ROADMAP FOR A EU WIDE STRATEGY ON NANOFABRICATION

SUSnanofab


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Integrated EU strategy, services and international coordination activities for the promotion of competitive and sustainable nanofabrication industry


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EXECUTIVE SUMMARY

Nanofabrication has the potential to address major socio-economic challenges, from better and affordable health care to cleaner energy and transports, improved consumer goods and higher living standards. The SUSNANOFAB project proposes an integrated strategy at a European Level that articulates the whole value-chain, aiming at the promotion of a competitive and sustainable nanofabrication industry.

The document proposes at first an overall introduction to the project SUSNANOFAB and aims. This is followed by a description of the methodology used to build the roadmap. Then, the vision of the roadmap for the nanofabrication sector is presented, altogether with drivers and challenges that are foreseen to play a key role for a successful market uptake of nanofabrication. Subsequently, the identified challenges collected are shown at large and discussed in details, while the related actions of the action plan for future research and innovation activities are presented.

This document represent a short hard-copy version of the full digital version of the roadmap which is available for reading and download both at the official website[1] and at the SUSNANOFAB Digital Platform[2].

SUSNANOFAB website

SUSNANOFAB Digital Platform

[1] www.susnanofab.eu
[2] www.susnanofab.oppornet.com/

THE PROJECT SUSNANOFAB

The global target of SUSNANOFAB project is to put in place an **integrated concerted action** for a long-term **sustainable nanofabrication**. The project establishes and promotes a robust network of European and international stakeholders and geographically distributed centres. These activities aim to provide current **missing links between policy, infrastructure, expertise, and industry requirements**, and contribute towards the **improvement of the current EU positioning and performance in the global nanofabrication market**.

SUSNANOFAB tackled the needs of the nanofabrication sector by addressing them on three different levels:

- At a **general level**, SUSNANOFAB established and **promoted a robust network** of EU and international stakeholders, connecting geographically distributed centres.
- At a **strategic level**, SUSNANOFAB found a common strategy to **enable all pre-competitive conditions for a successful market uptake** of nanofabricated products and solutions. This is reached using a structured road-mapping methodology and involving external experts in Coordination Groups.
- At an **operational and end-user level**, the project provided **an easy access point to affordable services, infrastructures, and knowledge** to EU stakeholders, and especially to SMEs. This is reached using different integrated methodologies, such as the organisation of a set **of training and brokerage workshops and services**, and via the development of a Digital Platform, which performs in an interoperable manner with ongoing initiatives (*e.g.*, the European Network for Pilot Production Facilities and Innovation Hubs, the European Material Modelling Council etc.).

THE ROADMAPPING METHODOLOGY

The **road-mapping activity** aims at the **development of a strategic plan for** the field of **nanofabrication and its path for industrial implementation**. This plan is able to bring forward the field of nanofabrication by identifying the **key drivers** to exploit **and key challenges** to be addressed to **enable a successful development** of a nanofabrication environment able to deliver high quality products. The main sectors, which are the focus of this roadmap, where nanofabrication can be relevant are:

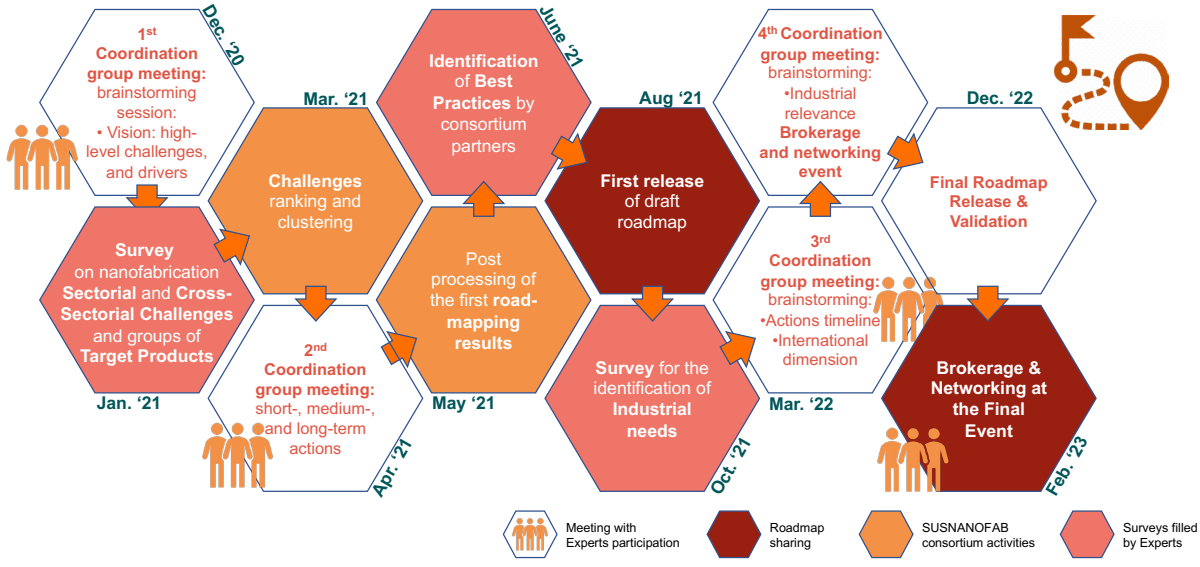
- Health
- Digital and industry
- Climate change and energy
- Mobility
- Food and natural resources
- Inclusive and secure societies

The **road-mapping activity** started from the analysis of the nanofabrication ecosystem including the identification of relevant stakeholders as well as past and ongoing relevant projects & initiatives with an analysis of the potential impact of nanofabrication on the overall European industrial competitiveness.

SUSNANOFAB was developed and expanded by a combination of expert workgroups and desk research, which integrated the results of key initiatives developed within the SUSNANOFAB network. Nanofabrication was considered by three different perspectives, which are represented in the three SUSNANOFAB coordination groups (CG), namely:

- Coordination group 1 (CG1): "Nanofabrication aspects from design to manufacturing upscaling"
- Coordination group 2 (CG2): "Environmental Sustainability, Health and Ethics in a life cycle perspective"
- Coordination group 3 (CG3): "Future skills and capabilities"

These working groups were established to gather experts from both Europe and USA to discuss their perspective on the future developments of nanofabrication and define how to satisfy the current and future needs of this sector with a comprehensive approach. The following figure shows the roadmapping steps performed by the Coordination Groups (CGs).



VISION TO 2030

SUSNANOFAB vision for 2030 foresees that Europe will **bridge the technological gap in nanofabrication and raise the competitiveness of European nanofabrication sector** to an international level, **raising Europe among the key players** in the nanofabrication field. **By leveraging the potential of nanofabrication** technologies, Europe aims at the d**evelopment of key technologies for a green transition** whilst fostering the inclusion of **responsible innovation, sustainability, and safety by design** in the current production methodologies. Nanofabrication is set to **improve the quality of life** of European citizens in terms of **retention of high-quality jobs in Europe**, availability of **customised, cleaner, safer, and affordable products, cleaner energy and mobility, and an effective and personalised medicine**. By collaborating **with leading international institutions** in the field of nanofabrication, we will establish a **cooperative exchange of ideas**, which will allow us altogether **to address current and future obstacles to unleashing the disruptive potential of nanofabrication**.

The following figure describes some of the **drivers** for the uptake of nanofabrication by the manufacturing environment organized in 4 areas (Scientific and Technological, Economic, Societal & Environmental, Policy & Regulatory).

- Unique attributes and new functionalities with high potential for new applications.
- Increasing number of patents and publications in nano.
- Improvements in performance.

- Increasing market pull and customer needs.
- The increasing demand is expected to impact in prices, foster scale economies and improve the manufacturing process.

- Reducing the environmental impact of manufacturing processes.
- Testbeds as catalyst for innovation in nanofabrication.
- Reducing material consumption.
- Improving societal acceptance providing safer materials.

- The directive for sustainable production and consumption to reduce the disposal of waste.
- Additional regulation to promote new nano-based developments in renewable energies (thin film technology, supercapacitors).

On the other hand, Europe must also address several **technical and non-technical challenges**, which may hinder nanofabrication development and market uptake, as depicted in the following figure.

- Lack of mass production techniques.
- Lack of nanoscale manufacturing capacity for some industries (electronics).
- Difficulty to get a balance among precision, performance and throughput.
- Inconsistencies between results in lab and the ones obtained when scale to industrial levels

- Economics of nano versus conventional applications.
- Need for Techno Economic Analysis of nanomanufacturing.
- Need more private capital and venture capital to bring the gap between research and market.

- Worries about the disposal and recycling of nanomaterials.
- Lack of knowledge about the effects on human health and environment.
- More information needed to improve public perception of nano.

- Complex regulation, especially in some sectors such as human health.

FROM CHALLENGES TO ACTIONS

The SUSNANOFAB Action Plan is a key component of SUSNANOFAB Roadmap, aimed at identifying key research and innovation actions where public and private stakeholders may invest in the near future for unleashing the full potential of nanofabrication. SUSNANOFAB action plan has been derived from a re-clustering process of SUSNANOFAB experts' inputs provided for the challenges identified throughout SUSNANOFAB CG meeting which have led to the definition of the **key actions to drive the nanofabrication sector towards a brighter future**.

The external experts involved in SUSNANOFAB workshops and surveys identified specific challenges herein reported as crucial to address for the current development of European nanofabrication sector.

SUSNANOFAB action plan has been derived from a re-clustering process of SUSNANOFAB experts' inputs provided for the challenges identified throughout SUSNANOFAB former meetings (described in the previous section). In this process, twelve recurring clusters of concepts were identified:

- Reduction of production costs, cost-efficient processes.
- Scaling up of the new nanotechnology-enabled manufacturing processes both for nanomaterial and nano-enabled material production.
- Lack of efficient mass-production techniques, methods, and manufacturing capacities causes inconsistent properties in scale-up and impairs process cost-efficiency. Unreliable results are a barrier for adoption in several sectors, including the automotive industry.
- Metrology for quality control; Production of 3D structures.
- Lack of investments in nanotechnology, especially for energy production.
- NEMS and MEMS meeting the requirements for mobility sector, nano-sensors for water, soil, and air monitoring; sustainable power sources for wearable devices; Energy efficiency of nanoelectronics
- Smart delivery systems require full regulatory approval; extensive clinical safety testing is required for nanoparticle-based drug formulations; safety issues of nanofabricated materials; safe-by-design approaches; lack of information on exposure to nanomaterials; health-risks of nano fertilizers or food additives; public perception of nanoparticles as harmful in healthcare
- Lack of information which contributes to the hesitance of the public about nanomaterials.
- Disposal and recycling of new materials; end-of-life for nanomaterials and nanoproducts.
- Uncertainty surrounding safety-related issues; lack of specific regulations and standards for risk assessments and risk management; regulatory framework too slow relative to the speed of progress in nanotechnology.
- Lack of a unified strategy at different levels of education; retrain and continually train skilled workers; lack of entrepreneurship and innovative management skills; lack of soft skills for researchers/workers who operate in transdisciplinary teams; Bridging the gap on Tech Transfer.
- Difficulty on introducing a new material (i.e., nanomaterial) in an already existing manufacturing/fabrication process.

Through a reorganization and integration of the less relevant clusters and a switch from an issue-oriented perspective (challenges) to an action-oriented perspective (research, innovation, and coordination actions) the following tentative topics have been obtained:

- **Action 1:** ***Mass-production techniques for a sustainable nanofabrication: volume scaling and product testing (IA)***
- **Action 2:** ***Digitalisation as enabler of optimized nanofabrication production practices (RIA)***
- **Action 3:** ***A nano-regulation framework: streamlined EHS assessment for nanoparticle-based delivery systems, formulations, and additives (CSA)***
- **Action 4:** ***Multi-level education strategy (upskill, reskill, and novel education curricula) for bridging the technology transfer gap from transdisciplinary nanotechnology innovation to entrepreneurialism management (CSA)***
- **Action 5:** ***Metrology for reproducible and reliable product quality in high-impact nanotechnology applications (e.g., mobility, health) (RIA)***
- **Action 6:** ***Reliable NEMS and MEMS for Key Enabling Technologies: future-oriented and energy efficient nano-sensors and systems for high-impact applications (e.g., mobility, health, and environment) (IA)***
- **Action 7:** ***Establishing a structured Safe- and Sustainable-by-Design (SSbD) approach for the European nanomaterial ecosystem (CSA)***
- **Action 8:** ***Living materials for multi-function devices (RIA)***

THE ACTION PLAN

The action plan describes in details each identified action with a cross-cutting impact throughout sectors and challenges of the nanofabrication segment. These actions enable our vision for the 2030 nanofabrication sector and lay the foundations for the vision for the 2050 nanofabrication sector.

ACTION 1: MASS-PRODUCTION TECHNIQUES FOR A SUSTAINABLE NANOFABRICATION: VOLUME SCALING AND PRODUCT TESTING (IA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Increase process reproducibility, yield, energy efficiency, and scalability for a broad range of valuable nanofabrication processes, particularly the ones with positive benefit-to-risk ratio applications (e.g., health, mobility, etc.).
- Involvement of key players (e.g. semiconductor industry) is essential for a true mass production.
- Decrease the environmental footprint of production due to the upscaling of volume production in terms of waste, unintentional release and so on during nanofabrication process and promote and implement responsible recycling strategies.
- Define process operational guidelines and quality criteria able to ensure product performance stability in upscaling processes.
- Contribute to the development and establishment of mathematical models that properly describe the mass production process.
- Circular strategy contribution to improve health, safety, and environmental product performance via the encouragement of responsible sourcing strategies
- Develop contactless characterization and non-destructive tests for a seamless production-line integration to support the development of production-line digital-twin models.
- Identify cost-effective strategies and up-to-date methodologies for metrology adoption and just-in-time rectification.
- Provide business opportunities for SMEs by linking the demand and supply of new services/products, as well as supporting their development/transformation to increase production volume.
- Promote process-related safe-by-design approaches (i.e., engineering controls).
- Assess sustainability over its three pillars (i.e., economic viability, environmental protection, and social equity).

Scope

Proposals should address the following activities:

- Development of solutions through industry- and user-driven interdisciplinary consortia covering processes and operational guidelines, aiming to increase process reproducibility, yield, and scalability in a broad range of nanofabrication production lines. Proposals should foster the dialogue between scientists&research and downstream development (industry).
- Development of solutions able to empower each and all the production chain steps in a holistic way, resulting in a systemic design advancement of the production processes developed up-to-now in the nanofabrication sector.
- Exploitation of metrology and contactless characterization techniques to support product standardization and just-in-time product rectification. The developed techniques should target the development of cost-effective, advanced characterization techniques, supporting a better-quality assessment and facilitating process rectification. Proposals submitted under this topic should include a business case and exploitation strategy. For TRLs 6-7, a credible strategy to achieve future full-scale manufacturing in the EU is expected, indicating the commitments of the industrial partners after the end of the project.
- Fostering the market uptake of solutions developed through industry- and user-driven multidisciplinary consortia covering the relevant value chain as well as promote the use of existing Open Innovation Test Beds (OITBs). In this process, standardisation aspects need to be considered and updated periodically. Market adoption of safe- and sustainable-by-design practices need to be promoted throughout the whole production life cycle (including packaging), when developing solutions.
- Clustering activities with other relevant selected projects for cross-project co-operation and joint activities on cross-cutting issues and sharing of results as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

Proposals submitted under this topic should include a preliminary list of concrete sustainability key performance indicators based on LCC, LCA, Safe by design evaluation after actions dedicated to obtaining reliable data which currently are missing in LCA software due to the interdisciplinary work needed.

Actions should justify the relevance of selected pilot demonstrations in different locations within the EU (and also outside, if there is a clear added value for the EU economy, industry, and society).

Actions should also contribute to improve the awareness of relevant external stakeholders and the general public across the EU about the importance of nanotechnology for society, the challenges faced in reaching stable processes for nanomaterial products upscaling and about proposed solutions supporting societal acceptance of and trust in nanomaterials and their production in the EU.

Specific topic conditions: Activities are expected to achieve TRL 6-7 by the end of the project.
Topic priority: medium-term action.

ACTION 2: DIGITALISATION AS ENABLER OF OPTIMIZED NANOFABRICATION PRODUCTION PRACTICES (RIA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Development of an advanced process-analysis modelling services through predictive techniques for an efficient scale-up to production scale. These services should become part of a centralized EC support desk.
- Development of cost-effective AI-enabled systems to facilitate just-in-time production rectification and to correlate multiple metrology techniques, which are currently not directed at addressing nanosized features, to adapt them to nanomaterials (e.g., indirect measurement of nanoparticles via regression of multiple macroscopic features to a specific nanoscale particle trough the correlation of nanofeatures to micro/macro scale features).
- Develop a standardised database of digital models, collecting past experiences to direct the future product and process upscaling.
- Identify cost-effective strategies for exploitation of material characterization in production modelling practices.
- Define operational guidelines directed at the standardization in production processes characterization.
- Provide business opportunities for SMEs by promoting and facilitating the sharing of production practises, hence fostering their digital transformation.

Scope

Proposals should address the following activities:

- Development of solutions through industry- and user-driven interdisciplinary consortia covering processes and operational guidelines, aiming to increase process reproducibility, yield, and scalability in a broad range of nanofabrication production lines.
- Development of solutions to empower the production chain in a holistic way, resulting in a systemic design and modelling advancement of current nanofabrication processes. This action should also consider the exploitation of metrology and contactless characterization techniques, with a particular attention for non-destructive ones, as key enablers of production chain digitalization and just-in-time AI-enabled production rectification. The development of such techniques should also support the estimation of production stability trough predictive modelling of process upscaling.
- Supporting cross-dissemination of successful experiences in the adoption of metrology and result in FAIR guidelines to allow transparency and transferability of industrial experiences across the nanofabrication processes (for example, in the development of digital twins). Actions should also contribute to the development of the industry 5.0 digitalization roadmap and foster cross-collaboration between the process upscaling and the EHS modelling trough the identification of common goals.
- Supporting new forms of cooperation across the entire value chain and consider the whole product life cycle as well as the safe handling of NMs along the whole production process and the definition and regular update of best practises.
- Clustering activities with councils (such as European Materials Modelling Council, EMMC, or European Society for Composite Materials, EECM) and other relevant selected projects for cross-projects co-operation, consultations, and joint activities on cross-cutting issues and share of results as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

Proposals submitted under this topic should include a business strategy. For TRLs 3-5, a credible strategy to achieve in a long-term perspective further improvement towards higher technology readiness level is expected, indicating the interest of the industrial partners after the end of the project.

Actions should also contribute to improving the awareness of relevant external stakeholders and the EU community about the importance of nanotechnologies for society, the challenges faced in reaching stable processes for nanomaterial products upscaling and about proposed solutions which could help to improve society's acceptance of and trust in nanomaterials and their production in the EU.

Specific topic conditions: Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project.
Topic priority: medium-term action.

ACTION 3: A NANO-REGULATION FRAMEWORK: STREAMLINED EHS ASSESSMENT FOR NANOPARTICLE-BASED DELIVERY SYSTEMS, FORMULATIONS, AND ADDITIVES (CSA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Harmonization of current Environmental Health and Safety (EHS) approaches and improvement of their robustness, whilst keeping in mind the easiness of implementation, to facilitate the development of standards.
- Contribute to the development of current and future standards, involving standardisation agencies.
- Assessment and modelling of the occupational risks related to the manufacture of nanomaterials.
- Assessment and modelling of the user and environment risks related to consumption of nano-enabled products over their whole life cycle.
- Decrease the environmental footprint of production due to the upscaling of volume production in terms of waste, unintentional release and so on during nanofabrication process.
- Support interlaboratory studies focused on promising alternative model for nanotoxicity.
- Promote the use of AI/ML in predictive toxicology to iteratively improve QSAR models with experimental data (HTS, HCS).
- Promote the live process of collecting high-quality data that fit in an AI/ML model (e.g., FAIR compliant, accurate data, etc.).
- Creation of a group of experts available to identify suitable technical solutions to specific needs, particularly for SMEs support and manufacturers. The group of experts should be reached via an accessible, findable single-entry point.
- Simplification/merging of existing nano-risk assessment methods based on the list developed in the NanoReg framework and, ideally, integration in existing chemical risk assessment tools rather than creating new ones.
- Consider synergistic/adverse effects of mixtures of NM in models and health consequences.
- Development of a structured communication campaign addressing public perception about the risks of nanoparticle-based delivery systems.
- Development of strategies for the adoption of metrology to aim at fully integrated quality assurance.

Scope

Proposals should address the following activities:

- Promotion of a generalized tiered approach, with general guidelines and specific questionnaires addressed separately to both processes and to formulations. This tiered approach should identify the high-risk hotspots and provide solutions to be implemented rapidly, particularly in case of health issues/urgent situations for rapid expertise and correction of the failing.
- Critical analysis on EHS risks related to nanoparticles manufacture (e.g., intentional/unintentional emissions, airborne particles, direct/indirect exposure, etc…). Where a direct assessment would not be viable, modelling and data extrapolation techniques should be envisaged to deliver a preliminary evaluation of the material hazards and hazard reduction procedures to be adopted (e.g., real-world hazard scenarios). The preliminary evaluation should be confirmed by on-site EHS risk analysis. Each assumption should be confirmed by on-site EHS risk analysis when it becomes possible. If possible, actions should add/integrate nanotechnological risk assessment into existing chemical risk methods/tools and push for standardization.
- Collection of all the methods/tools available on nanotechnology risk, review and rate them to select the most relevant ones, in collaboration with national bodies in charge of chemical risk assessment. Actions should make use of existing OA database of the exposure data related to nanomaterials, analysing the key information for the assessment of nanomaterials (e.g., particle size, structural allomorph, etc…).
- Collaboration with relevant authoritative bodies in the nano-safety cluster (e.g., European Partnership on Metrology, EURAMET) to facilitate the transition towards a harmonized and robust assessment process. Actions should follow an open collaborative strategy to allow for a transparent standardization process and justify the relevance of the adopted assessment approaches with respect to alternate ones. Inclusion of industrial stakeholders on current field developments should be envisaged to favour compliance and acceptance of the regulation requirements to access the market.
- Promotion of the exchange of good production practices amongst related industries, favour the adoption of standardised, market-ready safe-by-design approaches, and raise awareness on the already widespread use of nanomaterials in common consumer applications (e.g., food, drug, fertilizers, additives, etc.) and their valuable applications, and address about the complexities and uncertainties of nanomaterials (e.g., biomagnification, chronic exposure, trace materials, direct/indirect chronic exposure, complex matrices nanomaterials, low-dose/trace materials exposure). Actions should contribute to communicate the EU effort in being a pioneer in H&S regulatory activities (e.g., REACH regulation).
- Actions should envisage clustering activities with other relevant selected projects for cross-projects co-operation, consultations, and joint activities on cross-cutting issues and share of results as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

Actions should also contribute to support the improvement of the wider public perception on nano-topics allowing for the direct adoption of nano-enabled technologies in particular for nanoparticle-based delivery systems.

Specific conditions:

To achieve the expected outcomes, and safeguard the Union's strategic interests, regulatory bodies should take part to the consortium with co-participation to such projects of industrial partners, which may enable a faster adoption of the developed standards.

Topic priority: short-term action.

ACTION 4: MULTI-LEVEL EDUCATION STRATEGY (UPSKILL, RESKILL, AND NOVEL EDUCATION CURRICULA) FOR BRIDGING THE TECHNOLOGY TRANSFER GAP FROM TRANSDISCIPLINARY NANOTECHNOLOGY INNOVATION TO ENTREPRENEURIALISM MANAGEMENT (CSA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Establishment of an international roundtable on educational standards aiming at current nanomaterials needs and standards.
- Creation of an open-access model curriculum to direct education on nanofabrication at all education levels, from schools, to academia, as well as for technician work force.
- Definition of an implementation strategy, internationally shared, of the identified educational goals.
- Development of virtual learning courses and exchange programs for the lifelong training of current workers.
- Development of interdisciplinary trainings focused on fostering innovation and entrepreneurialism management.
- Educate through several channels the wider public about nanoscience (e.g., internet, general education curriculum).

As the nano-landscape changes quickly, the strategy should include the development of basic courses with additional courses updated along the evolving needs.

Scope

Proposals should address the following activities:

- Development of a unified open-access model curricula. Actors should be engaged from both education and nanofabrication ecosystems (e.g., academia, educators, scientists, engineers, and high school teachers) to identify and overcome gaps present within the current model curriculum. The developed curricula will become an enabler for new training opportunities with a transdisciplinary approach, focused on the nanotechnology/fabrication ecosystem. The training opportunities identified should be addressed at all education levels, and lifelong training activities incentivised (e.g., accreditation/certification of the trainings, study exchange programmes, business translation advisory boards, junior researchers mentoring programmes). Actions should also contribute to the education of the general population to nanotechnologies and the associated risks whilst promoting sustainable nanofabrication to young generations of researchers.
- Development of an organized database of the trainings with a simple and effective filtering and sorting system. The courses within such database should be monitored for content and kept up to date with current state-of-the-art developments. The best practices and experiences gathered by the trainings performed by federations and interest groups should be collected and to support future training development and allow for training benchmarking activities.
- Actions should be able to cross-benchmark current best practices and training experiences and provide feedback to further develop effective learning experiences for lifelong education. Activities should also foster collaboration between local institutions and industries or professional societies to promote educators' professional development by offering opportunities for visiting cutting-edge nanofabrication research and technology centres.
- Contribution to develop shared educational standards (e.g., ASTM International Education Standards) and promote the fostering of transdisciplinary skills of nanofabrication researchers and workers in the translation of nanotechnologies to added value products. Employers' participation should be envisaged to demonstrate the efficacy of the developed interdisciplinary education activities on process innovation.
- Clustering activities with other relevant selected projects for cross-projects co-operation, consultations, and joint activities on cross-cutting issues and share of results as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

The inclusion of transdisciplinary topics in the curricula for the development of skills of nanofabrication researchers and workers concerning nanotechnology innovation, entrepreneurship, and translation of nanotechnologies to added value products should be promoted.

Topic priority: short-term action.

ACTION 5: METROLOGY FOR REPRODUCIBLE AND RELIABLE PRODUCT QUALITY IN HIGH-IMPACT NANOTECHNOLOGY APPLICATIONS (E.G., MOBILITY, HEALTH) (RIA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Developing open-source reliable, easy to be implemented, and high-resolution metrology techniques for a trustworthy quality control defining a "zero-defect strategy"
- Developing modular interconnectable devices for metrology
- Developing reliable correlation across multiple, readily available, and cost-effective micro- and macro-scale metrology techniques, to deliver effective assessment of nanosized features by their indirect effects (e.g., viscosity, scattering, stiffness, etc...).
- Development of metrology techniques directed at quality control for specific applications, such as 3D manufacturing technologies
- Development of contactless characterization techniques linked to robust modelling and simulation techniques
- Development of AI-ready interfaces, able to provide the characterization outputs in a standardised format
- Development of solutions for handling missing data by means of machine learning methods and/or simulation
- Development of solutions for reliable benchmarks for each technique used (test harmonisation)
- Promoting investments in the development of cost-effective, advanced characterization techniques and promote the widening of their application range to a broader number of sectors.
- Provide business opportunities, especially for SMEs, facilitating the adoption of shared metrology.

Scope

Proposals should address the following activities:

- Development of metrology technologies easily integrable in the production line (e.g., electrical, optical) allowing for overcoming current technological limits, whilst easing the adoption of shared metrology techniques to all entities, including the ones with a limited budget (e.g., start-ups) and fostering the collaboration between academia-SMEs.
- Definition of criteria/measured quantity that best describes the quality of the production. Actions should place particular emphasis on technologies enabling for radical advancements in the field of nanofabrication (e.g., top-down 3D manufacturing, AI integrated systems) and promote additional private investment in the sector of metrology, to facilitate the development of cost-effective, advanced characterization techniques by translating the developed technologies to the market. In addition, actions should include the creation of platforms for sharing facilities that are very expensive for SMEs.
- Definition of business case and exploitation strategy, as outlined in the introduction to this Destination. For TRLs 6-7, a credible strategy to achieve future full-scale manufacturing in the EU is expected, indicating the commitments of the industrial partners after the end of the project. Actions should address the knowledge gap present within the industry and the academia by establishing means of facilitation for the adoption of up-to-date techniques and methods via trainings dedicated to the dissemination from academia to industry and promoting the adhesion to already existing EU exchange programmes (e.g., MSCA RISE).

- Clustering activities with other relevant selected projects for cross-projects co-operation, consultations, and joint activities on cross-cutting issues and share of results as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

Actions should also contribute to removing the barriers in accessing highly specialized tools, traditionally used only within the research field. In this sense, actions should promote and give access (via an accessible, findable single entry point) to nano characterization platforms with available specialists and/or provide training courses on these instruments. The access rules (time slots and cost) should be adapted to the size of the user/public (large or small industries, academics,..). Generation of digital product twins by their characterization data to enable the direct development of virtual models to support nano-characterisation, production, and development processes. The quality of the DTs should be confirmed by on-site analyses.

Proposals submitted under this topic will foster the approval of the developed technique by trusted regulatory bodies. Specific topic conditions: Activities are expected to achieve TRL 3-5 by the end of the project.

Topic priority: short-term action.

ACTION 6: RELIABLE NEMS AND MEMS FOR KEY ENABLING TECHNOLOGIES: FUTURE-ORIENTED AND ENERGY EFFICIENT NANO-SENSORS AND SYSTEMS FOR HIGH-IMPACT APPLICATIONS (E.G., MOBILITY, HEALTH, AND ENVIRONMENT) (IA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Reducing NEMS and MEMS production costs; for example, by improving product upscaling and production efficiency.
- Development of low-cost quality-control manufacturing technologies; for example, by adapting already existing technologies to new applications.
- Improving the cost/quality ratio of reliably produced devices at a high level of precision.
- Overcome product integration barriers by meeting operational requirement conditions.
- Improve the energy management and efficiency of the produced devices via consumption reduction and energy diversification.
- Increase competitive sustainability of SMEs through the uptake of advanced technologies and a cooperative development integrating user/customer needs.
- Technology transfer acceleration to market-ready devices by the development of NEMs and MEMs ready out of the box.

Scope

Proposals should address the following activities:

- Development of NEMS and MEMS by overcoming the current barriers in the implementation of NEMS and MEMS by addressing several issues (e.g., cost/quality, competitiveness against traditional technology, energy management and efficiency, multi-material integration, precision) to allow the integration and operation in real conditions (e.g., advanced energy management).
- Development of novel nano-devices and -sensors applicable for several cutting-edge applications especially for health, environment, and mobility sectors, such as cell activity sensing, environmental monitoring sensors, nano-bio interaction, nano-topologies, and nano bio-blocks. Action should meet production and performance repro-

ducibility requirements needed for health and mobility sectors (i.e., nano-sensors), for example addressing the need to reduce energy consumption by improving energy efficiency and complementing it with energy conversion and harvesting. Digital technologies such as Blockchain and AI based approaches could be included as useful assets (not mandatory).

- Proposals submitted under this topic should include a business case and exploitation strategy, as outlined in the introduction to this Destination. For TRLs 6-7, a credible strategy to achieve future full-scale manufacturing in the EU is expected, including interest and potential commitments by the industrial partners after the end of the project.
- Clustering activities with other relevant selected projects for cross-projects co-operation, consultations, and joint activities on cross-cutting issues and share of results as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

Actions should facilitate integration of the developed mechanical nano-sensors into final products (e.g., health and mobility) and assay for potential applications in the nanofabrication production-line (e.g., metrology-oriented sensors). An investment's framework for the developed technologies after project end should be also foreseen. Actions should look for synergies with the metrology actions to increase production precision whilst promoting investments in metrology, especially for 3D manufacturing technologies. The developed technologies should meet product trustworthiness and reliability expectations of customers.

Actions should pave the way to the development and leadership of EU industrial manufacturing in this field targeting markets where Europe can still play a strong role.

Specific topic conditions: Activities are expected to achieve TRL 6-7 by the end of the project.
Topic priority: long-term action.

ACTION 7: ESTABLISHING A STRUCTURED SAFE AND SUSTAINABLE-BY-DESIGN (SSBD) APPROACH FOR THE EUROPEAN NANOMATERIAL ECOSYSTEM (CSA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

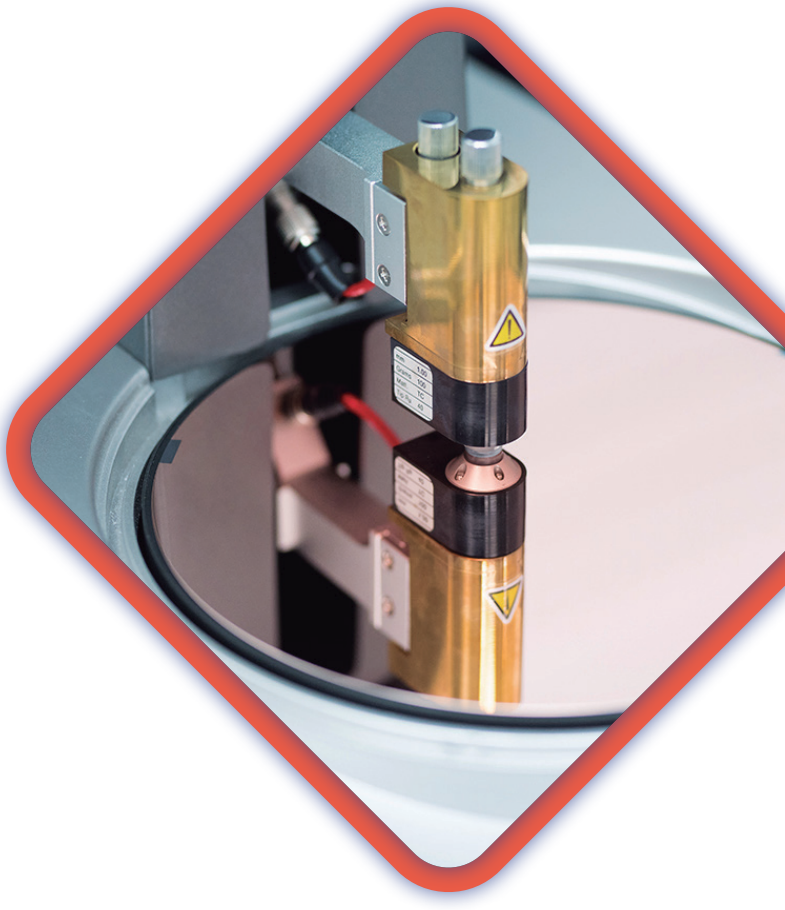
- Strategies for the adoption of safe and sustainable-by-design by industry and SMEs, end-users, regulatory and public authorities, research organisations, and academia.
- Provide tiered-guidance system for adopting SSbD and circular approach.
- Adoption of tailored approaches adapted to the size of the players (academia, start-up, SMEs, large industries).
- Improvement of cross-KETs activities to provide better integration of safe- and sustainable-by-design in the product development.
- Development of an inclusive approach to implement safe- and sustainable-by-design strategies early in the innovation process, a systematic and standardized risk-analysis assessment and of market-ready approaches; fitting the industry needs and following market products regulations.
- Promotion of safe- and sustainable-by-design approaches by the verification/validation of applicability robustness and correctness of tools, models and platform; encourage the development of NEP passport to tack/trace ENMs all along their value chains.
- Contact major publishers to include SSbD into the scope of more journals.
- Monitoring of material streams to identify circular approaches for by-products as well as for products.
- Improvement of EU nanofabrication competitiveness through market-ready safe- and sustainable-by-design approaches.

Scope

Proposals should address the following activities:

- Activities contributing to develop open standards and standard operating procedures repositories for standardized safe-by-design development procedures, combining both experimental and theoretical approaches. Actions should facilitate the harmonisation in the data collection for the development and sharing of successful experiences in safe-by-design product and process development, considering all the actors of ecosystem. Actions should address safety aspects as they are important for the market uptake of nanomaterials.
- Activities contributing to the analysis on the use nano-enabled materials along the whole process life cycle, assessment of the risks at all stages, and integration of the impact of the nanoparticles character on the final solution by setting up appropriate collaborations with applicable actions. A variety of different use cases have to be developed to be effectively adopted by anyone in the early stages of the product development process need to be covered.
- Supporting the adoption of such standardised procedures by a wide range of users, making them accessible to LEs and SMEs. Actions should seek for validation of the developed procedures by collaborating with the evaluation process users. Process validation could be obtained from direct validation and/or cross-validation of computational and experimental workflows, allowing for a wider scope for the repository procedures collection process.
- Clustering activities with other relevant selected projects for cross-projects co-operation, consultations, and joint activities (e.g., AI Nano annotation DataUnion resource) on cross-cutting issues and share of results and benchmarking tools as well as participating in joint meetings and communication events. To this end proposals should foresee a dedicated work package and/or task and earmark the appropriate resources accordingly.

Topic priority: short-term action.



ACTION 8: LIVING MATERIALS FOR MULTI-FUNCTION DEVICES (RIA)

Expected outcomes

Projects are expected to contribute to the following outcomes:

- Development of multi-scale (from nano to micro and macro scale) and multi-function devices integrating complex living materials with a positive impact on regenerative medicine strategies and in vitro models.
- Development of improved biomimicry of intended biological systems and increased production speed.
- Implementing solution for monitoring or stimulating different biological events and tissues at a time.
- Development of ready-to-use methods & technologies to be included in this multi-function devices.
- Increasing the competitiveness of high-tech European SMEs which will be able to commercialize multi-scale and multi-function devices and related materials and technologies.

Scope

Proposals should address the following activities:

- Development of new bio-fabrication technologies (including nanofabrication technologies) able to work with multiple materials, which results in enhanced properties of the finally produced devices (for example more fundamental enhancement of mechanical properties, but also combination of properties such as a material used for sensing, and another for biological activities and actuating).
- Involvement of technologies such as, for example, volumetric bioprinting, digital light processing, extrusion-based bioprinting, allowing the fabrication of multi-scale objects with fast speed of fabrication and high resolution.
- Optimization of the afore-mentioned technologies through innovative complex multi-scale modelling and digital twin approaches.

Proposals submitted under this topic should include a business case and exploitation strategy.

Projects should build on or seek collaboration and clustering activities with existing projects and develop synergies and cross-projects co-operation with other relevant European, national, or regional initiatives, funding programmes and platforms.

Topic priority: medium-term action.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