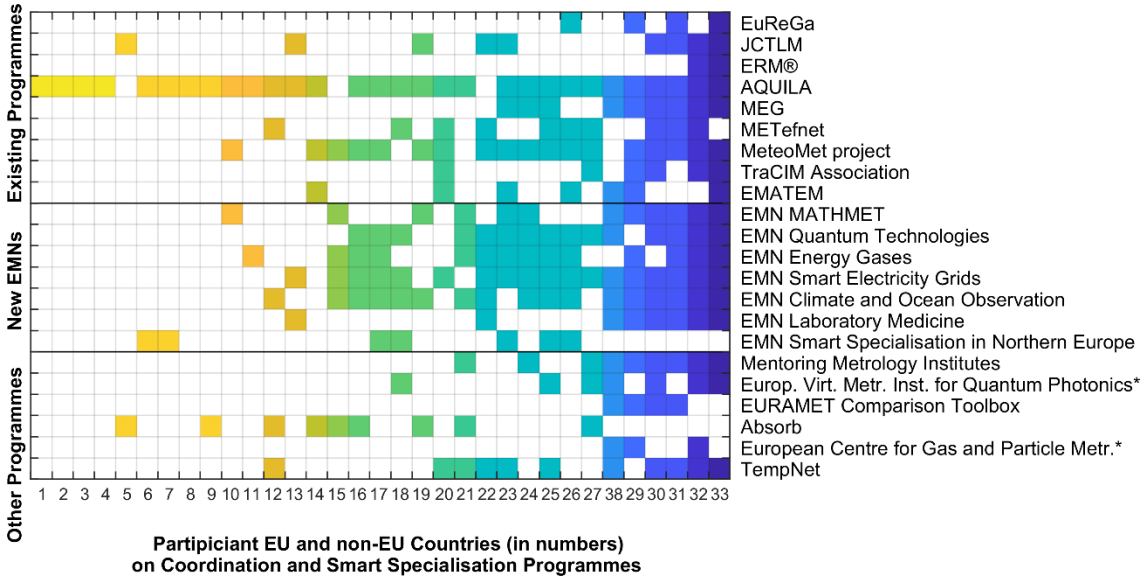


Share of publications that can be assigned to one of the defined **generalised topics**.
Note that multiple assignments are possible.



Portfolio analysis of publications in which metrology **gaps** were identified.

Coordination and Smart Specialisation Programmes in metrology



Analysis of other European initiatives

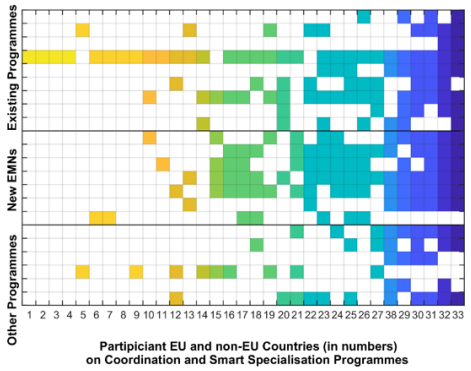
NPL, UK:
Daniel O'Connor

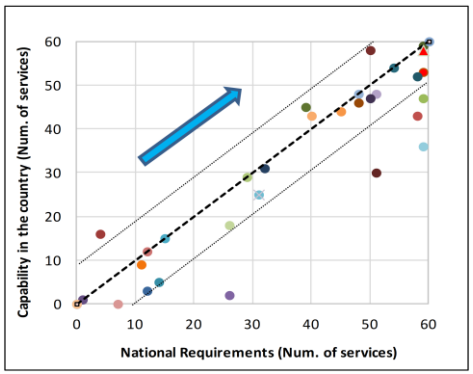
Common factors in initiatives that have lasted well in excess of 3-years:

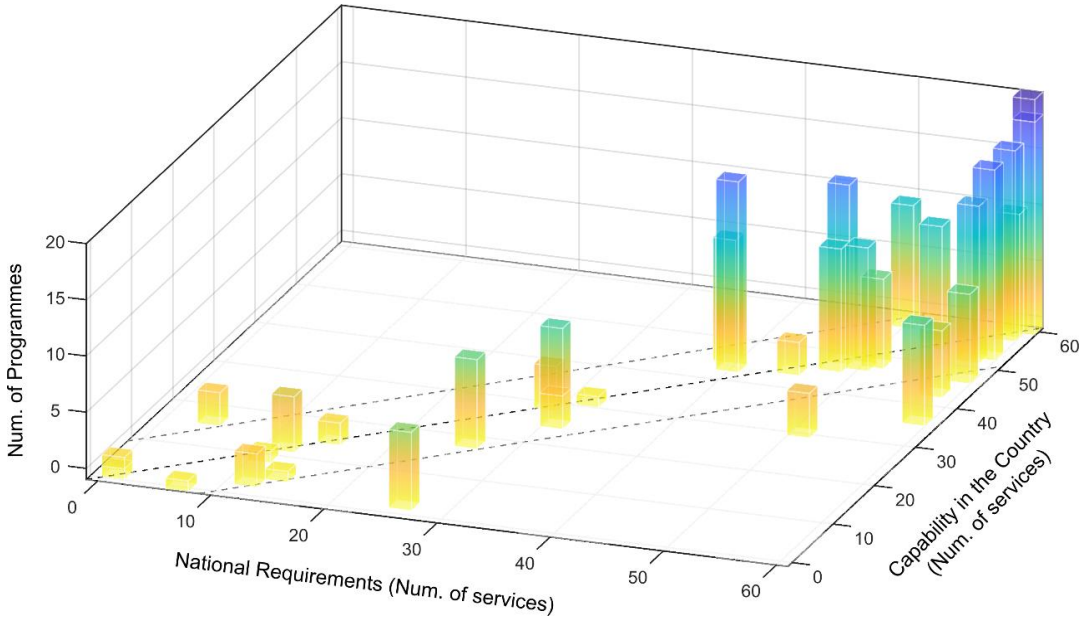
- Initially supported by a funded EU project
- Clearly identified needs in a specific area that remain relevant or have been refreshed
- Clearly identified the benefits to a European initiative over a national one
- Created and maintained useful databases and/or services for a specific area
- Participants involved in major collaborative research projects in a specific area
- Participants actively supporting the development of the initiative
- Significant growth in participation level beyond the initial formative project

Benefits to participation in programmes and initiatives to develop metrology capability

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







Key roadmap analysis

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

Integrated metrology–10-year roadmap for advanced manufacturing	CATAPULT High Value Manufacturing (UK)	2020
Factories of the Future –The Italian Flagship Initiative	National Research Council of Italy (I)	2019
Challenges and trends in manufacturing measurement technology – the "Industrie 4.0" concept	VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (DE)	2016
Digital Economy. How new technologies are changing the world (translated)	Przemysł 4.0 programme (Industry 4.0) promoted by the Polish Government (PL)	2020
Innovation Strategy of the Czech Republic 2019–2030	Research, Development and Innovation Council of Czech Republic (CZ)	2019
Digitalisation and automation in the Nordic manufacturing sector – Status, potentials and barriers	NORDEN promoted by Nordic Council of Ministers (DK,FI,IS,NO,SE,FO,GL,AX)	2015
Roadmap AF Austria – Roadmap on the development of Additive Manufacturing (AF) in Austria with an industrial focus (translated)	Austrian Ministry of Mobility, Innovation and Technology (AU)	2018
Industry 4.0 in Turkey an imperative for global competitiveness – An emerging market perspective	TÜSIAD and the Boston Consulting Group (TR)	2016

NPL, UK:
Daniel O'Connor

Advanced Manufacturing Network

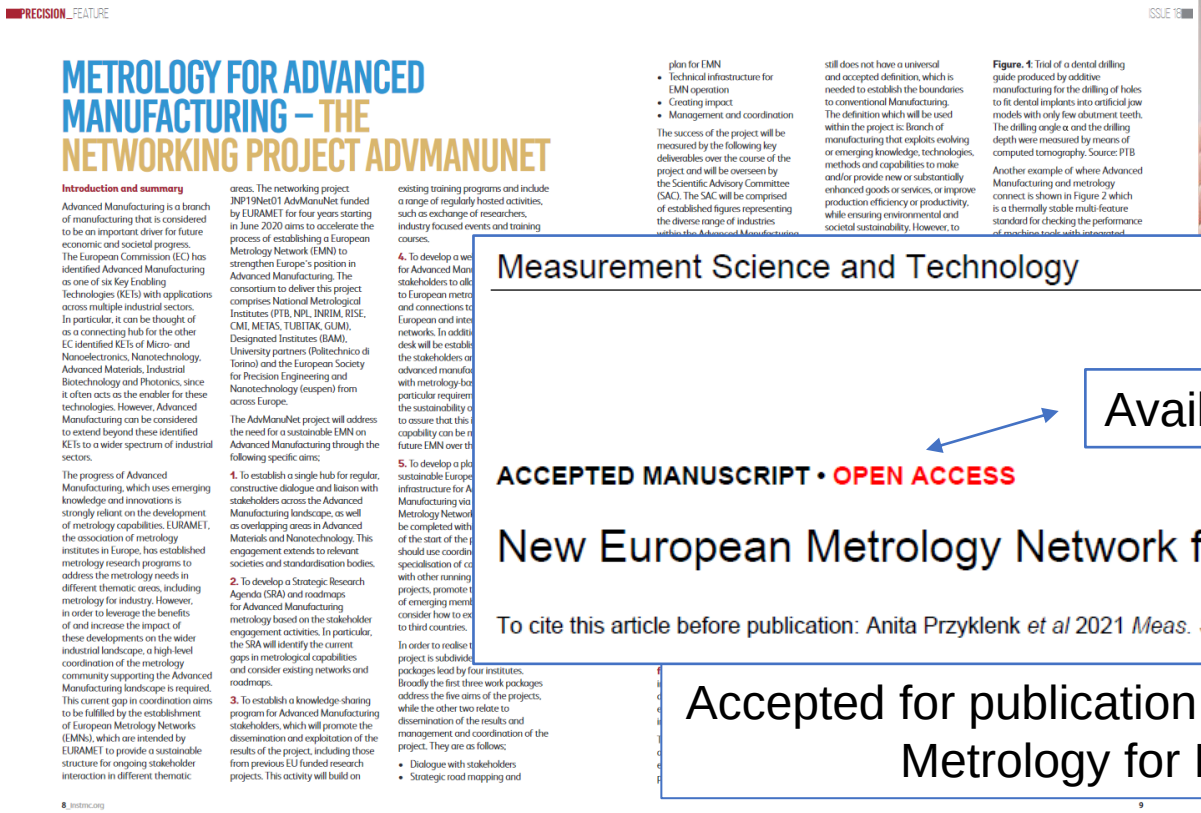
Publications

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

euspen's 20th International Conference & Exhibition, Geneva, CH, June 2020
www.euspen.eu

AdvManuNet: a networking project on metrology for advanced manufacturing

Harald Bosse[1], Alexander Evans[2], Vit Zeleny[3], Darisz Czułek[4], Alessandro Balsamo[5], Daniel O'Connor[6], Tanfer Yandayan[7], David Billington[8], Felix Meli[9], Carlo Stefano Ragusa[9], Olena Flys [11]



PRECISION_FEATURE ISSUE 18

METROLOGY FOR ADVANCED MANUFACTURING – THE NETWORKING PROJECT ADVMANUNET

Introduction and summary

Advanced Manufacturing is a branch of manufacturing that is considered to be an important driver for future economic and societal progress. The European Commission (EC) has identified Advanced Manufacturing as one of six Key Enabling Technologies (KETs) with applications across multiple industrial sectors. In particular, it can be thought of as a connecting hub for the other EC identified KETs of Micro- and Nanoelectronics, Nanotechnology, Advanced Materials, Industrial Biotechnology and Photonics, since it often acts as the enabler for these technologies. However, Advanced Manufacturing can be considered to extend beyond these identified KETs to a wider spectrum of industrial sectors.

The progress of Advanced Manufacturing, which uses emerging knowledge and innovations is strongly reliant on the development of metrology capabilities. EURAMET, the association of metrology institutes in Europe, has established metrology research programs to address the metrology needs in different thematic areas, including metrology for industry. However, in order to leverage the benefits of and increase the impact of these developments on the wider industrial landscape, a high-level coordination of the metrology community supporting the Advanced Manufacturing landscape is required. This current gap in coordination aims to be fulfilled by the establishment of European Metrology Networks (EMNs), which are intended by EURAMET to provide a sustainable structure for ongoing stakeholder interaction in different thematic areas. The networking project JNP19Net01 AdvManuNet funded by EURAMET for four years starting in June 2020 aims to accelerate the process of establishing a European Metrology Network (EMN) to strengthen Europe's position in Advanced Manufacturing. The consortium to deliver this project comprises National Metrological Institutes (PTB, NPL, INRIM, RISE, CMI, METAS, TUBITAK, GUM), Designated Institutes (BAM), University partners (Politechnico di Torino) and the European Society for Precision Engineering and Nanotechnology (euspen) from across Europe.

The AdvManuNet project will address the need for a sustainable EMN on Advanced Manufacturing through the following specific aims:

1. To establish a single hub for regular, constructive dialogue and liaison with stakeholders across the Advanced Manufacturing landscape, as well as overlapping areas in Advanced Materials and Nanotechnology. This engagement extends to relevant societies and standardisation bodies.
2. To develop a Strategic Research Agenda (SRA) and roadmaps for Advanced Manufacturing metrology based on the stakeholder engagement activities. In particular, the SRA will identify the current gaps in metrological capabilities and consider existing networks and roadmaps.
3. To establish a knowledge-sharing program for Advanced Manufacturing stakeholders, which will promote the dissemination and exploitation of the results of the project, including those from previous EU funded research projects. This activity will build on existing training programs and include a range of regularly hosted activities, such as exchange of researchers, industry focused events and training courses.
4. To develop a we… for Advanced Manu… stakeholders to allo… to European metro… and connections t… European and inte… networks. In additi… desk will be establi… the stakeholders ar… advanced manufac… with metrology-bo… particular requirem… the sustainability o… to assure that this … capability can be … future EMN over th…
5. To develop a pla… sustainable Europe… infrastructure for A… Manufacturing via … Metrology Networ… be completed with… of the start of the p… should use coordin… specialisation of co… with other running … projects, promote t… of emerging memb… consider how to ex… to third countries.

In order to realise t… project is subdivide… packages lead by four institutes. Broadly the first three work packages address the five aims of the projects, while the other two relate to dissemination of the results and management and coordination of the project. They are as follows:

- Dialogue with stakeholders
- Strategic road mapping and
- plan for EMN
- Technical infrastructure for EMN operation
- Creating impact
- Management and coordination

The success of the project will be measured by the following key deliverables over the course of the project and will be overseen by the Scientific Advisory Committee (SAC). The SAC will be comprised of established figures representing the diverse range of industries within the Advanced Manufacturing…

still does not have a universal and accepted definition, which is needed to establish the boundaries to conventional Manufacturing. The definition which will be used within the project is: Branch of manufacturing that exploits evolving or emerging knowledge, technologies, methods and capabilities to make and/or provide new or substantially enhanced goods or services, or improve production efficiency or productivity, while ensuring environmental and societal sustainability. However, to…

Figure. 1: Trial of a dental drilling guide produced by additive manufacturing for the drilling of holes to fit dental implants into artificial jaw models with only few abutment teeth. The drilling angle α and the drilling depth were measured by means of computed tomography. Source: PTB

Another example of where Advanced Manufacturing and metrology connect is shown in Figure 2 which is a thermally stable multi-feature standard for checking the performance of machine tools with integrated…

8 _instmc.org 9

Measurement Science and Technology

Available since June 21

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New European Metrology Network for Advanced Manufacturing

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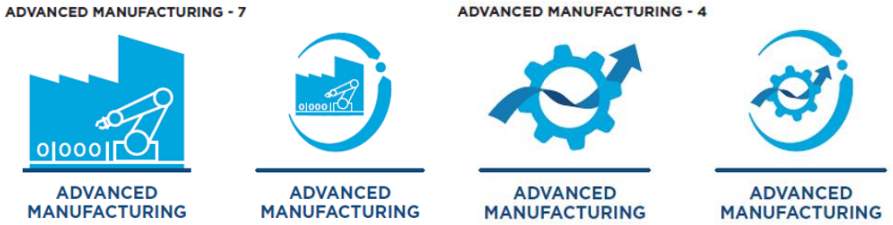
Accepted for publication in MST in Special Issue Metrology for Manufacturing

Outline

- Introduction to EMN and JNP (short presentation to EURAMET GA, 8.6.)
- Achievements of JNP: euspen workshop, 7.6.:
  - Introduction to the AdvManuNet project
  - Definition of advanced manufacturing and stakeholder engagement
  - Literature study on advanced manufacturing
  - Analysis of dimensional metrology capabilities and demands in Europe
  - Analysis of established networks and of existing roadmaps
- Current state of EMN and further steps
  - Formalities: MoU, RoP, 1st General Meeting
  - Interaction with partner organisations and stakeholders
  - Working in the 3 sections of the EMN:
    - Stakeholder dialogue
    - Development of strategic research agenda (SRA)
    - Roadmap development & implem.: Metrology for advanced manufacturing
    - Timelines

Formalities



EURAMET

01.06.2020: JNP AdvManuNet started to accelerate process of EMN establishment

07.06.2021: EURAMET GA approved EMN proposal on Advanced Manufacturing (EMN AdvanceManu)

??.09.2021: Memorandum of Understanding (MoU) is signed by at least 3 EMN members => EMN formal start, based on signed MoU

??.??.2021: Rules of Procedure (RoP) for EMN AdvanceManu finalised

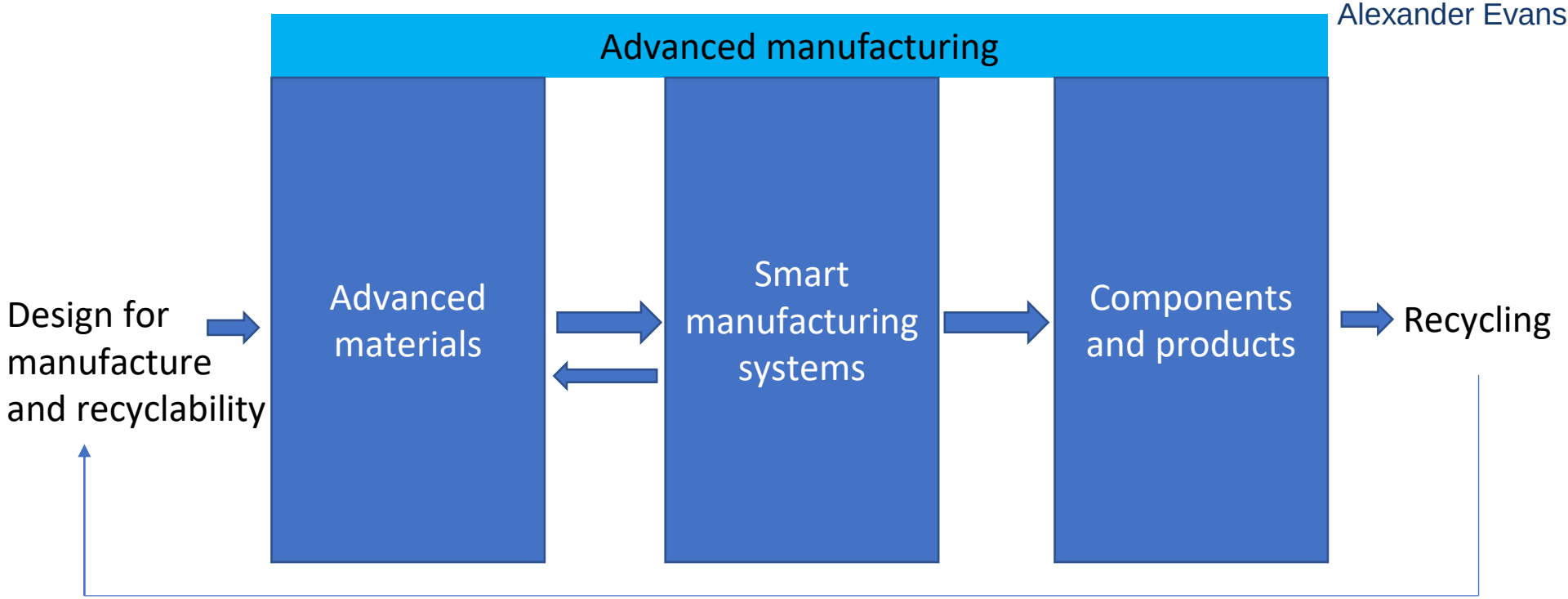
11./12.10.2021: 1st EMN General Meeting planned at PTB

- 11th, afternoon: Keynote presentations from stakeholders
- 12th, morning: work on SRA in 3 sections of EMN
- 12th, afternoon: election of EMN officials, logo decision, …

Interaction with stakeholders and partner organisations along EMN 3 sections

- Targeted stakeholder dialogue within and along the 3 EMN sections
- Partner organisations: should be willing to support EMN activities
- Stakeholder advisory council:
  - good representation of sections, KIS, partners and regions

BAM, DE:
Alexander Evans



Work in the 3 sections of the EMN: 1) Advanced Materials

Advanced materials are used in

smart manufacturing systems to create

new components and products

Advanced manufacturing can involve the creation of advanced materials

What are advanced materials?…..

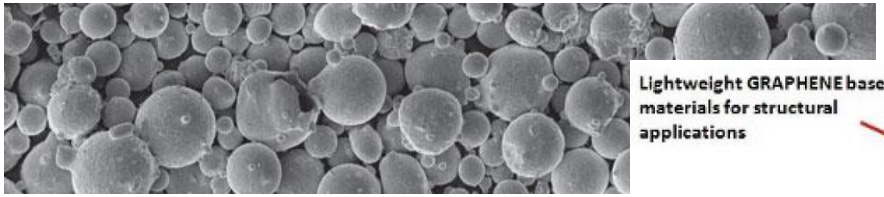
From DAMADEI report (2013), https://www.damadei.eu/report/

- "An **advanced material** is any material that through the precise control of its composition and internal structure, feature a series of **exceptional properties** (mechanical, electric, optic, magnetic, etc) or functionalities (self-repairing, shape change, decontamination, transformation of energy, etc.) that differentiate it from the rest of the universe of materials; or one that, when transformed through **advanced manufacturing** techniques, features these properties or functionalities"

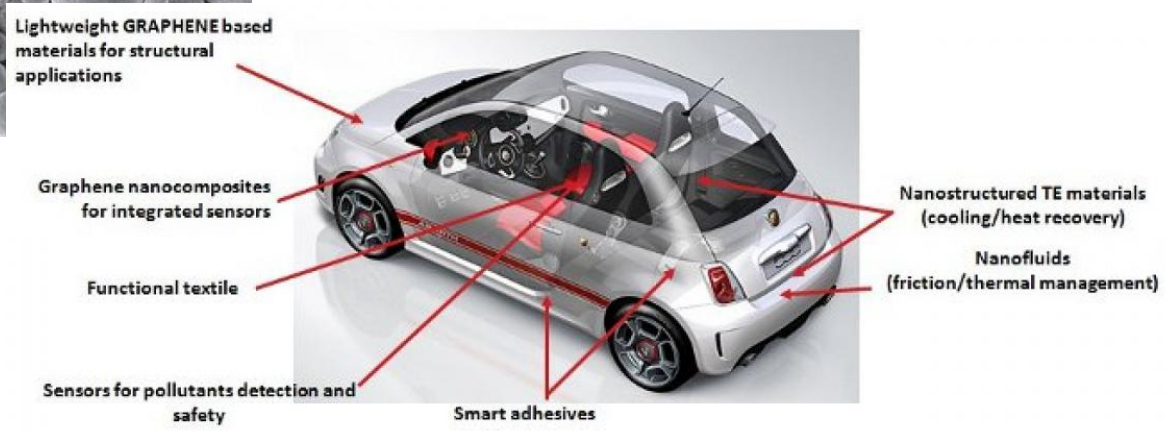
Work in the 3 sections of the EMN: 1) Advanced Materials

What are advanced materials relevant for advanced manufacturing?

- Nanomaterials (nanoscale or nano-enhanced materials)
- New composites (nano reinforced, e.g. based on Graphene)
- Advanced alloys (computer aided design)
- Metamaterials
- New powders for additive manufacturing (new chemistries, functionalise surfaces)
- Functional materials
- Photonics and optical materials



Source: EPMA
(Metal powders key features)



Source: Fiat, Graphene Flagship

Work in the 3 sections of the EMN: 1) Advanced Materials

What are the metrology challenges in characterisation of advanced materials?

- Characterisation of embedded nanomaterials in matrices of adv. bulk material
- Chemical properties
- Particle metrology
- Thermal properties
- Magnetic and nanoscale electrical prop.
- Optical properties
- Mechanical properties
- Acoustic properties
- Functional properties
- ……

Metrology instrumentation of the EMN members for Advanced Material charact.

EMN Section	Major facilities, instrumentation and planned investments
1) Advanced Materials	*Chemical properties:* synchrotron-radiation-based XRF & SAXS, ICP-MS, Raman spectroscopy, surface characterization (XPS, ToF-SIMS, Auger electron spectrometer & TXRF), EDX (Energy-Dispersive X-ray spectroscopy), ultra-high purity process gases; trace water analysis *Particle metrology (size, surface area, concentration)*: SAXS (lab), DLS, SMLS, sp ICP-MS, A4F-MALS-UV, BET, DMAS (Differential Mobility Analysis System) & APS, TSEM, AFM *Thermal properties:* thermal expansion coefficient, thermography, radiative properties (spectral emissivity), thermophysical characterisation (specific heat) up to 2000 °C, enthalpy of fusion, thermomechanical analysis, dilatometry, thermal diffusivity & conductivity, nanoscale thermal properties (SThM), glass transition temperature, calibration & testing of thermal radiation detectors (spot & imaging) *Magnetic & nanoscale electrical properties*: Magnetic materials and sensors test facilities, Electronics reliability testing, 4-point probe, SMM (Scanning Microwave Microscopy), C-AFM, EFM/KPFM (Electrical contrast combined with topography, Sheet resistance, Mapping of conductive areas on sample surface and I/V curves) *Optical properties*: Functional properties of advanced optical surfaces and components (absorbance, transmittance, reflectance, polarization, refraction, modulation transfer function, appearance, infrared emissivity) *Mechanical properties:* Hardness metrology facilities, fatigue testing, dynamic measurements of mechanical quantities, creep, intermediate rate testing, impact excitation, TMF, nanoindentation up to 800 °C, nanoscale mechanical properties testing and testing on thin layers *Acoustic properties*: Resonance ultrasound, free-field acoustics *Material functional testing*: Materials testing under simulated operational and accelerated conditions, battery testing, corrosion test facilities, engineering textile 3D permeability, wear and friction testing

Work in the 3 sections of the EMN: 2) Smart Manufacturing Systems

What are **smart manufacturing systems**?

Our proposal for an approach to a definition:

Autonomous, intelligent, interconnected and quality-oriented manufacturing systems

Specific manufacturing technologies:

- Laser based machining incl. fs-lasers
- Multi-axis machine tools
- Hybrid machine tools
- 3D, 4D printing/Additive manufacturing (metals, ceramics, polymers)
- Advanced joining technologies (solid state)
- Advanced surface treatments
- Automated composite manufacturing
- Robotics

…

Source: Moore/PTB, 5-axis machining

Source: WZL, DFKI: AI-based production environments

Source: MoriSeki hybrid machining

Work in the 3 sections of the EMN: 2) Smart Manufacturing Systems

What are metrology challenges for **smart manufacturing systems**?

- Positioning metrology
  - e.g determination of tool center point in machine tools under operating conditions
- Thermal metrology
  - e.g. online process monitoring (absolute temperature meas. for in-situ thermography in Additive Manufacturing)
- Mechanical metrology
  - e.g. dynamic in-process cutting force metrology
- Flow metrology
  - e.g. outgassing rates of advanced materials in smart manufacturing system under vacuum conditions

Metrology instrumentation of EMN members for characteris. of **smart manufacturing systems**

2) Smart Manufac-turing Systems	*Positioning metrology:* Optical frequency generator and MeP-lasers, Laser wave-length calibration & interferometer calibration, 6DoF controlled vacuum length interferometer; high speed interferometer data analysis; positioning control of mul-tiaxis systems; angle and gauge block metrology; Laser tracker, LaserTracer, Mul-tichannel absolute interferometer *Thermal metrology:* Primary thermometry, calibration facilities for PRTs, thermo-couples and surface thermometers, phosphor thermometry *Mechanical metrology*: Mass (1 mg to 5000 kg); primary pressure standards from 5 * 10^{-6} Pa to 1 GPa; prototype of optical pressure standards; primary dynamic pressure up to 20 MPa and > 1 MHz; force facilities (0.5 N to 6 MN) including dy-namic forces; torque (0.2 N×m to 5 kN×m) *Flow metrology*: leak testing facilities including vacuum chamber for testing of objects up to 1 m^3; flow metrology down to a few nL/min; pyknometry system *Manufacturing facilities*: additive (metals, polymer, ceramics, bioprinting); SLA-3D laser-printer, filament 3D-printer, surface technology; EBeam lithography system; robot technology & automation; hybrid manufacturing (combine additive and clas-sical technologies)

Work in the 3 sections of the EMN: 3) Components and Products

Advanced Manufacturing produces **components and products** (along the 13 KIS)

What are metrology techniques and challenges for qualification of components and products?

Examples:

- General: unified digital protocols for communication of metrological data
- Nano and microscale:
  - Hybrid metrology on nanostructures
  - Nanomaterials embedded in complex matrices
- Medium scale:
  - Traceability for XCT for internal and external defects
  - Surface roughness on complex (re-entrant) AM structures
  - 6DoF positioning metrology in measurement systems
- Large scale:
  - Gear metrology
  - 3D scanning of large structures
  - Large volume metrology in harsh environment
  - In-situ deflection of large structures (i.e bridges)

DMIS

I++ DME

DCC

Source: Siemens

Source: PTB

Work in the 3 sections of the EMN: 3) Components and Products

Advanced Manufacturing produces **components and products**

Metrology instrumentation of EMN members for characterisation of manufactured **components and products**

3) Manufac-tured compo-nents and products	*Nano- & Microscale*: Nanometrology under cleanroom conditions; nano-characterisation platforms: mAFM (metrological AFMs), high speed AFMs; Large Range-mAFM; (E)SEM, HR-TEM, optical microscopy (confocal, interference, …); lab and synchrotron-radiation-based XRR, EUV reflectometry & scatterometry; (imaging) ellipsometry and DUV scatterometry; diffraction grating metrology; µCMM, nano-GPS (geometrical product specifications); nano-roughness and surface trueness testing; thin films and layer systems testing in products *Medium scale*: Different high precision CMM with contact, optical or multisensor probes; multilateration algorithms; X-ray computed tomography (X-CT) 3D metrology systems (laboratory & synchrotron); simulation of X-CT; XR microprobe; precision roundness and diameter; form and surface texture metrology, 2D mask metrology (300-400 mm); Fizeau flatness interferometers (up to 300 mm aperture), freeform measurement instruments; different optical form measurement systems (up to 1.5 m x 1.5 m); linescale and encoder metrology; *Large volume*: large CMM (5 x 4 x 2 m), reference wall for portable 3D metrology systems (10 m x 6 m x 3 m), photogrammetry systems, 3D laser scanner; geodetic interferometric baselines, multilateration algorithms; laser tracker, LaserTracer, high accuracy ADMs; FSI interferometry; multiwavelength interferometry *Digitalisation*: virtual instruments and validation of data evaluation software; data interfaces for transfer of full metrological information

Summary and outlook

European Metrology Network for Advanced Manufacturing established

JNP AdvManuNet successfully prepare EMN proposal

JNP did work on scoping the EMN activities and prepared publications

EMN to be single point of contact for stakeholders in adv. manufacturing

EMN to establish knowledge base, metrology training programme and website with service desk

EMN to develop and regularly update strategic research agenda (SRA) on metrology needs for advanced manufacturing

EMN to implement SRA in cooperation with partner organisations and in alignment with smart specialisation plans of the EMN within EURAMET