ÖWGP
Österreichische Wissenschaftliche
Gesellschaft für Produktionstechnik

NEW DEAL
IN PRODUCTION

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Preface

Can machines think?

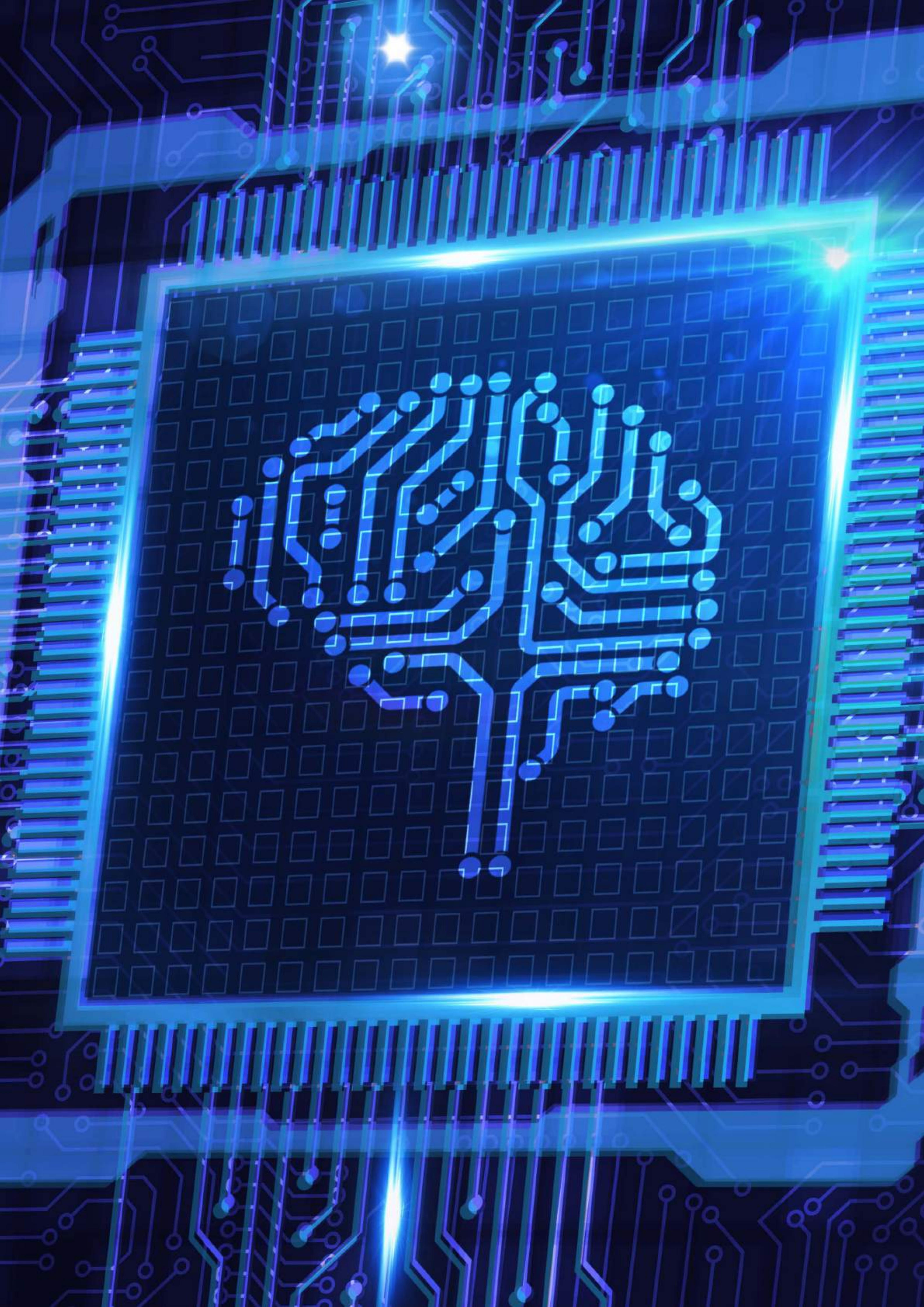
"I propose to consider the question 'Can machines think?'" – This was the opening sentence of Alan Turing's 1950 paper "Computing Machinery and Intelligence" in the scientific journal MIND (Oxford Academic). Drawing on his other theoretical and mathematical work, Turing stated that instruction-processing machines comprised of memory and an arithmetic logic unit – that is, computers and thus also computer-controlled systems – are able to solve algorithmic problems. John McCarthy, who would later be awarded with the Turing Award, took up the topic of "Artificial Intelligence" (AI) at a scientific workshop at Dartmouth College in 1956. In this "first wave" of AI research, which lasted into the 1980s, humans programmed intelligent machine behaviour in a rule-based manner using extensive if-then relationships. Now, in the "second wave", computers themselve learn intelligent behaviours from vast amounts of data and collections of examples. Training of large artificial neural networks has resulted, for instance, in AI breakthroughs in image recognition and success in boardgames such as chess and go.

We are reaching the cusp of the "third AI wave", which – propelled and motivated by the inadequacies of training-data-based machine intelligence – is heading towards logical interactions between individual intelligences to identify and exploit interrelations in a wider context, especially when data is scarce or unreliable.

Today's production systems and products are increasingly – and will in the future become entirely – AI-controlled. It is easy to extrapolate from this observation that future production systems and products will "think". However, this evolution will require completely new science in engineering design, production technology and product development that surpasses the solutions brought by the "industrial revolution" proclaimed a few years ago.

The Austrian Scientific Society for Production (ÖWGP) addresses the essential nature of transformation in scientific production, product and materials research, also in the light of humanity's current exceptional challenges, such as climate change, pandemics, circular economy, increasing scarcity of natural resources, structural changes of work, geopolitical shifts and demographic developments. ÖWGP members are committed to the scientific challenge of finding solutions to policy problems in research, industrial, environmental, societal and social contexts. Inspired by current international industrial research and the latest technological achievements, but also shaken by COVID-19, the CO_2 crisis, unemployment, short-time working and decreasing economic performance of growth-oriented national economies around the world, the ÖWGP has developed a catalogue of perspectives: the NEW DEAL. ■

Alois Ferscha
President



1. New Challenges – “NEW DEAL”

Gabriele Kotsis, Christian Ramsauer, Sebastian Schlund

For a country such as Austria, which has neither a significant domestic market nor large deposits of natural resources, the most important resource is – and will always be – highly motivated and well-qualified people.

Austrian manufacturing – particularly in 2020 and 2021 – is confronted not only with the foreseeable developments in production technologies, materials and products, but also with fundamentally new challenges. While 2020 was marked by the pandemic-related downturn, in 2021 opportunities and challenges will be in balance. At best, it will take years for the Austrian economy – with its numerous companies of all sizes – to recover from the consequences of the present exceptional situation. In addition to the tragic loss of human life and serious consequences to the health of many, the impact on Austria’s economy was immense.

For example, 25.8% of production workers in manufacturing industry were switched to short-time working. Some Austrian core industries, such as the automotive supplier and the aviation industries, made vastly disproportionate use of this (for 56% and 88% of their workers, respectively). Austria’s gross domestic product for 2020 shrank by 7%. The effects of the second lockdown – and of those that might follow it – are primarily felt by employees in the form of job loss. We must now implement strong countermeasures to maintain our position as an internationally competitive production location.

Not all Austrian companies were hit equally hard by the crisis; the recent months have shown that companies with digital networking already implemented in their engineering and business processes have a clear advantage. However, a wave of insolvencies is to be expected once state support ceases. A national effort is therefore required to strengthen manufacturing industry and its substantial contribution to innovation in Austria, and thus create future-proof jobs.

Another important task is to learn from the effects of the COVID-19 crisis, which has revealed the vulnerability of globally interconnected value chains and the possible consequences of dependency on individual suppliers. Austrian production will become stronger if critical dependencies are reviewed and value networks are redesigned to become more resilient while considering sustainability and environmental protection. The aim of this redesign is to create agile organisations and adaptable production approaches and thus increase value chain resilience.

25,8 - 88% of production workers in Austrian manufacturing industry were switched to short-time working.

Austria’s gross domestic product for 2020 shrank by **7%**

In addition to addressing the consequences of the current pandemic-related economic crisis, Austrian industry will have to search actively for solutions that enable the transition to resource-efficient – and ultimately resource-neutral – value creation. Innovative solutions for sustainable economic activity and carbon-neutral products and production processes are becoming critically important. A glance at the European and Austrian political agendas and upcoming programmes shows that great effort will be made to promote sustainable and climate-friendly processes and projects. Based on the European Green Deal and related European initiatives alone, several hundred billion euro of the EU budget will be used to fund climate-related programmes in the period from 2021 to 2027. At the same time – and especially in the absence of positive results – expensive regulatory measures in the context of resource use are to be expected.

For a country such as Austria, which has neither a significant domestic market nor large deposits of natural resources, the most important resource is – and will always be – highly motivated, well-qualified people.

A basic requirement for closing this obvious competence gap is a qualification campaign that (i) combines competencies in digitalisation, agility and sustainable economic activity with the needs and peculiarities of industrial production and (ii) considers how they interact. Only with highly skilled and committed people in specialist and management positions in industrial production will it be possible to navigate the long-term consequences of the current crisis and to harness innovation to power transformation to digitised and resource-saving production technology. The central measures of a new strategy for Austrian production thus derived are detailed below. ■

- Industrial strength as a foundation for rapid economic recovery
- (Re)design of international supply networks to build resilient value-creating systems
- Consistent focus on sustainable value creation
- Qualification campaign for industrial production

1.1. Industrial strength as a foundation for rapid economic recovery

It will be some years before we can assess how manufacturing industry has been damaged economically and what the potential long-term consequences of the pandemic-induced crisis will be. Despite this uncertainty, it is essential to start without delay to invest major effort to build a post-COVID-19 economy. Against this background, digitalisation of products, services and processes is critical to success. Digitalisation of production makes possible products and processes that can be adapted and tailored to suit particular contexts. Business models based on integrated networking, near-real-time recording of and response to environmental data and customer needs are accepted increasingly across industry sectors. Considering information on individual living and working environments in the design of products and services allows faster, better and more direct customer integration, and results in improved customer satisfaction. The amount of data customers are willing to supply for use in designing such solutions depends on their perception of benefit. Technology and technology integration enable new business models and thus offer a competitive advantage. ■

Austria needs an innovative ecosystem of manufacturing industrial partners, a “hands-on” culture of unfettered experimentation, and an open discourse on the opportunities and risks of new technologies and business models. This requires, despite the prevailing situation, a climate of optimism and the courage to fail, tolerance of failure and a willingness to learn from setbacks as quickly as possible.

Rapid economic recovery requires an extraordinary alliance between industry, science and politics, with all partners on an equal footing.

Extension of the low-threshold “Innovation Cheque” funding instrument for SME products and processes.


otic Arm Performance
30 %

1.2. (Re)design of international supply networks to build resilient value-creating systems

The future of digital production in value-creating networks will be shaped by a further increase in complexity and by uncertainty about future developments, driven predominantly by the ever-increasing variety of products and by shortening development and delivery times ("time to market"). Additionally, global availability of data and information stimulates immediate reaction to changes in value-creating networks and in global competition.
The global dynamics of political and business decisions and the ability of competition, customers and the ecosystems involved to react directly require entrepreneurial flexibility in terms of alignment with agile business processes. This expands on and replaces both planning cycles and business processes, and opens up opportunities for businesses to profit from the time advantage of faster decision-making.
Complete digital models of products, production processes and value-creating networks form the basis for real-time exchange of vast amounts of data. Miniaturised and distributed sensor technology, near-sensor data preprocessing, and fusion of diverse sensor data make possible digital real-time images and close the gap between the digital twin of production and the production processes and conditions in the company.
Comprehensive provision of high-performance 5G communications infrastructure allows fast, wireless transfer of great amounts of data. In the context of production, this requires environments for testing and experimentation to define, test and assess realistically the most promising applications. Guaranteed network coverage not only in metropolitan, but also in industrial areas constitutes an essential locational advantage.

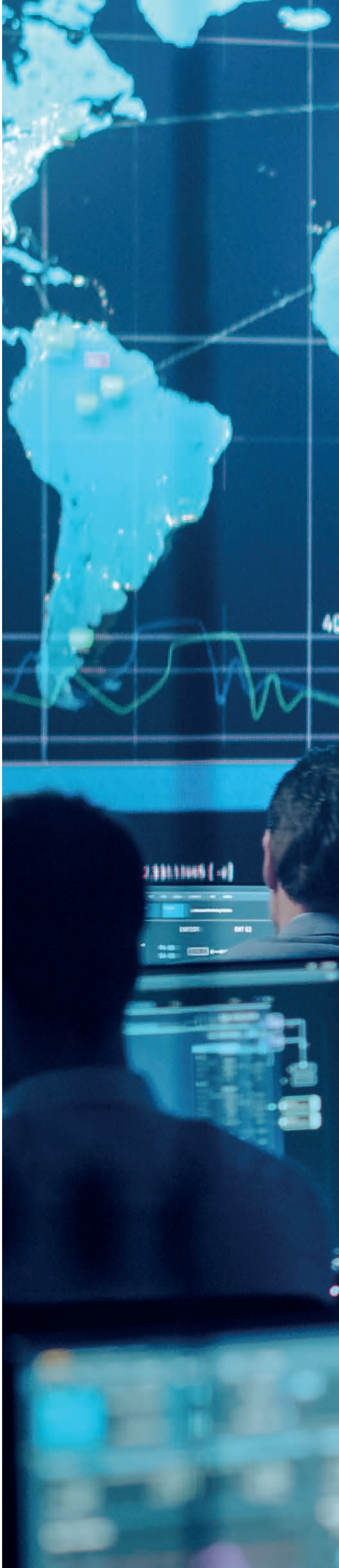
Personal safety, data security and data protection (privacy) form the foundation of digital production in value-creating networks. Occupational safety of employees and third parties and – ultimately – entirely accident-free production processes are a primary aim. New challenges arise from increasing

Strategically, manufacturing companies must simultaneously drive forward computer-aided automated decision-making and actively empower their employees at all levels.

Promotion of cross-company resilience programmes (supplier strategy, interchangeability of materials and components and make-or-by decisions).

Promotion of investment in rapid-prototyping infrastructure and expanding the possibilities for simulation (especially in SMEs).

Standards and shared guidelines are the cornerstones of infrastructure development. Austrian research in manufacturing drives the development of standards in the relevant bodies and supports domestic stakeholders in competently assessing future-proof standards and guidelines.



interconnectedness of machines and systems and from replacing protection devices that form physical barriers with alternative (i.e. optical, infrared, ultrasound, etc.) monitoring systems. Only by means of measures that enable reliable and incorruptible data exchange between distributed objects and actors can security concerns be decreased and smaller companies realistically reap the benefits of real-time inter-company data exchange.
In addition to security and safety, protection of personal data is a hallmark of Central European industrial locations. New technological and organisational measures to protect data privacy in production processes are increasingly called for. ■

Pilot projects and protected environments for experimentation allow – in cooperation with the social partners – a consensus-based, sustainable strategy to be developed in which the benefits of data use to employers and employees outweigh both risks and concerns.

1.3. Sustainable Value Creation

Production will continue to be inextricably linked to the transformation of materials, energy, auxiliary materials and human work into innovative products and services, with responsible use of resources being key. Material- and energy-efficient practises and an economic optimisation parameter are primarily human necessities that are related to global activities dealing with climate change. Carbon-neutral production is a declared goal in this context. Circular industrial production, processing and treatment allow products to be recycled. ■

Environmental protection and production must not be mutually exclusive. In addition to goals for efficiency and elimination, the pursuit of technological progress and use of innovation for more sustainable production are of central interest.

Promotion of measures for (i) reducing energy use in manufacturing (in particular Scopes 1 & 2 of the Greenhouse Gas Protocol) and (ii) qualification especially in the area of Scope 3 to build awareness of sustainable products.

1.4. Transformation as an opportunity for diversity

That women are underrepresented in technology – especially in German-speaking countries – is a well-known and oft-lamented fact. However, basing a solution on the assumption that this is due to women lacking interest in technology, which needs to be sparked and stimulated, and to outdated stereotypes that are being eroded over generations is insufficient. A central problem in industrial production lies in outdated conventional structures within which women have long faced difficult daily working lives and numerous incompatibilities between work and family. Adjusting to such working environments was previously considered absolutely essential, and – under these conditions – management positions were practically out of reach for women. Manufacturing industry can only remain competitive if women are not considered merely as potential users of new products, but also as active agents in shaping products and production processes, and if women thus become technology creators.

The ÖWGP sees itself as a driving force in the design of sustainable and competitive industrial production and must therefore also take a contemporary approach to addressing the topic of diversity. First, the ÖWGP will work to counteract gender stereotypes and lack of interest by actively participating in existing programmes and initiatives (e.g., FiT, Girls Day, various programmes for students, mentoring and career development programmes). The ÖGWP members' remit lies primarily with university students, who are to be supported and promoted with special mentoring and career programmes.

Second, another set of measures focuses on the approaches to transforming production that are addressed in this position paper. It is important to ensure that structural adjustments improve gender equality in particular and lead overall to more diversity and inclusion. The central demands and concerns of the ÖWGP in this context are: a rethinking and a change away from the need for women to adapt to existing structures and working environments and towards considering their interests and perspectives and creating opportunities for them to contribute actively to the upcoming transformations of production processes.

Third, the ÖWGP has set itself the goal of increasing women's visibility and participation in research, and thus effectively counteracting their underrepresentation in its own sphere of activity. Possible measures include tenure-track initiatives, programmes promoting honorary and junior professorships, and support and guidance for attracting female applicants. The ÖWGP views itself as a contact point – for applicants and as an interface to (international) appointment processes in academia or for comparable management positions in business, and for placing suitable researchers in workshops, forums, symposia and conferences. ■

It has been shown that mixed leadership teams are more likely to succeed than male-only teams.

The “New Deal” requires more women in production.

The significant imbalance must be corrected.

Active participation by women is a prerequisite for achieving optimal processes in the transformation of digital production.

1.5. Qualification campaign for industrial production

Digitalisation of production will fundamentally change the competencies that are required of employees. At all qualification levels, we will see a massive increase in digital skills alongside expertise in basic scientific practise and in production technology. The core competencies required of tomorrow's skilled workers, engineers and managers will include integrated thinking in terms of digital pervasiveness, integration of digital and physical processes and design and evaluation of the materials, products, processes and systems involved. Skills for making decisions under uncertainty, supported by real-time data and Artificial Intelligence, will be increasingly required, as will data-driven linking of various production technologies and processes. Successful transformation of skills will require training and education concepts that use innovative media and learning formats to enable skills development near, and integrated with, the workplace. At the same time, the process of learning itself will change massively. Meeting the future requirements of a much more digitalised and automated process of production will require increasingly hybrid and team- and task-centred learning, and ultimately human-machine reciprocal learning. ■

Government funding, educational institutions, companies and employees are equally obliged to make available and actively use the resources required.

The “New Deal” requires teachers who demonstrably combine theory and practise and have the courage to discard old knowledge and to broaden their horizons.

The “New Deal” requires, above all, that students and their teachers embrace network thinking and accept that, as ever, practical knowledge and the theoretical principles of various disciplines are the foundations of successful future concepts. Further, creative approaches to problem-solving and entrepreneurial culture that tolerates failure must be promoted.

Promotion of practical teaching and learning facilities – especially for staff in manufacturing – to teach modern production processes (pilot and learning factories, digital production, additive manufacturing, FabLabs).

2. Production Systems

Fritz Bleicher, Franz Haas, Andreas Otto, Klaus Zeman

The current process of change in production – with its goal of intelligent machines as elements of the “Smart Factory of the Future” – is driven by the availability of technological innovations coupled with powerful communication technology and data management.

Milestones of production technology have always been closely linked to societal development and economic history. In preindustrial times, the prosperity of a society was determined by its level of proficiency in craft processes. Invention of the steam engine led to the first industrial revolution and laid the foundations for the development of modern production machinery. The ensuing increased use of iron-based materials spurred rapid advances in machining and forming technology. The second industrial revolution led to production based on the division of labour (e.g., assembly line production), and the third used the achievements of microprocessors in CNC technology for automation and robotics.

The resulting potential for applications in production engineering has increasingly been tapped and has already given rise to current topics such as “Industry 4.0”, “Digital Transformation” and “Smart Production and Services”.

Today, technological challenges arise not only from the development and use of new materials and from information and communications technology (ICT), but also from the increasing importance of sustainability and ecological aspects, for example, in individual mobility. In this context, the “Green Deal” is often discussed, especially at the political level.

These developments are currently being overshadowed by the global coronavirus pandemic and the associated economic crisis. Cities devoid of people, universities without students, an abrupt end to international passenger air traffic and a negative oil price in April 2020 are just examples of the immediate consequences of severely restricted public life. The 2008 financial crisis and the current COVID-19 crisis show us how vulnerable our sophisticated economic systems are to such disruptions. From a system-theoretical point of view,

this is unsurprising, as it has long been known that highly optimised systems are particularly sensitive to imperfections. This means that a minimal change to a system can lead to a (qualitatively) completely altered behaviour, and this applies to production systems as well as economic and social systems. Crises and cuts in the economic performance of numerous industries are leading increasingly to discussions of sustainability and of resilient economic models. The present section reflects on the current situation from a technological point of view and risks a glimpse into the future. ■

2.1. Adaptable and autonomous production systems

Despite the continuous development of new production technologies, classic manufacturing processes such as casting, sintering, forming, machining and welding remain central to the value chain and must also be developed further.

In machining technology, new cutting materials and coatings in conjunction with optimised control strategies enable a significant increase in productivity. Due to their resistance to chemicals and high temperatures, cutting materials based on ceramics offer up to 50 times the cutting speed of those based on hard metals. In the field of components, non-iron-based alloys (e.g., titanium alloys and high-temperature superalloys) and compositae materials are difficult to machine, and their processing is simplified, for example, by tools with CVD hard coatings. Model-based methods are used increasingly to optimise tool geometries. Cutting tools, comprising cutting edge and tool holder, are becoming very complex technological systems: Sensors and actuators integrated within the tool holders offer great potential for optimising and increasing the flexibility of manufacturing processes. In this context, additive manufacturing is also growing in importance, as it enables, for example, the production of complex cooling lubricant systems in tool holders and thus opportunities for topological optimisation and weight reduction.

These trends also guarantee Austrian industry a leading technological role in primary shaping and (metal) forming processes or in joining technologies, where, for example, conformal design of heating or cooling channels enables process capability and productivity to be improved. Integration of sensors allows monitoring mould-filling behaviour and effects in forming processes, such as cutting impact.

Photonic technologies, now an accepted standard, benefit themselves from current innovations in laser technology. Pulsed high-power laser systems with an average power in the kW range and pulse durations in the femto- and picosecond ranges enable cost-efficient and flexible processing for functionalization of large surfaces with minimal heat input; thus, tribological, optical and fluid dynamic effects can, for instance, be achieved. In addition, these pulsed systems allow heterogeneous materials such as fibre-reinforced plastics to be processed delicately and with high precision.

New types of laser systems in which the spatial and temporal distributions of beam intensity can be controlled purposefully allow, for example, in laser-beam welding a significant reduction in – or complete avoidance of – processing errors while increasing the achievable processing speed. Despite various ongoing European research projects focusing on these innovative laser systems, their potential – especially in terms of process and material flexibility – is far from being fully understood and realised. Particularly in laser-assisted additive manufacturing processes, these developments open up new possibilities for controlling heat introduction and thus for improving component properties.

As additive manufacturing has matured, it has developed into a key general technology in modern production that opens up completely new possibilities, especially in product development and design: for instance, novel lightweight constructions and energy-efficient cooling systems that use new materials and can be produced only by additive manufacturing.

Additive manufacturing processes will also play a crucial role in the effort to make production more flexible; they will surely not replace established manufacturing processes entirely, but will

expand the range of available manufacturing technologies. Their true potential will be tapped in synergy with other processes, for example, in hybrid machines. Deficiencies of additively manufactured components in terms of achievable surface quality and dimensional accuracy can, for instance, be compensated for by subsequent machining.
Further, the high costs of purely additively manufactured components can be reduced by combining additive and conventional processes in one machine. Clearly, this also requires the development of appropriate software tools that enable optimal planning of hybrid processes considering the potential of each technology used.
The development of hybrid machines in which several ("additive" and "subtractive") manufacturing processes are combined is an important trend in machine tool flexibility.

Even further reaching are innovative concepts for flexible, modular, adaptable and reusable production systems, which will in future increasingly replace capital-intensive means of production designed and built for only one specific task.
Central issues in the development of these production systems are the control technology used and its programming, information and communications technologies, self-organisation and self-optimisation, the degree of flexibility of the system architecture, and stability and optimality of the control of resource and energy consumption. On this basis, the demand from volatile and complex future markets for innovative, highly flexible and economical manufacturing technologies and production systems can be met.

Integration of sensors, real-time data analysis and feeding back of results into the manufacturing process enable manufacturing systems to take on aspects of quality assurance already during processing (in process). Thus, the risk of loss due to rejects seen in the prevailing ex-post quality assurance method is reduced, and the resource efficiency of production can be increased.
En route to these integrated systems, a trend has emerged in production metrology and quality assurance towards 100% workpiece inspection within the production machine (in situ) and directly in the production line with feedback to process control (in line) or random sampling at the production machine (at line). Classic random sample measurement is increasingly becoming obsolete, as measuring devices take on the role of reference test equipment and calibrate or validate quality assurance algorithms in the integrated systems described above. In combination with data evaluation technologies and Artificial Intelligence, these algorithms will control more complex relationships, which will ultimately enable self-learning and self-optimising manufacturing systems. Precision engineering in toolmaking, the semiconductor industry and optics remains an exciting field of research with great potential for future sustainable production. ■

Classic manufacturing processes will continue to be of central importance in production and must be further improved. This also applies to photonic technologies, the potential of which is far from being exhausted.

Additive manufacturing is now a key technology in modern production.

Modern production will be shaped by autonomous, modular and adaptable production systems that will replace inflexible and capital-intensive production lines.

2.2. Digital Transformation

Studies have shown that Austrian workers do not generally expect to be replaced by artificial-intelligence-based technologies. However, AI will undoubtedly change most job profiles, and its advantages outweigh its disadvantages. In production, AI algorithms are increasingly used to optimise processes and to analyse data. The aim of this current development should be an innovation campaign across Austria supported by numerous new products in machine and plant construction that have been improved by machine learning. In parallel, a completely new generation of automation technology could lead to a modernisation surge in industry and commerce. Autonomous production overnight using automated loading of machines with workpieces is becoming increasingly common: Production runs in night shifts keep capacity free in the day for individual parts and short runs. The lean automation programme for cost-effective automation of machine tools is another contemporary example.
Automated Guided Vehicles (AGVs) have become an integral part of modern production. Interacting with a fleet management system for central control of several "shuttles" with heavy payloads and longer charging intervals, AGVs are proving to be the pacemakers for agile production of the future. Recently introduced location technologies enable use of driverless transport systems and drones in production, with integrated monitoring of the supply chain via ultra-broadband, RFID, 5G and GPS. The underlying idaea is system openness for flexible configuration of complete systems.

Our Aim

An innovation campaign across Austria, using machine learning to trigger a modernisation surge in industry and commerce.

In addition to various aspects of digital transformation in all phases of the product life cycle – that is, from the first product idaea to product development, production, distribution, use, service and replacement – the relationship between manufacturer and customer is gaining in importance. “Classic” industries will increasingly deploy and use technologies that are based on the Internet of Things and data and online services. The associated real-time networking of products, processes and infrastructure will permanently change the working world of the future. New challenges thus arise from the increasing flexibility and complexity of production systems and of internal logistics.

The hitherto prevailing interpretation of Industry 4.0, according to which networked production resulted from linking manufacturing solutions and IT, is being expanded – or replaced – by agile, self-learning systems.
Manufacturing systems will have the ability to programme and organise themselves, will impose new requirements on themselves, and will adapt and optimise themselves. This requires research, primarily into new approaches to the integration of various control and communication systems (breaking up the common automation pyramid), technologies for safety and IT security, and development and adaptation of information interfaces and data semantics. Further, interdisciplinary virtualization of processes, machines and procedures is gaining in importance in this context. The development and use of multi-physical, coupled simulation models to master growing system complexity is coming increasingly to the fore. Machine learning and AI methods will play a decisive role in the use of information in future production systems.
Particular attention must be paid to the transferability of established information systems and solutions for future uses. Complete penetration of value creation processes by integrated information systems and cross-system optimisation methods is key to resource-saving production. ■

Artificial Intelligence and machine learning will trigger a modernisation in industry and commerce and will change many job profiles in the long term.

Mastering the growing complexity of new types of production systems requires the development and use of multi-physical, coupled simulation models.

Sustainable and resource-saving production requires integrated information systems and cross-system optimisation methods to completely penetrate value creation processes.

2.3. Contribution of Production to the Green Deal

In her role as President of the European Commission, Ursula von der Leyen has laid out the strategic goals. By 2030, greenhouse gas emissions are to be reduced by 50% compared to 1990, and by 2050 the EU is to be completely climate-neutral. This can only be achieved by extensive restructuring of all economic sectors. In the context of industrial production, the “Green Deal” entails a strategy of circular economy with significantly reduced use of resources and systematic reusability of products via intelligent upcycling and recycling. Closing of energy and material cycles is a prerequisite for the circular economy. The Association of German Machine Tool Builders (VDW) sees an opportunity to develop new revenue streams in the process of analysing how the ambitious goals of CO_2 reduction might feasibly be achieved. The VDW considers digital networking using new business models to be the greatest driver towards achieving goals. This is also evident in the sustainability of steel production (decarbonisation) and the innovative use of hydrogen as an energy source. Following the hydrogen path, from hydrogen generation via its distribution to its application in mobility, requires joined forces.

The new industrial and consumer goods necessary for sustainable energy supply, distribution and use must also be produced. Particularly in Austria and in Europe, this will in some regards necessitate disruptive redesign of production facilities to form new value-creating centres and networks for ecological production. This requires mastery of complex causal relationships and use of newly conceived closed material cycles. Society must immediately launch focused innovation programmes in order for implementation to achieve the proclaimed goals. ■

The medium- and long-term climate goals of the EU - including complete climate neutrality by 2050 - can only be achieved via far-reaching restructuring of all economic sectors.

This requires – in part – disruptive redesign of production facilities, mastery of complex causal relationships and use of newly conceived closed material cycles.

Focused innovation campaigns must be launched immediately if implementation is to attain the climate goals proclaimed.

50% reduction in greenhouse gas emissions by 2030

climate neutrality by 2050

3. Products

Alois Ferscha, Klaus Zeman

Products of the future, i.e., “thinking“ products, will have to be built on a fundamentally new industrial technological principles, underpinned by robust, reliable, flexible, autonomous, energy-aware and real-time capable embedded tiny Artificial Intelligence.

3.1. Cognitive Products

Up until now products have been classified according to the areas of their constituent components, such as products of mechanical, electrical or software engineering. Nowadays, products are increasingly categorised according to their capabilities and not just according to their components. Flexible, adaptable, personalizable, and time-, location- and utilisation-sensitive products are increasingly labelled “smart” or “intelligent”, depending on the degree of autonomy or intelligence embedded in their material, hardware and software. Product development itself has undergone a significant change from highly specialised individual fields to complex, multi-disciplinary, synergistic orchestrations which are also highly differentiated into product design, prototype construction, production organisation, quality assurance, interoperability, usability, recyclability, etc.

Technological progress in the past two decades, in particular the miniaturisation of microelectronics, in combination with global interconnectedness via the Internet and WWW, and more recent advances in AI methods, have led to completely new industrial and business-relevant application scenarios for embedded information and communication technologies, and thus have given rise to highly innovative alternatives for product design. Miniaturisation, digitalisation, data entanglement and virtualisation open up an unprecedented spectrum of possibilities for future products (intelligent products, digital products, Product-as-a-Service) and their manufacturing processes (intelligent factories, digital production, virtual factories). For the first time, products and production systems can and must be tightly interwoven - understood, designed, developed and operated. In future, products and their development and production will be more intertwined than ever before. Autonomous adaptation to changed boundary conditions and updates during utilisation, reuse of material product components (upcycling) or feeding back operational data into product development are just some of the trends that will gain in importance.

Central to this entanglement will be the design of autonomous, real-time capable, trustable, interconnected, embedded intelligence in products. The next generation of products augmented with intelligence will foreseeably have human-like cognitive abilities, such as recognition, perception, interpretation, understanding, awareness, memory and learning, anticipation and prediction, planning, forgetting, intuition, reasoning, and decision-making, and will be equipped with corresponding cognition-controlled ability to act. They will – in a technical sense – be cognitive products that “think”. As a consequence, completely new, “intelligent” product and industrial technologies will emerge that are controlled by small or tiny, robust, reliable, flexible, autonomous, in part energy self-sufficient and real-time capable embedded Artificial Intelligence.

Cognitive products collect data about their environment, their utilisation, their owners and operators, and their own status from a variety of multimodal sensors. The collected data and the derived patterns of circumstances, utilisation, mobility and interaction are analysed and interpreted, and trigger appropriate context-sensitive reactions via embedded actuators. Pivotally, reactions are adapted to situations and not based on rigid control algorithms. The aim of the research in the field of cognitive technical systems (CTS), in general, is to draw inspiration from cognitive psychology and thus to imitate human-like cognitive abilities, particularly in the context of technical products. This is where conventional reactive hardware-software co-designs and mechatronic products with a closed control loops (e.g., in accordance with VDI 2206) differ from cognitive products, as the latter's adaptability affects not only predictable, but also unpredictable circumstances supported by data-driven assessment of the situation, which requires flexible, adaptable control loops with learning ability. Cognitive technical systems do not necessarily always react deterministically to a given input with the same output, but produce (correct) outputs that reflect the actual situation, driven by knowledge, experience, expectation and conclusion. In addition, the behaviour of CTS is not only determined by individual cognitive components, but also by the interaction of many different cognitive elements. CTS must be able to explain and justify their behaviour and should ideally act in a human-like manner.

A normative categorisation of CTS capabilities does not exist yet, but it would undoubtedly include the abilities mentioned above, such as perception, learning, planning, knowledge-model-based negotiation and decision-making, having a self-reference model, awareness of the environment, ability to communicate, interact and act in unstructured environments.

The outstanding technological enablers of cognitive products include the dramatic miniaturisation of digital electronics (microcontrollers, microprocessors, system-on-chip), high-performance signal processing (analog signal processing, adaptive filters, time-discrete integration, DSP hardware), wireless communication and radio modules such as WiFi 6, 5G cellular, LPWA, MMW, software-defined radio, RFID, NFC, BTLE, ZigBee, LoRa, LTE, positioning (UWB indoor) and localisation (GPS, BeiDou, GLONASS, NavIC, Galileo, Quasi-Zenith , Skymark, ImageNav), multimodal sensors (light, noise, vibration, chemical, electrical and electromagnetic, metal detectors, thermal, optical, imaging, pressure, force, acceleration, flow, viscosity, smoke, gas, etc.) and sensor networks. ■

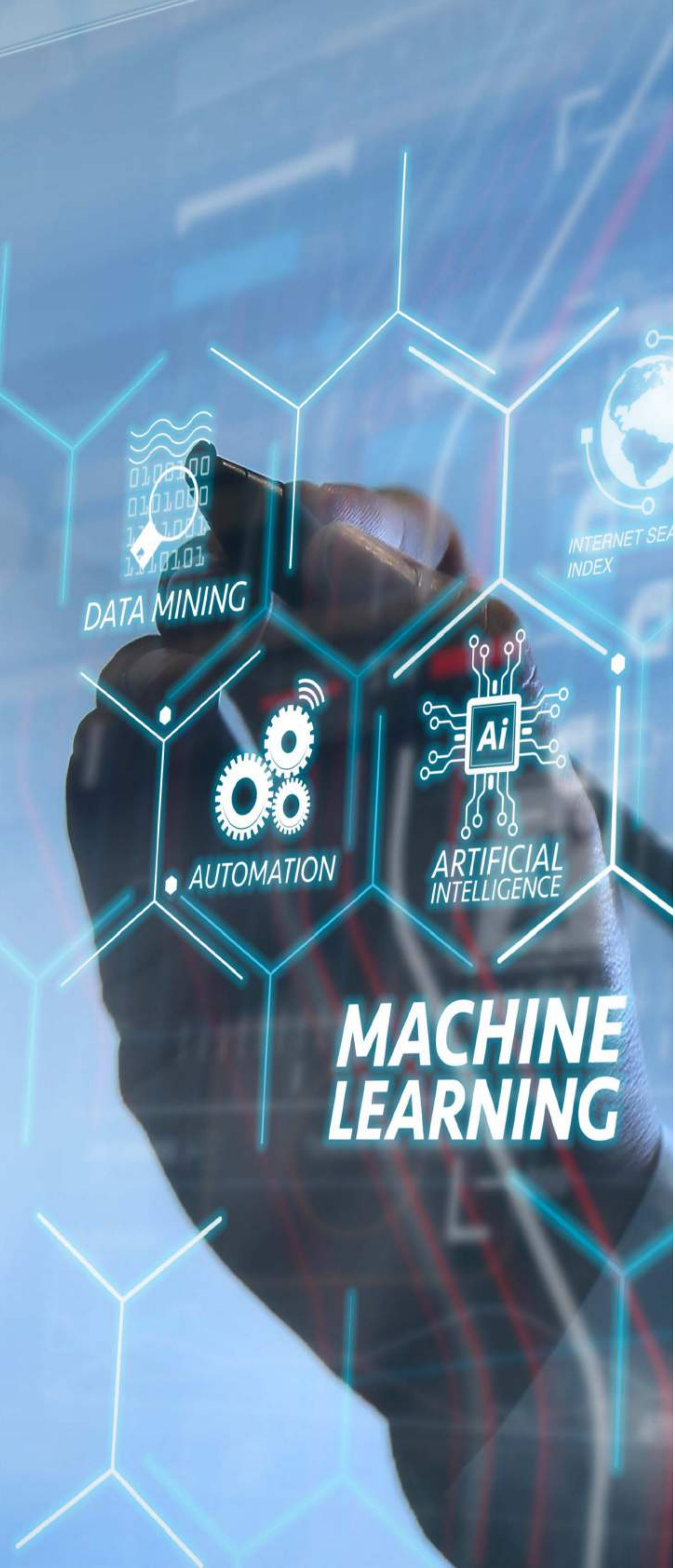
The digital transformation augments physical products with digital product representations or complements digital services with physical embodiments. The resulting entanglement of traditional manufacturing with the emerging digital goods industry can be regarded as the strongest driver of innovation in industrial history.

The next generation of intelligence-augmented products will – foreseeably – exhibit human-like cognitive abilities, such as recognition, perception, interpretation, understanding, awareness, memorisation and learning, anticipation and prediction, planning, forgetting, intuition, reasoning and decision-making, and will be equipped with corresponding cognition-controlled ability to act.

The technological underpinning of cognitive products are tiny embedded systems, especially those that implement autonomous on-device artificial intelligence (embedded AI).

3.2. Embedded AI

Machine learning and knowledge representation will play an essential role in future generations of such cognitive products. While traditional methods of mathematical pattern recognition (classification, clustering, regression analysis, statistical inferencing such as estimating and testing, Markovian processes) have so far been used in industrial sectors such as electronics and semiconductor technology, avionics, agriculture, banking and insurance, social media, consumption and consumer-behaviour analysis, healthcare, raw materials development, transport and logistics, tourism, telecommunications, and last but not least, the automotive industry mainly and on large computer systems (supercomputing) with extremely large data sets (big data), there is a clear trend towards small and tiny AI solutions for small and tiny execution platforms. This is accompanied by a rapid advancement in learning and pattern recognition methods, most of which are based on neural network models. In deep learning, machine learning techniques are pursued, in which artificial neural networks are used in multiple layers to represent different levels of abstraction of learning content including feed-forward networks (FFNs), convolutional neural networks (CNNs), recurrent neural networks (RNNs) and generative adversarial networks (GANs). The learning principle of reinforcement by reward (reinforcement learning), the transfer of learning results to similar and comparable learning problems (transfer learning) and learning in the collective of different learning algorithms (ensemble learning) turn out to be the most promising strategies of deep learning, since they do not require the involvement of time-consuming and cost-intensive human control and monitoring. Consequently, learning strategies are designed and developed that avoid the pre-generation or availability of so-called training data and thus realise an evolutionary form of learning (one-shot learning, few-shot learning). This change of method in pattern recognition and machine learning is accompanied by an enormously agile and varied development of algorithms, reference implementations as well as program, software and tool libraries such as TensorFlow, Keras, PyTorch, Caffe, Microsoft Cognitive Toolkit, PaddlePaddle or OpenNN - to name but a few. For robots as products, cognitive product capabilities implemented in this way are already a de facto reality today. The momentum of this development, observable on a daily basis, will lead in the very short term to embedded AI in practically every product being a pervasive reality. A particular acceleration in “cognification“ – comparable to the electrification of mechanical systems due to ubiquitous access to electrical energy – is observable in products of the digital goods industry. In this field, enabling cognitive capabilities via networking, i.e., through ubiquitous online access to sensors and self-learning artificial intelligence, is comparatively easy. The effects that



can be achieved are industrially and economically groundbreaking. If we the Volkswagen Group as a reference example of the European material goods industry with an enterprise value of 33,797 M€ (in 2020) and 200,000 employees (0.17 M€ / employee) and compare it with Microsoft as a reference for the US digital goods industry with an enterprise value of 1,470,106 M€ (in 2020) and only 163,000 employees (9.02 M€ / employee), it becomes clear that the raw materials of the capital-intensive material goods industry (steel, aluminium, plastics) are fundamentally different from those of the know-how-intensive digital goods industry (cognitive competence, intelligence). Moreover, the cognification of digital goods - and thus the generation of added value – requires next to no employee involvement: self-learning artificial AI becomes smarter and better with each use.

Edge AI as an implementation strategy for cognification in the production of material goods builds on the principle of data analysis and intelligence control at the place of origin, to avoid time-consuming and communication-intensive data transmission to central server or cloud resources as a consequence. A foreseeable follow-up development of currently storage-based implementations will be a consistent stream-based intelligence implementation, in which data from online sensors can be collected, evaluated, and - if necessary - transformed, but not stored or archived for later reprocessing ("transform-and-forget"). Small and tiny execution platforms have only extremely limited storage capacities and, due to very limited energy resources, hardly any wireless communication options. Especially from the perspective of maintenance-free use of cognitive products, operating energy becomes the all-important implementation question. Energy self-sufficiency through sensors that are operated according to the energy harvesting principle (energy conversion from light, heat, sound, acceleration, pressure, etc.) becomes a key technological issue. For cognitive products as reactive systems, a continuous real-time capability of the system behaviour is required, i.e., time-limited reaction and response guarantees are mandatory. Best-effort strategies, as found in today's standard operating systems (Windows, Linux, MacOS) or in standard communication protocols (IPv4) prove to be unsuitable for the implementation of adaptable, self-organising, error-detecting, fault-tolerant, autonomous products. Such products must be able to autonomously collect and understand information about the situation, be operational without human intervention, learn and acquire new knowledge without human assistance ("self-evolving intelligence"), or protect the user, themselves or other objects in the operating or usage environment from dangers or threats. Especially here, the importance of real-time capabilities of cognitive products becomes clear. With increasing deployment, usage-density and usage-frequency of embedded AI powered cognitive products, compatibility and friction-free coexistence of human and artificial intelligence becomes a key question. Cognitive products will only gain user acceptance and ultimately user trust if they are able to explain the motivation and rational of their behaviour towards the user in a comprehensible - explicit or implicit - way (from "Black-Box AI" to "Explainable AI"). ■

The currently observable evolutionary momentum of the entanglement between the material and digital goods industries, coupled with scientific (AI) and technological (miniaturisation, radical networking) progress, leads, by logical necessity, to a post-digitalisation era of cognification. Embedding intelligence into products (cognitive products) must be a major priority for research- and industrial policy.

The design, development and operation or use of AI-driven cognitive products, product ensembles and product federations require a harmonisation of the symbiosis between human intelligence and artificial intelligence.

3.3. Dependable IoT

The rapid evolution of the Internet and the associated interconnectedness of all things (Internet of Things, IoT) in a wide variety of areas, and especially in critical application domains such as intelligent health systems, traffic and control systems, building technology, complex manufacturing plants and production systems, and critical infrastructure, increase the need for robust, fault-tolerant, reliable and resilient operating and networking technologies that (must) function reliably and stably even under highly dynamic, unpredictable and harsh environmental conditions.

Cognitive products designed as IoT devices are highly resource-limited and are exposed to adverse natural (e.g., cold, heat, moisture, radiation, acceleration, electromagnetism, gases, etc.) or induced (by incorrect operation, destructive use, cyber-physical attacks, etc.) environmental conditions. Common threats to IoT systems are intentional attacks and the risk of malfunction resulting from systemic complexity. Since these are often designed as systems-of-systems, the inherent risk of malfunction is exacerbated by spontaneous changes in system topology and configuration, replacement or reorganisation of critical system components, additions, expansions or limitations of operational functionality due to software or service updates, addition or removal of hardware components, the presence of design and/or scaling errors and, last but not least, the complexity-related inability to validate the overall system. Secure energy supply and secure wireless communication are essential to the reliable operation of homogeneous and heterogeneous cognitive product ensembles. The realisation of energy-autonomous cognitive products can only be ensured by high (i.e., expensive) redundancy, due to physical and technical limitations (battery-supported: zinc-air, lithium; autonomous: solar, wind, thermal; storable: super-capacitor). The choice of a wireless communication technology depends, for instance, on the operating environment (range, signal propagation, attenuation, distortion, scattering, noise, signal interference, etc.), the operating mode (duplex, half-duplex), power consumption (low-energy), media access control, the selected communication protocol, and addressing schemes. To date, there are few or no suitable technologies available that would both provide very low-energy, mid-range, and spontaneous (pre-arrangement-free) networking with simultaneous support for vast scaling.

Furthermore, human safety in handling such systems must be guaranteed over the entire product life cycle. Any deviation from the specified system behaviour due to perception or assessment of a situation, can lead to dramatic safety violations, physical damage to people and things, or enduring loss of confidence in operational safety. Possible triggers are loss of messages due to trivial overloads of radio channels, signal interference between radio systems, short-term power supply failure, proximity to electromagnetic fields or signal attenuation due to open glass doors. Unfavourable environmental conditions usually have a strong impact on the reliability and energy efficiency of IoT communication, which makes it difficult to develop a system suitable for all possible conditions. Consequently, the role of IoT solutions is currently severely limited and its use restricted mostly to non-critical monitoring applications. Conventional resilience methods are usually based on redundancy, which conflicts with IoT re-

source constraints. Application-specific IoT reliability is therefore an extremely important open topic for research. The future Internet of "reliable things" must consist of situation-, context- and location-aware cognitive components that are organised in coordinated collectives or ensembles and ensure fault-tolerant, fail-safe and resilient operation, including safety-critical missions. In terms of network technology, reliability must be implemented on the physical, data link, network and transport level. This is a basic requirement for dependable cognitive product ensembles. Only real-world capable, socially acceptable, field-tested, spontaneously resilient and dependable IoT solutions will lead to an industrially, economically, and socially accepted digital transformation in such systems. ■

Even under highly dynamic, unpredictable and harsh environmental conditions it is required, that robust, fail-safe, dependable and resilient operating and networking technologies function reliably and stably.

The future Internet of "reliable things" must consist of situation-, context- and location-aware cognitive components that are organised in coordinated collectives and ensure fault-tolerant operation even for safety-critical missions.

3.4. Sustainable Products

With the Circular Economy Action Plan as an essential component of the new European growth strategy "European Green Deal" (Ursula von der Leyen, Dec. 2019: "It shows how to transform our way of living and working, of producing and consuming so that we live healthier and make our businesses innovative.") the European Commission has presented a challenging programme for achieving climate neutrality across Europe by 2050. The new action plan announces initiatives along the entire product life cycle: Sustainable product design, the design and embedding of products in circular economy systems, the transformation to sustainable products and the attempt to keep raw materials in the cycle as often and as long as possible are key approaches and requirements in this context.

As effective measures for achieving this, the plan mentions: making sustainable products the norm in the EU, strengthening the role of consumers and users within the circular system, promoting industrial sectors that have high potential for circular resources (electronics, IT, batteries, vehicles, packaging, plastics, textiles, construction industry, buildings, food, water, nutrients), minimising waste, making the circular economy regional and its urban realization human-friendly, and thus setting a global example. Overall, the aim is to consistently implement and strengthen the principle of circularity in production processes; a focus on circularity is also seen as a prerequisite for climate neutrality.

Sustainable product design, the design and embedding of products in circular economy systems, the transformation to sustainable products and the attempt to keep raw materials within the cycle as often and as long as possible are central approaches and requirements of the European Commission in the Circular Economy Action Plan.

Sustainability is realised by measures such as: increase in energy and resource efficiency, for instance, by means of AI-optimised processes; product updates during and after the use phase; remanufacturing that avoids carbon emissions; high-quality upcycling and recycling; limits on single-use products and planned obsolescence; banning of the destruction of unsold durable goods; incentives for Product-as-a-Service business models; and full use of the potential of digitalizing products, engineering and production processes.

A stronger focus on sustainability both in product design and in production becomes concrete in a number of possible ways; for example, by improving the durability, reusability, upgradability or repairability of products, by reducing or banning the use of hazardous chemicals in products, by increasing energy and resource efficiency (e.g., by employing AI-optimised processes in production), by consistently increasing the proportion of recycled material in products while guaranteeing their performance and safety, by carbon-emission-avoiding remanufacturing and high-quality recycling, by restricting the use of single-use products and "built-in" planned obsolescence, by banning destruction of unsold durable goods, by creating incentives for Product-as-a-Service or other business models in which the manufacturer retains ownership of the product or is responsible for its performance throughout its life cycle, and by consistently harnessing the potential of the digitalisation of product information, for example, in the form of "product memory" or product identity traceability solutions, such as digital identity management and identification using RFID, NFC, QR codes or digital watermarks.

The desired change in the context of products and their production can be set in motion by goal-oriented research, "circular innovations" and extensive digitalisation, and can ultimately be implemented and guaranteed sustainably.

This offers enormous potential for "circular innovators" in Austria and Europe (steel and light metal, petrochemical, paper, plastics, supply, and textile industries and energy suppliers).
Austria and the EU can only be successful if their efforts also advance the transformation to a fair, climate-neutral, resource-efficient and circular economy at the global level. All local and regional measures and efforts in product and production management must be considered in a global context. ■

4. Materials

Clemens Holzer, Christof Sommitsch, Martin Stockinger

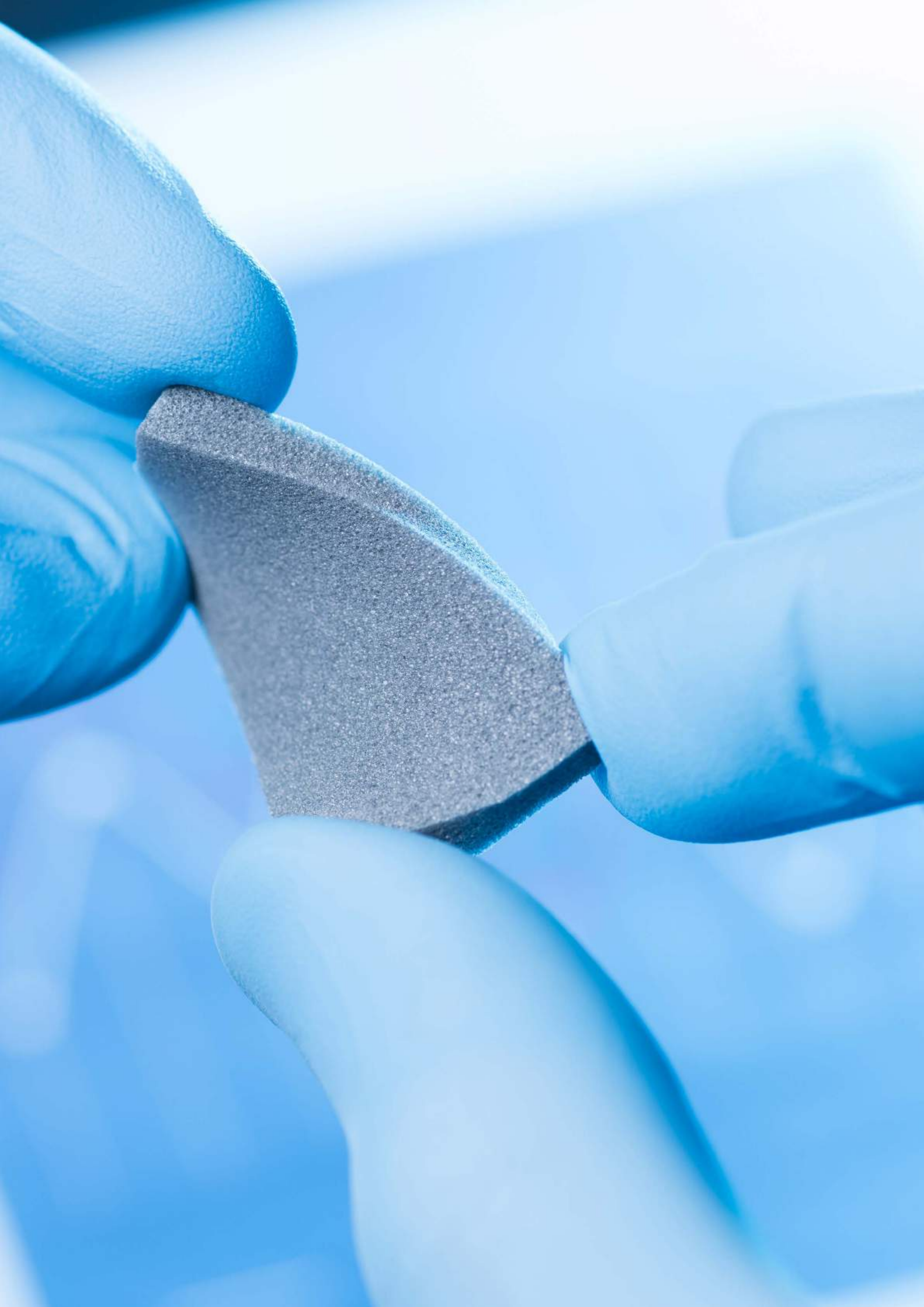
Progress in digitalisation offers a unique opportunity to produce in a resource-saving manner while avoiding negative effects on product uses, quality and production costs.

4.1. Introduction

Materials are central to all sustainable future developments in the key issues of global concern (globalisation, urbanisation, mobility, health, resources).

At Austrian universities and research institutes, materials science is intensively researched, and a number of Austrian companies are among the international leaders in this area, such as AMAG, Borealis, Infineon, RHI, TDK, TI and voestalpine. Materials science is an interdisciplinary field and the basis for new developments that can be continuous or disruptive.

Progress in digitalisation offers a unique opportunity to produce in a resource-saving manner while avoiding negative effects on the usefulness and quality of the products manufactured. The materials used represent a significant cost factor. New materials must meet future technical requirements, be available in sufficient quantities and meet customer expectations in terms of price. ■



4.2. Material Development

Science is empirical, theoretical, numerical and data-based, and these four paradigms are also reflected in materials development, where development of broad scientific understanding as a basis is required.

In recent years, advances in ICT have brought great developments in modelling and simulation of materials and materials production. Another important trend – learning from nature – leads to conceptually new materials, especially due to an improved understanding of the functions of various levels of size and hierarchy. Further, use of multi-materials enables creation of products with properties that would not be possible with materials used individually.

In addition to continuously increasing requirements and functionalization, the drivers of materials development are: new technologies such as additive manufacturing; resource conservation in extraction, production and use; recyclability; and costs. Materials are increasingly customised not only to their applications, but also to their optimal production technologies. ■

Due to climate change and the increasing demand for a circular economy, the requirements imposed on newly developed materials and material systems are changing. A holistic approach in the development process that considers not only the classic goals of product properties, development costs and development time, but also sustainable production and ecological goals, including recyclability, life cycle assessment and avoidance or recycling of waste generated during production, must become standard in the future.

4.2.1. Materials Modelling and Simulation

Materials modelling uses the knowledge of physical and chemical laws applicable for materials to describe them by means of mathematical and numerical methods. The macroscopic functional characteristics of a material result from its structure or changes therein in the course of production, processing and use. The structural material parameters at all scales – from electronic and atomic scale to macroscopic – must be taken into account.

This is done in multi-scale modelling, which uses mesoscopic, atomistic and quantum-mechanical modelling to trace (multi-physical) constitutive laws back to basic mechanisms and thus improve them significantly. Coupling across different scales allows material systems to be described seamlessly by elementary electronic and atomistic processes, as information is passed along the simulation chain from the nano- to the macro-scale. Considerable progress is being made in linking electronic structure, statistical and molecular-field theories, for instance, by means of ab-initio methods (density functional theory, quantum chemistry). These approaches aid in identifying the bonds and elementary excitation states that determine all properties of a material. At the next (higher) level, molecular dynamics and Monte Carlo methods are used to describe kinetic mechanisms. At the mesoscopic level, averaged dynamic properties are calculated by means of molecular-field approximations and with the help of automatons such as the cellular automaton method. Finally, continuum-based, thermodynamic or constitutive kinetic models (phase-field method, Navier-Stokes equations) are used at the mesoscopic and macroscopic levels.

Simulation routines or programmes can be based on various numerical solution methods, such as the finite-difference, finite-element and finite-volume methods.

In the future, as increasing computational power becomes available (e.g., Vienna Scientific Cluster, VSC, in Austria, European High-Performance Computing, EuroHPC, at the European level), larger and more complex structures will become calculable. ■

Access to powerful computing clusters and to the software required for materials modelling is essential to maintaining Austrian excellence in this field and to optimally supporting the scientific community. In basic research, elaborate grant application phases with a low probability of success (as excellent applications are rejected due to insufficient funds) are the greatest obstacles to internationally competitive scientific excellence.


Face Tracking and Recognition
Block Diagram
Documentation
Debug Log

4.2.2. Materials Characterisation

From the perspective of faster and optimised development of new materials, and considering the importance of modelling as emphasised in the previous section, a strong focus must be placed on research into particularly efficient characterisation methods. Derivation of model parameters and verification of existing modelling approaches for new materials require high-quality data. The new options now available for rapid processing of large amounts of data make it possible, for example, to simulate the measurement process directly during measurement, and thus to obtain significantly more accurate results.
The ÖWGP has therefore identified an increased need for research activities in the following areas of analysis:

4.2.2.1. Imaging analysis
Imaging methods, from light microscopy to transmission electron microscopy, have been used globally for years and are therefore very well developed. Nevertheless, new measures that further increase efficiency are also called for in this context. Easier operability both locally and via network, faster detectors and evaluation software and thus less costly options for analysis in electron microscopy should be particular priorities. However, high-quality analysis, in turn, requires preparation techniques to be developed further. Smaller laboratories should thus also be able to produce good sample material, for instance, for high-resolution EBSD analysis. In the context of large-scale manufactured materials, characterisation of variations in structural characteristics is a particular challenge. With metals, for example, chemical segregation from the liquid phase and different thermal cycles in the production process lead unavoidably to metallographic differences and consequently to variations in local properties. For a clean, statistically meaningful evaluation, methods must therefore also be developed that enable fast analysis of large areas, such as the Frequency Spectrum Spatially Resolved Acoustic Spectroscopy (F-SRAS) method.

4.2.2.2. Chemical analyses
In addition to structure, chemical composition plays an important role. The methods for its analysis have also been well researched, but there is scope for improving time-efficiency and accuracy. Fast techniques, such as spark erosion spectroscopy, exhibit a relatively wide scatter range; more precise, wet-chemical analyses, however, are very laborious. Methods for the equally important analysis of local chemical composition close to the surface (e.g., Auger electron spectroscopy) are difficult to access and require high-level expertise to evaluate. In this context, easier access to high-quality methods should also be realised with the help of digitalisation.

4.2.2.3. In-situ analysis
Methods that enable direct observation of physical processes are particularly valuable in the design of adequate material models. For example, small-angle scattering experiments in a synchrotron can quantitatively capture phase transitions during thermal cycles. However, since access to such complex and expensive methods is limited, the development of less costly approaches that produce results of similarly high quality and of methods with higher temporal resolution is a major challenge. Promising examples in this context are advances in high-temperature XRD and in confocal and scanning electron microscopy, and the coupling of thermomechanical testing devices with laser-ultrasound or eddy current sensors.

4.2.2.4. Further analysis methods

While the development of new materials should focus on their properties and their uses, it should also consider potential subsequent manufacturing processes. Simulation of production processes at the laboratory scale is therefore also essential research. In terms of analysis, the main issue is the transfer of information – and thus of relatively simple data such as time, temperature, pressure, and deformation – from the real process to the laboratory environment; recording of the variables must be highly accurate and reproducible. ■

In order to advance digitalisation in materials development and thus guarantee an optimal process, materials must be characterised in terms of their various properties, model parameters must be derived from experiments and material models must be verified. This requires not only investment in modern analysis methods on site, but also that Austrian researchers have access to international research institutions. Digitalisation results in new business models – companies and institutes that produce, manage and sell data.

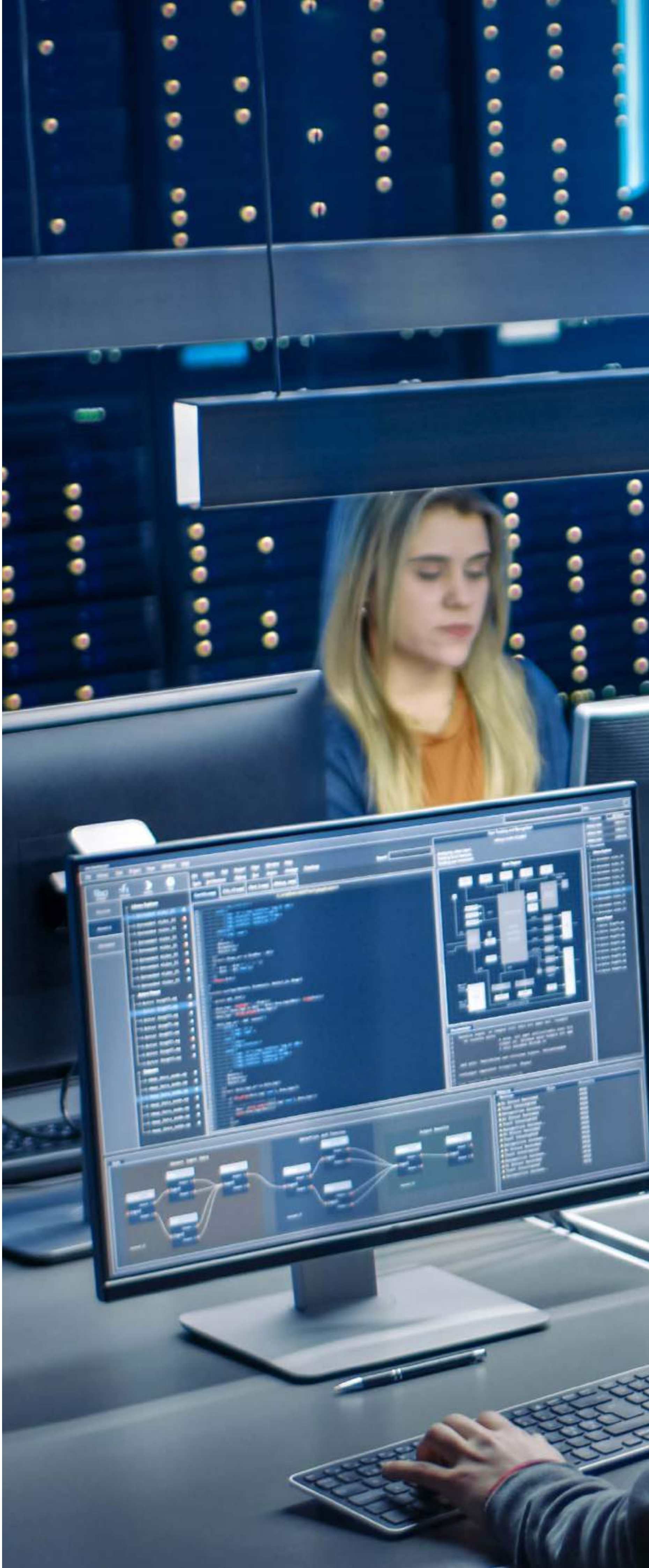
4.2.3. Materials Data Processing

Another major challenge is efficient linking of material and process data with suitable material models and a heterogeneous software environment.

Today's very labour-intensive, stepwise manual method must be largely automated to become faster and to reduce human influence. This requires (i) data from individual sensor systems and analysis methods to be linked and archived using accurate time stamps, and (ii) implementation and exploration of fast methods that evaluate error measures for the data depending on their origins.
Strong research focus in the field of material data processing, especially in the operational environment, must be placed on the development of suitable systems for reducing disruptive errors that arise from inadequate data and on the chaining together of software products.
In linking material and process data to the world of models, methods that are not rigid, but improve independently with increasing amounts of data will in future be of particular interest.

This requires not just unidirectional, but bidirectional coupling of data and model, for instance, by means of AI methods. The higher the amount of usable, high-quality data, the better these methods will work.
In basic research, it makes sense to make raw data available globally in the spirit of broader open-source use to support the creation of data-based models. A problem of such databases on materials, processes, and past and future experiments is that they often contain proprietary data, and thus further development of secure systems for use of anonymised data is a promising field of research and a potential source of new business ideas.

Considering the sustainability of materials reveals another great benefit of digitalisation. Environmentally relevant data should be collected in a form that enables simulation and not just material flow analysis. Data analysis across entire systems would then become possible and environmental databases could thus be improved. ■



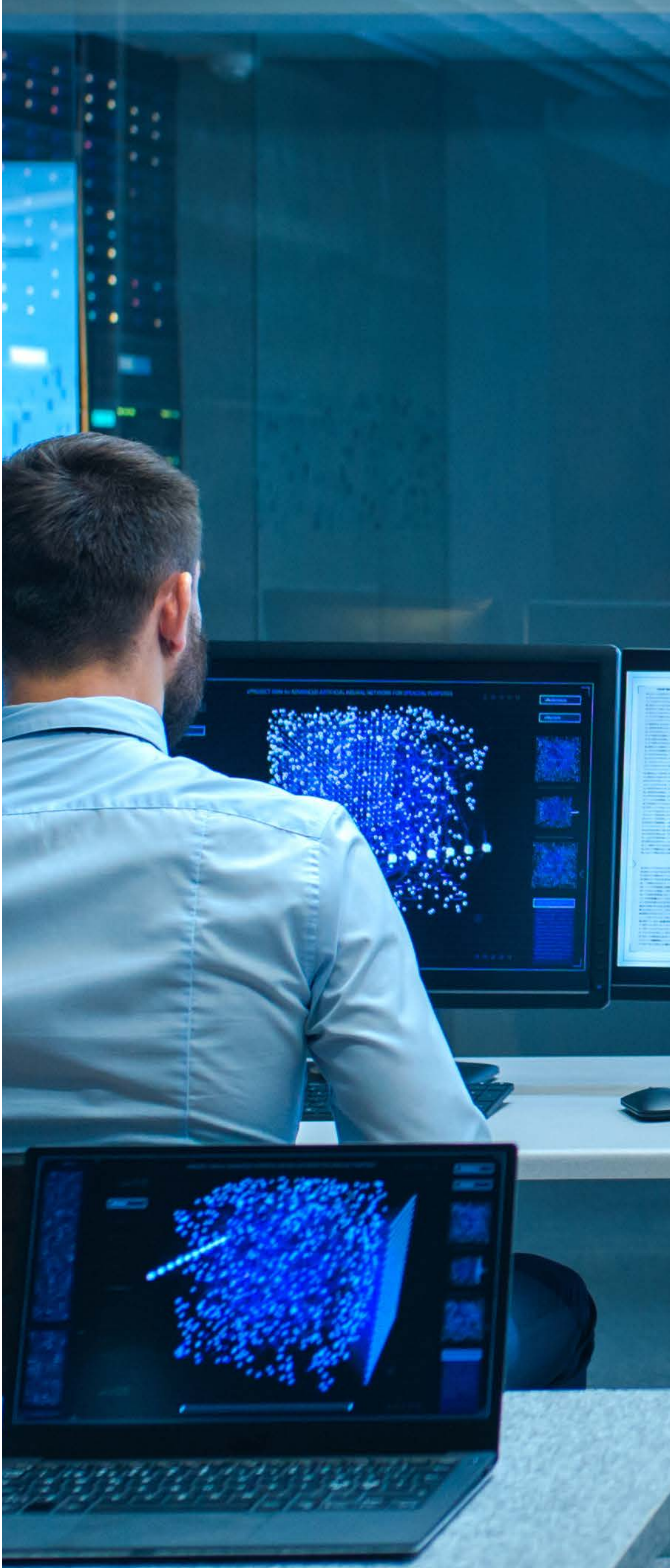
In future, greater emphasis must be put on the collaboration between materials research, data science and sensor development. The agility required in the data-based sciences represents a barrier for "old" domains that can only be broken down by a targeted cultural change. The "common language" required for this purpose can be developed – and application of modern methods can be achieved – via interdisciplinary training programmes, collaborative research and targeted funding for multidisciplinary research projects.

4.2.4. Artificial Intelligence in Materials Development

According to the fourth paradigm, data-based science, existing amounts of data (data pools, Big Data) can be analysed – for instance, by means of neural networks – in order to identify regularities or data relationships that are purely mathematical and statistical, but not physical.

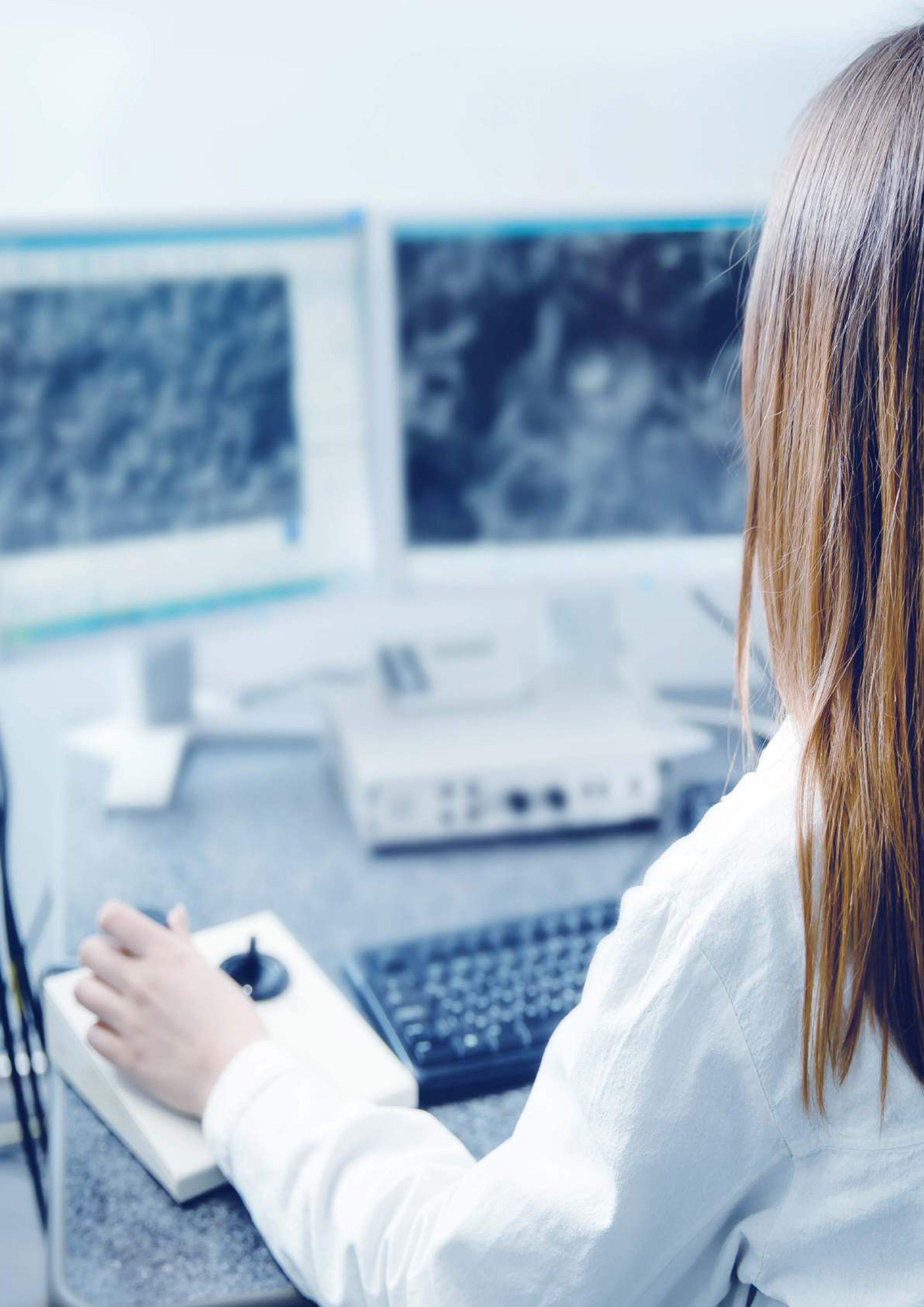
In materials research and production, a large pool of material- and processing-specific measurement data is available, including chemical composition, mechanical and physical material parameters and process data (production and processing). This data can be expanded qualitatively and quantitatively by means of physics-based material modelling, process simulation and data for life cycle assessments (LCAs).

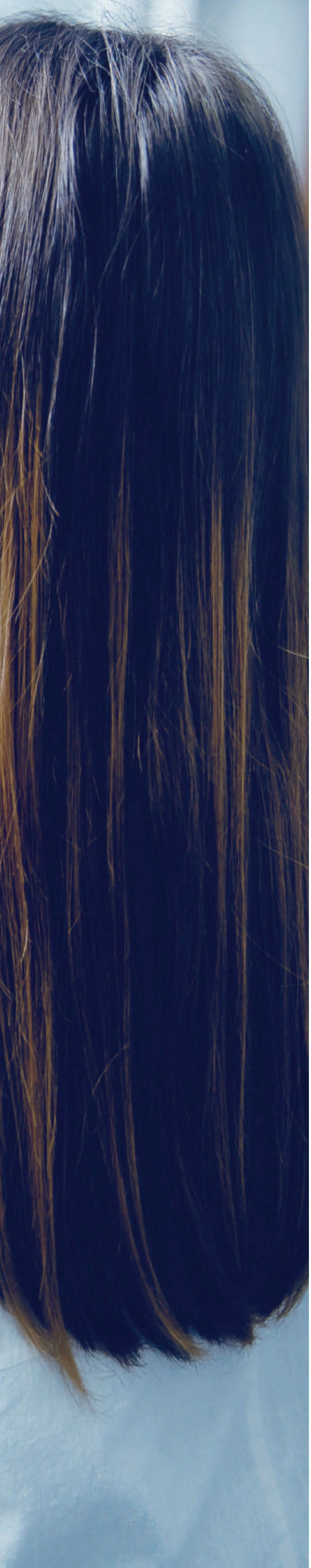
This expansion of the data pool can be controlled using Artificial Intelligence methods. Hence, algorithms must be developed that select existing physics-based models to cheque existing – and to generate new – data points and thus create an optimised data pool (hybrid AI models).



Various Big Data analysis methods (reverse engineering) can be used and developed further in order to predict material properties for new chemical compositions and given processing routes. Conversely, processing routes optimised for a given chemical composition can be calculated to achieve specified material properties.
AI methods can thus generate new, improved materials and also optimise process routes. ■

The real-time capability of physics-based models is inversely proportional to the number of influencing variables in the process to be simulated. Making optimal use of the properties of modern materials while minimising variation requires efficient modelling of the manufacturing process chain. Data-based models such as AI approaches allow complex relationships to be simulated in real time and guarantee optimised processes. In this context, promoting collaboration between specialists is, again, important for successful implementation.





4.3. Materials in Use

4.3.1. Modelling

Components and their materials in use can be monitored at various levels. Cyclically loaded parts are examined for cracks at defined maintenance intervals. Fracture mechanics is used to calculate cracks, their growth rates, and thus the component's remaining service life until replacement. In power plants, reference samples exposed to the same loads as real components are installed and examined for damage at specified test intervals. Structural health monitoring methods are used, for example, in bridge construction, in the aviation and aerospace industries and in wind turbines to determine and monitor the condition of parts.

The materials modelling methods described earlier can also be used to predict the remaining service life throughout a product's life cycle. Based on knowledge of the modelled structure of the component, and taking into account material production and processing, the structural changes in the course of use can also be calculated. Given precise knowledge of the loads occurring during operation, this method can be used to design components. Alternatively, measurement data of the loads can be fed directly into a service-life-accompanying model in order to calculate the current condition of the material.
In addition to models of the structural evolution of the undamaged structure as described above, damage models to the material (initiation and growth) are to be used. An example of this is the calculation of thermomechanically loaded components and their creep. The primary, secondary and tertiary creep including pore nucleation, growth and coagulation can be used as a basis for determining the remaining service life. Use of AI methods is also possible in this context if sufficient data is available. ■

Being able to statistically evaluate the changes in properties and – in particular – failure of materials in use and to automatically derive measures from this information requires data to be collected in a diligent and structured manner during product use and then made accessible to the scientific community. Aside from further development of sensors and service-life models, particular central challenges to be addressed are the development of secure methods for external data access and clear information governance rules.

4.3.2. Life Cycle Management

The increasing exploitation of natural resources and its negative impact on our environment also gives rise to significant challenges in materials development. Although for many materials circular processes have been developed, in many cases scope remains for improving efficiency and environmental compatibility. For new materials, it will in future also be important to consider circular economy scenarios during development. It is very likely that materials with greater eco-efficiency will have better market prospects than those that are poorly recyclable. Hence, this area also requires intensive future research.

In the case of metals, the focus is clearly on classic liquid-phase recycling, which is very energy- and cost-intensive even when processing pure materials. Promising new approaches process the material directly in its solid state and create new products with little effort, although with compromises in terms of properties. Direct processing of individual parts of a product, also called upcycling, is another important trend. Here, there are no limits for creative minds, but also on a larger, technological scale, upcycling offers untapped potential.

The development of smart materials, such as self-healing materials, that adapt themselves to environmental conditions is also an important field of research with great potential.
A digital image of a material beyond its first life cycle could provide valuable support in all life-cycle processes, but can only be realized with the help of cross-company material data tracking. This approach has therefore interesting potential, but requires a complex, very long-term implementation process. ■

Today's linear economy with its high demand for raw materials is one of the main drivers of climate change. Sustainable use of our resources within a circular economy is the solution towards which the EU is working. Hence, the end of the life cycle of new materials and products must already be considered comprehensively in the conception phase of their development. The focus should not only be on designing for recycling (for both materials and products) and on optimising recycling methods, but also on repair plans, self-healing systems and alternative reuse of materials. Evaluating which solutions are best requires extensive life cycle assessments.

Goals

The way to the “NEW DEAL IN PRODUCTION“

The tasks to be tackled on the challenging path to climate neutrality involve taking on greater responsibility than ever for ensuring that an environment worth living in is passed on to future generations.

The age-old conflict between economic and ecological goals (climate goals) can only be resolved by means of new and improved sustainable technologies and systems.

This requires – more than ever – creativity, motivation and highest qualification.

Attractive products, efficient production systems and high-performance materials are the cornerstones of a successful future of the manufacturing industries in high-wage countries such as Austria. The technologies used to implement products must build on the latest research results in order to continue to generate new advantages due to innovations in products and processes and to enable the implementation of overarching societal objectives such as carbon neutrality, resource conservation and circular economy.

From the current challenges faced by Austria’s manufacturing industry as identified in Section 1 and the detailed insights into the three areas of production systems, products and materials given in Sections 2 to 4, we derive, in summary, the following goals, measures and key topics for the implementation of the “NEW DEAL in Production” and thus for strengthening production in Austria.

Climate Goals

- Climate neutrality in Europe by 2050
- Resource conservation, carbon neutrality
- Sustainable products via sustainable product design and sustainable production
- Circular economy systems for (raw) materials and products (reuse, upcycling, recycling)

▼

Sustainable Technologies

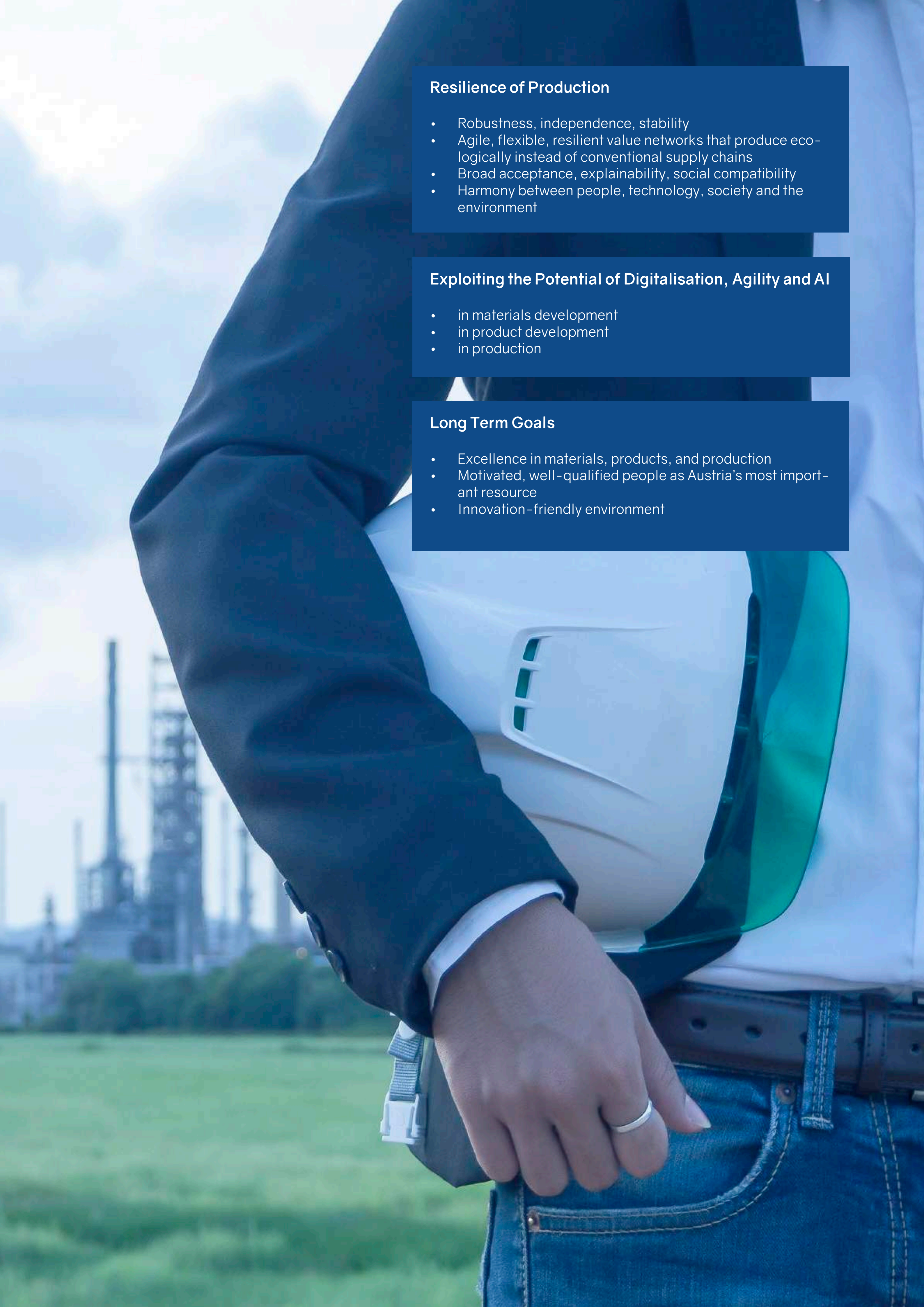
with potential to resolve trade-offs between
- economic goals
- climate goals
- acceptance

through funding programmes and incentive systems

▲

Economic Goals

- Rapid recovery during/after the COVID-19 pandemic
- Strengthening production, competitiveness, prosperity of the Austrian economy
- Strengthening Austrian “product owners”
- Creation and safeguarding of jobs



Resilience of Production

- Robustness, independence, stability
- Agile, flexible, resilient value networks that produce ecologically instead of conventional supply chains
- Broad acceptance, explainability, social compatibility
- Harmony between people, technology, society and the environment

Exploiting the Potential of Digitalisation, Agility and AI

- in materials development
- in product development
- in production

Long Term Goals

- Excellence in materials, products, and production
- Motivated, well-qualified people as Austria's most important resource
- Innovation-friendly environment

Key Topics

Transformation into Agile, Resilient, Ecological Value Networks

- autonomous, agile, cognitive products and production systems
- with the ability to “think”, “memory” and goals
- automated decision-making
- cross-system optimisation for resource-saving production

Seamless Digitalisation

- seamless, digital representations (digital twins) of
  - materials, including manufacturing and processing technologies
  - products along all life-cycle phases
  - production systems and processes
  - engineering processes (product engineering, digital engineering, MBSE)
- integrated, comprehensive information systems
- standards (interfaces, compatibility)
- modeling, simulation, optimization of complex, interconnected systems

Model-Based Methods

Modelling, simulation and optimisation of

- materials (multi-scale)
- products and production systems (multi-physics, multi-level)
- engineering processes

Improving the continuity, consistency and traceability of models, parameters, information and data

Data-Based Methods (Big Data, AI, Machine Learning)

Use of the wealth of data from production, product use and service for

- predictions
- condition monitoring
- product updates
- product improvement

Fusion of Model and Data-Based Methods

Use of

- data-based methods to adapt models
- models to support data-based methods

Climate Neutrality

- of products and production systems
- readiness for circularity and resource efficiency of
  - materials
  - products (along all phases of the life cycle)
  - production systems
  - engineering processes
- sustainable product design and production
- evaluation of sustainability using life cycle assessment
- exploiting the full potential of digitalisation, cognification and AI
- design of circular economy systems (remanufacturing, upcycling, recycling)
- “Green Technologies” as opportunities for industry and work
- environmental protection as an opportunity and a meaningful goal

Cognitive Technical Systems

- products and production systems as cognitive systems
- embedding of cognitive skills
- human-like action
- explainability of decisions
- justification of behaviour

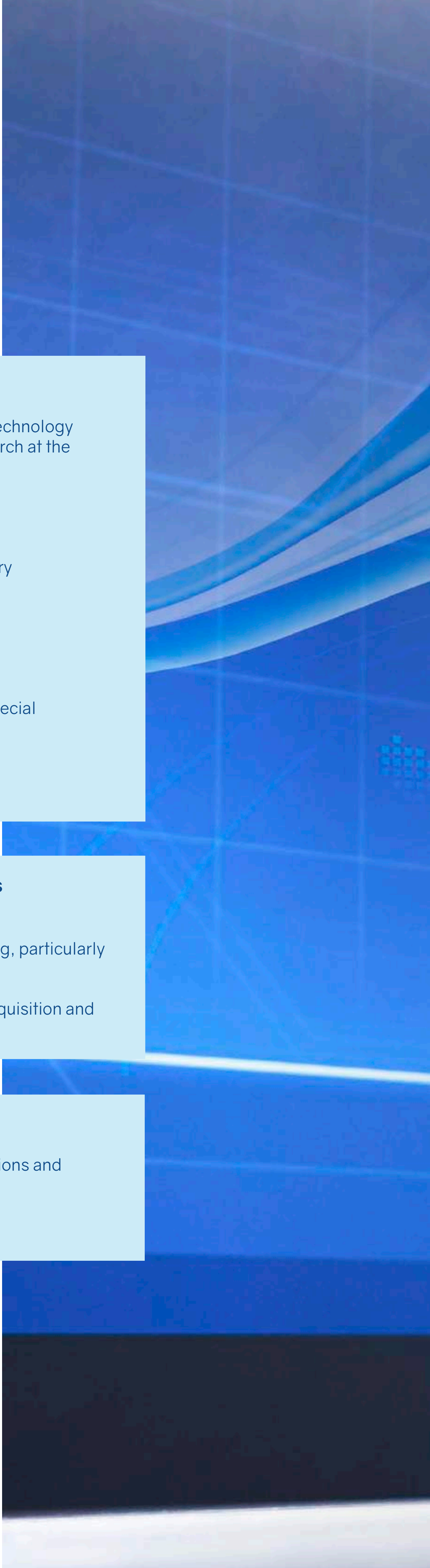
Embedded AI

- miniaturisation, tiny platforms (mobile AI, edge AI, embedded AI)
- internet of “thinking things”
- Edge AI for cognification in manufacturing
- energy self-sufficiency through energy harvesting as a key issue

Dependable IoT

- reliable operation even under highly dynamic, unpredictable and harsh environmental conditions
- internet of “reliable things” for fault-tolerant operation also for safety-critical missions
- proof of practicability as a prerequisite for broad acceptance

Structural Measures



Funding Programmes

- bipolar structural support: for parallel projects in ICT and production technology
- stimulation of innovation spurts: by intensifying the promotion of research at the interface of production technology and ICT

- for investment in rapid-prototyping infrastructure
- for investment in cross-sector data-sharing infrastructure
- to expand the possibilities for simulation (especially in SMEs)
- for measures that reduce energy consumption in manufacturing industry

- to increase cross-company resilience
- for the development of supplier and procurement strategies
- for the interchangeability of materials and components
- to support make-or-buy decisions

- for new materials and their processing into innovative products with special functionalities
- development and expansion of low-threshold entry aids for SMEs ("Innovation Cheque")
- adaptability of funding programs across all TRL levels

Funding for Pilot Projects, Pilot and Learning Factories, FabLabs

- for quick and early validation of ideas and concepts
- for training in the fields of digital production and additive manufacturing, particularly for people working in manufacturing industry

- for unconventional, experimental and talent-promoting knowledge acquisition and knowledge transfer techniques

Qualification

- support measures to get young people inspired for technical qualifications and professions
- training of highly qualified specialists at all organisational levels
- funding to support a culture of diversity and inclusion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“Cultural” Measures

Innovation-Friendliness

- strengthening of a climate conducive to innovation
- commitment to research / development / innovation
- appreciation and recognition of innovations
- optimism, courage to fail, fault tolerance, perseverance
- harnessing setbacks to generate belief and conviction
- innovation as a catalyst for building cultural capital

Openness and Trust

- hands-on culture and joy of experimentation
- open discourse on the opportunities and risks of new technologies and business models
- promotion of creativity through acceptance of different solution approaches in a fault-tolerant entrepreneurial culture

Partnership

Alliance between
- industry
- science
- politics

on an equal footing

Claim to Excellence

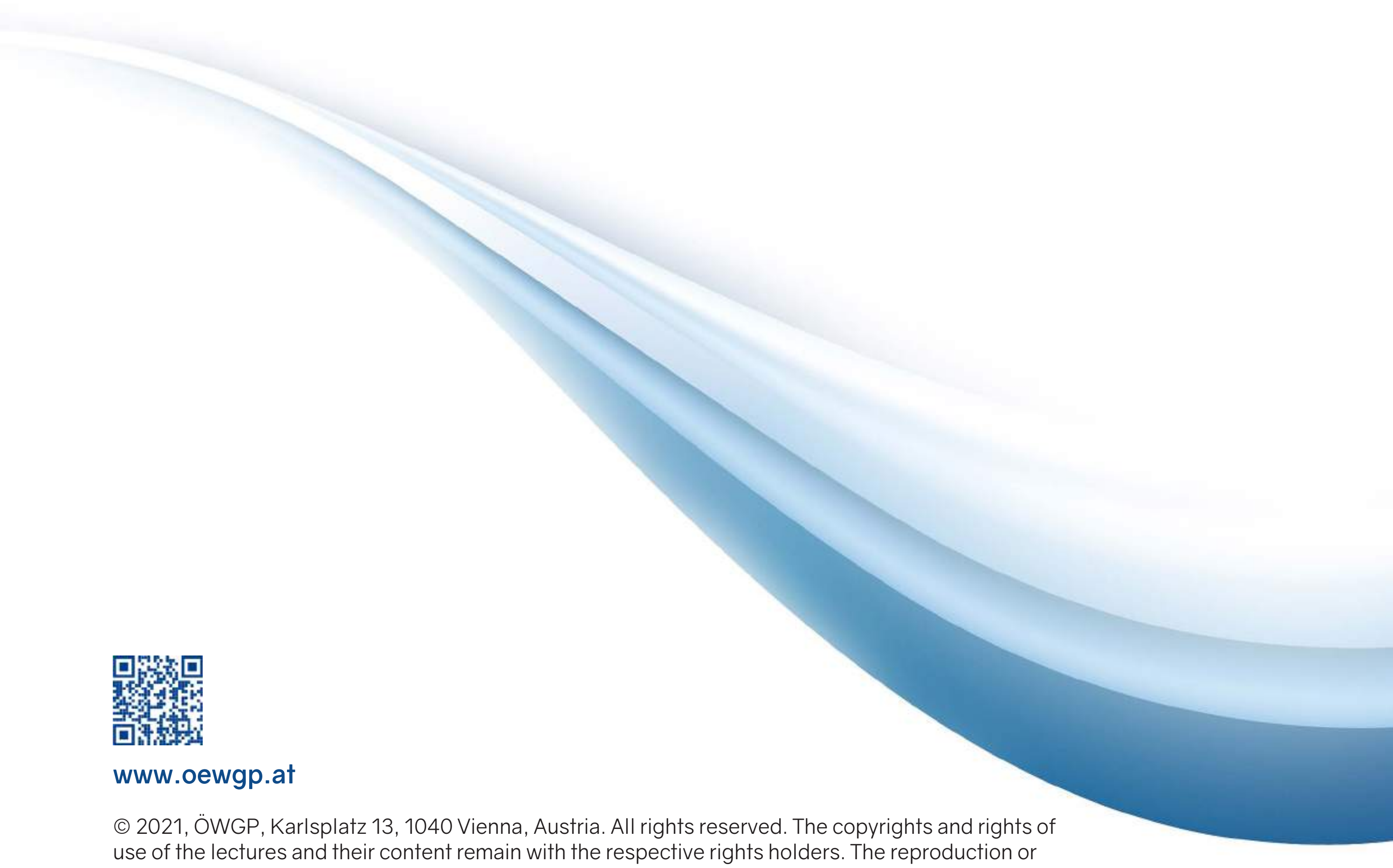
- commitment to excellence in research as a fundamental strategy
- long-term perspective in building excellence
- long-term perspectives to accompany research excellence at all levels
- review by periodic evaluation

Pragmatics

- seek and recognise opportunities and take risks
- focus on strengths and new, promising opportunities
- success by leveraging emerging opportunities and taking promising chances

Incentives for Climate Goals

e.g., by
- limiting the use of single-use products and planned obsolescence
- banning the destruction of unsold durable goods
- incentives for Product-as-a-Service business models



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