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European Association of the Machine Tool Industries
and related Manufacturing Technologies

THE EUROPEAN MACHINE TOOL SECTOR AND THE CIRCULAR ECONOMY



Credits

CECIMO Circular Economy Report

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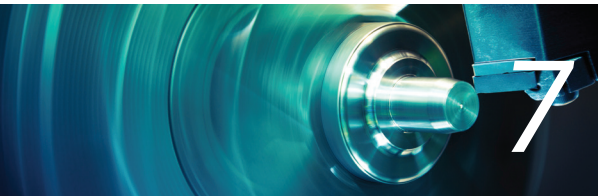
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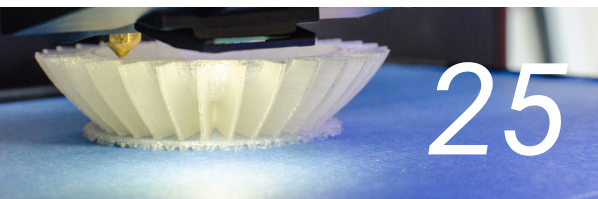


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Foreword

A circular economy is the logical solution for a resource-constrained world.

Here in Europe, we import six times more materials and resources than we export, and resources make up the largest part of companies' costs. To keep Europe competitive, we need to maximise resource efficiency and put the materials contained in our waste back into productive use. We need to replace virgin materials with recycled secondary raw materials, in a circular manner, on a European scale.

Taking a sustainable path requires fundamental changes throughout the value chain, from product design, production processes and business models to consumption patterns, waste management and the use of secondary raw materials. This in turn calls for technological, financial, social, and organisational innovation, with new forms of governance that enable and encourage public and private actors at all levels to play their part. It's ambitious, but it's eminently feasible.

As this report shows very clearly, the machine tool manufacturing sector is rising to the challenge. Numerous actors are rethinking traditional industrial processes, eliminating unnecessary waste, developing innovative advanced manufacturing technologies and doing all they can to promote recycling and reuse. By taking a whole life-cycle approach, the sector is putting circular thinking into action on the ground, and setting out a model for others to follow. And with so many SMEs focused on export, you are showing the best face of high-tech EU manufacturing to the world.



The EU too is doing its part, striving to energise markets through a mix of updated legislation and dedicated projects. The centrepiece of Europe's waste legislation, the Waste Framework Directive, was recently amended, raising recycling rates and introducing general minimum requirements for the design and operation of schemes for Extended Producer Responsibility.

Europe has everything to gain from the further development of applications and manufacturing technologies that optimise the use of resources and materials. Funds are available to help develop new applications to accelerate the transition to a circular economy, and to bring them to the market under Horizon 2020 and its successor Horizon Europe, the EU funds for Research and Development. I would strongly encourage you to make the most of these opportunities.

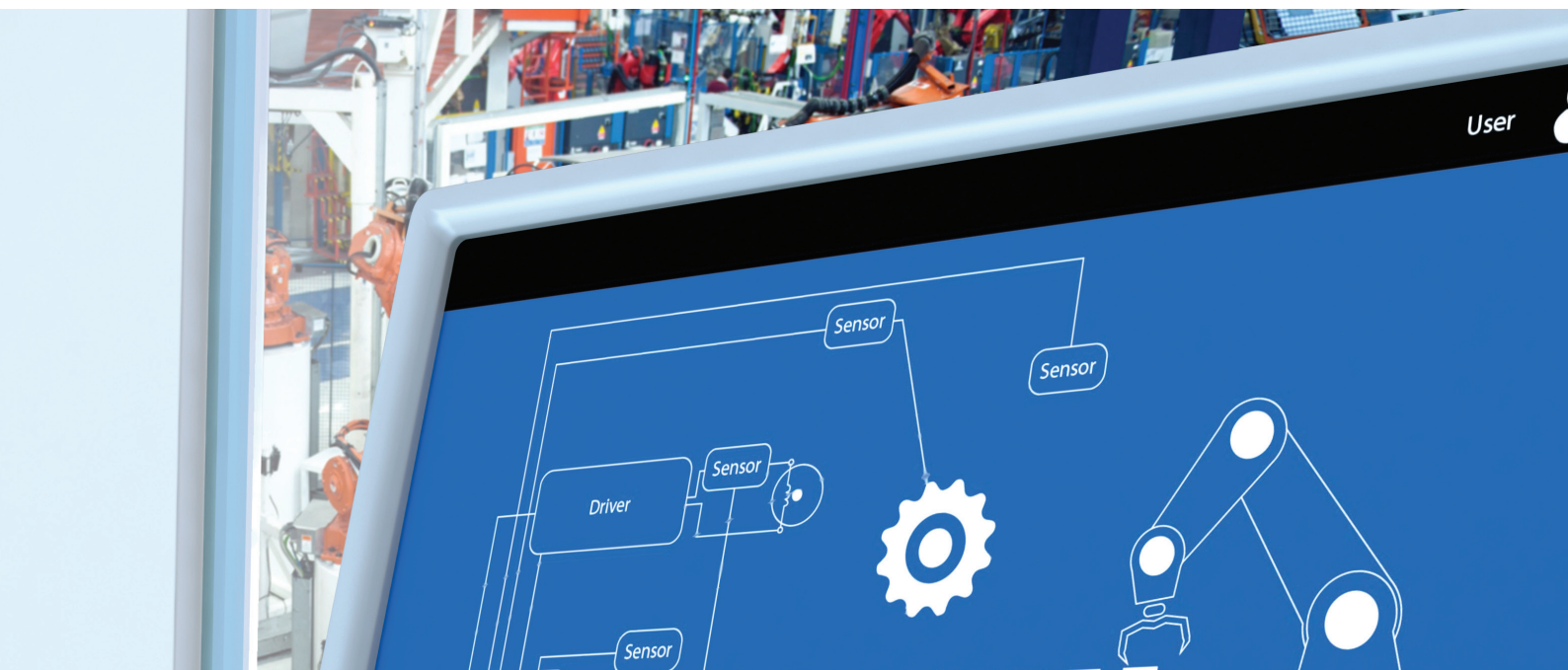
I wish the industry sustained success with its circular ambitions. With your high rates of re-use, remanufacturing and recycling, you are forging a path that many other industries can follow. Congratulations on the excellent results to date – and long may this trend continue.

Karmenu VELLA
**European Commissioner for Environment,
Maritime Affairs and Fisheries**



THE MACHINE TOOL SECTOR

The diverse and globalised world of machine tools



A key enabling technology

Machine tool technology is a critical and often unseen element of manufacturing. Machine tools are at the starting point of almost every manufacturing activity. They are used to manufacture everyday objects such as home appliances, pens, bicycles, cars, planes, medical devices or wind turbines. The machine tool industry is a key enabling sector having a direct impact on the productivity and competitiveness of European manufacturing and in the transition to a more circular economy.

Machine tools can be defined as stationary (not portable by hand) machines, used to work with a large variety of materials – in particular, metal – to produce the required shape. They are extremely complex products for industrial use. They contain hundreds or sometimes thousands of parts – including nuts and bolts, bearings and pins, sheet metal enclosures, belts, shafts and so on. Modern machine tools are real engineering marvels. Some can produce components with extreme accuracy (within less than a micrometer) and many do so in a fully automated way.

Extremely heterogeneous sector

One of the main characteristics of the machine tool sector is its heterogeneity in terms of company size, as well as the use and type of machine tool products.

The company size in the sector varies from small companies that employ a few people and manufacture a few units per year, to large companies with thousands of employees that manufacture many hundreds of machines per year. As a result, the company management and business capabilities also differ greatly. The average European machine tool company is a Small or Medium-Sized Company (SME). The average number of employees per company in 2017 was around 106¹. The type of metalworking machine tool is very diverse, depending on the technology used. The most conventional processes are cutting and forming. Cutting machines (e.g. milling, grinding or boring machines) create a shape from a sheet or block of metal by using a tool with one or more cutting edges, whereas forming machines (e.g. stamping, bending or punching machines) create a shape by applying a force and using specially-shaped tools. In addition to these technologies, we can also find other 'less conventional processes',



such as laser cutting, waterjet cutting or electro-discharge machining, or a combination of different techniques to obtain more complex pieces. If you add to this a high level of customisation and variety regarding workpiece size and material, level of automation, speed or performance, you will realise machine tools are indeed a very heterogeneous group of products.

High level of customisation

There are rarely two identical machine tools on the market. The machine tool sector is a supplier of many European and international manufacturing industries and requirements are very different depending on the application. As a result, machine tools are rarely mass-produced, and, in most situations, modifications to their basic designs are needed to match customers' specific requirements in terms of workpiece geometry or production performances. This also requires the machine tool builder to offer a wide range of services to the customer, including application engineering, maintenance, repair and on-site training of operators. Today, machine tool builders increasingly provide complete production solutions to their customers rather than individual machines.

An export-oriented sector

Despite the fact that the majority of European machine tool companies are SMEs, the machine tool market is highly export oriented. 77% of CECIMO member countries production is shipped abroad, whereas around half - 52% in 2017 - is exported outside Europe², mainly China and the USA. Therefore, machine tools are produced for a global market and, in some cases, Europe is not the main source of sales. European producers are focused on high-end, customised machines with a relatively long production cycle, as opposed to standard machines with short lead times. The European machine tool industry is the leader on the global market, with a highly innovative, diversified and precise offer. Producers have kept their global market share at around 33% of the global machine tool market in recent years³, but they are facing increasing competition from China, Japan or South Korea.

To meet increasing challenges, proposing new innovative solutions and adapting to constant production and market changes is key, while also continuing to meet customer demands in relation to reliability, productivity, accuracy, efficiency, quality and durability.

FACTS AND FIGURES

MACHINE TOOL TRADE

77%

of CECIMO countries production is exported

52%

of CECIMO countries production is exported outside the EU

6

main customer countries outside Europe are: China, USA, Russian Federation, Mexico, Turkey and Japan.

MAIN CUSTOMER SECTORS



ELECTRICAL
ENGINEERING



AUTOMOTIVE



METALS AND
METAL PRODUCTS



MACHINERY



AEROSPACE



PRECISION AND
OPTICAL INSTRUMENTS

How circular are machine tools?

The shift towards a circular economy necessitates a prominent role of manufacturing. Machine tools have a hand in most manufactured products and therefore they have an essential role to play in sustainable manufacturing.

According to the Ellen MacArthur Foundation⁴, the circular economy aims to retain as much value as possible for as long as possible in the economy – in terms of products, parts and materials. The aim is to allow for the long life, optimal reuse, refurbishment, remanufacturing and recycling of products and materials. Many of these aspects are already present in the machine tool sector, but to what extent are machine tools already circular products and contribute to the circular economy?

Energy consumption during the use phase is the most significant environmental impact

Machine tools are one of the product groups that have been considered by the European Commission for the establishment of ecodesign requirements. In this context and in preparation of a possible Ecodesign self-regulatory initiative⁵, CECIMO carried out in 2009 a Life Cycle Analysis (LCA) of two types of machine tools – milling and turning machines. Nine machine tools – ranging from five tonnes to nearly 100 tonnes in weight, from five companies in Germany, France and the UK – were considered for this assessment. The LCA concluded that the most significant environmental impact of machine tools occurs during the use phase compared to other phases such as, construction, transport, installation and dismantling. Moreover, the consumption of energy during the use phase is by far the most relevant environmental aspect of machine tools over their life cycle. These conclusions have been confirmed by the preparatory study on machine tools carried out in the framework of the Ecodesign Directive⁶.

Although, traditionally, factors such as precision, speed, reliability or flexibility have

been the main factors when purchasing machine tools, in the last few years we have been seeing an increasing focus on environmental aspects such as energy efficiency. Machine tool manufacturers can influence the energy efficiency of a machine tool during its design phase, but user behaviour plays a major role in the actual energy consumption and performance of the equipment⁷. Therefore, in addition to the introduction of measures contributing to energy efficiency during the design phase, it is also important to support the machine tool user during the use phase. In this respect, many machine tool providers already give recommendations to end users in instruction manuals, relating to procedures connected to energy efficiency (e.g. correct maintenance and avoiding overloads), or they provide specific training to ensure optimum performance of their equipment.

In the case of metal working processes, cutting fluids and metal chips are the most relevant waste products generated during the use phase. Nevertheless, the environmental impact of these products can be considered minor. Metal chips are normally separated from cutting fluids and then recycled. In addition, cutting fluids can also be recovered from metal chips and reused⁸. Moreover, currently there are bio-based lubricants available in the market, which provide the same or even better performance than petroleum-based lubricants⁹. To reduce the use of cooling lubricants, dry machining and minimum quantity lubrication (MQL) have also been explored as options, but this can negatively affect energy consumption and tool wear¹⁰.

Predominance of recyclable materials such as cast iron, steel and other metals

Regarding the production phase, machine tools are mainly made of cast iron, welded steel and other metallic materials¹¹. As explained previously, machine tools are very diverse but, in general, around 83% of the machine is made

of metallic materials¹². These materials are easily recyclable and can be used to produce new products again and again with no loss of quality. Metal components are also valuable, and this means that there is an incentive for metal to be recovered during the disposal of machine tools at the end of their lifetime - either by the manufacturer or by scrappers.

Modular products with several lives

The circular economy goes beyond the recycling of materials: An important element is the long life, reuse and remanufacturing of products, with the aim of keeping them in the economy for as long as possible.

Machine tools are products with a long life. Many products are used for more than 20 years and then completely refurbished. According to available figures, in Italy, the average age of the total installed machines in 2014 was 12.8 years¹³ and, in Germany as of 2015, the average age of computer-numerically controlled (CNC) and non-CNC machines was 10.5 and 19.7 years, respectively¹⁴. Data provided to CECIMO by some machine tool manufacturers also shows that, on average, 80% of machines are still in service ten years after installation, while 65% are still in service after 20 years. This information provides evidence of the durability and long-life span of machine tools, but it is also important to recognise that, on the other side, advanced manufacturing technologies are always evolving, and a long lifetime may also translate into an extension of the lifetime of machinery with lower efficiencies and productivities.

Machine tools are usually designed in a modular way. To reduce down-time of the machine in case of problems, access to key components for replacement is very much taken into account in the design of the machine. This simplifies maintenance, helps to reduce construction costs and facilitates remanufacturing and disassembly at the end of life. Given the relatively high value of machine tools, their refurbishment and remanufacturing



“ *Repair, refurbishing and recycling of products are already a reality in our sector, but as important as these aspects is the role of machine tools and related manufacturing technologies as key enablers of the circular economy. By providing our clients with the latest manufacturing technologies we assist them to move towards a circular economy by increasing their productivity and giving them the means to optimize resources and processes*”

JUHA MÄKITALO
CHAIRMAN, CECIMO TECHNICAL COMMITTEE

is very common after a certain amount of time in use. This ranges from small improvements through to full rebuilds, which incorporate full automation and control systems. When a machine tool is remanufactured, it is often possible for newer more energy efficient components or controls to be added, thus leading to a reduction in the energy consumption of the whole machine. According to data from the Ecodesign preparatory study on machine tools, 80% of machine tools are retrofitted and refurbished when they are between five and 15 years old depending on the specific sector and application¹⁵.

Finally, it is important to highlight that although it is difficult to find specific data, the second-hand market for machine tools is also very important. In 2003, the proportion of second-hand machinery in total machinery sales in Germany was estimated at between three and five percent, but this percentage could be higher in developing countries.

Machine tools already incorporate key elements of the circular economy

As we have seen, machine tools already embrace some key principles of the circular economy. Machines are designed with ease of maintenance in mind and much of the materials are recycled at the end of life. Machine tools are designed to last, and retrofitting and remanufacturing are common practices in the sector.

Improvements are always possible and machine tool manufacturers are constantly

looking to improve the performance of their products, including from an environmental point of view. As discussed, energy consumption in the use phase is the key aspect in improving the environmental performance of machine tools and much of the work in the sector is focusing on this aspect, while not neglecting customer demands for productivity, precision and reliability.

Finally, it is important to highlight that although the machine tool and related manufacturing sector may not seem too big, the impact it has through its customers enabling them to have more sustainable manufacturing processes is enormous. The sector provides advanced manufacturing technologies allowing for better control of the manufacturing process and traceability, which results in less waste, more efficiency and better management of resources.

HOW CIRCULAR ARE MACHINE TOOLS?

80% of machines are still in service ten years after installation



65% are still in service after 20 years



83% of the machine is made of recyclable metallic materials





**THE MACHINE TOOL
SECTOR ACTIVITIES
IN SUPPORT OF
SUSTAINABILITY
AND THE CIRCULAR
ECONOMY**

The machine tool commitment to sustainability



“The multiple initiatives undertaken by the machine tool and related manufacturing technologies sector clearly show the sense of responsibility and commitment of our industry towards sustainability and, environmental performance in particular. These initiatives aim to encourage product and process innovation taking into account the need to protect the environment and the requirements of our clients. We see sustainability as an integral part of the competitiveness of our sector.”

FILIP GEERTS
DIRECTOR GENERAL, CECIMO

Sustainability concerns are increasingly being incorporated both into the agendas of policymakers and the strategies of companies. This evolution is by no means alien to the machine tool sector and, in the last few decades, it has taken concrete steps to embed the principles of sustainability in the sector. Sustainability must be understood as a broader concept, integrating not only environmental but also economic and social aspects. In this context, the circular economy can be seen as a way to redefine the economic model with sustainability principles in mind. As explained previously in this Environmental Report, energy consumption in the use phase of the machine tool is the most significant environmental aspect. Due to this, much of the work of companies has been focused on improving the performance and energy efficiency of their products. Nevertheless, the sector's commitment to sustainability is not restricted to energy efficiency and also embraces topics such as the optimal use of resources, safety and employee well-being, as well as supporting local communities. As mentioned, the sector is also very diverse from the point of view of products and structure, with the majority of

the companies being SMEs. This means that each organisation needs to build its own path towards long-term sustainability, with specific goals and taking into account the company's own strengths and weaknesses.

This part of the report gives further information on the different initiatives developed by the machine tool sector, both at national and European level. Sector specific Initiatives such as Blue philosophy and Blue competence have been created to help companies to integrate sustainability into their business operations in a systematic way and to provide platforms for companies to present, exchange and improve their practices. Some initiatives at company level within the sector will also be highlighted.

Blue Philosophy

Blue Philosophy¹⁶ is an initiative of UCIMU, the Italian machine tool, robots, automation systems and ancillary product manufacturers' association. It aims at showing the sense of responsibility and commitment of Italian machine tool manufacturers towards sustainability and, in particular, towards energy efficiency and environmental aspects. Blue

Philosophy was integrated into the UCIMU mark in 2011. Previously, the UCIMU mark was granted to UCIMU member companies which were able to demonstrate their commercial reliability, financial strength, attention to safety, function testing and customer care. Since 2011, the attention to environmental issues and sustainable manufacturing were integrated as an additional criterion to be awarded the UCIMU mark. The procedure for granting the mark provides for a verification (documental and/or on-site) of the company to assess its ability to manage problems concerning the development of products and services. In addition, it looks into whether the company meets the needs of machine tool users and complies with legal obligations and sustainability criteria.

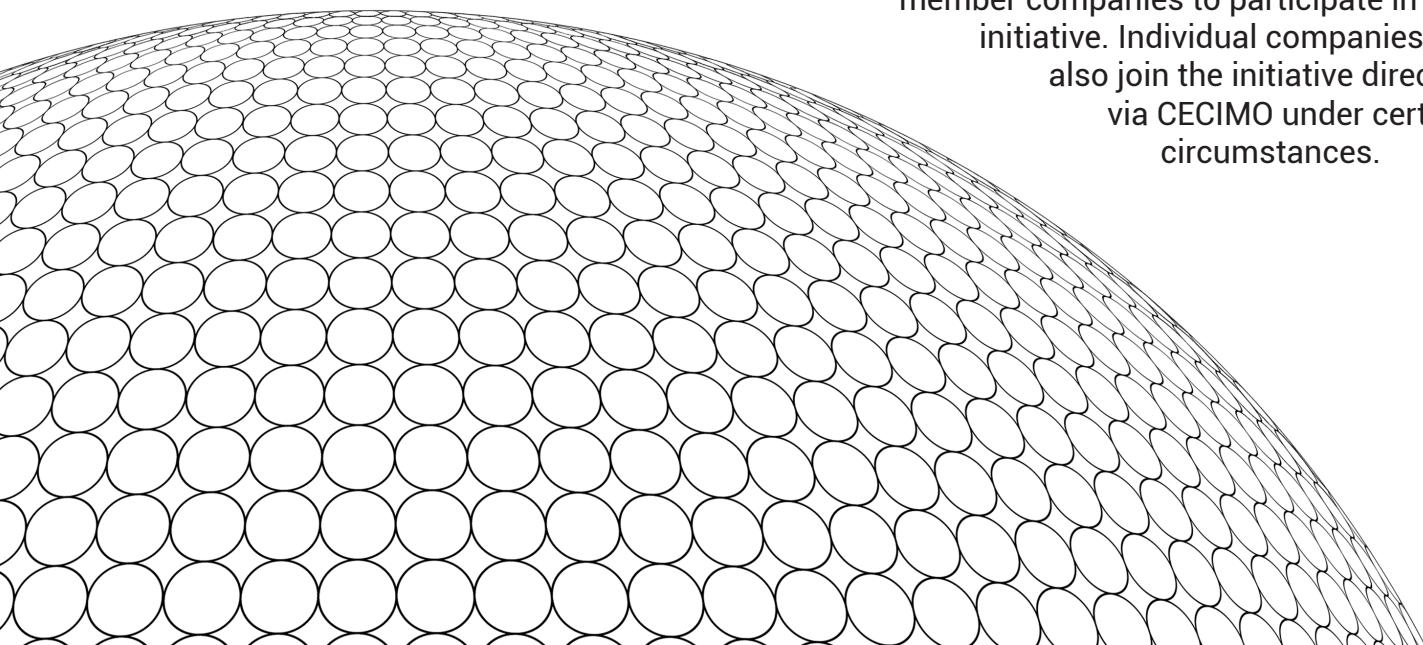
To help Italian machine tool manufacturers to benchmark sustainability, UCIMU has also produced a guide, 'Blue Philosophy – The Right Way of Innovation', which contains a self-assessment questionnaire with a list of reference criteria for environmental impact and energy efficiency. The list offers the possibility for companies to assess their performance with respect to other organisations.

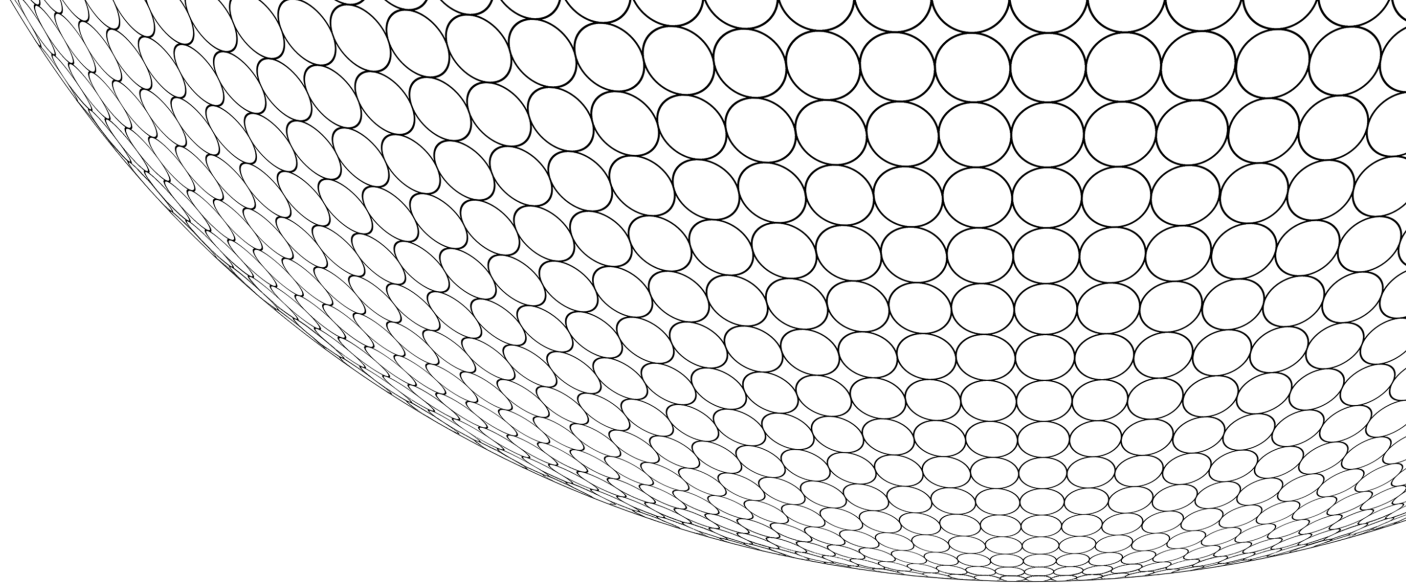
Currently, there are more than 70 companies that have been granted the use of the UCIMU mark.

Blue competence

Blue Competence is an initiative of the mechanical engineering sector, originally launched in Germany in 2009. Since 2012, CECIMO has been coordinating the Blue Competence initiative for the machine tool sector at European level. In the beginning, the focus of the initiative was on energy efficiency and environmental sustainability. But in January 2018 the initiative was revamped into a broader initiative that not only embraces environmental sustainability, but also economic and social sustainability. The initiative is in line with European policy objectives and highlights the machine tool industry's commitment to contributing towards the European Union's climate and sustainability goals.

Companies participating in the initiative show their long-term commitment to embed sustainability into their business practices and make a public commitment to abide by 12 principles which cover societal, environmental and economic aspects. CECIMO manages the initiative at European level thanks to the support of participant National Associations, which play an important role in the implementation of the initiative. They assume the main responsibility for the initiative's promotion within their country. As of January 2018, the UK (MTA), German (VDW), Spanish (AFM), Swiss (SWISSMEM) and Czech (SST) machine tool associations have joined Blue Competence, allowing their member companies to participate in the initiative. Individual companies can also join the initiative directly via CECIMO under certain circumstances.





THE TWELVE BLUE COMPETENCE PRINCIPLES

PREAMBLE: Our comprehension of trend setting sustainability is based on the principles of economic success, fairness, respect & responsibility and includes the dimensions of society, ecology & economy. We comprehend sustainable action in terms of the definition of the Brundtland report and the definitions of the German "Rat für Nachhaltige Entwicklung".

STRATEGICAL:

1. Sustainability is a crucial part of our company strategy.
2. We create solid business schemes with sustainable values and secure entrepreneurial success.
3. Our technologies and solutions promote worldwide sustainable development.

OPERATIVE:

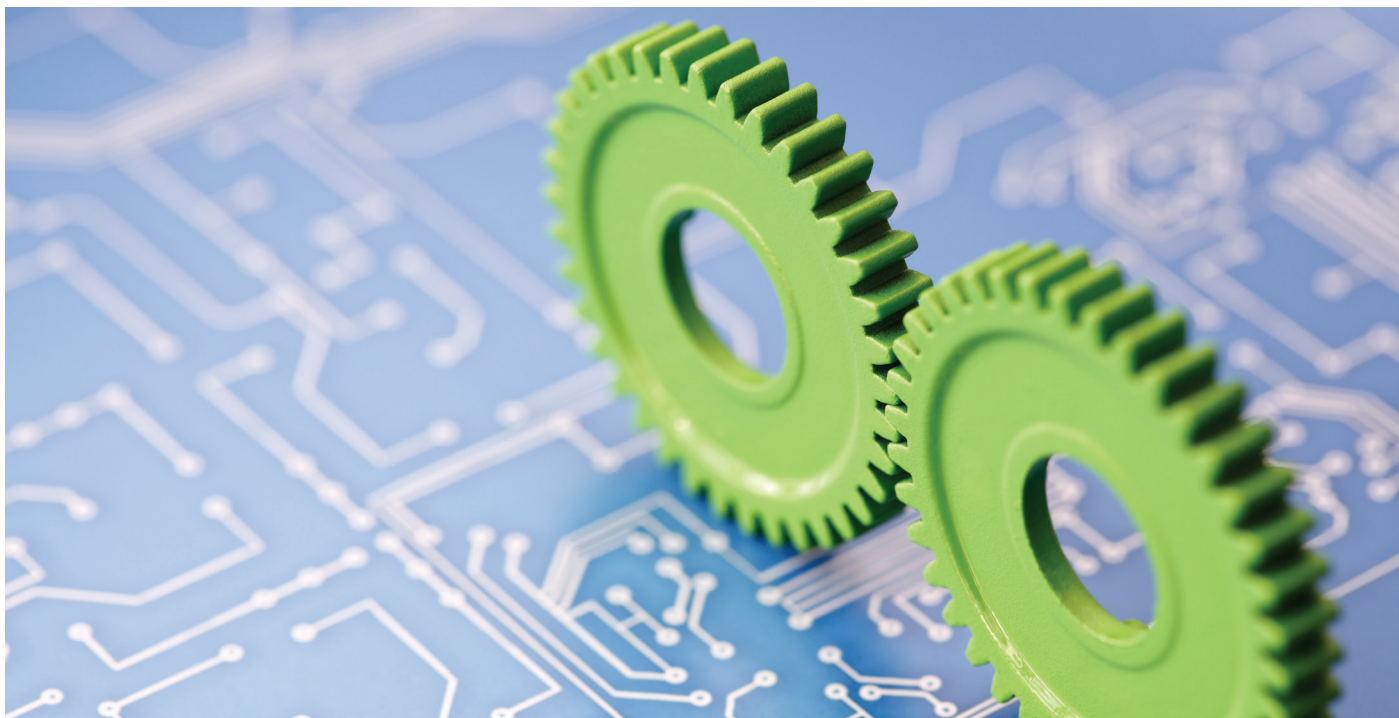
4. Sustainable thinking and action are represented in our processes and products.
5. We act with consideration of resources and stand up for climate protection.
6. Our staff is our most valuable asset. We promote engagement and participation.
7. We stand up for human rights.

CULTURAL:

8. Our company is a habitat.
9. We take responsibility in our region.
10. We do what we promise!

COMMUNICATIVE:

11. We actively cultivate the network with all participants.
12. We communicate our sustainable action transparently.



Company specific initiatives

Alongside the above-mentioned initiatives, some companies have also decided to launch their own initiatives. An example of this is the Engineered Sustainability® Ecodesign programme, launched by Fives¹⁷. Fives is an industrial engineering group that designs and supplies machines, process equipment and production lines for industrial customers. Fives introduced this programme as part of its aim to lead by example in terms of the energy efficiency and environmental aspects of its equipment. The programme sets out a structured methodology for evaluating the environmental impacts of products and to search for the best combination of environmental performance, ease of use and minimum operating costs, while maintaining a high level of product quality. Engineered Sustainability® involves Fives' affiliates in a demanding ecodesign process designed for long-term implementation and application. To date, nine products have received the Engineered Sustainability® brand in the Automation, Steel and Aluminum business lines, and 10 eco-design projects are under way.

“ In 2012, FIVES developed its own eco-design programme called “Engineered Sustainability”, which has been applied on several innovation projects on the Aluminium, Automotive, Steel, Logistics and Combustion markets. Today, we are developing a more comprehensive approach, in order to make the environmental performance of our equipment more affordable for our customers. This gives our design offices the opportunity to contribute even more effectively to the fight against climate change.”

YANNICK LEPRÊTRE
CHIEF INNOVATION & DIGITAL OFFICE,
FIVES GROUP



A tool for evaluating the energy efficiency of machine tools: ISO 14955

Growing awareness of climate change, legal and policy developments and rising energy prices all lead to increasing social and economic pressure to reduce energy consumption in as many domains as possible. This is also the case for the manufacturing industry and the machine tool sector. Machine tool companies are increasingly seeing energy efficiency as an important strategic topic that is driven forward by machine tool users who demand low operational costs, as well as social and legislative forces who require environmentally friendlier manufacturing. Nevertheless, evaluating the energy efficiency of machine tools presents a series of challenges.

Machine tools are a complex and heterogeneous product group

Machine tools are highly customised products tailored to customers' needs. They are complex systems used to manufacture parts of varying shapes, sizes and materials. The product group of machine tools is highly heterogeneous. It includes a wide variety of machines that can be grouped according to different characteristics – such as the materials processed, the technology used (e.g. turning, milling, grinding) or their size.

Machine tools typically process metal, wood or plastic. The workpiece material and its properties, such as breaking stress – the maximum stress a material can stand before it breaks – can have an influence on the main cutting force, and thereby on the energy needed. For example, the same machine tool might need more energy when processing a workpiece made of titanium than a similar workpiece made of steel¹⁸.

The product group of machine tools encompasses different technologies, such as milling, turning, grinding, laser processing, forming and, more recently, Additive

Manufacturing. Machine tools can also be manually or automatically operated and can range from machines making pieces of a few millimetres, such as dental implants, to big machines that manufacture pieces tens of metres in size, such as wind turbine blades.

Moreover, in order to remain competitive, machine tools are becoming more complex and offer more functionalities, which increases the number of factors impacting their energy use. This level of diversity is reflected in the number of categories listed in the EU Production Statistics (Prodcom)¹⁹. Prodcom lists 59 categories for metalworking machine tools only, without including woodworking or plastic-working machines. Moreover, the catalogue of EMO 2017 included 32 general categories, which are further subdivided into about 450 product subcategories related to machine tools²⁰.

The ISO 14955 approach

The amount of energy supplied to a machine is not an adequate indicator of its energy efficiency, especially in the case of complex products like machine tools. To determine the energy efficiency of a machine tool, energy consumption needs to be considered against the results achieved – for instance, the number of workpieces produced, their shape, quality, accuracy and other relevant factors that are determined by the specific application. Moreover, the strong individuality in machine tool design, applications and other factors means that it is not possible to define general energy efficiency measures that are effective for all types of machine.

Since 2009, the machine tool sector under the auspices of the International Organization for Standardization (ISO)²¹, has been working on international standards to assess the energy efficiency of machine tools. The ISO 14955 standard series proposes analysing machine

tools from the perspective of the different functions they execute, e.g. the machining process, tool handling, and machine tool cooling. According to this ISO standard, all machine tools can be characterised by six general functions. The functional description of machine tools is general and independent from the design of the machine tool and the machining process. This allows for a generalised approach for a wide range of machine tools to evaluate their environmental impacts.

The functions described in the standard are carried out by various machine tool components, such as hydraulic pumps, cooling units, spindle drives and so on. Each of them contributes to the total energy use of the

“With the development of ISO 14955, the machine tool industry – together with other relevant stakeholders – is proactively developing an approach that helps machine tool companies to maximise the environmental performance of their products, keeping in mind their specific application and other characteristics. The standard series is based on technical knowledge and technological possibilities and has the advantage of considering the real needs of the sector at an international level.”

RALF REINES

CONVENOR ISO/TC 39/WG 12



machine tool. By mapping the components to the different functions and evaluating the share of energy supplied to each of them, it is possible to identify the components that are relevant in terms of energy use. The standard contains a list of possible energy efficiency improvements, whose effectiveness and application would then need to be considered in view of the specific system, functionality and technologies of the machine tool under evaluation.

This approach, which is outlined in the first part of the standard (ISO 14955-1²²), provides a very useful resource for machine tool designers who wish to maximise the environmental performance of a certain machine, while keeping in mind its specific application. The second part of the standard, ISO 14955-2²³, supports the energy-saving design methodology outlined in the first part of the standard by providing practical methods for measuring the energy supplied to machine tools.

Even though ISO 14955-2 provides standardised methods for measuring energy supplied to machine tools, comparing the energy efficiency of the two is not as straightforward as it might seem. The performance of machine tools is multi-dimensional, in regard to economic value, technical specification and operation requirements – all of which are influenced by the specific application. And, again, these can be truly specific.

The results of the measurements carried out based on the ISO standard are intended to document improvements to the design and/or to allow for the evaluation of the energy involved in manufacturing a certain workpiece with a given machine tool. They can also be used to identify potential energy-related weak points within the machine tool configuration. Depending on the application, the same machine tool can show rather different characteristics concerning its supplied energy. Therefore, any comparison would require identical requirements and conditions. Nevertheless, it can be concluded that the generic approach outlined in the ISO 14955

The World of Machine Tools

Machine tools are **highly customised products** tailored to customers' needs. They are very diverse and can be classified depending on:



the material processed



the technology used
(i.e. grinding, milling, turning, bending, etc.)

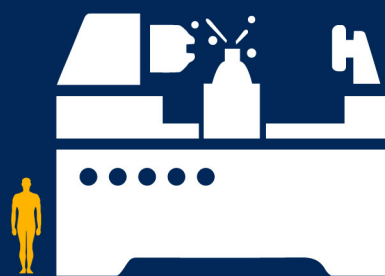


the degree of automation and precision

DO MACHINE TOOLS HAVE THE SAME SIZE?



Machine tools range from machines making pieces of a few millimetres, such as dental implants ...



... to big machines that manufacture pieces tens of metres in size, such as wind turbine blades.

But then what they do have in common?

ISO standard 14955 identifies **6 functions common to all machine tools**.



series²⁴ is a useful resource, based on the real needs and technological possibilities of the sector, and is at the disposal of machine tool companies to improve the environmental performance of their products and meet the increasing demands of their customers in this area.

Validation by industry

The overall applicability of the ISO 14955 approach to various machine tool types and applications was validated through 50 machine tool assessments performed in the industry within the framework of the EE4MT (Energy Efficiency for Machine Tools) project²⁵. These assessments were funded by the Swiss Federal Energy Office (BFE) and conducted by Swissmem, the Swiss mechanical and electrical engineering industries association, together with SIGMAtools.

The project offered machine tool users and manufacturers a personalised evaluation, which provided ways to optimise their production and helped them to define concrete and targeted measures to be implemented. Above all, this was an opportunity to validate the ISO standard. The assessment started with the definition of a typical individual reference scenario, or a set of relevant manufacturing processes based on the indications given by the third part of the standard (ISO 14955-3²⁶). The definition of an individual reference process is an essential step towards the objective, meaningful and effective assessment of the various types of machine tools, configurations and applications. The definition of these reference processes allows for the assessment of the machine tool's performance, the identification of potential optimisation measures and/or determining energy performance indicators (EnPIs), based on the intended industrial application instead of unrealistic or optimised machining processes. Machine tool manufacturers found the assessments useful for identifying potential improvements. These kinds of improvements cannot always be implemented by retrofitting the machine, since the effort necessary to implement them cannot be justified from an economic point of view in some cases. Nevertheless, these improvements – for instance, the cooling concept of the



“Machine tool manufacturers, as well as users, strongly support this approach. The fact that the assessment of the environmental performance of the machine tool is based on the intended application – and not on artificial and unrealistic data – means it helps to identify real improvement potential, which is useful in designing the next generation of even more efficient machine tools.”

ADAM GONTARZ
TECHNICAL MANAGER MACHINE TOOLS
MANUFACTURERS, SWISSMEM

machine, process conditioning or component dimensioning – can be used in the eco-design, research and development process of the next generation of machine tools.

The application of the standard also helped to build a better understanding between the machine tool manufacturer and the user on how the machine is operated. This is essential when aiming to provide a customised and/or process-related configuration that meets the customers' needs. In addition, this results in the indication of potential optimisation measures in relation to, for example, the machine tool's usage, compressed air leakage or component control.

The project also showed that the standard provides a good compromise between the required measurement effort and the results from the machine tool assessment.

R&D+I – The cornerstone of a sustainable machine tool sector



The machine tool sector is a knowledge-intensive industry, characterised by companies' continuous investment in innovation, research and development. The EU 2017 Industrial R&D scorecard placed the industrial engineering and machinery industry in the medium-to-high category. In terms of R&D activities²⁷ in Spain, for example, companies allocate an average of six percent of total sales to Research and Development plus Innovation – or R&D+i²⁸. A big part of these resources is dedicated to testing and validating new approaches for improving the energy efficiency and performance of machines, as well as developing new low energy and resource-consuming manufacturing strategies, tools and techniques.

Dematerialising machine tools

The DEMAT²⁹ project is a good example of a

European-level initiative led by the machine tool sector that tests new technology approaches to support the circular economy. The project aimed to develop lightweight machine structures to maximise productivity, while minimising the environmental impact. The production of machine tools requires a large amount of metals, often in the range of several tonnes. These materials are mainly used for building the structure of the machine, which requires a high stiffness and vibration-damping ratio, in order to guarantee its stability, productivity and accuracy. By 'dematerialising' machine tools and reducing the weight of the machine's moving parts, power and material demand can be reduced. The DEMAT project proposed a revolutionary approach that reduced the mass of both passive and active structure building blocks by over 50%. Moreover, these building blocks

were 100% reusable in the modules of other machines and carry with them a high level of accuracy and reliability.

Micro-machining

The INTEG-MICRO³⁰ project is another example of a European project that looked to develop new technologies – in this case, high-precision micro-manufacturing technologies – that could bring environmental benefits to industries such as medical, automotive, aerospace or watch manufacturing. The miniaturisation of machines is expected to be accompanied by a reduction in energy consumption (40-60 percent) and a reduction of waste emissions – leading to a positive impact on sustainability. Moreover, the project also looked into dry and

“In our company we systematically invest in research and development so that we can offer the best solutions to meet our customer increasing demands for improved quality, productivity and environmental performance. In a sector like ours, characterized by an ever-increasing competition, continuous innovation is extremely important to keep our competitiveness at European and international level.”

MONIKA ŠIMÁNKOVÁ

GENERAL DIRECTOR, HESTEGO A.S.



high-speed cutting processes, with the aim of eliminating the need for cutting fluids.

Providing practical tools for SMEs

The machine tool sector has also been proactive in developing practical tools that support the ecodesign innovation efforts of SMEs in the sector. The PROLIMA³¹ project, for example, supported SMEs in developing milling and grinding tools that last longer, are better for the environment and are more cost efficient. PROLIMA worked on improvements during the design phase, taking into consideration the lifecycle cost from the onset. From this, it is possible to adopt a decision-support system. The project also focused on the concept of Reliability, Availability, Maintainability and Safety (RAMS). In parallel, it worked on the manufacturing and use phase by developing tools adapted to the needs of SMEs, such as best practice manuals and software systems that can help companies to assess the sustainability of machines by evaluating functionality, cost and environmental impact.

R&D funding essential for sustainability and competitiveness

Research and development activities are becoming more and more important, given the ever-increasing demand for sophisticated and more environmentally friendly products across industries and the increasing competition from non-European machine tool builders. Research and technological innovation are also essential in the way towards a more sustainable and circular economy. The machine tool sector is already investing heavily in R&D and in new, innovative solutions to support the development of more environmentally friendly technologies and processes that can help the sector to keep its competitive edge. Nevertheless, the availability of R&D funds for the manufacturing sector at national and European level and improved access to funds for SMEs is key if we want to advance further in the path towards sustainable manufacturing.

**THE ROLE OF NEW
TECHNOLOGIES
FOR A MORE EFFICIENT
AND SUSTAINABLE
MANUFACTURING**

Towards digital circular manufacturing

Digital technologies are increasingly transforming all sectors of the manufacturing industry, including the machine tool sector. This trend towards greater digitalisation – enabled by advances in data, analytics and connectivity – provides immense opportunities for the realisation of sustainable and resource-saving manufacturing. Improvement in the collection and use of data makes it possible to optimise business operations, maximise energy efficiency and use fewer resources more efficiently. Digital technologies are therefore pivotal in bringing about a change towards a more circular manufacturing sector.

Real-time information increases transparency and product quality

Digital technologies transform machine tools into intelligent assets, which are able to collect and communicate real-time information about themselves and their surroundings, thus enhancing transparency in the production process. This means that it is possible to observe the production process in real-time and to react to any circumstance during the process, by using real-time problem-solving, advanced process control or real-time error corrections³². Processes can therefore be optimised and product quality improved, which reduces waste and production time.

Digitalisation is making the consumption of resources easier to measure which means that processes with excess energy and resource consumption can be identified and optimised. According to a study by the International Energy Agency³³, real-plant data showed that energy efficiency gains from the application of advanced digital process controls can lead to significant savings with little-to-no net costs. In the United States, for example, improved process controls led to estimated energy savings of over \$330 million in small and medium-sized manufacturers, with a total

investment cost of \$235 million over the period of 1987 to 2015.

Moreover, the collection, exchange and analysis of real-world data on component and overall machine state and performance can help machine tool manufacturers to maximise the equipment productivity and efficiency, as well as allowing them to develop new services such as predictive maintenance.

The digital twin

Digitalisation and advanced analytics also enable the creation of digital replicas of physical assets. This is what we call a digital twin; a virtual model of a physical asset such as a machine on the shop floor or even the whole production process in their intended environment. It provides a connection between the physical and the digital worlds³⁴.

Digital twins of products, such as machine tools, can be used by manufacturers to analyse the actual product behaviour in relation to its original design. This allows us to recognise any behaviour deviations and to influence the development of future products. Moreover, by simulating and validating product properties of a manufacturing system on a computer, prior to physical production, the amount of physical testing and experiments can be significantly reduced. This does not only enhance the ability of industry to innovate and to reduce the time necessary to put new products on the market, it also helps to optimise products in advance and to reduce the resources needed for their development.

As mentioned above, it is not only possible to create digital twins of products, but also of processes to encompass the entire production environment³⁵. In this case, the digital twin serves as a virtual replica of what is happening on the factory floor in near-real time. Data is

continuously communicated and analysed by the digital twin, which can also accurately model the impact of changes to an existing production process, simulate different options, and optimise processes in a transparent way. The digital twin also enables intelligent, machine-level decision-making at a factory level. For example, digital twins of processes can present engineers with options to fix the machine tool and help technicians to choose the best time for repairs, while taking into consideration the entire downstream process. The consulting company Gartner predicts that, by 2021, half of large industrial companies will use digital twins, resulting in those organisations gaining a 10% improvement in effectiveness³⁶.

“The digitisation of European manufacturing can definitely have a strong impact in the circular economy. Data driven solutions providing access to information in real-time are key in the optimization of manufacturing processes, capacity, energy and raw materials use.”

JOSÉ PÉREZ BERDUD

CEO, FAGOR AUTOMATION S.COOP.



Extending the lifetime of assets

Reducing machine tool downtime and assuring quality are important aspects for the customers of machine tool builders. Quality, however, heavily depends on the condition of the equipment³⁷. Digitalisation and the permanent, remote monitoring of machinery condition makes it possible to reduce downtimes through the early detection of possible problems prior to asset failure. This is achieved by implementing predictive maintenance. Predictive maintenance increases product reliability and availability and enables us to extend the lifetime of products. According to various studies, the use of predictive maintenance enables us to decrease total machine downtime by 30-50%, while increasing the machine's lifetime by 20-40%³⁸. But equipment data does not only increase the efficiency of maintenance operations, it can also help in the remanufacturing of products. Having the data history of the machine means that the manufacturer knows the wear and tear of each component. It is therefore easier to identify which component needs intensive work or replacement and which one needs some small adjustments or no repair at all.

Addressing the barriers to the uptake of digital technologies

But despite the opportunities that digitalisation can bring to manufacturing, by increasing its sustainability and competitiveness, only 5% of manufacturing SMEs have networked their machinery, plants and systems across the board and only a third of them are taking the first steps in that direction or at least have concrete plans to do so³⁹. The degree of digitalisation of large companies and some sectors is higher, but most companies are still at the beginning of their digitalisation journeys. If we want to make the most of digital solutions for the benefit of the circular economy, we need to address the barriers to their uptake

and maximise synergies between the digital and circular economy agendas. Some companies remain unaware of the potential of digitalisation in terms of resource efficiency and productivity gains. Financing is also critical. The slowdown in demand for new equipment hampers the ability to develop breakthrough production technologies, as innovation is mainly driven by customer demands and cooperation between suppliers and users in the machine tool sector. Tax incentives are therefore necessary to invest in digitalisation.

Similarly, access to data and the free flow of non-personal data across the EU could make it easier for companies to analyse and transfer data and scale-up innovative – including circular – business models. Standards play a key role here, too. Standards allow smart connected products, machines, and assets from different manufacturers to interact in

a transparent way. 64% of senior executives say integrating data from disparate sources/formats and extracting business value from that data is the biggest challenge presented by the Industrial IoT⁴⁰.

In this respect, it is important to highlight some sector own initiatives such as UMATI⁴¹, an initiative of the German Machine Tool Manufacturers' Association (VDW), to develop universal interfaces to enable machine tools and peripherals from different manufacturers to communicate with each other on a single production line. These sector initiatives aim at contributing to the creation of globally-accepted connectivity standards, which could address one of the main obstacles to reaping the benefits of digitalisation.



Additive Manufacturing as an enabler of the circular economy

Additive Manufacturing (AM), also known as 3D printing, is the general term used to refer to technologies that, based on a 3D digital model, build up parts by adding material layer by layer. Subtractive manufacturing methods, in contrast, start from a solid block of material and then remove the excess to create a finished part.

Additive Manufacturing was initially used in industrial environments to produce prototypes. As technical performance improves and costs decrease, AM is progressing from rapid prototyping to the production of end-use products and components. AM is already being used in sectors such as aerospace, automotive, construction, the creative industries or healthcare, with new and innovative applications constantly being developed. Additive technologies offer significant advantages in terms of design freedom, mass customisation and provide for innovative business models. Another important aspect of AM is its potential to support the move towards a more circular economy.

Lightweight design and enhanced durability and functionality of components

Often the best solutions for the design of products and processes can be found in nature. Nevertheless, designs inspired by nature tend to have organic shapes that are more difficult or even impossible to reproduce using traditional manufacturing techniques. AM technologies have very limited shape and geometric constraints, allowing the production of alternative optimised complex parts which have a lighter weight and improved functionality. This can help to reduce the consumption of energy and natural resources during the use phase of the final

product, leading to a positive impact on the environment.

An example of such functional improvement can be found in lightweight components for transport systems. AM-produced metal parts can, in some cases, be up to 50% lighter than machined parts. In areas such as aerospace or the automotive sector, the use of AM can translate into a positive effect on the environmental performance of the product during its use phase. According to some sources⁴², one kilogram removed from every aircraft of a 600+ fleet of commercial jet-liners saves about 90,000 liters of fuel every year and reduces emissions by up to 230 tons of CO₂.

Further benefits obtained by using Additive technologies can be found in the consolidation of the number of components within an assembly and the creation of new material structures. An example of component consolidation is the CFM LEAP fuel nozzle tip⁴³, which combines 20 parts into one, offering five times the durability and 25% less weight. Fewer components to be assembled leads to fewer logistical requirements, less need for tooling, fewer errors in production, and reduction of production and assembly time – resulting in cost saving and the reduction of environmental impact. Moreover, the nature of the AM process allows the creation of new material structures that can enhance the properties of the components being fabricated, e.g. increased strength, stiffness, corrosion resistance...

Increasing material efficiency and recycling

Additive technologies can also help to reduce waste in the production process, since they only use the material that is needed to produce a part. Some post-processing of the part is often required and – for example, in the case

of metal-powder bed systems – waste is generated in terms of support material and residual powder, but a big part of it can be recycled or reused. For metal powders, it is estimated that 95-98% can be recycled⁴⁴. In this context, the EcoTitanium project is particularly of interest⁴⁵. The project makes alloys from titanium solid scrap and chips collected from the major aircraft makers and their subcontractors, and is said to provide Europe with a titanium supply source that is independent of the major global producers. Indeed, one of the most promising uses for titanium powder is Additive Manufacturing. In the case of plastics, waste plastic filament, misprints and undesired outputs can also often be reclaimed and reused. The AM process, in addition, provides the opportunity to create value by recovering waste as material to produce new goods. The Perpetual Plastic Project (PPP)⁴⁶ investigated and demonstrated the feasibility of recycling plastic waste from everyday products, such as cups or bottles, into input material for Additive Manufacturing. There are already 3D printers on the market using filament made in part from recycled bottles⁴⁷.

Enabling on-demand and distributed manufacturing

As mentioned above, the characteristics of AM enable on-demand manufacturing and on-demand changes to components and products. The shift from traditional mass production methods and economies of scale to small batch production of customised or personalised goods is made possible at a lower cost. This means that inventories of components and products can be reduced or eliminated, thus reducing the economic losses and environmental impacts associated with unsold and obsolete components.

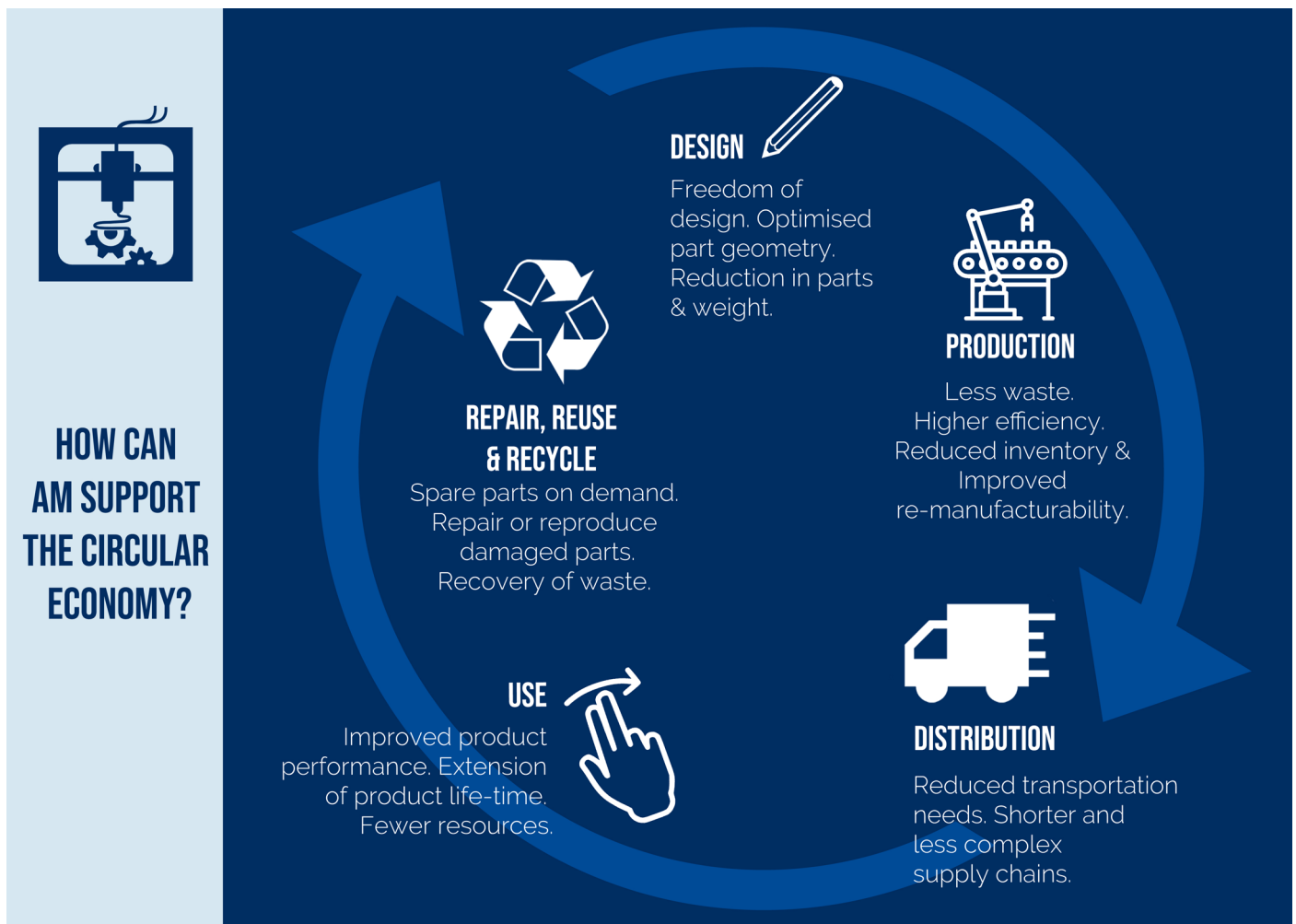
Since the Industrial Revolution, manufacturing has progressively become more and more centralised⁴⁸. Nevertheless, AM can create opportunities for more distributed and localised

manufacturing, allowing to set the production location at the optimum distance between the material resource and the customers. A shift towards a more de-centralised manufacturing system implies that AM will have substantial positive effects on the environmental impacts of transportation. Furthermore, product and component redesign could potentially amplify this effect. Simplifying complex multi-component products into single-component products could also, in turn, simplify the complex value chains associated with them.

“Additive Manufacturing has an important role to play in increasing the competitiveness of European industry and in supporting circular economic models. To capitalize on the opportunities provided by Additive Manufacturing it is important to support its market uptake by ensuring an appropriate legal and policy framework, the development of relevant standards and the necessary skills in this area, in addition to financial support for further research and development.”

STEWART LANE
DIRECTOR, GROUP SALES DEVELOPMENT,
RENISHAW PLC





Reparability and remanufacturing becomes easier and more cost-effective

Additive Manufacturing (AM) can play a very important role in the circular economy by making repairs and remanufacturing easier and more cost-effective. Currently, many products are rendered useless by the breakdown of a single part. Parts needed for repair may not be available, may take too long to be delivered or repair may not be cost-effective. AM allows spare parts to be printed on demand and closer to where they are needed. This helps to reduce inventory waste and customer waiting time. Deutsche Bahn, the German railway company, is a good example of a company using AM to produce spare parts, which are no longer available or difficult to find, for older vehicles or systems in the infrastructure sector⁴⁹. AM also offers a more effective alternative to the traditional production of the small quantities needed in these cases.

The repair or remanufacturing of damaged components allows products to last longer, thus avoiding the production of new ones. Turbine blades are a well-known example of remanufacturing using AM. According to a comparative Life Cycle Assessment (LCA)⁵⁰, the remanufacturing of a damaged turbine blade by AM, versus producing a new blade by means of casting, offers considerable environmental benefits in addition to economic ones. For a repair volume of 10%, the estimated energy and carbon footprint savings are 36% and 45%, respectively. The repair of damaged tool components is an application area in which AM has also shown its strengths. Rather than replacing damaged tools, additive technologies can be used to quickly repair only the damaged areas, resulting in simplified repair, decreased downtime, longer operating life and reduced operating costs.

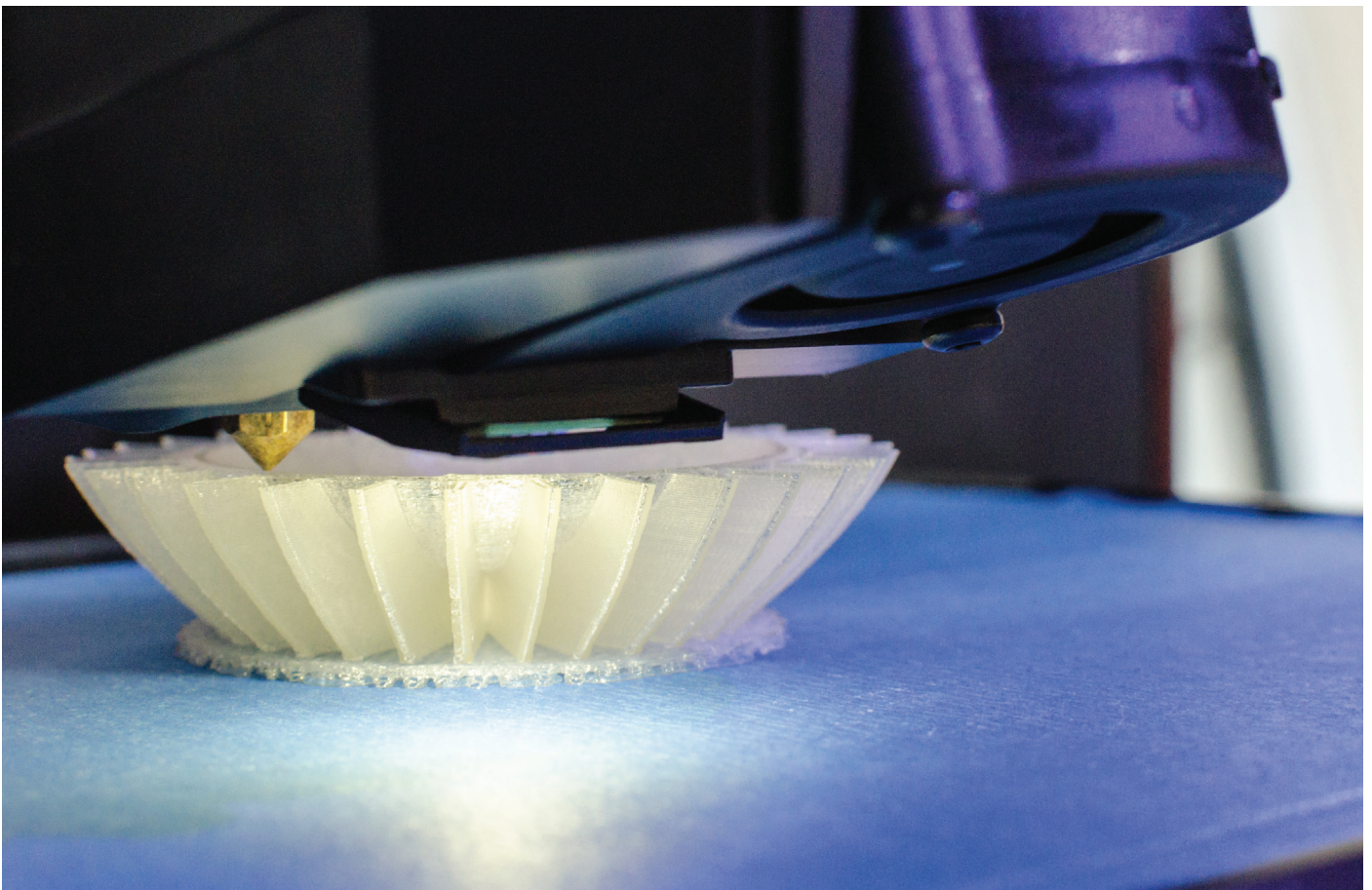
Additive Manufacturing as a complement not a substitute to subtractive manufacturing

Additive Manufacturing is not a standalone technology and will, for the most part, complement – not replace – traditional forms of production. The technology has incredible utility for small, one-off production runs and for the manufacturing of small custom workpieces that would normally need a lot of specialised tooling to make. Nevertheless, there are still many items that are needed in high volumes and for which traditional, highly-efficient manufacturing technologies are more cost effective and environmentally efficient than AM.

There is also a great deal of uncertainty as to what exactly the effect of a broader adoption of AM would be, especially in relation to existing supply chains. Nevertheless, what seems clear is that additive technologies have an important role to play in the future of manufacturing and in allowing our society to become more circular. This paper has mentioned some of the ways in which AM has begun enabling

improvements to resource efficiency and new models of sustainable production and consumption. AM-manufactured parts seem to bring bigger benefits in relation to small batches and advantages in cases where AM-based redesigns offer substantial functional advantages and properties, such as lightweight designs or increased strength. It also plays an essential role in extending the lifetime of products through repair and remanufacturing and bringing new value to waste – for example, plastic bottles.

We should not forget, however, that AM technologies are at an early stage in their development and still have lots of potential to improve. Additional benefits could be obtained if additive technologies evolve appropriately and are introduced into large-scale production. Increasing the AM process automation, speed and accuracy, as well as broadening the available materials, are some of the key issues our sector is currently working on.





RECOMMENDATIONS FOR THE MACHINE TOOL SECTOR AND POLICY MAKERS

The shift towards a circular economy calls for a prominent role of manufacturing. In this respect, machine tools play a crucial role. Thanks to more accurate, efficient and capable machine tools the manufacturing industry can improve its productivity and resource efficiency and consumers can enjoy products such as cars, that last longer and use less energy than ever before.

The European machine tool and related manufacturing technologies sector contributes to the circular economy through different actions aiming at improving the performance of its products, developing and implementing new technologies (i.e. digital technologies and Additive Manufacturing) and imbedding sustainability principles in its everyday operations.

Putting stronger emphasis on resource and energy efficiency does not represent a shift away from traditional elements of competitiveness such as precision, speed or reliability and safety. It rather adds to these strengths the element of sustainability, which emerges as a new paradigm of competitiveness. Environmentally efficient machine tools profit to both manufacturers and users: the user can save on material and energy costs thanks to optimised production processes, whilst the machine tool builder can gain a competitive edge by offering value-added products.

To a big extent the machine tool sector already embraces core principles of the circular economy. Continuous performance improvement, maintenance, upgrading, refurbishing and recycling are already common practices in the sector but there is always space for improvement. In this respect it is important to consider the heterogeneity of the sector from the point of view of structure and products, making impossible to implement one-size-fits all measures.

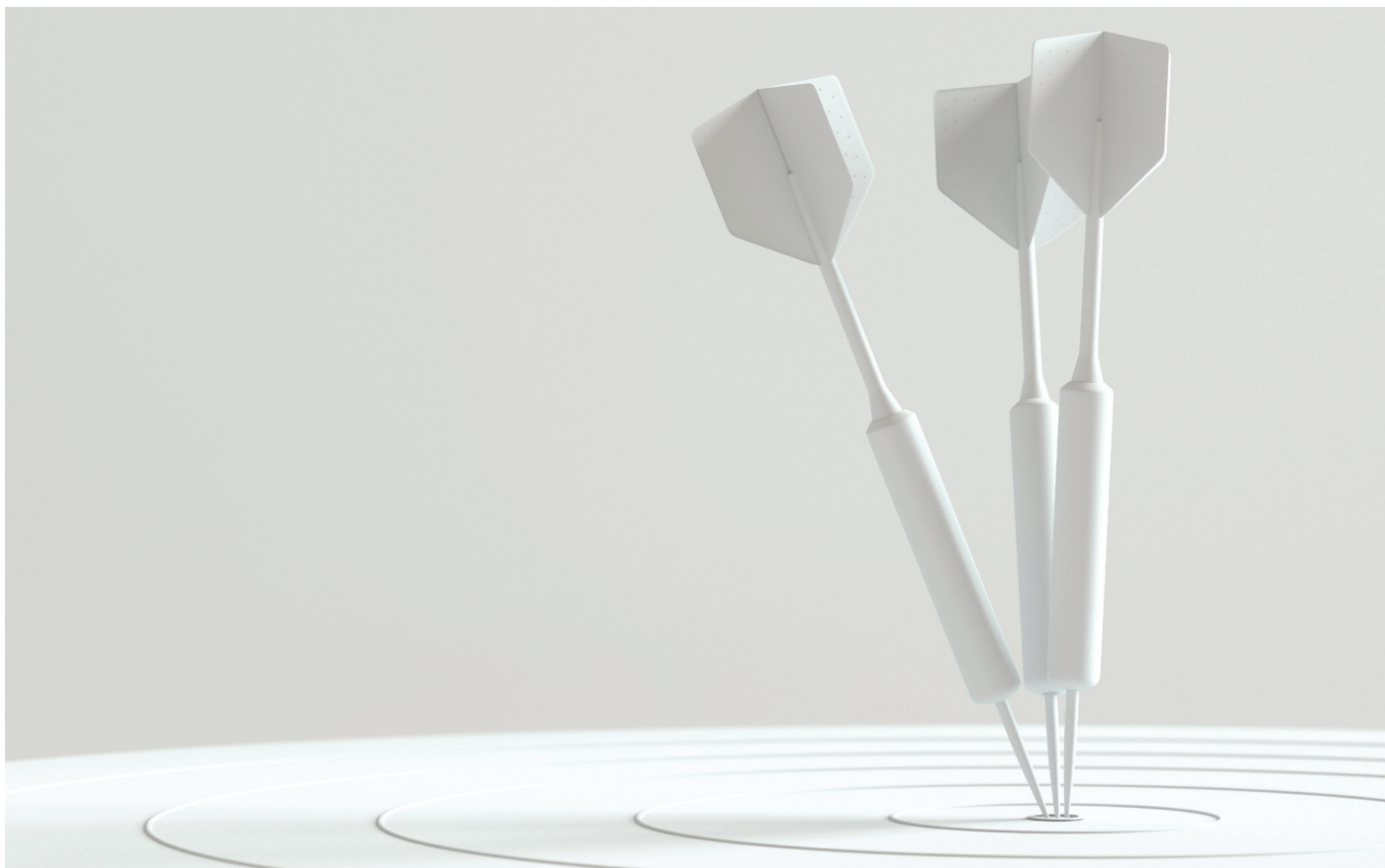
Recommendations for industry

1. Embrace the opportunity and Implement sustainability and circular economy principles in a systematic way in your business. Although key principles of the circular economy are already present in the sector it is important to embed them in your organisation in a systematic way. Implementing circular economy provides opportunities to improve total life cycle costs of your products and to maximize value beyond the point of sale, thus improving your competitiveness. Start by further building on existing proven good practices in your company. Engage relevant people from functions across the organisation to support sustainable innovation, define those areas where you can improve, define clear goals and monitor your progress.

2. Showcase circular economy best practice and real-life success stories from the sector. Sharing best practices is an excellent way to fill knowledge gaps, improve efficiency and performance. This can be done through CECIMO, national associations and existing initiatives such as Blue Competence and Blue Philosophy.

3. Work together with your clients and your supply chain. Businesses cannot become circular on their own. You need to work closer with your customers and suppliers to improve product efficiency, remove waste from the supply chain and create new more circular business models and products that create added value to your customers.

4. Continue to work on global industry led standards. Standards such as ISO 14955 on the environmental evaluation of machine tools offer valuable guidance and tools for companies to maximise the environmental performance of their products while considering the real needs of the sector at global level.



Recommendations for policy makers

1. Avoid one-size-fits-all approaches and legislate in a technology neutral way only where market failure exists. The machine tool sector encompasses very diverse companies (mainly SMEs) and of products. This should be considered when developing new policy and legal initiatives in support of the circular economy. Policy and legal initiatives should be technology neutral and properly balance environmental sustainability principles with economic sustainability to avoid any additional burdens that could lead to a loss of competitiveness of European companies.

2. Support the digitisation of European industry and more specifically SMEs. Digitalisation of the industrial sector helps to increase energy and resource efficiency and contributes to keeping materials in use for a longer time. It is important to exploit the synergies between the different EU initiatives in support of the circular economy and to support companies and specially SMEs in their digital transformation . SME access to competence centres is essential so that they can understand the benefits of digitisation and test their solutions.

3. Provide R&D funding for manufacturing and support the development of new enabling technologies. Investing in R&D is essential to keep the competitiveness of the machine tool companies and to develop new cleaner and more efficient technologies. It is important to promote the development of new technologies such as Additive Manufacturing, artificial Intelligence and machine learning, that can enable the transition to a more circular economy.

4. Tax incentives and financial advantages can support a more rapid transition to the circular economy. Innovation is driven by customer demand. The slowdown in demand for new equipment hampers the ability to deploy more efficient and cleaner production technologies and to speed the digitisation of European industry. Some countries such as France and more recently Italy adopted incentives as part of their National Industry 4.0 plans to create incentives for investment into digital and interconnected machinery and systems. Similar approaches could also be adopted by other EU member states to encourage investments in digital and more energy efficient products and systems.

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cecimo

European Association of the Machine Tool Industries
and related Manufacturing Technologies

Member Associations

Austria: Metaltechnology Austria
Association of Metaltechnology Industries
www.metalltechnischeindustrie.at

Belgium: AGORIA
Federatie van de Technologische Industrie
www.agoria.be

Czech Republic: SST
Svazu Strojírenské Technologie
www.sst.cz

Danish Manufacturing Industries Cooperation
A part of the Confederation of Danish Industry
www.isa.di.dk

Finland: Technology Industries of Finland
www.teknologiateollisuus.fi

France: SYMOP
Syndicat des Entreprises de Technologies de
Production
www.symop.com/fr

Germany: VDW
Verein Deutscher Werkzeugmaschinenfabriken e.V.
www.vdw.de

Italy: UCIMU
Associazione dei costruttori Italiani di macchine
utensili robot e automazione
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Netherlands: FPT-VIMAG
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www.fpt-vimag.nl

Portugal: AIMMAP
Associação dos Industriais Metalúrgicos,
Metalomecânicos e Afins de Portugal
www.aimmap.pt

Spain: AFM – Advanced Manufacturing Technologies
Asociación española de fabricantes de máquinas-
herramienta, accesorios, componentes y
herramientas
www.afm.es

Sweden: SVMF
Machine and Tool Association of Sweden
www.svmf.se

Switzerland: SWISSMEM
Die Schweizer Maschinen-, Elektro- und Metall-
Industrie
www.swissmem.ch

Turkey: MIB
Makina Imalatçileri Birliği
www.mib.org.tr

United Kingdom: MTA
The Manufacturing Technologies Association
www.mta.org.uk

cecimo is the European Association representing the common interests of the Machine Tool Industries and related manufacturing technologies globally and at EU level. We bring together 15 National Associations of machine tool builders, which represent approximately 1500 industrial enterprises in Europe (EU + EFTA + Turkey), over 80% of which are SMEs. CECIMO covers more than 98% of total machine tool production in Europe and more than one third worldwide. CECIMO assumes a key role in determining the strategic direction of the European machine tool industry and promotes the development of the sector in the fields of economy, technology and science.