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An overview on European Manufacturing research visions and roadmaps as an answer to economical and societal challenges and opportunities

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Abstract

This document provides an overview on European Manufacturing research vision and roadmaps. In 2017, a year of crossroads for the research community, a joint and collaborative Europe-wide effort is needed to define the main research priorities. This paper provides an overview on the ongoing roadmapping work and proposes some research lines that could become the core of the European manufacturing research strategy.

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1. Introduction

This contribution provides an overview on European Manufacturing research vision and roadmaps. 2017 is a year of crossroads at the European manufacturing research and innovation arena: the framework program for research and innovation, Horizon 2020, comes to its mid-term, its first years will be evaluated and the research agendas for the last

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three years will be defined; negotiations will start in order to define the broad lines of the next (2021-2027) framework program (FP9) [1-2]; a new KIC (Knowledge and Innovation Community) will be established in the frame of added value manufacturing [3]; the MANUFUTURE Technology Platform will issue its updated Vision document [4] and, last but not least, diverse pan-European, national and regional initiatives (RIS 3 initiatives) will address the digitalization of manufacturing industries (Industry 4.0 and the like) [5-10]. All these initiatives, inter-related and very relevant in the manufacturing research and innovation arena, are defining or will define in the short term research visions and roadmaps, i.e., structured views on research priorities. This paper explain the main contents of these initiatives, their inter-relations and the rationale behind, with the aim of addressing Europe-wide economical and societal challenges.

2. Methodology or Experimental Procedure

This work is based on the analysis of existing manufacturing research plans and roadmaps, issued by diverse initiatives, Europe wide such as Manufuture, Factories of the Future, the AVM KIC, as well as some relevant national and regional initiatives. The authors have elaborated on top of that ground their views on the research and innovation agendas, highlighting the common priorities and the most relevant aspects for the manufacturing research community. These views have been discussed and assessed at diverse levels, such as the Manufuture High Level [4] Group or the EFFRA (European Factory of the Future Research Association) Partnership Board and Governing Board [2].

2.1. Manufuture

ManuFuture is a European Technology Platform and, therefore, one of its main objectives is to provide guidance, mainly to industry, about the future prospects of science and technology and their impact on the future of European manufacturing. With this purpose, at its Vision 2030 document to be published this year, Manufuture highlights some needs and opportunities that arise from the European manufacturing industry, as well as the potential contribution to address these industrial challenges by means, mostly, of technological developments but without forgetting the contribution from both the basic sciences and the social sciences and humanities.

European society is facing diverse challenges (demographics, energetic, environmental, employment, European socioeconomic model...) and so does industry as well (increasing competitors worldwide, mass customization, scarcity of raw materials...). Science and Technology contributes to addressing part of these challenges and may provide solutions to them. Some of the contributions will be in niche areas, where deep scientific specialization is needed; others will address complex challenges by means of multidisciplinary approaches. The Vision 2030 document emphasizes in contributions from the engineering and technology areas, from the basic sciences ad from social sciences and humanities. The main contribution from the scientific and technological field to the competitiveness and innovativeness of manufacturing comes from the diverse engineering fields and, more specifically, from manufacturing science and technology combined with associated advances in e.g. digital and materials sciences (including micro and nanoscale) and engineering. Therefore, relevant contributions are expected from production technologies, with the development and integration of new production processes and from manufacturing systems engineering that will reinforce the European capability to design, manufacture and provide globally the best production equipment and systems. More specific fields of engineering will also contribute to better European products and factories, as well as to better service provided by European manufacturing industries. The role of product design engineering, mechanical engineering, mechatronics, and electrical and electronical engineering will be crucial.

A revolutionary influence will be in the digitalization of industry: cyber-physical production systems, cloud and edge based manufacturing, manufacturing as a service and smart manufacturing are expressions that emphasize how digitalization fundamentally change manufacturing paradigms and provide the means to address challenges such as mass customization and the need for continuous improvements in flexibility, productivity, accuracy, security and sustainability.. It is crucial that the manufacturing community can develop and exploit the associated technologies (eg. artificial intelligence, robotics, wireless connectivity, big data, digital platforms & standards, as well as next generation connectivity, MEMS, sensors and energy harvesting technology) to the best benefit of European production sector. Also the effective digital value chain from early design to manufacturing and use is important, with a remarkable example of 3D printing (but not limited to that alone). Some of the technologies will impact the physical properties of the European components and products as well as the processes needed to manufacture them: materials engineering,

process engineering or chemical engineering will play a key role. Besides, the full life-cycle of products and processes must be considered and therefore, technologies related to environmental engineering and industrial biotechnologies will strongly contribute to the sustainability of European industry.

On the other hand, Basic Science has been the engine for innovative solutions through decades and this is still the case. Europe is a strong global player in basic science but the connection of basic science with more applied research and technology development needs to be reinforced. For this purpose, new Europe-wide instruments are needed where this connection will take place, where the flow of knowledge from basic science to applied research and innovation will be ensured. The future of manufacturing will rely, therefore, on scientific discoveries coming from diverse fields: applied mathematics and computer sciences will impact e.g. manufacturing networks, industrial cyber security, complex manufacturing processes and systems modeling, a renewed era of artificial intelligence and learning systems, novel human-technology interaction. Physical sciences (e.g. materials, nano/micromaterials, functional materials, magnetics, superconductivity, fluids, plasma, quantum science ...) as well as chemical sciences (e.g. new polymers, batteries...) and biological sciences (e.g. new synthetic biological processes, biopharmaceuticals) may impact on many fields, related to the properties of product materials, the way they are processed, new integrated devices, etc. Finally, in an increasingly complex society as well as increasingly complex manufacturing value networks, most of the challenges cannot be faced by science and technology alone. Human behavior, perceptions, emotions, as well as social aspects related to the type of society we want in Europe, and also in the rest of the world, the relationships between stakeholders, etc. require approaches that will combine technical matters, as described in the previous paragraphs, as well as knowledge related to humanities and social sciences.

One of the challenges relates to making more attractive products in Europe, to offering better places to work, at the end, to being able to generate positive emotions to the people involved in one way or another with manufacturing. This leads to considering aspects not only of marketing or communication, but also arts for product design or to architectural design for plants and working offices design. Also, the role of the manufacturing worker will be changed from manufacturing operations towards e.g. maintenance, monitoring and IT support. The fields of economics and business can provide new proposals and insights about new Business Models, industrial relations, production management, networked enterprises, all these aspects being very relevant to the future of our industry. In addition, there is a need to address the framework conditions of our economy and industry, to set European (and world-wide) standards, to address working conditions... Law and Political sciences, as well as Ethics will play a role in these subjects. Finally, an aspect of relevance to European manufacturing relates to the perception of manufacturing, the role of women and men in the factories, how to make these factories more attractive to young talents, life-long training of industrial workers, fostering entrepreneurship... Education, psychology and sociology will have their say about these matters.

2.2. Factories of the Future

Factories of the Future (FoF) is the manufacturing R&D public-private-partnership (PPP) in the frame of the European research program Horizon 2020. The European Factories of the Future Research Association (EFFRA) brings together manufacturing research stakeholders (Companies, research and technology organizations, universities) and represents the private side in the FoF PPP. In the frame of the strategic discussion with the European Commission about the 'Factories of the Future' work program 2018-19-20, covering the three last calls under Horizon 2020, EFFRA prepared a document, 'Factories 4.0 and beyond', that is providing a set of recommendations to support this discussion through a set of key priorities and research headlines. The key priorities and research headlines described in this document are heavily supported by the vision laid out by the FoF2020 roadmap which is the basis of the contractual arrangement for the Factories of the Future PPP. Although submitted to the European Commission at the end of 2013, the FoF 2020 roadmap contains many pointers to concepts that are heavily promoted under the name 'Industry 4.0'. This was not surprising since the Industry 4.0 initiative was created during the same period as the compilation of the FoF 2020 roadmap. In order to stress this strong relation and coherence, this document carries the title 'Factories 4.0 and beyond'. The document indicates how the FoF PPP 18-19-20 work program can further implement this vision in synergy with the ongoing waves of Industry 4.0 while building on the past and ongoing achievements of the FoF PPP. The following set of key priorities describes the main focus areas and targets at the 'Factories 4.0 and beyond' document (fig. 1): **Agile value networks**; **Excellence in manufacturing** (Advanced manufacturing processes and services for zero-defect processes and products); **The human factor** (Human competences in synergy with

technological assets); **Sustainable value networks** (Manufacturing in a circular economy); and **Interoperable digital manufacturing platforms** (supporting and eco-system of manufacturing services). Digital platforms will play an increasing role in the achievement of the other key priorities. The key priority ‘Interoperable digital manufacturing platforms’ therefore plays a pivotal role in the realization of Factories of the Future. The key priorities are heavily building on the vision laid out by the FoF2020 roadmap.

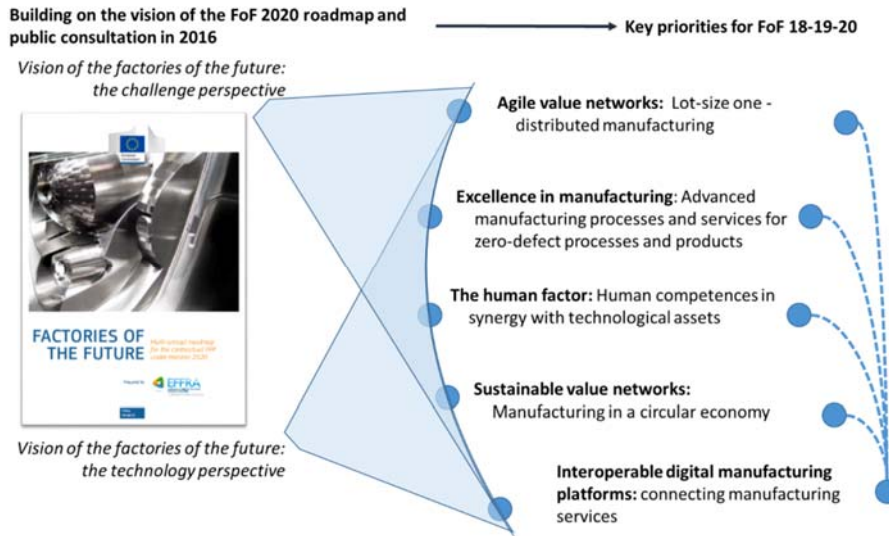


Fig. 1. Vision of the factories of the future and some key priorities

2.3. RIS3 strategy: Smart Specialization in Advanced Manufacturing

Figure 2 gives the distribution of regions with priorities in advanced manufacturing.



Fig. 2. Distribution of regions with priorities in advanced manufacturing (source S3 platform)

The concept of ‘Smart specialization’ was developed by the “Knowledge for Growth” expert group advising the European Commission. Smart specialization is defined by the group as “an entrepreneurial process of discovery that can reveal what a country or region does best in terms of science and technology....a learning process to discover the research and innovation domains in which a region can hope to excel”. This implies regions should seek to ensure a more effective use of public and private funds by concentrating resources on few key priorities rather than spreading investment thinly across areas and business sector. As part of the Europe 2020 strategy, the Commission adopted the “Innovation Union” flagship initiative. It sets out a comprehensive innovation strategy to enhance Europe's capacity to deliver smart, sustainable and inclusive growth and highlights the concept of smart specialization as a way to

achieve these goals. In the particular case of Spanish regions, the main lines related with Advanced Manufacturing are available in [5, 6] and are mainly associated to the KETs on Advanced manufacturing systems and on Advanced materials.

2.4 *Vanguard Initiative*

Created in 2013, the Vanguard Initiative (VI) [7] currently groups 30 European regions eager to strengthen their industrial partnership by mobilizing and aligning resources on the basis of the principles of smart specialization and interregional cooperation. The ultimate aim of the Vanguard initiative is to contribute to the European industrial renaissance by developing collaborative projects very close to the market and arising as a result of an interregional entrepreneurial discovery process between the different actors of the triple helix (companies, technological centers and Universities). Regarding the technical objective, as a result of the process of entrepreneurial discovery among all the member regions of the VI, 5 pilot actions have been defined:

- **Efficient and Sustainable Manufacturing** (led by Lombardy and Catalonia) which objective is to create a network of demo sites and pilot lines at regional level that will enable manufacturing companies in different sectors, including SMEs, to develop and introduce highly efficient and sustainable processes, technologies, systems and methods. The ESM initiative [8] will promote the utilization of enabling technologies within the framework of the following two main domains: (i) Manufacturing efficiency, with the goals of increasing throughput, quality and reducing costs; and (ii) Environmental and social sustainability of manufacturing, with the goals of reducing energy, materials consumption and emissions, and increasing the inclusion of humans in the factories. The Spanish regions involved in this project are Catalonia, Euskadi, Navarra and Galicia. The demo cases currently under development are De and Remanufacturing, Adaptive and Intelligent Manufacturing, Manufacturing of Advanced Components and Materials, Digital and Virtual Factory and Efficient Manufacturing Processes.
- **Advanced Manufacturing for energy applications in hostile environments** (led by Euskadi and Scotland) is an initiative to promote interregional cooperation in industrial and technology development among European firms making equipment and components for marine renewable energy, such as wave or offshore wind power, and energy extraction in harsh sub-sea and deep-underground environments, such as oil and gas drilling. The current themes for development of demo cases are Real condition testing of new materials for offshore: composites, steel, ductile iron and light metals; Cost-effective power transfer; and Optimized corrosion management – including modeling, sensing and design. The Spanish participating regions are Euskadi, Asturias, Navarra and Andalucia.
- **High performance production through 3D printing** (led by Flanders and North Brabant) which goal is to create a network of industry-led demonstrators across European regions to improve the uptake of solutions provided by 3D-printing technologies. By exploiting the potential of regions, regional clusters and of interregional collaboration at the level of demonstration and piloting activities, development of the emerging industry in 3D-printing will be accelerated on the basis of organized complementarities (smart specialization). For this project, the demo cases currently under development are Automotive (Hybrid Materials for Lightweight, Structural Components metal-CFRP; Functionally Graded Components); Machinery & Tooling (Structural Parts with Complex Shapes); AM-Subtractive Platform (3D additive subtractive transversal pilot line concept); Creative Industries (3D Printed wearables, lighting and decoration, fashion); Textiles (Adding a dimension to 2D textiles); 3DP Smart Bike (Open source platform for customize bike and accessories); and Healthcare (Customized protheses and exoprosthesis components). The Spanish participating regions are Asturias, Catalonia, Andalusia and Aragon.
- **Nanotechnology** (led by Tampere and Skane).
- **Bioeconomics: innovative uses of biomass** (led by Lombardy and South Holland).

2.5 *MANUKET platform*

MANU-KET is established as the Spanish Technological Platform for Advanced Manufacturing [9]. Its aim is to identify technological needs required by future products and services, in which the incorporation of advanced materials, microelectronics, photonics and nanotechnologies (all of them, considered Key Enabling Technologies as defined by the EC) require new processes, equipment and production systems with new levels of productivity, safety, functionality or precision. These new technological developments will place Spanish companies in positions of international competitive and leadership. The technological platform MANU-KET will deal with the needs identified by the five key enabling technologies and their impact on the developments to be taken by the following innovation

lines (fig. 3):

- **Advanced Manufacturing Processes** which major challenge is how to produce more using fewer resources (how to save materials through new manufacturing approaches and how to minimize energy consumption during manufacturing).
- **Smart and Adaptive Production Equipment.** Innovative Information and Communication Technologies tools (ICTs), as well as the introduction of mechatronic components into key machine components, new and advanced structural materials or systems able to increase process stability by damping or suppressing vibrations, for example, contribute to achieve flexible, autonomous and reconfigurable manufacturing systems, able to respond to product customizations or to respond quickly to new requirements that may ask the markets.
- **Human-Machine Collaboration.** In that sense manufacturing systems with embedded intelligence will be able to interact with the user, providing him/her with key information at specific times (maintenance, repair, tuning, optimization...). Because of it, the job will gain more attractiveness (mainly for young people) and will be also safer for the employee. These intelligent production systems will be able also to interact with the operators to collect, store and transmit employee's knowledge and expertise and not to lose it when the employee left the company.
- **Digital, Virtual and Efficient Factories.** New paradigms in the way plants are designed and managed leveraging the best practices of enabling technologies are required to cope with competition and sustainability related issues. Simulation, modeling and forecasting tools will help to reduce costs and manufacturing defects due to imperfections on the manufacturing systems and/or processes and during the design or the operation phases. The virtual models in the company will extend beyond the machines, dealing with issues such as plant logistics, layouts, process planning, technology selection, operation, execution, etc.
- **Customer Centric Manufacturing.** Concepts, around product and process customization, lead time reduction, new trends on market requirements, small series production, and access to raw material or environmental footprint, will determine how the future manufacturing technologies should look like.
- **Sustainable Manufacturing.** Actual technologies, strategies and industry trends aimed at reducing the consumption of materials and waste recycling, allow us to analyze sustainability from different points of view: sustainability oriented to reduction on raw material consumption and increase recycling, sustainability regarding energy due to machine technologies and processes able to minimize energy needed in the manufacture of components; and finally, the environmental sustainability regarding the generation of waste, environmental footprint, noise, etc.

The roadmap developed by the MANUKET platform should serve as a basis for the calls of the Spanish Ministry of Economy, Industry and Competitiveness.

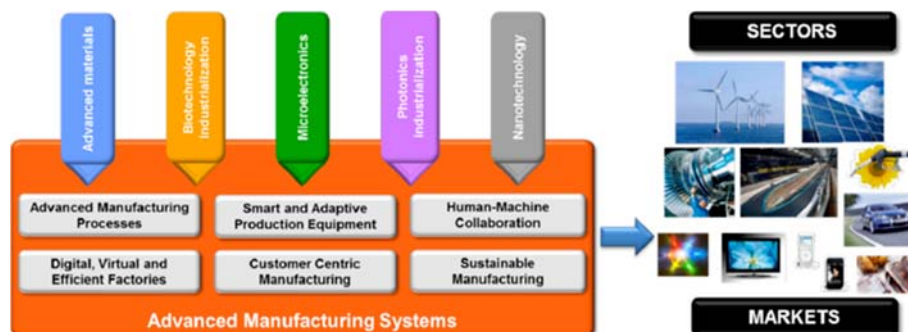


Fig. 3. Innovation lines of the MANUKET Platform

2.6 Eureka SMART cluster

The SMART cluster is a Spanish initiative led by Mondragon Corporation and approved in June 2017 to boost the competitiveness, growth and attractiveness of the European discrete manufacturing industries through the promotion of collaborative R&D&I among key stakeholders of the value chain (Large industries, SMEs, Research Institutes and Academies) [10]. It encourages cooperation and development of Large and SME manufacturing companies through rapid exploitation and implementation of innovative products, advanced services and innovative manufacturing processes. This vision requires the development of a systemic link between the optimal use of innovative

manufacturing technologies complemented by a new generation of skilled people entering industry, universities and research. This development will build on the current strengths of the EU discrete manufacturing sector with its leading capabilities and technologies in simulation, modelling, automation, processing and servitizing. Priority application sectors targeted by SMART cluster include Aerospace, Automotive, Railway, Energy, Capital goods, and Consumer goods sectors. The SMART Roadmap document defines the challenges, barriers, objectives and technologies that each application sector requires in relation to advanced manufacturing. Building on the "Factories of the Future 2020" multi-annual strategic research roadmap produced by Manufature European Technology Platform's EFFRA, the seven research and innovation domains which have been considered are those defined in §2.7 plus Value chain integration. SMART will be focused in achieving strong proximity with end market needs, that is, with high TRLs (TRLs 5-8). It will support R&D projects at the junction between innovation, product development, and production, the critical zone where many innovations die and never reach the market place.

3. Results and Discussion

The advanced manufacturing thematic has been attracting increased interest in the recent period as one of the key sectors for supporting economic growth and job creation in Europe. Concerning Advanced manufacturing systems, the category related to technologies for Factories of the Future is clearly the one in which regions have expressed most priorities, possibly as this may be linked to the sectorial or thematic priorities for regional development (Table 1). It might be linked to the presence of traditional industrial sectors or basins in the respective regions. The examples of Catalonia and Puglia should be highlighted in this context. The two regions have the expressed Smart Specialization priorities on the basis of articulated regional economic development strategies. Regions also indicated some priorities concerning sustainable and low carbon technologies in energy-intensive process industries. For example, Cataluña indicated that through the **Vanguard Initiative**, several proposals for pilot projects in this field were being drafted together with other regions, in particular focusing on **energy efficiency, emissions, waste and materials into global manufacturing processes**. This also highlights another issue concerning the inter-regional cooperation dimension.

The most common priority for the European regions in the *main categories* of “research and innovation capability” and “business areas and target markets”, is manufacturing and industry (34.6 and 35.3% respectively), probably because this sector encompasses large parts of the economy. Moreover, an important goal of smart specialization is to stimulate R&I activities linking industry and research, in order to create structural change.

Table 1. Responding regions in Advanced Manufacturing systems subKETs

SubKET category	Regions
Technologies for Factories of the Future	Berkshire, Buckinghamshire and Oxfordshire, Scotland, Norra Mellansverige, Pohjois-Pohjanmaa, Norte, Mazowieckie, Puglia, Languedoc-Roussillon, Haute-Normandie, Bretagne, Catalonia, Castilla y León, Euskadi, Sachsen, Region Wallonne
Sustainable and low-carbon technologies in energy-intensive process industries	Berkshire, Buckinghamshire and Oxfordshire, Norra Mellansverige, Pohjois-Pohjanmaa, Norte, Mazowieckie, MALTA, Puglia, Languedoc-Roussillon, Euskadi, Catalonia, Moravskoslezsko, Région Wallone.

The main instruments to implement the Advanced Manufacturing Program (AMP) priorities are the Horizon 2020 program (AMP program) and the Public Private Partnerships implemented through open calls under Horizon 2020, notably Factories of the Future and SPIRE (Sustainable Process Industry through Resource Efficiency). In addition, there are other PPP's which may be relevant for this sector in the area of Robotics, Photonics and the European Green Vehicles Initiative (EGVI).

Many initiatives have been developed concerning advanced manufacturing. The successive Commission Industrial Policy Communications have established an articulated policy framework. The planning and coordination of the support measures and other programs related to this sector should also be reviewed in detail. In this context for instance it is necessary to consider what may be the most effective types of intervention. The various types of dynamics between the possible instruments (LEIT-NMP, Vanguard, PPPs, etc.) should also be closely considered. How can the existing or planned initiatives be leveraged? How can possible synergies between the various instruments be further developed?

Concerning technologies for Factories of the Future, where regions have expressed most priorities, the question arises whether the foreseen investments correspond to the need to support traditional industrial sectors or basins in the

respective regions or to the establishment of new capabilities to meet the foreseen development objectives of the regions.

It appears that the regions will increasingly use both EU financial instruments and regional investment/VC etc. to support the development of SMEs in targeted (RIS3) sectors and the diffusion of KETs. Technology transfer actions aimed at SMEs and technological research support are the most used measures by the Regions. Both are rather traditional measures and well embedded in regional RDI ecosystems. The maturity of technology transfer and commercialization initiatives has been a major focus and priority of European Structural and Investment Funds (ESIF) support in the previous programming period. For example in Germany we seen the establishment of PVA (Patent Valorization Agencies) in most Lander and in France SATT (Technology transfer accelerators) have been set up in half of French regions. In both cases the transfer actions are focused on the thematic strengths of the region and in line with the current RIS3 priorities.

4. Conclusions

The European research and innovation landscape has changed over the last 12 years. After the first years of the XXI century, where the relevance of manufacturing and industry was close to be neglected in many of the European countries and regions, now the European societies in general, together with all relevant stakeholders (industries, universities, RTOs, decision makers...) are aware of the importance of having a strong manufacturing industry for a sound economy and a better society. All this means that manufacturing R&D is relevant at all involved research agendas, at European, national and regional levels. In order to promote and support manufacturing related research, public administrations, as well as engaged industries, have recently developed manufacturing research plans, where diverse visions and roadmaps have been defined and used to guide the research activities. This paper summarises the most relevant contents of these guiding documents, where some trends, relevant to all of them, can be identified: the digitalisation of the industry, the sustainability aspects, new processes such as additive manufacturing, the role of humans in manufacturing...

These vision and roadmapping activities will be ongoing activities during the next years, where this type of documents will be renewed and updated, addressing new social and industrial needs, as well as the opportunities that will arise from new scientific and technological results.

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