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4M2020

Advanced Manufacturing of Multi-Material Multi-Functional Products Towards 2020 and Beyond

Instrument: Coordination and Support Action

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Deliverable

D5.3 Roadmap report

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Content

I- INTRODUCTION

4M2020 roadmap process

The 4M2020 roadmapping process was presented in detail in a previous deliverable of the 4M2020 project [i]. As a brief summary of this process (Figure 1), successive steps were implemented to collect (State of the Art, Needs and Forecasts) information from within the 4M community, to analyze and refine this information and finally to formulate some expression of interest of the community fitting the format of the roadmap originally issued by NANOfutures in 2012 [ii] and revised by Value4Nano in 2015 [iii].

1. A foresight meeting was organized in 2014 gathering 21 EU project coordinators in the field of 4M2020. A set of 8 RIA/IA/CSA actions were screened by the coordinators out from the 7 value chains originally prioritised by NANOfutures, as having particular relevance for multimaterial micro-nano manufacturing.
2. These 8 actions were subsequently presented, discussed and completed with additional information provided by a total of 77 international experts attending the 4 workshops collocated with different conference events in 2015. From this work, the top 3 of the 8 actions (Figure 2) were finally screened out as a consolidation of the overall priority of the 4M2020 community for future R&D activities (Figure 1, Figure 2). These 3 actions were:

Integration of novel materials into existing production and assembly lines (VC1-002-s)
Integration of nano particles and aggregates into materials (VC4-003-l)
3D manufacturing control, Process control, analytical control, Material interfaces, Extrusion (VC6-005-m)

3. During a final workshop (2016), the top 3 actions were presented, discussed and completed with industrial representatives of 10 key products as well as 9 EU project coordinators who attended the Foresight meeting at the start of the process. The result of this process is presented in this report as the final 4M2020 roadmap.

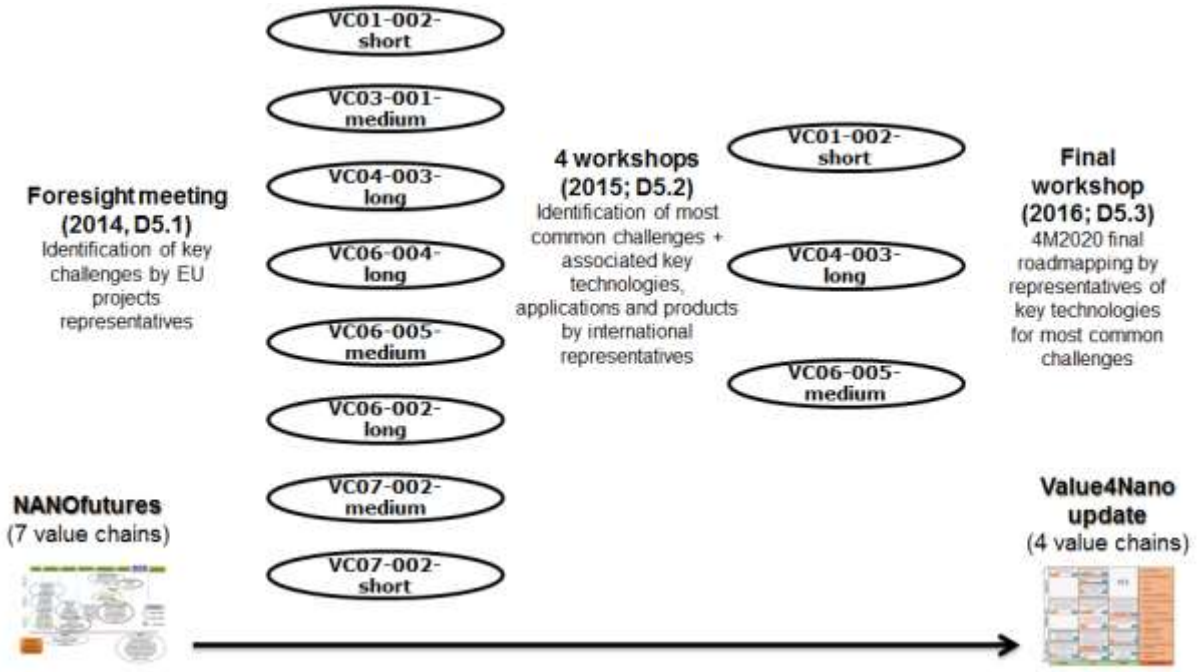


Figure 1: 4M2020 roadmap process from NANOfutures roadmap to Value4Nano update.

VC4-003-long - Integration of nano particles and aggregates into materials (239)								
MATERIAL								TOOL
Improved process (and additives) to improve the homogeneity of nano materials (23)	Multimaterial 3D-Printing (14)	Additive manufacturing with multifunctional materials (13)		Self - assembly (16)		Sol. gel chemistry & Processes (16)		Hybrid additive manufacturing "3D- printing" (polymers) of electronic devices (13)
Production & Manufacturing (23)	Production & Manufacturing (66)	ICT (32)	Energy and Environment (39)	Health (43)	Environment & energy (28)	Health (23)	Environment & energy (22)	Production & Manufacturing (23)

VC1-002-short - Integration of novel materials into existing production and assembly lines (246)						
MATERIAL					METROLOGY	TOOL	
Additive manufacturing with multifunctional materials (24)		Multimaterial 3D- Printing (13)	Self - assembly (12)		Hybrid / multi- sensor high speed metrology (12)	Hybrid additive manufacturing "3D- printing" (polymers) of electronic devices (21)	Hybrid micro manufacturing (milling, EDM, ECM, laser) (18)
Environment & energy (39)	ICT (32)	Production & Manufacturing (66)	Environment & energy (28)	Health (43)	Production & Manufacturing (46)	Production & Manufacturing (55)	Production & Manufacturing (83)

VC6-005-medium - 3D manufacturing control, Process control, analytical control, Material interfaces, Extrusion (252)					
MATERIAL		METROLOGY		TOOL	MODELLING
Self-assembly (17)		Non destructive testing (20)	Hybrid / multi- sensor high speed metrology (12)	Hybrid micro manufacturing (milling, EDM, ECM, laser) (16)	Simulation for 3D Printing (11)
Health (43)	Environment & energy (28)	Production & Manufacturing (20)	Production & Manufacturing (46)	Production & Manufacturing (83)	Production & Manufacturing (32)

Figure 2: The three NANOfutures actions of highest priority to the 4M2020 community. The numbers indicate the numbers of votes awarded to the priotities in the set of 2015 workshops.

Value4Nano value chains (VC1, VC2, VC3, VC4)

The focus of 4M2020 is on developing advanced nano and micro manufacturing processes for multimaterial multifunctional products. It is therefore to be expected that there is an overlap between the interests of 4M and NANOfutures which is the European initiative for sustainable development by Nanotechnologies. However, with an emphasis on manufacturing processes, there will inevitably be essential aspects important to the uptake and integration of the (nano)materials which are not covered by NANOfutures. So as not to repeat the excellent work already carried out and to ensure the needs of multimaterial manufacturing are represented, the 4M2020 team has, from the outset, based their roadmap activities on the NANOfutures original pattern.

The NANOfutures roadmap [ii] contained originally 7 value chains upon which the 4M2020 roadmapping exercise was set. However, during the course of the 4M2020 project, Value4Nano published an updated roadmap [iii] merging the 7 initial value chains from NANOfutures into 4 consolidated value chains. Implementing this change, the 4M2020 team has integrated its own specific findings into a new and 5th value chain (VC5) to the Value4Nano roadmap, which is presented in this report from chapter 2 and onwards.

The 4M2020 roadmap activities have been finalized in an intensive workshop held in Brussels 2-3 February 2016. With the aim to complement the Value4Nano activities the 4M2020 team together

with the workshop participants, first examined which interests of the 4M community were already represented in the 4 value chains. These crosscutting interests (RIA/IA/Pilot Line/CSA actions) are summarized in Annex 1. Although no additional information to the Value4Nano roadmap is reported here, it emphasizes the relevance of the Value4Nano roadmap on 24 (RIA/IA/PL/CSA) different actions encompassing topics across multi-materials micro-/nano-manufacturing fields of application.

H2020 2016/17 related actions

Also of importance was to consider the implementation of the 4M2020 roadmap in the frame of H2020, at the right pace, capitalizing on recent actions in 2016 (or about to be launched in 2017) and consolidating key topics appropriately on the long run. All calls launched under the *Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing* 2016-17 programme were screened and 18 RIA/IA/CSA calls were identified (including pilot lines) to be relevant to 4M2020 (Annex 2).

II- 4M2020 ACTIONS SUMMARY (VC5)

All topics of interest identified by the 4M2020 team but not directly covered by Value4Nano nor H2020 2016/17 were found to fit a common theme and are presented here as the VC5 value chain which is proposed as an updating to Value4Nano. VC 5 carries the following title and forms the foundation for the 4M2020 roadmap:

VC5 - ADVANCED MANUFACTURING FOR MULTIMATERIAL, MULTIFUNCTIONAL PRODUCTS

A total of eight technical actions specific to 4M2020 needs have been prioritized (Table 1) within the new VC5 value chain, and this concludes the roadmapping process describedabove. These actions list from VC5-x-001 to VC5-x-008 following NANOfutures/Value4Nano formalism where *x* indicates the short/medium/long term need for each action. Each action carries a dedicated and self-explanatory title and is specified in terms of RIA/IA action type and targeted TRL windows. Also specified are the 3 NANOfutures value chains (VC1-002-short, VC4-003-long, VC6-005-medium) which the 8 4M2020 actions originated from. Each action is described in terms of scope, challenges, materials, products, applications and technologies hereafter. All actions are mapped together across challenges and along the time scale to constitute, as a whole, the 4M2020 roadmap for *Advanced manufacturing for multimaterial, multifunctional products* (Figure 3).

Action ID	Action Title	TRL Expected	Type	NANOfutures source
VC5-S-001	Integration of novel multi-materials into modular, automated and reconfigurable production lines	5-6	IA	VC1-002-short
VC5-M-002	Integration of nano particles and aggregates into new and precise micro- and macro-engineering tooling and processes	4-5	RIA	VC4-003-long
VC5-S-003	Multi-materials, multi-scale and 3D-shape closed-loop control strategies for micro- and nano- manufacturing	3-4	RIA	VC6-005-medium
VC5-M-004	In-line control & inspection solutions of novel materials for modular, updatable, reconfigurable and disassemblable products	3-4	RIA	VC1-002-short
VC5-L-005	Multiscale and multiphysics modelling solutions for novel material systems and products performance & robustness	3-4	RIA	VC6-005-medium
VC5-S-006	Modular, updatable and reconfigurable manufacturing solutions for micro/nano-enabled miniaturized products	3-4	RIA	VC1-002-short
VC5-S-007	Pilot line for standardized manufacturing of hybrid and structured materials with customized properties	7-8	IA	VC1-002-short and VC4-003-long
VC5-M-008	Pilot line for 3D-manufacturing, process, analytical and material interface control and modelling of products integrating hybrid and structured materials	6-7	IA	VC1-002-short, VC4-003-long and VC6-005-medium

Table 1: VC5 actions Summary.

III- 4M2020 VALUE CHAIN (VC5)

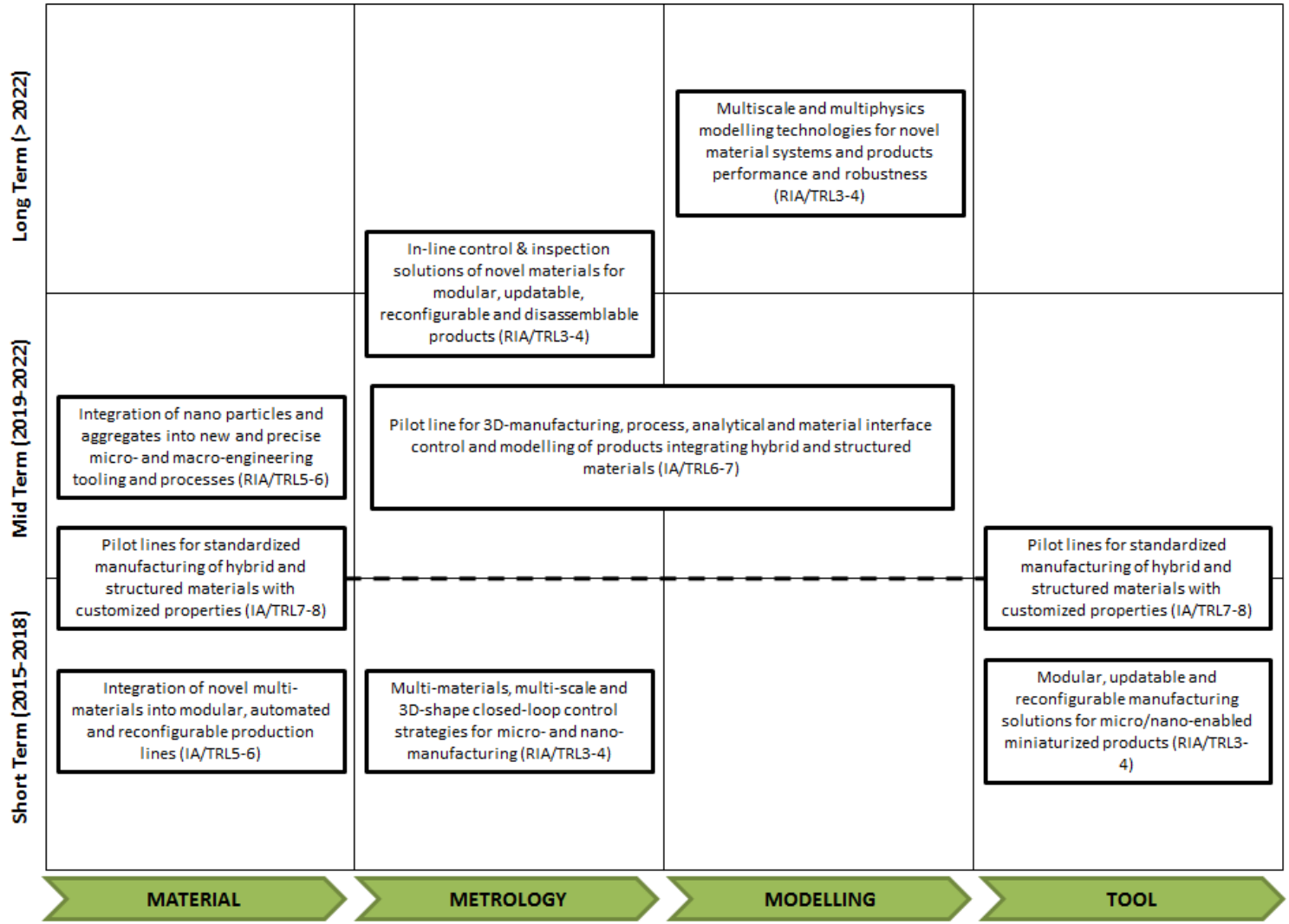


Figure 3: Advanced manufacturing for multimaterial, multifunctional products (4M2020 value chain VC5).

4M2020 MATERIALS CHALLENGES

Scope: Deployment and advanced processing of novel multi-materials with micro-precision by existing and new micro- and macro-production equipment that have a modular design and integrate automation solution to implementing flexible and reconfigurable manufacturing platforms.

Manufacturing solutions for miniaturized, modular, updatable, reconfigurable and disassemblable products underpinned by the latest advances in multi-material processing technologies.

Development of advanced joining and assembly technologies for novel multi-materials that can be integrated in existing production and assembly lines or can be used as component technologies in the development of new manufacturing platforms.

Challenges: Novel multi-materials and their applications in new miniaturized products are continually being developed in universities, commercial laboratories, at material providers and in research oriented organizations around the world.

Existing technologies are adopted or novel processing solutions have been developed for their processing, especially to retain their attractive mechanical and physical properties, and thus to improve the performance of existing technologies or develop new manufacturing platforms, such as lightweight solutions, or to enable new functionalities in highly flexible and reconfigurable systems for many different applications.

To make objects for everyday use in customer and industrial applications, these novel multi-materials have to be used under controlled conditions in existing industrial processes (blending/mixing, additive manufacturing, subsequent processing, etc.).

Integration of novel multi-materials into modular, automated and reconfigurable production lines (VC5-S-001)

Materials & Products & Applications	Technology
Materials: Combinations of conductive/non-conductive materials, porous/non-porous, hard/soft materials, multi 3D printed materials, functional hybrid components, fiber/powder mixtures, CRM-free materials. Products: ● Key: Micro integrated in machine tools, micro parts for wearable devices, µ-connectors, micro gas turbine, fuel cells for electric car, energy efficient buildings and environment monitoring. ● Others: Electronics, hearing aids, medical devices, product performing in geothermal boreholes, filtering devices, scaffolds for regeneration of dental tissues, high reliable& high temperature-use robust products, housing parts and micro-mechanical parts, environment sensing devices. Application: Health, energy, environment	• Multi-material 3D printing; • PIM of Ceramic matrix composites (CMC); • Self-assembly; • Additive manufacturing in combination with laser-based MID technologies and with printing technologies; • Sintering processes.

Table 2: VC5-S-001.

The Value4Nano actions consolidated by this new action are VC2-S-003 and VC4-S-004 addressing the following topics (Annex 1):

Novel processes and technologies for engineering surface modification and functionalities incorporation; Composite or Hybrid Multifunctional Materials and Systems.

The previous H2020 calls setting-up the basis for this action are NMBP-04-05, FOF-01-05-06-07 addressing the following topics (Annex 2):
Architectured /Advanced material concepts for intelligent bulk material structures; Advanced materials and innovative design for improved functionality and aesthetics in high added value consumer goods; Novel hybrid approaches for additive and subtractive manufacturing machines; Support for the further development of Additive Manufacturing technologies in Europe; New product functionalities through advanced surface manufacturing processes for mass production; Integration of unconventional technologies for multi-material processing into manufacturing systems.

The new VC5-S-001 action targets TRL5-6 under an IA action launched in 2018.

Integration of nano particles and aggregates into new and precise micro- and macro-engineering tooling and processes (VC5-M-002)

Materials & Products & applications	Technology
Materials: Ceramics, functional surfaces, nano-coatings, thermoset-based hybrid, 3D printed substrates, photoactive nanocomposites, electrical/thermal active materials, thermoplastic materials, bioactive/biocompatible surfaces, biodegradable materials. Products: ● Key: Micro gas turbine, fuel cells for electric car, energy efficient buildings. ● Others: Turbines, medical implants, filtering devices (filters for nanoparticles, filter for water remediation, functional filters (e.g. antibacterial)), biomed sensors, environmental MEMS. Application: Health, energy, environment, packaging.	• Printing technologies • Multi-material 3D printing; • Polymer processing; • Additive manufacturing • Combination with laser-based MID technologies and with printing technologies • Surface processing; • Online integration tool for NP integration.

Table 3: VC5-M-002.

The Value4Nano actions consolidated by this new action are VC1-S-004, VC1-M-003, VC2-S-001, VC2-M-003 and VC3-L-003 addressing the following topics (Annex 1):
Surface functionalization by structuration in injection moulding, embossing technologies and roll to roll; Industrial oriented research and demonstration on injection moulding of polymeric-based products with nanostructured functionalized surfaces; Advanced industrial research to enhance the performance of functional nanocoatings; Support innovative new technologies for efficient handling and manipulation of nanoparticles; Synthesis of 'hosted' nano particle systems for nanomedicine.

The previous H2020 calls setting-up the basis for this action are NMBP-04, FOF-01-06 addressing the following topics (Annex 2):
Network to capitalize on strong European position in materials modelling and to allow industry to reap the benefits; Novel hybrid approaches for additive and subtractive manufacturing machines; New product functionalities through advanced surface manufacturing processes for mass production.

The new VC5-M-002 action targets TRL4-5 under an RIA action launched in 2020.

4M2020 METROLOGY CHALLENGES

Multi-materials, multi-scale and 3D-shape closed-loop control strategies for micro- and nano-manufacturing (VC5-S-003)

Scope: Materials and shape control are very important especially in processing nanostructured materials where the precision and reliability is a major issue. Quality assessment technologies for geometrical accuracy, such as integrated micro/nano metrology, functional characterization and in line monitoring are required.

The challenge toscale up in MNT-enabled 3D manufacturing capabilities, and increase the degree of automisationtion of the utilized technologies necessitates more complex process control solutions . The role of process control subsystems is becoming more and more important and must take into account the following manufacturing characteristics in processing nanostructured materials, i.e. precision, speed, real-time, repeatability, reliability, yield, quality (0-defects), functionality, cost and redesigning of machining strategies;

Challenges:

- Robust systems for the measurement of process-material specific properties for serial production of mass customised parts/products.
- High speed & online metrology for high volume manufacturing of parts with critical dimensions at micro- and nanoscales. Large area scanning/processing that is capable of detecting micron scale defects, 3D inspection, characterization systems and non-destructive testing.
- Modular and miniaturized micro-precision component technologies for integration into micro- and macro-production equipment (e.g. hybrid / multi-sensor high speed metrology).
- Joining and assembly technologies for advanced and multi‑material manufacturing of modular, updatable, reconfigurable and disassemblable products.
- 2D/3D technologies for function and length scale integration in products: processing and structuring of materials at different length scales and modelling process-material interactions at both micro and nano scales. Robust measurement systems for extraction of surface texture and geometric features.
- Tools for intelligent data sampling, data fusion and novel integration of complementary processes in hybrid manufacturing platforms.
- Metrology and monitoring techniques for 3D visualization of hidden or hollow geometrical features at micro and nano scales.
- Closed loop control strategies for optimization and deviations mitigation of micro-nano fabrication processes taking into consideration the adaptability to the widest possible range of MNT processes, particularly for implementations of roll to roll (high speed) and multi-componnets' processing, and for optimization of micro and nanoreplication technologies, e.g. micro-/nanoinjection and nanoimprinting, where on line monitoring of the processing accuracy and the surface/structure functionality evolution can improve the final quality of the end product.
- Flexible and reconfigurable machinery and robots with feedback control for high precision control. Modular in-line instrumentation/equipment for integration in flexible and reconfigurable manufacturing lines.

- Process and production planning tools for achieving function and length scale integration in high quality end products.

Materials & Products & applications	Technology
Materials: Multi-material (polymer, Si, fabrics, fiber based, ceramics, metals,…), combinations of conductive/non-conductive materials, porous/non-porous, hard/soft materials, functional hybrid components, fiber/powder mixtures Products: ● Key: In-line metrology, micro processing capabilities integrated in machine tools, micro parts for wearable devices, µ-connectors, flexible screens. ● Others: Optical 3D metrology sensors (small footprint, wireless, robust, cost efficient), biomed sensors and environmental MEMS, roll to roll metrology. Application: Manufacturing, textile, biomedical, energy.	• Micro and nano-replication technologies; • Printing Polymer/wax moulds for injection moulding; • 3D printing with variable resolutions for fast production.

Table 4: VC5-S-003.

The Value4Nano actions consolidated by this new action are VC1-M-001, VC2-M-003 and VC4-M-003 addressing the following topics (Annex 1):
Development and enhancement of inspection technologies and methods for nanostructures over large areas; Support innovative new technologies for efficient handling and manipulation of nanoparticles; Advanced techniques for experimental assessment of nano-materials properties .

The previous H2020 calls setting-up the basis for this action are NMBP-07, FOF-03-08 addressing the following topics (Annex 2):
Systems of materials characterization for model, product and process optimization; Zero-defect strategies at system level for multi-stage manufacturing in production lines; In-line measurement and control for micro-/nano-enabled high-volume manufacturing for enhanced reliability.

The new VC5-S-003 action targets TRL3-4 under an RIA action launched in 2018.

In-line control & inspection solutions of novel materials for modular, updatable, reconfigurable and disassemblable products (VC5-M-004)

Scope: The development of new products and also the integration of new functionalities in existing products require combining the properties of different materials, e.g. polymers, nanomaterials and composites, and the use of process chains that integrate different micro- and nano-manufacturing processes.

Also, high volume manufacturing at micro and nanoscale, joining and assembly operations for advanced and multi‑material manufacturing will require in-line instrumentation & equipment solutions for modular, updatable, reconfigurable and disassemblable products as well as their integration onto flexible and reconfigurable application-specific manufacturing platforms.

Challenges: There are several challenges in the integration of novel materials into existing manufacturing lines calling for:

- Design of new process chains and manufacturing routes which improve the geometrical quality, alignment accuracy and shape control at nanoscale for novel materials systems into currently available manufacturing processes.
- Processing, structuring and integration of materials at different length scales with associated non-destructive methods for control & inspection: dimensional accuracy, simultaneous measurement (e.g. geometry and nanoparticle distribution), high aspect ratio structures, roughness, form and thickness , material quality, adhesion/joining properties of dissimilar materials.
- Integration of inline 3D metrology in existing production and assembly lines with capability for large area scanning & processing.
- Hybrid/multi-sensor on-line and high speed process metrology and characterisation for quality assurance.
- Metrologically traceable, precision tomography (X-ray) for multi-material systems with embedded elements, uncertainty modelling and reconstruction algorithm.
- Joining and assembly technologies for multi‑material manufacturing.
- Direct assessment of parts/products functional property for different process-material combinations. Modelling process-material interactions at both micro and nano scales. Model based metrology, tools for intelligent data sampling and data fusion to be implemented in hybrid processing and instrumentation solutions.

Materials & Products & applications	Technology
Materials: Multi-material (polymer, Si, fabrics, fiber based, ceramics, metals,…). Products: ● Key: In-line metrology, Customized health monitoring, micro parts for wearable devices, µ-connectors. ● Others: Optical 3D metrology sensors (small footprint, wireless, robust, cost efficient), multimaterial and integrated products (e.g. additive parts with integrated electronics). Application: Mechanical components in aerospatial or automotive sectors.	• Micro and nano-replication technologies; • Micro-injection molding; • Printing; • Laser patterning; • High speed roll-to-roll solution deposition processes and hybrid processing technologies.

Table 5: VC5-M-004.

The Value4Nano actions consolidated by this new action are VC1-S-003 and VC4-M-002 addressing the following topics (Annex 1):
Development of 3D printing systems (advanced material manufacturing approaches, additive manufacturing, metrology and smart software); Innovative manufacturing equipment for advanced nano-integrated materials (e.g. on-line characterization controls and operational standards compliance evaluation).

The previous H2020 calls setting-up the basis for this action are NMBP-07, FOF-03-08 addressing the following topics (Annex 2):

Systems of materials characterization for model, product and process optimization; Zero-defect strategies at system level for multi-stage manufacturing in production lines; In-line measurement and control for micro-/nano-enabled high-volume manufacturing for enhanced reliability.

The new VC5-M-004 action targets TRL3-4 under an RIA action launched in 2022 or beyond.

4M2020 MODELLING CHALLENGES

Multiscale and multiphysics modelling solutions for novel material systems and products performance & robustness (VC5-L-005)

Scope: Multiscale and multiphysics modelling technologies for a range of material systems and for various key problems (temperature control, cost, product thermal stability, reliability). Modelling should address:

- Material processing including material synthesis processes;
- Material growth processes;
- Material properties;
- Material/process interaction;
- Thermomechanical stress, environmental conditions;
- Failure mechanisms, lifetime prediction.

Challenges: capture the essential physics and guide the design of products without a large number of expensive, precision experiments. Control and tailor structural properties and design optimal responses for precise advanced applications.

Materials & Products & applications	Technology
Materials: Multimaterials, metal powders. Products: ● Key: µ-connectors, environment monitoring, energy efficient buildings, customized health monitoring. ● Others: Printed parts, hearing aids, extrusion shells, biomed sensors, environmental MEMS. Application: Manufacturing, Energy, Health, Transport, Buildings.	• Multi-scale modelling & simulation of 3D printing processes; • Rapid micro-manufacturing 3D simulation for CAD/CAM enabling inline automatic redesign of machining strategies; • Numerical modelling for the predictive assessment of geometrical properties and residual stress of additive manufacturing (AM); • Numerical modelling of thermomechanical properties of anisotropic and isotropic material structures and multi material composites; • Synergistic models for (AM) surfaces; • Software packages for simulation of OEM applications.

Table 6: VC5-L-005.

The Value4Nano actions consolidated by this new action are VC3-S-001, VC3-M-001, VC3-L-002 and VC4-S-002 addressing the following topics (Annex 1):
Modelling tools for microfluidic behaviour of nanoparticles and/or advanced fluids; Simulations and proof of concepts on materials for energy storage (e.g. materials for natural gas storage); Development of new comprehensive methods and multiscale modelling across full value chains to

design new nano-related materials or to increase their TRL; Development of hybrid LCA/LCC and FE modelling techniques for smart lightweight composites.

The previous H2020 calls setting-up the basis for this action are NMBP-07-23-24 addressing the following topics (Annex 2):
Systems of materials characterization for model, product and process optimization; Advancing the integration of Materials Modelling in Business Processes to enhance effective industrial decision making and increase competitiveness; Network to capitalize on strong European position in materials modelling and to allow industry to reap the benefits.

The new VC5-L-005 action targets TRL3-4 under an RIA action launched beyond 2022.

4M2020 TOOL CHALLENGES

Modular, updatable and reconfigurable manufacturing solutions for micro/nano-enabled miniaturized products (VC5-S-006)

Scope: Deployment of advanced processing of novel (nano-) materials with micro-precision by existing and/or new micro- and macro-production equipment that have a modular design and integrated automation solution to implementing flexible and reconfigurable manufacturing platforms.

Development of advanced joining and assembly technologies for novel (nano-)materials that can be integrated in existing production and assembly lines or can be used as component technologies in the development of new manufacturing platforms.

Challenges: Novel (nano-) materials and their applications in new miniaturized products are continually being developed in universities, commercial laboratories, at material providers and in research oriented organizations around the world. Existing technologies are adopted or novel processing solutions have been developed for their processing, especially to retain their attractive mechanical and physical properties, and thus to improve the performance of existing technologies or develop new manufacturing platforms, such as lightweight solutions, or to enable new functionalities in highly flexible and reconfigurable systems for many different applications. To make objects for everyday use in customer and industrial applications, these novel (nano-) materials have to be used under controlled conditions in existing industrial processes (blending/mixing, additive manufacturing, subsequent processing, etc.).

Significant improvements are needed in the usage of existing production and assembly lines for novel (nano-)materials whilst addressing specific requirements in regards to their precision, speed, reliability, yield, quality, functionality and cost and validating their implementation in pilot line settings.

Increased capabilities are needed to provide value added products/services and flexibility to respond rapidly to the market dynamics by developing reconfigurable manufacturing platforms.

There needs to be an advance in the scientific and technical knowledge for enabling the broader use of novel materials in existing and new products by employing existing production and assembly lines and thus to readily create market opportunities for European industries.

Materials & Products & applications	Technology

Materials: polymers, CNTs, nanofibers. Products: ● Key: Customized health monitoring, environment monitoring, micro parts for wearable devices, µ-connectors. ● Others: Environment sensing devices, high precision polymer parts, thermosets for micro-injection moulding. Application: polymers transformation.	• Hybrid additive manufacturing ; • Hybrid micro manufacturing (milling, EDM, ECM, laser); • Laser micromanufacturing processes assuring high surface quality and functionalities.

Table 7: VC5-S-006.

The Value4Nano actions consolidated by this new action are VC1-S-003, VC1-S-004, VC1-L-002, VC1-L-003, VC1-L-004, VC2-S-003, VC2-M-003 and VC4-M-002 addressing the following topics (Annex 1):
Development of 3D printing systems (advanced material manufacturing approaches, additive manufacturing, metrology and smart software); Surface functionalization by structuration in injection moulding, embossing technologies and roll to roll; New generation of disruptive injection moulding machines; Development of customized solutions for printing processes ; Development and upscaling of 3D processes (e.g. direct laser writing and stereolithography) for more complex nanotructured components, for a breadth of applications e.g. health and PV; Novel processes and technologies for engineering surface modification and functionalities incorporation; Support innovative new technologies for efficient handling and manipulation of nanoparticles; Innovative manufacturing equipment for advanced nano-integrated materials (e.g. on-line characterization controls and operational standards compliance evaluation).

The previous H2020 calls setting-up the basis for this action are FOF-01-05-07 addressing the following topics (Annex 2):
Novel hybrid approaches for additive and subtractive manufacturing machines; Support for the further development of Additive Manufacturing technologies in Europe; Integration of unconventional technologies for multi-material processing into manufacturing systems.

The new VC5-S-006 action targets TRL3-4 under an RIA action launched in 2018.

4M2020 MULTI CHALLENGES

The Pilot Lines presented in the Value4Nano roadmap cover PL1 to PL4 (Annex 1). PL5 and PL6 are the two additional pilot lines identified by 4M2020. These two pilot lines are complementary: PL5 focusses on the materials and tools challenges of manufacturing of hybrid multi-material products whereas PL6 is dedicated to metrology and modelling. The proposed pilot lines are timely in a European context and provide a focus for the valorization of the results of recent H2020 funded activities.

Pilot line for standardized manufacturing of hybrid and structured materials with customized properties (VC6-S-007)

This pilot line relates to both **MATERIALS** and **TOOL** challenges and addresses the manufacturing of multi-material products that are enabled by the latest advances in both material engineering at nanoscale and multi-scale shaping/structuring/patterning technologies. The introduction of nanomaterials and/or nano-structured materials will enable functionalized surfaces of macro products and/or miniaturized components with enhanced properties (thermal, electrical, mechanical, biological). These novel materials will underpin existing and new emerging high impact products and

also the production lines for their scale-up manufacture. The pilot line must also address the standardization and unification of operating procedures to assess quality at various scales (materials & feedstocks, equipment & process, manufacturing, staff qualification).

It will enable processing of engineered materials at nano, micro and meso scales that builds upon PLs aim at in H2020 16-17 calls and also those proposed in NANOfutures 2015 roadmap. These PLs are focused on addressing multifaceted objectives from different application viewpoints. In particular, the following four aspects in the valorisation of nano-enabled technologies, services and products: i) application/product or process specific solutions/processes for families of materials; ii) increased spatial resolution (even down to atomic scale), accuracy, and reproducibility of engineered materials and their multi-scale shaping/structuring/patterning technologies; iii) the necessity to combine technologies in application specific pilot lines; iv) convergence of technologies driven by advances in KETs as more and more products, processes and materials integrate physical, chemical and biological principles from other scientific disciplines. In this context, PL5 aims to create the necessary underpinning technological pre-requisites for processing engineered materials at nano-scale by: i) implementing pilot technology platforms for achieving function and length-scale integration on large surfaces and/or in miniaturized multi-materials' products by consolidation and/or deposition of engineered materials; ii) enabling a systematic approach for synergistic process-material engineering and thus to enable the integration of different functions at surfaces and components' levels; iii) minimizing risks/uncertainties associated with the deployment of manufacturing platforms for processing engineered materials by pilot implementations of characterization techniques to enable process control, process optimization and quality assurance in applying synergistic process-material engineering.

The materials, products, applications & technologies associated to this pilot line are presented in Table 2, Table 3 Table 7.

The Value4Nano pilot lines consolidated by this new action are PL1, PL2, PL3 and PL4 addressing the following topics (Annex 1):
Nanostructured surfaces and nanocoatings; Manufacturing of lightweight multifunctional materials with nano-enabled customised thermal/electrical conductivity properties; Printed microfluidic MEMS and biological; Non mainstream Micro-Electro-Mechanical Systems and Architectures.

The previous H2020 calls setting-up the basis for this pilot line are NMBP-04-05-06, FOF-01-06-07-08, EEB-01, PILOTS-01-02-03-04 addressing the following topics (Annex 2):
Architectured /Advanced material concepts for intelligent bulk material structures; Advanced materials and innovative design for improved functionality and aesthetics in high added value consumer goods; Improved material durability in buildings and infrastructures, including offshore; Novel hybrid approaches for additive and subtractive manufacturing machines; New product functionalities through advanced surface manufacturing processes for mass production; Integration of unconventional technologies for multi-material processing into manufacturing systems; In-line measurement and control for micro-/nano-enabled high-volume manufacturing for enhanced reliability; Highly efficient insulation materials with improved properties; Pilot lines for manufacturing of materials with customized thermal/electrical conductivity properties; Pilot Line Manufacturing of Nanostructured Antimicrobial Surfaces using Advanced Nanosurface Functionalization Technologies; Pilot Lines for Manufacturing of Nanotextured surfaces with mechanically enhanced properties; Pilot Lines for 3D printed and/or injection moulded polymeric or ceramic microfluidic MEMS.

The new pilot line action targets TRL7-8 under an IA action launched on the 2018-19 period.

Pilot line for 3D-manufacturing, process, analytical and material interface control and modelling of products integrating hybrid and structured materials (VC7-M-008)

This pilot line relates to both **METROLOGY** and **MODELLING** challenges and addresses topics like 3D-manufacturing control, process control, analytical control and material interface for existing products integrating novel materials.

PL6 will be focused on the pilot implementation of manufacturing platforms with build in multisensorial capabilities (Cyber-Physical System), appropriate sensing devices (pyrometers, thermal cameras, vision cameras, etc.) and also post-process evaluation workstations (defectology check). PL6 should target zero defect fabrication of representative key components. The key components would require processing of novel materials for a given number of application sectors as initial targeted objectives. Materials to be measured should also be non-transparent. Surfaces should exhibit Ra values of less than 100nm. Structures to be inspected should have lateral dimensions smaller than 10µm. The measurement tasks should be focus on in-process 3D inspections of small geometric features with micrometer tolerances (e.g. replicated structures and/or machine functional micro structures/patterns)**.**

Modelling capacity will also numerically assist additive manufactured parts with improved reliability.

A large scale demonstrator should be developed for this pilot line that implements closed loop control strategies for optimization and deviations mitigation of micro-nano fabrication processes (e.g. production of miniaturized smart 3D-components, hybrid multi material products) taking into consideration the adaptability to the widest possible range of processes where online monitoring of processing accuracy and surface/structure functionality evolution can improve the final quality of the end product (geometrical, mechanical, electrical,…). The demonstrator would be a pilot manufacturing platform with build-in metrological multisensorial capabilities for executing wide-range in-line process monitoring and quality assessment procedures for miniaturized products (towards zero defect manufacturing capability).

Processing, structuring and integration of materials at different length scales with associated non-destructive methods for control & inspection should be implemented in PL6, i.e for: dimensional accuracy, simultaneous measurement, high aspect ratio structures, roughness, form and thickness, material quality, adhesion/joining properties of dissimilar materials. This will require integration of in-line 3D metrology in existing production and assembly lines with capability for large area scanning & processing. PL6 will integrate hybrid/multi-sensor in-line and high speed process metrology and characterization for quality assurance. A demonstrator featuring all these and other related quality assurance methods would be essential in underpinning development of capabilities for implementing zero-defect manufacturing strategies. Particular components with especially difficult-to-measure functional features/characteristics should be used for the demonstrator.

The materials, products, applications & technologies associated to PL6 are presented in Table 4, Table 5 Table 6.

No Value4Nano pilot lines are directly relevant to the new action.

The previous H2020 calls setting-up the basis for this pilot line are NMBP-07-23-24-25 and FOF-03 addressing the following topics (Annex 2):

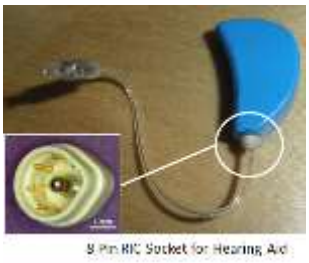
Systems of materials characterization for model, product and process optimization; Advancing the integration of Materials Modelling in Business Processes to enhance effective industrial decision making and increase competitiveness; Network to capitalize on strong European position in materials modelling and to allow industry to reap the benefits; Next generation system integrating tangible and intangible materials model components to support innovation in industry; Zero-defect strategies at system level for multi-stage manufacturing in production lines.

The new action must be a test-bed pilot line and thus to create the necessary pre-requisites for seamless implementation and validation of multi-stage process chains with capabilities for executing zero-defect manufacturing strategies. Especially, PL6 should target the implementation and validation of: i) multi-stage manufacturing solutions for serial manufacture of miniaturised products with diverse technical requirements that combines the capabilities of existing and new emerging material processing technologies (predominantly used currently as stand-alone processes); ii) process control and inspection modules as a flexible and scalable modular technologies for realizing close-loop processing configurations to enable zero-defect manufacturing strategies, especially for automated process setting-up and calibration, detecting or rectifying defective components and enabling ''zero-error'' interfacing of different material processing modules; iii) hybrid/multi-sensor in-line and high speed process metrology for quality assurance to prevent the propagation of products defects in multi-stage production lines; iv) data management, processing and decision support tools enabled by Industry 4.0 (I4.0)/Industrial Internet Things (IIoT) paradigms to achieve different levels of digitization (depending on the specific requirements of carefully selected demo products) and enable the execution of zero-defect manufacturing strategies.

The new pilot line action targets TRL6-7 under an IA action launched on the 2019-20 period.

IV- 4M2020 IMPACT (VC5)

Table 8 summarises VC5 expected impact on society distinguishing from industrial leadership, examples of products, societal Impact, excellence in science, and benefit for SMEs.

Value chain impact	
Industrial Leadership in target markets (from Roc-KET7 markets)	• Electronics and Communication Systems • Manufacturing and automation (including robotics) • Energy (including energy generation, storage, transmission and distribution) and environment (including water supply, sewerage, waste management and remediation) • Transport and mobility (including road, rail, marine and air transport as well as logistics, besides Space) • Health and healthcare
 Micro-parts for wearable devices  Customised health monitoring  Fuel cell for electric cars	
Societal Impact (from Societal Challenges of Horizon 2020)	• Health, demographic change and wellbeing • Secure, clean and efficient energy • Smart, green and integrated transport • Climate action, environment, resource efficiency and raw materials • Europe in a changing world - inclusive, innovative and reflective societies
Excellent Science	• Accelerate the uptake of advances in materials science to marketable applications • High dimensional quality additive manufacturing processes, and related materials • Multisensing and integrated knowledge for advanced quality toward zero-defect fabrication • Optical design; precision mechanical actuators; electronics with low power consumption and high processing power; wireless technologies with high data throughput • High entropy alloys offering higher thermal stabilities • Applicable understanding of the rheology of powder / fibre filled fluids and the sintering of CMC • New active components coming from natural materials; possible recycling and re-use; low-cost , low environmental impact • More flexible production in order to adapt products to application (including multifunctional bio-devices) • Laser-based micromanufacturing processes; MID technologies; thermoset injection moulding • Multimaterial products in harsh / extreme environment

	• Removing the barrier of computation time by high rate capture and processing of imaging data and the application of optical difference engines for real-time defect detection
Benefit for SMEs	• Development of novel, multifunctional products which open new market niches • Improve productivity for SME, by making it easy to custom manufacture solutions (high mix low quantity) • Generalised deployment of micro-components markets • Improvement of design capabilities, quality product, and micro-production control • Market opening and deployment based on product quality (including properties related to stability, surface quality, etc.) • Production of complex products with high integration for inserts or implants in humans bodies • Increase technological / knowledge basis, chance for European SME's to become technology leader • Strong traceability chain improves the ease and value of SMEs investing in metrology and process / quality control. Increases penetration in high value markets. • Investment reduction • Enabling vertical integration within industry 4.0 • Ease crossing the valley of death • Reduce the use of raw materials, reduce environmental impact

Table 8: VC5 Impact.

V- CONCLUSION

An extensive work has been carried out to collect and consolidate information within the 4M2020 community through several events spreading across the 2014-16 period. Analysis of the consolidated information showed that topics of interest identified by the 4M2020 community could fit a common theme which has been issued as a new VC5 value chain, according to NANOfutures/Value4Nano formalism. VC 5 carries the following title and forms the foundation for the 4M2020 roadmap:

VC5 - ADVANCED MANUFACTURING FOR MULTIMATERIAL, MULTIFUNCTIONAL PRODUCTS

A total of eight technical actions specific to 4M2020 needs have been prioritized within the new VC5 value chain concluding the roadmapping process presented in this report. These actions have been described in terms of scope, challenges, materials, products, applications and technologies. They have been mapped also across challenges and along the time scale to constitute, as a whole, the 4M2020 roadmap for Advanced Manufacturing for Multimaterial, Multifunctional Products.

As an ultimate goal, the new information held by VC5 is complementing the VC1-4 information issued by Value4Nano and will help guide lining the setting-up of future RI collaborative actions in the fields of advanced materials, processing and manufacturing.

Finally, recommendations can be also formulated based on the several exchanges between the 4M2020 team and the participants to all roadmap workshops :(i) coordinated and support actions (CSA) are required to harness synergistically the latest advances in processing engineered materials at nano scale with their machining/structuring/forming technologies at European level; (ii) a holistic approach is required in defining the scope of PLs and thus to encompass a wide range and complementary process-material engineering aspects with the underlining basic science and technology; (iii) the synergistic process-material engineering at nano scale together with I4.0/IIoT paradigms can underpin the design and implementation of a broad range of manufacturing platforms for miniaturised multi-material products that are not available in EU or elsewhere; (iv) there is a need for CSAs to re-enforce the joint research and industrial collaborations and thus to address the fragmentation of European expertise and capabilities in the “race” to capitalise on the latest advances in “bottom up” and “top-down” technologies for processing engineered materials at nano scale.

ANNEX 1 - Value4Nano related actions

Action ID	NANOfutures Action Title	Type	4M2020 interest
VC1-S-003	Development of 3D printing systems (advanced material manufacturing approaches, additive manufacturing, metrology and smart software)	RIA	
VC1-S-004	Surface functionalization by structuration in injection moulding, embossing technologies and roll to roll	RIA	
VC1-M-001	Development and enhancement of inspection technologies and methods for nanostructures over large areas	RIA	
VC1-M-003	Industrial oriented research and demonstration on injection moulding of polymeric-based products with nanostructured functionalized surfaces	RIA	
VC1-L-002	New generation of disruptive injection moulding machines	RIA	
VC1-L-003	Development of customized solutions for printing processes	RIA	
VC1-L-004	Development and upscaling of 3D processes (e.g. direct laser writing and stereolithography) for more complex nanotructured components, for a breadth of applications e.g. health and PV	RIA	
VC2-S-001	Advanced industrial research to enhance the performance of functional nanocoatings	RIA	
VC2-S-003	Novel processes and technologies for engineering surface modification and functionalities incorporation	IA	
VC2-M-003	Support innovative new technologies for efficient handling and manipulation of nanoparticles	RIA	
VC3-S-001	Modelling tools for microfluidic behaviour of nanoparticles and/or advanced fluids	RIA	
VC3-M-001	Simulations and proof of concepts on materials for energy storage (e.g. materials for natural gas storage)	RIA	
VC3-L-001	Developing joint interdisciplinary experimental platforms, including virtual platforms, with open access for SMEs	IA	
VC3-L-002	Development of new comprehensive methods and multiscale modelling across full value chains to design new nano-related materials or to increase their TRL	RIA	
VC3-L-003	Synthesis of 'hosted' nano particle systems for nanomedicine	RIA	
VC4-S-002	Development of hybrid LCA/LCC and FE modelling techniques for smart lightweight composites	RIA	
VC4-S-004	Composite or Hybrid Multifunctional Materials and Systems	RIA	
VC4-M-002	Innovative manufacturing equipment for advanced nano-integrated materials (e.g. on-line characterization controls and operational standards compliance evaluation)	RIA	
VC4-M-003	Advanced techniques for experimental assessment of nano-materials properties	RIA	
VC4-L-002	Encourage stronger industrial environment of cooperation and culture of funding for development of forthcoming technologies	CSA	

Table 9: Cross-interest between Value4Nano (VC1, VC2, VC3, VC4) and 4M2020

Pilot Line ID
PL1 - Nanostructured surfaces and nanocoatings, divided into: • Pilot 1a: Nanostructured antimicrobial, antiviral surfaces for medical devices, hospitals... • Pilot 1b: Nanocoatings for mechanically enhanced surfaces
PL2 - Manufacturing of lightweight multifunctional materials with nano-enabled customised thermal/electrical conductivity properties
PL3 - Printed microfluidic MEMS and biological applications divided into: • Pilot 3a: Nozzles, filters, sensor applications and multi-use chip • Pilot 3b: Bio-medical/bio-physicals sensors, actuators and other devices
PL4 - Non mainstream Micro-Electro-Mechanical Systems and Architectures" related to: • Pilot 4a: Advanced CMOS compatible digital fabrication • Pilot 4b: Cheap flexible hybrid or full polymer MEMS ecosystems

Table 10: Value4Nano VC1 to VC4 pilot lines.

ANNEX 2 – H2020-2016/17 related actions

CSA 2016	**NMBP-24-2016**: Network to capitalize on strong European position in materials modelling and to allow industry to reap the benefits; start at TRL 4 and target TRL 6. **FOF-05-2016**: Support for the further development of Additive Manufacturing technologies in Europe.
RIA 2016	**NMBP-06-2017**: Improved material durability in buildings and infrastructures, including offshore; start at TRL 4 and target TRL 6. **NMBP-23-2016**: Advancing the integration of Materials Modelling in Business Processes to enhance effective industrial decision making and increase competitiveness; target TRL 5. **FOF-01-2016**: Novel hybrid approaches for additive and subtractive manufacturing machines; target TRL 4-6.
RIA 2017	**NMBP-04-2017**: Architectured /Advanced material concepts for intelligent bulk material structures; start at TRL 4 and target TRL 6. **NMBP-07-2017**: Systems of materials characterization for model, product and process optimization; start at TRL 4 and target TRL 6. **FOF-06-2017**: New product functionalities through advanced surface manufacturing processes for mass production; target TRL 4-6. **FOF-07-2017**: Integration of unconventional technologies for multi-material processing into manufacturing systems; target TRL 4-6.
IA 2016	**EEB-01-2016**: Highly efficient insulation materials with improved properties**;** Levels 5 to 7 and to be centred around TRL 6. **PILOTS-01-2016**: Pilot lines for manufacturing of materials with customized thermal/electrical conductivity properties; start at TRL 4-6 and target TRL 7. **PILOTS-02-2016**: Pilot Line Manufacturing of Nanostructured Antimicrobial Surfaces using Advanced Nanosurface Functionalization Technologies; start at TRL 4-6 and target TRL 7. **FOF-03-2016**: Zero-defect strategies at system level for multi-stage manufacturing in production lines; 5 to 7 and to be centred around TRL6.
IA 2017	**NMBP-05-2017**: Advanced materials and innovative design for improved functionality and aesthetics in high added value consumer goods; start at TRL 4-6 and target TRL 7. **NMBP-25-2017**: Next generation system integrating tangible and intangible materials model components to support innovation in industry; target TRL 6. **PILOTS-03-2017**: Pilot Lines for Manufacturing of Nanotextured surfaces with mechanically enhanced properties; start at TRL 4-6 and target TRL 7. **PILOTS-04-2017**: Pilot Lines for 3D printed and/or injection moulded polymeric or ceramic microfluidic MEMS; start at TRL 4-6 and target TRL 7. **FOF-08-2017**: In-line measurement and control for micro-/nano-enabled high-volume manufacturing for enhanced reliability; 5 to 7 and to be centred around TRL6

Table 11: H2020 2016/17 related actions.

[i] D5.2 - Roadmap workshop findings (31th August 2015)

[ii] Integrated Research and Industrial Roadmap for European Nanotechnology, NANOfutures Coordination and Support action (Grant agreement no 266789) – 2012.

[iii] Implementation Roadmap on value chains and related pilot lines, Value4Nano: Industrial valorisation of strategic value chains for nano-enabled products (Grant agreement no. 608684) - 2015