European TOOLING Platform

TOOLING TECHNOLOGY ROADMAP

2030

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Content

1. Why a ROADMAP?

A ROADMAP is a strategic tool that allows the identification and mapping of future, coherent and aligned development paths over a certain period. Thus, a ROADMAP allows us to present the main paths for future technological developments, assisting in the future investment decisions of companies and institutions, helping to develop R&D and innovation skills, new products, new processes and activities. A ROADMAP encourages entrepreneurship and start-ups in strategic and differentiated areas, supports value chain and market expansion, and helps companies to find alternative solutions to today's economic, political and environmental challenges of the markets.

The ROADMAP also supports policy decisions as well as the creation of new public policy instruments to support economic and social development.

2. European Tooling Industry Context

The European Tooling Industry is a multi-disciplinary industry assuming a key position in global value systems, instrumental to the deployment of product-service systems, providing “infrastructural” support to economy.

Tooling is a horizontal enabler, being one important and fundamental pillar of the whole European industrial structure, whether on the development and industrialization of new products, or on the sustainability of industrial employment. Tooling, Mold and Die Making companies are infrastructural strategic players towards the development, sustainability and digitizing of the European Industry, promoting the Circular Economy.

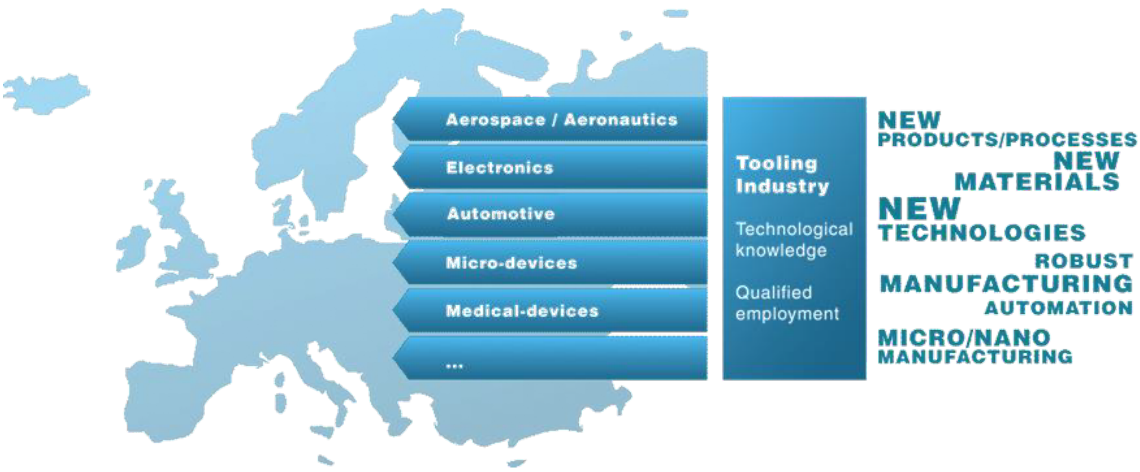

Figure 1. Tooling Industry is in the critical path of product development.

The Tooling Industry is a capital intensive and knowledge-based-Industry, supported in innovation and playing the rules of global co-opetition. Molds, Dies and Tools are present in the design and manufacturing of almost all industrial products, from aeronautics and automotive, to electronics, household, equipment goods and micro-devices. Having interfaces to the final parts (products and components) and production equipment (such as, machine-tools), the

Tooling industry is in the core of the production system of final products, determining its competitiveness, efficiency and robustness.

Product innovation, technological development and the optimization of the whole manufacturing system strongly depend on innovations and developments in Molds, Dies and Tools. Tooling costs and time to market, as well as their quality and reliability, are key competitive factors, which, directly or indirectly, have a structural and horizontal strategic effect in the sustainability of the European industrial competitiveness.

3. Market and Challenges

The Tooling Industry (molds, dies and special tools) in Europe represents an average annual turnover of 12 billion € and comprises more than 8.100 companies, being 95% of them SMEs, representing a high added value workforce (more than 115 000 workers directly in the sector) with a remarkable know-how in design and manufacturing processes. Tooling companies have remarkable know-how in design engineering and manufacturing technology.

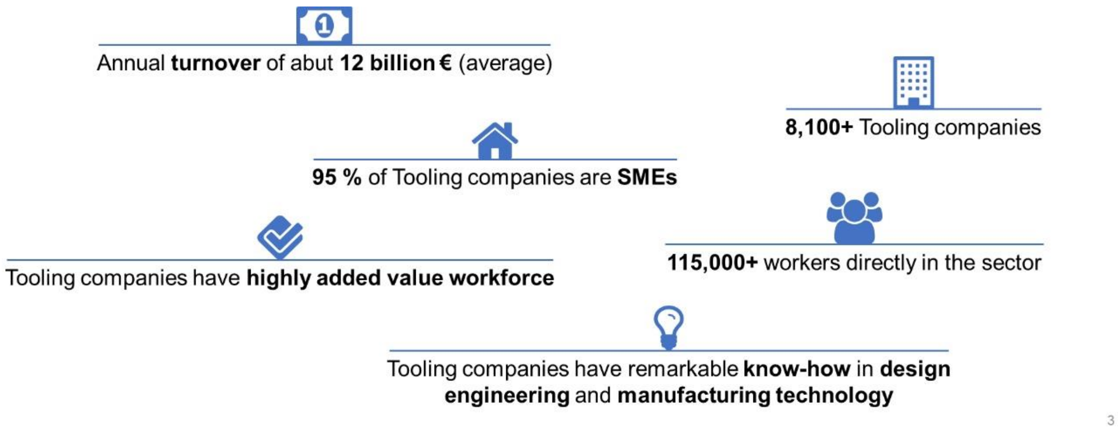

Figure 2. European Tooling Market facts and figures

The European Tooling industry, is recognized as one of the most technologically advanced at world-wide level, based on a wide range from design to the production of products and components in plastic, metal and composites, for the various sectors of activity. Tooling means offering a diverse portfolio of qualified high complex products.

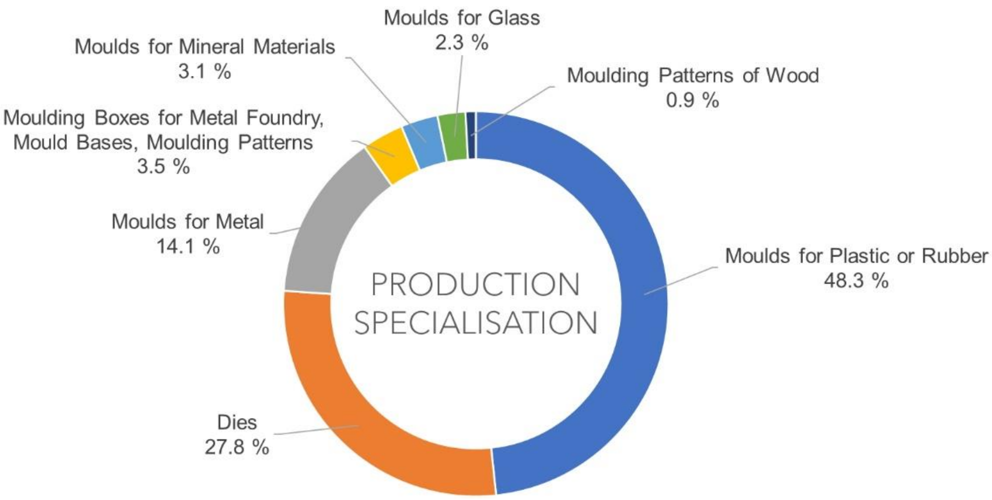

Figure 3. Tooling distribution per application

It is no longer new that we are living in challenging times of great uncertainty, on a path to the future, which presents difficulties in anticipating and mitigating risks.

The phenomenon of the globalization of markets is reaching limits that have never been experienced before and most of the time does not allow to perceive the origins of business and investment decision-making (such is the network of crossed multinational capital, the pressures for the accelerated transfer of skills and knowledge to developing countries, and the unregulated impositions of impossible prices that are not compatible with the real cost structures of organizations).

As if this was not enough, we are witnessing a process of digital transformation of the economy, "INDUSTRY 4.0", complementing the robotization/automation of production processes, assuming the *Internet* as the basic infrastructure of business, which challenges the current model of economic and social development.

In addition, we are witnessing a tremendous effort on the part of companies (SMEs) to integrate international value chains in the offer of sophisticated "turnkey" solutions of high modernity and technological complexity (*turning into intensive capital and knowledge*).

In this sense, the strengthening of intelligence activities (strategic information capture) is becoming increasingly important for the foreseeing of market opportunities.

Despite the adversities, the Tooling Industry in Europe keeps growing as can be seen in the following graphic.

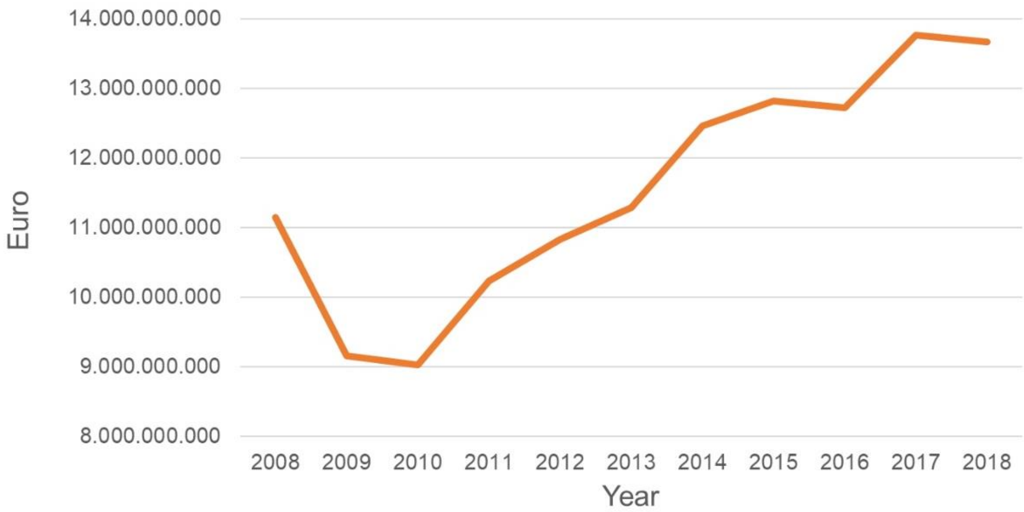

Figure 4. European Tooling Growth

The Tooling industry seeks to address these challenges in higher value-added markets (automotive, aeronautics, health, energy, electronics and packaging) as they are moving towards areas of high development, involving highly advanced products and new materials.

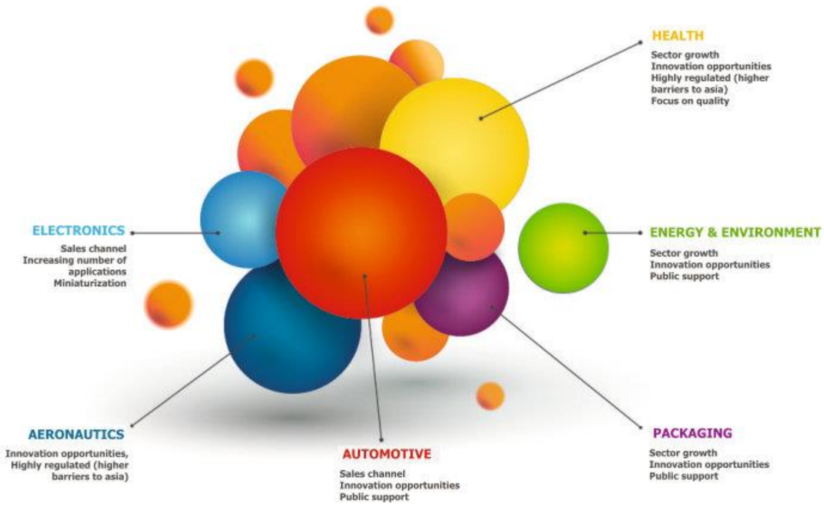

Figure 5. Markets and challenges for Tooling

On other hand, European Tooling companies should be focused and supported on important main drivers for their competitiveness:

- Develop new products, tools and components within the tooling value chain, in order to create greater added value for customers.

- Innovate on Products and Manufacturing Processes, in order to present to the World Market an extended value chain based on engineering services.

- Develop and produce special tools and high-precision machined parts with high added value for the customer, based on a strong commitment to product and manufacturing process innovation.

- Diversification of supply in sectorial and geographic markets, characterized by the high rigor of quality and added value for the customer.

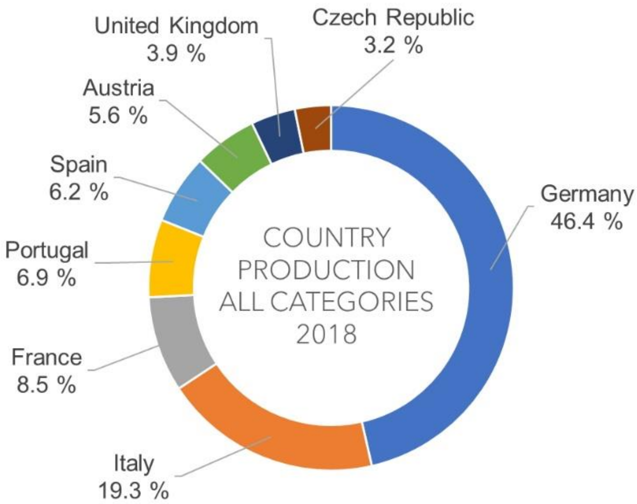

Figure 6. Geographic markets tooling diversification

Finally, European tooling industry should meet the increasing global consumer demand for greener, more customised and higher quality products through the necessary transition to a demand-driven industry with lower waste generation and energy consumption.

4. The European Vision - HORIZON 2020

Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020) – in addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market.

Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness.

Seen as a means to drive economic growth and create jobs, Horizon 2020 has the political backing of Europe’s leaders and the Members of the European Parliament. They agreed that research is an investment in our future and so put it at the heart of the EU’s blueprint for smart, sustainable and inclusive growth and jobs.

By coupling research and innovation, Horizon 2020 is helping to achieve this with its emphasis on excellent science, industrial leadership and tackling societal challenges. The goal is to ensure Europe produces world-class science, removes barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation.

Horizon 2020 is open to everyone, with a simple structure that reduces red tape and time so participants can focus on what is really important. This approach makes sure new projects get off the ground quickly – and achieve results faster.

The EU Framework Programme for Research and Innovation will be complemented by further measures to complete and further develop the European Research Area. These measures will aim at breaking down barriers to create a genuine single market for knowledge, research and innovation.

Source: https://ec.europa.eu/programmes/horizon2020/what-horizon-2020The H2020 consists of three programmatic pillars with different scopes:

- Pillar I - Scientific Excellence
- Pillar II - Industrial Leadership
- Pillar III - Societal Challenges

Figure 7. Official website of HORIZON 2020.

Source: http://ec.europa.eu/programmes/horizon2020/

5. Horizon Europe

HORIZON EUROPE will build on the achievements and success of Horizon 2020, bridging the past and the future of research and innovation in Europe. The European Commission has published the proposal for the next Research and Innovation Framework Program, set to launch in January 2021 until 31 December 2027 with an overall budget allocation of around **EUR 97 billion** (of which EUR 3,5 billion are allocated to the InvestEU Fund) and EUR 2.4 billion for the Euratom Research and Training Program.

The HORIZON EUROPE is structured on three pillars: **Excellent Science, Global Challenges and European Industrial Competitiveness and Innovation Europe.**

The **Excellent Science** pillar will support scientific excellence in a bottom-up approach to reinforcing Europe's scientific leadership, knowledge and skills development through the European Research Council (ERC), the Marie Skłodowska-Curie Actions (MSCA) and the Research Infrastructures.

The **Global Challenges and Industrial Competitiveness** pillar includes the clusters: Health; Inclusive and Insurance Societies; Digital and Industry; Climate, Energy and Mobility; and Food and Natural Resources. This pillar is based on a top down approach, is aligned with European and international policies (e.g. the Sustainable Development Goals) and has cooperation and competitiveness as catalysts. This pillar will include missions on cross-cutting themes that ensure socio-economic impact as well as partnerships with industry (JTIs) and Member States.

Innovation will be supported across the whole of the HORIZONTE EUROPA program, but it is the third pillar, Open Innovation, that focuses on creating new markets through the European Innovation Council (EIC). The EIC will leverage the European innovation ecosystem, act as a one-stop shop for high potential innovators and secure support for the European Institute of Innovation and Technology (EIT).

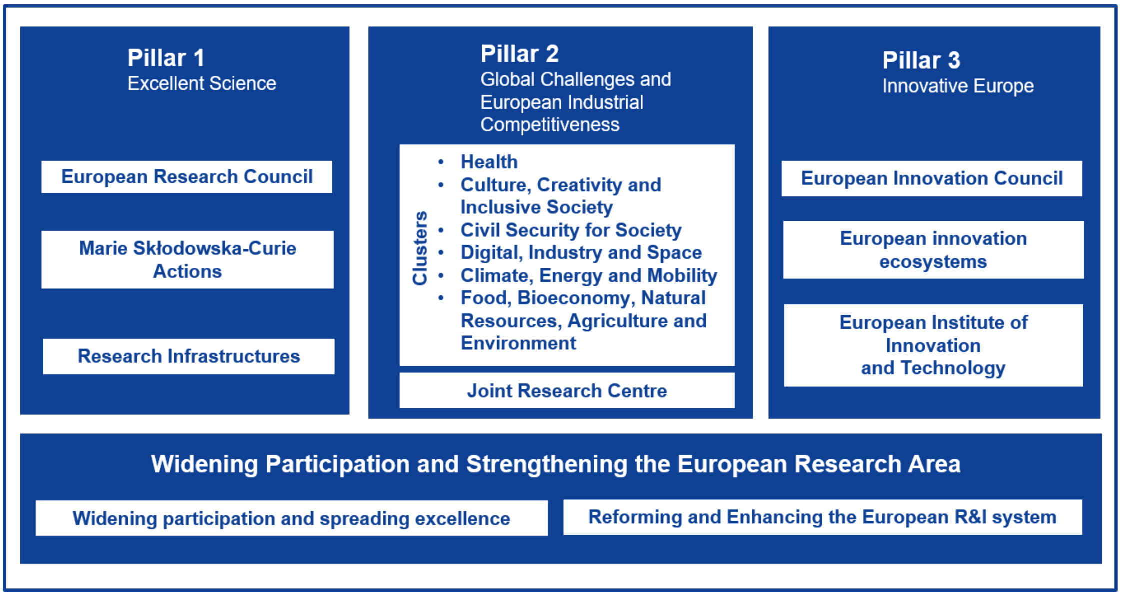

Figure 8. Preliminary structure of Horizon Europe

Source: https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en

6. Manufuture Platform

MANUFUTURE Technology Platform (manufuture.org) was created with the support of the European Commission, involving European Companies, Universities, Research Centers and public decision bodies, to support the development and competitiveness of Manufacturing in Europe.

MANUFUTURE MISSION is to propose, develop and implement a strategy based on Research and Innovation, capable of speeding up the rate of industrial transformation to high-added-value products, processes and services, securing high-skilled employment and gaining a major share of the world Manufacturing output in the future knowledge-driven economy.

The main ROLE of MANUFUTURE is to govern research, technological development and innovation (RTDI) efforts aimed at the transformation of the European manufacturing industry at two levels:

- Policy level aimed at the continuous development of the MANUFUTURE vision and the promotion of the Lisbon objectives;
- Operational level using a technological approach capable of exploiting all possible synergies arising from the converging nature of science and technologies.

The technological approach should address common problems or bottlenecks faced by the several sectorial platforms.

The HIGH LEVEL Objectives of MANUFUTURE are the following:

- Competitiveness in manufacturing industries
- Leadership in manufacturing technologies
- Eco-efficient products and manufacturing
- Leadership in products and processes, as well as in cultural, ethical and social values

Considering that the European Tooling Industry is a horizontal enabler and a fundamental pillar of the whole European industrial structure, whether on the development and industrialization of new products, or on the sustainability of industrial employment, MANUFUTURE promoted and supported a special working group under the coordination of Portuguese MANUFUTURE Platform - Forum MANUFUTURE Portugal – in order to gather European Tooling SMEs, related Research Organizations and Public Decision bodies, for the implementation of the MANUFUTURE Action Plan.

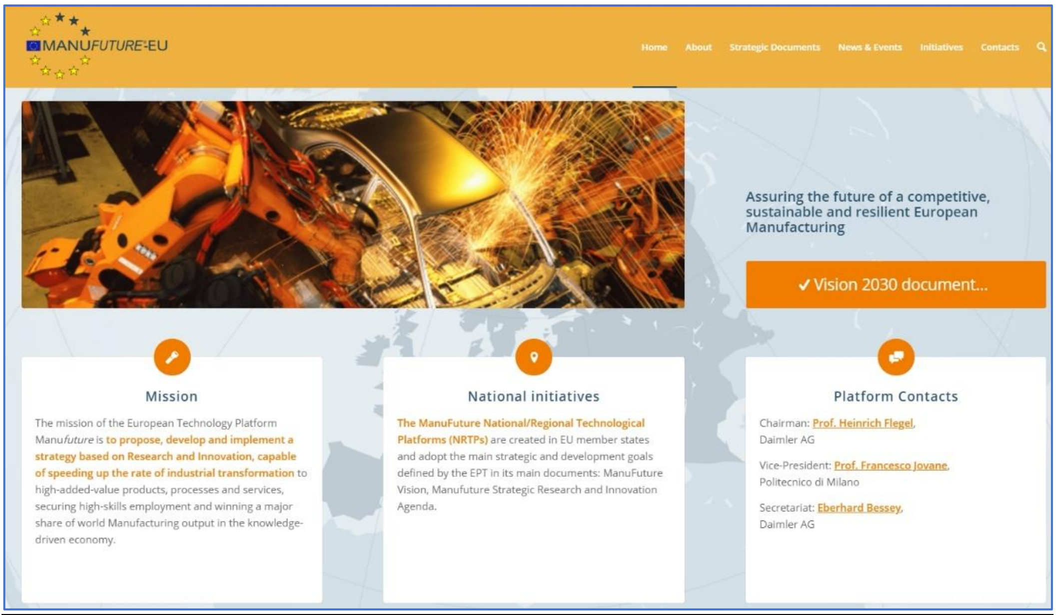

Figure 9. Official website of Manufuture.

Source: http://www.manufuture.org/

MANUFUTURE - Research domains

MANUFUTURE developed a Vision document for 2030 were it identified the broad main contribution from applied research and technological development domains to manufacturing competitiveness and innovativeness:

- Agile manufacturing systems design and management
- Manufacturing technology and processes
- Robotics and flexible automation
- Customer driven manufacturing
- Human centered manufacturing
- Digitalization, Artificial Intelligence and Cybersecurity
- Nano-technology and new materials
- Circular economy, resource and energy efficiency
- Biotech transformation of products and processes
- Fundamental Research and Social sciences and Humanities

Figure 10. MANUFUTURE Vision 2030 document.

7. The European Tooling Platform

In 2008, the European Commission, recognizing the importance of the ***Tooling*** Industry for the development of Europe (*since this industry is in the critical path of development of most products*), formalized the recognition of the ***European Tooling Platform,*** which since then has been coordinated by Portugal, through ***CENTIMFE*** - Technological Centre of the Molds, Special Tools and Plastics Industry.

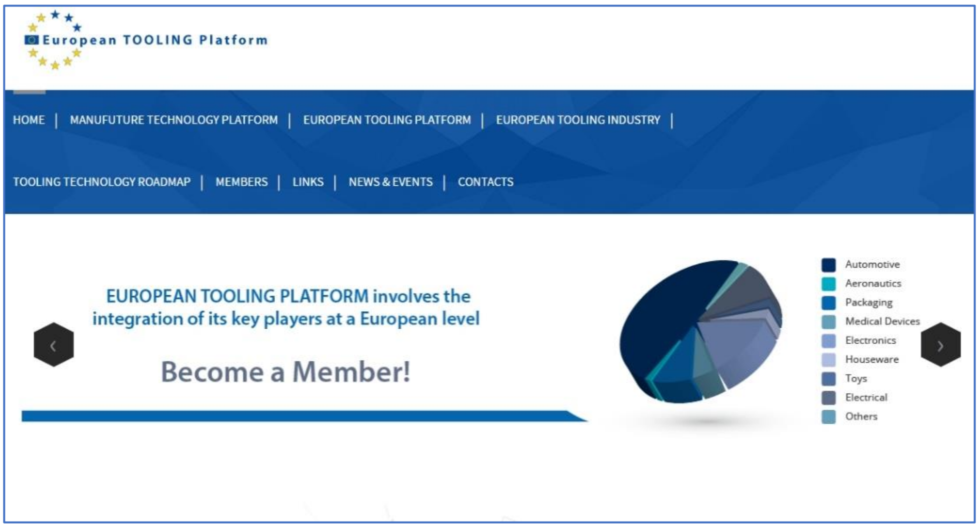

Figure 11. Official website of the European Tooling Platform.

Source: http://toolingplatform.manufuturenet.eu/ptool/en

The ***European Tooling Platform*** integrates a vast network of European partners, namely Molds, Special Tools and Plastics Companies, Technology and Innovation Centres, Business Associations (from ISTMA Europe) and individuals. This Technology Platform meets every two years in the country holding the EU presidency through the ***European Tooling Forum***.

The role of the ***European Tooling Platform is to*** represent the "***Tooling"*** Community in the *Technological Platform MANUFUTURE* and at the European Commission, to present its ***Technological Roadmap***, as well as to defend the R&D and Innovation priorities in the framework of the European programs.

MISSION

The Mission of European Tooling Platform, within a common Vision of the MANUFUTURE strategy, is to support the global integration of the European Tooling key players, towards the proposal, development and implementation of Research and Innovation activities to promote the competitiveness and differentiation of the Tooling companies in Europe and create the conditions to gain a major share of world Manufacturing output in the future knowledge-driven economy. The Platform is the Tooling focal point for Research and Innovation at a European level, in line with the strategy and representativeness of the member states, and will support Tooling companies to strengthen their competitiveness and also their European engineering and production base.

VISION

The Tooling Industry is a horizontal enabler, being one important and fundamental pillar of the whole European industrial structure, whether on the development and industrialization of new products, or on the sustainability of industrial employment. Tooling, Mold and Die making companies are infrastructural strategic players towards the development and sustainability of the European Industry.

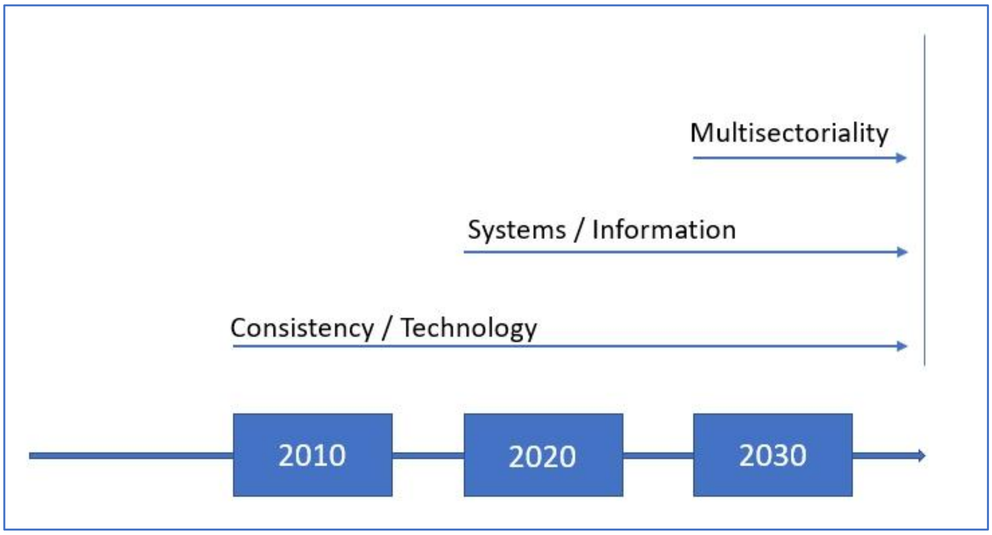

Figure 12. The European Tooling Platform vision.

The formalization of the European Tooling Platform within MANUFUTURE allow the European Tooling Industry to have a formal representation in the MANUFUTURE High Level Group, participating in its main strategic decisions.

Since the focus is on the Industry needs, the European Tooling Platform promotes an integrated and intelligent system to monitor policies and competitive issues and propose future actions to be taken at the different levels (local, regional, national and European) to reinforce the competitiveness of the whole European Industry.

The consolidation of the European Tooling Platform within MANUFUTURE will bring in a horizontal and structural industry and, simultaneously, it will open new opportunities for Tooling SMEs in Europe, taking advantage of this global and integrated movement to promote the competitiveness of European Manufacturing Industry.

Tooling Industry & Joint Technology Initiative (JTI)

The formalization of the European Tooling Platform within MANUFUTURE allow the European Tooling Industry to have a formal representation in the MANUFUTURE High Level Group, participating in its main strategic decisions.

Since the focus is on the Industry needs, the European Tooling Platform promotes an integrated and intelligent system to monitor policies and competitive issues and propose future actions to be taken at the different levels (local, regional, national and European) to reinforce the competitiveness of the whole European Industry.

A set of initiatives are being promoted by MANUFUTURE, namely a Joint Technology Initiative (JTI) in production technologies, in the scope of the “Factories of the Future” Initiative.

Considering the formalization of the European Tooling Platform as a MANUFUTURE sub-Platform, the participation of the Tooling Industry (as a horizontal enabler) in this JTI can be foreseen, in line with its Technological Road Map defined for the MANUFUTURE. Within this context, the European Tooling Platform will propose to actively participate in the JTI development process, namely indicating relevant topics to address complementary research at a global level, for the next years.

The Management of the European Tooling Platform will coordinate this work with the MANUFUTURE Technology Platform, to maintain the integrative consistency with the global policy of MANUFUTURE.

8. The European Tooling Technology Roadmap

The ***European Tooling Platform*** launched a study at European level, through its Industrial and Scientific Community, seeking to identify the main technological areas of R&D, Innovation and Investment, which the main *stakeholders of the* "Tooling", considered most relevant to develop, in the short, medium, and long term. This work involved several European countries, including companies, business associations, innovation centers and universities.

A Technology Roadmap was developed to support the Tooling industry in the identification of critical development axis for the period 2014-2020. The Tooling industry supply-chain, academic and research groups and governments were involved in its development, having jointly identified and prioritized the technologies needed to support strategic R&D, marketing and investment decisions.

In this context, the next graphic presents an overview of European Tooling Technological Road Map for the period 2014-2020, foreseeing the major challenge areas for the Tooling Industry, on the short, medium and long term.

	Short Term	Medium Term	Long Term
Micro Manufacturing	20%	70%	10%
Micro Moulding	10%	80%	10%
Micro Assembling	10%	50%	40%
Micro Forming	20%	60%	20%
Distributed / Integrative Engineering	40%	40%	20%
In-Mould Technology	20%	70%	10%
Coatings and Surface Technologies	70%	20%	10%
Rapid Manufacturing and Prototyping	60%	20%	20%
Small Batches Production	60%	30%	10%
New Design and Engineering Techniques (Eco-Design)	40%	60%	0%
Advanced Automation, Remote Control and Production Cells	40%	50%	10%
Advanced Technologies for Micro Tools	30%	60%	10%
New Functional Materials	20%	70%	10%
Innovative Materials (Bio-Materials, Eco-Materials)	30%	30%	40%
Nano Technologies	0%	60%	40%
Production of structural composites parts	40%	40%	20%
Simulation Methods and Tools for Knowledge Services	60%	40%	0%
Environmental Friendly Fabrication Processes	56%	33%	11%

Figure 13. European Tooling Technological RoadMap: 2014 – 2020.

Considering the European Commission's strategic objective of promoting R&D and Innovation activities within the scope of HORIZON 2020**,** stimulating multidisciplinarity and the crossing of various KETs (Key *Enabling Technologies),* thus enhancing multi-sectoral impacts, areas of strategic interest were also identified, which cross the various European Technology Platforms, namely:

European Platforms	Areas of Articulation
Advanced Engineering Materials and Technologies-EuMat	Bio polymers
	For innovative materials and joint work with non plastic experts (hybrid materials)
	Functional materials
Advisory Council for Aeronautics Research in Europe-ACARE	Efficient production for Small Series
	New materials for Aeronautics
European Road Transport Research Advisory Council-ERTRAC	For the development of light cars and the necessary tools that have to be jointly developed
Micro Nano Manufacturing-MINAM	Design for micro production
	For the development of spart plastic products
	Micro assembling
	Micro forming
	Micro handling
	Micro injection moulding
	Micro manufacturing
	Production of micro Tools
Rapid Manufacturing-RM	Better surface finish
	Materials for RM
	New materials for RM
	Prototypes on the micro scale
	Small series
Robotics-EUROP	Helping operators in the moulding industry doing physically hard manual work by collaborative robots (cobots).

Figure 14. European Technology Platforms and areas of articulation.

2020-2030

For the period 2020-2030 a new study was performed involving all the Tooling Community and other platforms in Europe. The result from this work revealed that the main technologies previously identified remain as the most relevant for the upcoming period. Additionally, these technologies were also classified regarding their level of consolidation to Industry and Academia and the result of this work is reflected on figure 11.

DEVELOPMENT OF THE EUROPEAN TOOLING ROADMAP 2020-2030
(In course involving all the Tooling Community and other Platforms)

Industry / Academia — Not Consolidated / Consolidated / In development

	Industry	Academia	Short Term	Medium Term	Long Term
Micro Manufacturing	In development	In development	20%	70%	10%
Micro Moulding	In development	Consolidated	10%	80%	10%
Micro Assembling	Not Consolidated	In development	10%	50%	40%
Micro Forming	Not Consolidated	Not Consolidated	20%	60%	20%
Distributed / Integrative Engineering	In development	In development	40%	40%	20%
In-Mould Technology	In development	In development	20%	70%	10%
Coatings and Surface Technologies	Consolidated	Consolidated	70%	20%	10%
Rapid Manufacturing and Prototyping	Consolidated	Consolidated	60%	20%	20%
Small Batches Production	Consolidated	Consolidated	60%	30%	10%
New Design and Engineering Techniques (Eco-Design)	In development	In development	40%	60%	0%
Advanced Automation, Remote Control and Production Cells	In development	In development	40%	50%	10%
Advanced Technologies for Micro Tools	In development	In development	30%	60%	10%
New Functional Materials	Not Consolidated	In development	20%	70%	10%
Innovative Materials (Bio-Materials, Eco-Materials)	Not Consolidated	In development	30%	30%	40%
Nano Technologies	Not Consolidated	In development	0%	60%	40%
Production of structural composites parts	In development	In development	40%	40%	20%
Simulation Methods and Tools for Knowledge Services	In development	In development	60%	40%	0%
Environmental Friendly Fabrication Processes	In development	Consolidated	56%	33%	11%

Figure 15. European Tooling Technological RoadMap: 2020 – 2030.

9. Innovation in Materials, Processes and Products

In recent years we have seen the development and implementation of tools that allowed huge increases in the productivity of manufacturing and service activities. This evolution will continue for decades to come as productive activities benefit from new design technologies, simulation, new materials leading to a deep change in business models, and new market scale options.

Advances in materials continue with the development of lightweight materials and their use in mobility sectors, such as in the automotive and aircraft industry. The materials business is evolving with the development of new solutions in response to demand from increasingly demanding markets including bio and eco materials, new functional materials, smart and multifunctional materials, and new surface and coating technologies.

In addition, new production technologies, such as Additive Manufacturing, come up with new production concepts and solutions that will revolutionize the way products are manufactured. In terms of production areas, we have seen the expansion of the philosophies associated with recycling and reusing of old materials to manufacture new products, with high levels of productivity and efficiency. Also at the information level major developments are taking place with the use of information concepts associated with products and processes, this information is supported by advanced analytical solutions, social technologies and the use of smart devices to monitor production equipment, supply chains and products in use, bringing intelligence to the way things are designed, produced and used.

Companies should develop detailed knowledge about the different markets in their surroundings, particularly emerging ones, gathering information about their specific needs and requirements.

9.1. Eco and Biomaterials

Among these materials, Biomaterials and Ecomaterials stand out for their relevance and importance within the scope of current sustainability and safety policies.

Biomaterials involve polymeric and composite materials of natural or synthetic origin, including natural fibers, bioactive materials, biocompatible materials, biodegradable materials, among others.

Biomaterials can be defined as all materials that are used to assess, treat, enhance or replace any tissue, organ or function of the body or biological systems. Thus, biomaterials can be materials inserted into the human body to treat, improve or replace any tissue, organ or function of the body. These materials must comply with their "biocompatibility", which comprises the interactions of human tissues and fluids, including blood, with an implant or material, and can be defined as the ability of the material to respond appropriately to a specific application, without any allergic, inflammatory or toxic reactions occurring when in contact with living tissues or organic fluids.

Eco-materials are intended to be materials that are more in tune with the environment, i.e. to have a lower burden on the environment throughout their life cycle.

Despite numerous challenges on the processing of bio-based and biodegradable resins, such as design challenges and hot-runner choice to ensure a successful, eco-friendly, molded part, there is no doubt that there will be a growing demand for these materials and Tooling SMEs must be prepared for these challenges.

9.2. New functional materials

The need for new skills and response capacities at the level of materials, the need for customization and the focus on sustainability are factors of innovation to be considered in this area. In terms of objectives, the industry wants to increase its market, reduce costs, develop new solutions and applications.

Advances in nanotechnology, biology and low-weight composites have had a marked impact on industry, particularly in the mobility and packaging sector, where enormous technological progress has been made in the development and application of new materials, lightweight alloys and lightweight materials, which contribute to improving fundamental aspects such as weight reduction.

Other sectors such as electronics and lighting are promoting new functional materials such as photochromatic materials, photolithographic printing materials, LED lighting, flexible electronic display and lighting panels, materials with magnetic properties, and intelligent and multifunctional materials such as so-called environmentally sensitive materials, self-repairing materials, materials with memory and chemical sensors.

New tooling concepts are necessary in line with new manufacturing processes, hybrid processes for instance, and for transforming new materials, especially lightweight materials.

9.3. Coatings and Surface Technologies

The evolution of surface technologies involves materials and coatings with greater resistance to erosion, chemical aggression, heat, adverse and extreme weather conditions, anti-scratches, anti-reflection surfaces, easy to clean, anti-ice, anti-bacteria, low friction, among other properties that provide better product performance.

New tooling concepts are needed for producing nano-structured surfaces, for instance in injection molding to obtain functional components.

New coating technology for sensors embedded in tool surfaces, molds and products to collect operating data from systems.

9.4. Structural Composites

We are witnessing a huge increase in the use of new materials, such as composite materials. The mobility, aeronautics and automotive sectors are the most dynamic, looking for high-strength materials and mechanical performance with low specific weight. New materials, new manufacturing processes and development support *software* are areas where major developments will be observed.

Significant developments have occurred both in the production processes for small series, such as low pressure injection RIM (Reactive Injection Molding), RTM (Resin Transfer Molding) and SMC (Sheet Molding Compound), or in terms of materials for the mold making (polyurethanes, monolithic resins, etc.) as well as the properties of the materials that make up the parts produced. Additionally, additively manufactured or 3D-printed tools, using composite materials, are also becoming more common for both prototype and production parts.

Tooling costs and complexity for use in composite materials, increase as the requirements for part performance and/or finished surface aesthetics become more precise and the number of parts to be produced increase.

Through improved mold design and optimization of the process for composites it is possible to improve the applicability of low-pressure molding processes to composite manufacture. This can allow SMEs, to produce new polymer composite parts with increased quality and functionalities, large series and high productivity rate for cost-efficient manufacturing, reduce waste, lower energy consumption, reduce material in mold making, and minimal carbon foot-print.

Prospectively, the penetration of these processes and materials in the manufacture of molds for small series has a high growth potential. Ultimately, the main barrier to this growth has been the actors in the mold supply chain who retain some protectionism regarding the use of this type of molds.

9.5. Nano Technologies

Since the 1990s, there has been a global effort to investigate the areas of nanotechnology, with huge amounts of investment by companies and states. The application of these materials is now disseminated by semiconductors, electronics and structural materials. In terms of nano-technologies, nanostructured coatings and materials can be highlighted. The former may have tribological, functional, adhesive or insulating applications. As far as nanostructured materials are concerned, nanocomposites, carbon-based materials, ceramic and metallic-based materials, polymeric materials, among others, stand out.

One of the areas where nano technologies have evolved the most is in carbon nanotubes. These have exceptional mechanical properties, high thermal conductivity and stability, while others are characterized by their high electrical conductivity and chemical resistance.

Nanotubes and graphene are used in the manufacture of high-performance transistors and high-strength composite materials. Fluorescent particles are used in solar cells and biological applications.

In electronics and semiconductor manufacturing, nanomaterials should replace silicon. Advances in nanostructured materials should lead to the production of high-density batteries, cheaper and more efficient solar cells and ultra-high strength composite materials.

Advances in nanomaterials require a long-term view, with continuous investments of technical and technological resources for application in industry.

9.6. New Design and Engineering Techniques

Today, the manufacture of products is increasingly distributed, particularly when it involves different components, and there is a wide geographical distribution of the production of components and raw materials. As a result, product lifecycle analysis is increasingly complicated, requiring the use of sophisticated tools to support this analysis. Today, we know that sustainable practices are beneficial to businesses and may even lead to cost savings. However, the development and implementation of these practices can involve, from the outset, high costs and risks that should not be overlooked.

In the future this assessment should be extended beyond the production phase, it should analyze all impacts over the entire product life cycle, starting from raw material production to final dismantling, and should incorporate the philosophies of circular economy.

Sustainable product development requires a lot of future research, seeking to address concerns directed at reducing the environmental impact of products, considering their entire life cycle. This should include integration of design methodologies that cover all material and product lifecycle processes (development, industrialization, production and operations management, utilization and end-of-life), interconnection with smart platforms and their standardization, for the design of molded product excellence. This will involve the creation of cutting-edge models and design guidelines for design, material availability and technology excellence; the interconnection with digital platforms and machine learning; and the integration of new technologies and processes into the complete life cycle of a product.

9.7. Eco-Efficient Manufacturing Processes

Sustainability goals are associated with energy consumption, water use, oil use, and other environmental impacts. Eco-efficient manufacturing processes and Sustainable manufacturing refers to the use of production processes and materials following a philosophy of minimizing the ecological footprint. So, concerns associated with productivity, organizational innovation and competitiveness, and increasingly restrictive legislation environmental issues led Tooling to promote research and implement measures to reduce its negative environmental impacts.

Increasing sustainability involves future research in many areas of knowledge, including process management, mechanical engineering and materials engineering, which will have significant impacts on mold making processes and injection molding.

9.8. Simulation Methods and Tools

Simulation tools are increasingly becoming indispensable in the industry to ensure process reliability and increased productivity. The simulation tools supported by advanced *hardware* and *software* allow the realization of increasingly detailed and accurate models whose results are very close to reality.

Simulation tools have more and more interesting potential for industry and services, taking advantage of greater processing capacity and analysis of data and information. This ability associated with the systematization of knowledge in databases supports decision making with the simulation of processes in a safer and faster way.

Industry 4.0 requires new sensing methods, including hardware and software, and new process control knowledge, integrating the tooling as a relevant element. The sensing systems will enable advanced real time process simulation systems that can ultimately contribute to build the product digital twin.

Simulation also paves the path for developing tooling-specific Artificial Intelligence applications. For instance, developing specific algorithms to improve the design and manufacturing processes and the tooling durability.

9.9. Distributed / Integrative Engineering (Co-Engineering)

Co-engineering involves collaborative activities from different areas of engineering in order to respond to common challenges, being able to work in an integrated way (physically close and same tools) or distributed (physically apart and with similar tools).

The concept of Integrated Engineering is fundamental in the technology-intensive industry as is the case of Tooling, where the integration of technologies allows to reduce communication errors and increase its competitiveness and reduce *time to market*.

Computer integrated production systems are used to facilitate the exchange and use of information from different areas of a company or other companies, acting collaboratively.

High-speed, high-performance information and communication technologies (ICT) today enable collaborative tasks to be performed remotely by sharing and using the same basic information, enabling so-called distributed manufacturing systems to operate regardless of the physical distance between the various elements or actors.

IoT concept can be adapted to tooling, to enable an active network tooling integration. For instance, tooling geopositioning both indoor and outdoor, pay per use tools or tooling licensing per number of produced parts, tools knowledge exchange are possibilities to be considered.

9.10. Advanced Automation and Production Cells

Automation and its level vary from company to company; However, the results sought are greater efficiency, productivity and accuracy. Today's equipment have a high level of automation and autonomy, performing many functions and tasks automatically, without the need for human monitoring, such as tool change, pallet change and automatic lubrication. Today companies are looking for advanced automation solutions in order to have greater productivity gains, based on different production *layout* architectures. Integrated solutions are found where all equipment is interconnected in the same physical area, and solutions where their integration is ensured by advanced information management systems and advanced systems or methods of operation and *setup*, allowing independent equipment that is physically remote to be managed in an integrated manner by the same system, contributing to the same objective.

Tooling's implementation of advanced automation solutions and production cells are supported by centralized information systems, integrated CAD/CAM systems, robots and machines with automatic control and inspection systems. In addition, new capacities and improved performance of equipment are needed to standardize working methods, tools and support systems, including clamping systems. These solutions ensure faster production of molds and tools, and predictably with less labor.

New developments are needed in the area of collaborative robotics and advanced control systems to be applied to the most demanding and repetitive jobs.

New sensor technologies are needed to fully monitor all equipment and processes in a production chain. These developments are needed to increase factory efficiency from an INDUSTRY 4.0 perspective.

9.11. Small Series Production

The production in the tooling industry is essentially unitary, producing one mold or one tool for each plastic part, unlike other sectors that produce finished parts in small or large series.

As far as injection molding is concerned, it is mainly characterized by large scale production or long series ranging from a few thousand to millions of pieces. On the other hand, the rationalization of costs by manufacturers has led in recent years to a typology of production according to the needs and quantities of the market and not to warehouse stock.

The evolution of markets and aggressive marketing policies have also promoted changes in consumer tastes, creating the habit of differentiation in some areas of consumption, which has led to a change in production typology, with new products of different colors and details or accessories, and, inevitably, in smaller quantities for each specific series.

These changes promote the need for the development of less complex molds, materials with lower mechanical resistance, and advanced manufacturing technologies that allow to respond in quality, speed and cost to the production of small quantities of parts.

It should be added that the new additive manufacturing technologies, which present an enormous evolution, have huge potential in the production of small series of parts, whether metallic or polymeric.

9.12. Additive Manufacturing

Additive Manufacturing (AM) technologies are having major impact on product development and manufacturing chains in almost every industry. The demand for AM technology products and services has been growing strongly over more than two decades of history. Due to the increasing number of variants, customization and small batch production (1-100 pieces), the requirements on individual products are changing drastically and rapidly. AM is a process that is mainly aimed to produce prototypes and small batches, since it enables their production using only 3D CAD information, allowing changes in the product without any tool changes. In addition, this type of technology makes it possible to obtain parts and tools with very high complexity due to the intrinsic characteristics of layered manufacturing, the quantity of raw material and scrap and, consequently, catapulting a reduction in costs and environmental pollution.

The advancement of Additive Manufacturing will be much supported on standardization, software development, automation and streamlined Workflows, ensuring repeatability and quality control and on new solutions aimed at taking Additive Manufacturing further towards digital, connected factories.

A large market growth is expected for tool production via Additive Manufacturing. As the processes improve and companies explore new ways to use them, the confidence on the potential users of these techniques increases, opening the door to a huge potential for applications.

In addition to the reduction of time and cost, some Additive Manufacturing techniques offer the possibility of using Conformal Cooling, which allows to obtain better thermal properties in the tools, properties that cannot be obtained with tools machined by conventional processes.

The use of conformal cooling can reduce the cycle time by about 20 to 40%, while improving the quality of the injected parts. These facts are reflected in the increase in production rates and in the decrease in the cost of producing the final pieces.

9.13. In-Mold Technologies

The in-mold operations, namely *in-mold labeling* (IML) and *in-mold decorating* (IMD), allow a great flexibility in the design of the plastic parts, especially parts that need operations after injection such as graphics, various decorations including different colors, effects and textures, and in the last years, the internet of things features. With special tooling these operations can be performed in the injection phase, contributing to increased productivity.

In-mold decorating and *in-mold labeling* techniques are high-quality, efficient, durable, and economically viable alternatives to other technologies such as painting, pad printing, and other post-injection techniques. These two techniques provide greater geometric flexibility and variety that are not competitively achieved by other techniques in today's markets.

It should also be noted that *in-mold assembly* technologies and operations allow eliminating subsequent assembly operations that are often complex and present increased technological and engineering difficulties that lead to high rejection rates, high costs, namely those related the assembly of components using clips, welding technologies or co-molding of components of incompatible materials.

New developments on tooling should be achieved to perform over-molded devices with increased productivity. New tooling solutions are necessary to protect the over-molded device from being damaged during the molding process.

New materials to perform the compatible functional layers must be developed and characterized.

9.14. Micro Machining

The market has increased in terms of miniaturization, whether in the supply of micro parts or products, or in components or systems.

Examples of such products are micro-electromechanical systems, micro-reactors, fuel cells, micro-mechanical devices, micro-tools and medical micro-devices to industrial areas as automotive, aeronautics, telecommunications, home automation, medical implants, etc.

Micromachining is the link between macro manufacturing and nanotechnology, and in recent years there have been major developments in technology and equipment for manufacturing products and figures on the sub-millimeter scale. Micro-machining should be supported by the development of the technologies used in the production chain, including digitization and Industry 4.0. Therefore, major developments are expected in all technologies such as programming (CAM), simulation (CAE), knowledge of materials, cutting tools, production equipment and operational management, etc.

9.15. Micro Injection Molding

In recent years we have witnessed an increasing demand for molds and molding tools for the production of smaller and smaller parts, particularly for automotive, aeronautical, aerospace and medical markets. Developments in the microinjection process have focused on streamlining the production of micro parts for microsystems, broadening the range of processed materials and possible geometric shapes, and responding to manufacturing chains capable of meeting the technical and functional requirements of complex products. Some key areas of research in this area were identified:

- Biocompatible materials;
- Nanocomposites;
- Polymers of complex architecture with formulations of metallic and ceramic powders;
- Recycled polymers.

On the other hand, polymers have some limitations related to their processing, namely very tight processing temperature ranges, which in themselves unfold into new areas of research.

Also, in the recent years where announced some problems related with the use of plastics specially with microplastics.

Developments in micro-mold making and tooling technologies for micropart production are expected, as well as micro-surface finishing technologies. Finally, developments in industrial micro additive manufacturing technologies are is also expected, in order to respond to micro injection molding.

9.16. Micro Assembling

The demand for micro-parts is increasing in many sectors from mobility to medical devices. The manufacture and assembly of parts smaller than a millimeter raises several new issues related to the small size of parts and taking account that the positioning errors of the macro handling systems may be greater than thinner dimensions of those parts.

Microparts are very small in size and weight, so they must be handled carefully, delicately, and with high precision and accurate systems, and it's not just removing the part, but also gripping the part and transporting it in the correct position to a control area, or assembly. The current day-to-day handling systems do not allow this precise manipulation, because, given the small volume of those parts, even statics promotes uncontrollable displacements. It is necessary to create adequate systems for this kind of part, adapting to its geometry and properties, namely elasticity modulus, mechanical strength, ductility, resilience and hardness.

Are expected new developments to improve the reliability of the handling process, namely on vision systems and highly sensitive manipulation systems with gripping force control, to prevent the application of excessive forces. Also, the new developments on Artificial Intelligence (AI) must contribute to autonomous part selection and the correct picking of small and complex objects in different orientations, increasing productivity and cycle time.