Towards Sustainable Manufacturing

How is autonomy paving the way towards a sustainable industry?

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Executive summary

Manufacturing and industrial technologies are major drivers of societal wealth. In 2019, the manufacturing sector accounted for two million enterprises, €2,078 billion in gross value added, and 32.1 million jobs in the EU-27 area.[1] The European economy is highly dependent on the manufacturing industry and exporting of manufactured goods. Around 10 percent of all enterprises in the EU's non-financial business economy are classified as manufacturing.[2] The transition of societies to climate neutrality and circularity pushes for changes in operations and creates new business opportunities for companies. Markets are shifting towards green products and services to meet conscious consumers' needs and comply with the new and upcoming EU regulations that strive to reduce net greenhouse emissions by at least 55% by 2030.[3]

The pandemic and growing geopolitical frictions have highlighted that critical value networks have insufficient resilience. The autonomy of European manufacturing has become a priority and main concern. Companies are striving for multi-sourcing strategies and supplier flexibility. This has resulted in further investments in digital technologies, automation and robotics.

Parallel to the technological evolution, each company needs to prepare for the disruption of industrial work and the increasing shortage of personnel.[4] New generations are looking for meaningful work careers that aren't based on dull and repetitive tasks. Thus, industries need to rethink how to attract future workers and, at the same time, motivate and reskill current personnel.[5,6] Humans operate functions where their creative and cognitive processing capabilities and versatile skill sets are needed. People should be able to work on-site and remotely using friendly, engaging and intelligent interfaces and systems that reduce cognitive load and empower the whole work community.

At VTT, we see a clear transition towards a more sustainable and resilient industry. This transition requires increasing autonomy in the whole manufacturing ecosystem. Autonomy includes self-sufficiency in terms of know-how and resources but it is also based on increasing the level of automation. Thus, one key enabler of autonomy is the increasing use of robotics and artificial intelligence, which results in self-healing and self-learning processes and change of industrial work. Another important target is the shift of manufacturing towards green values. This shift requires the use of recycled materials and green energy, along with focusing on resource-efficient, demand-driven production and circular value chains.

This paper presents a vision of sustainable manufacturing in the future and provides insights into the transformation towards it. The vision is shaped by the experts from the VTT Technical Research Centre of Finland, a multidisciplinary and independent research institution owned by the Finnish state. The findings of this work portray a systemic transformation, which requires bold steps in technology development and business and societal advancements.

1. Autonomous manufacturing for sustainability

Most companies have two ambitions when moving towards a socio-economically and environmentally sustainable industry. One is to save resources (material, energy, time, labour) and become carbon neutral in processes and supply networks. The second is to produce new kinds of carbon-neutral and circular products urgently needed to mitigate climate change. Thus, the transition of societies to climate neutrality and circularity pushes for a change in industrial operations. The transition also creates new business opportunities for companies in the value networks to invest in operations and production and forecast the demand. Sustainable processes also help companies to meet the needs of conscious consumers and comply with upcoming regulations.

In this paper, **autonomy** is seen as a key enabler in the transition towards a more sustainable industry and is discussed from multiple points of view. **Technological autonomy** encompasses self-awareness, self-healing and self-learning processes, systems, machines and components. **Autonomy of future work** refers to more independent and conscious decision-making and the ability to realise individual preferences and job roles that increase well-being and the meaningfulness of work. **Geopolitical autonomy** strengthens European industry's ability to cope with unexpected global events. This requires self-sufficiency in critical resources, technological know-how and infrastructure. Thus, the sustain-able and autonomous industry transformation is a systemic change that requires optimisation at all

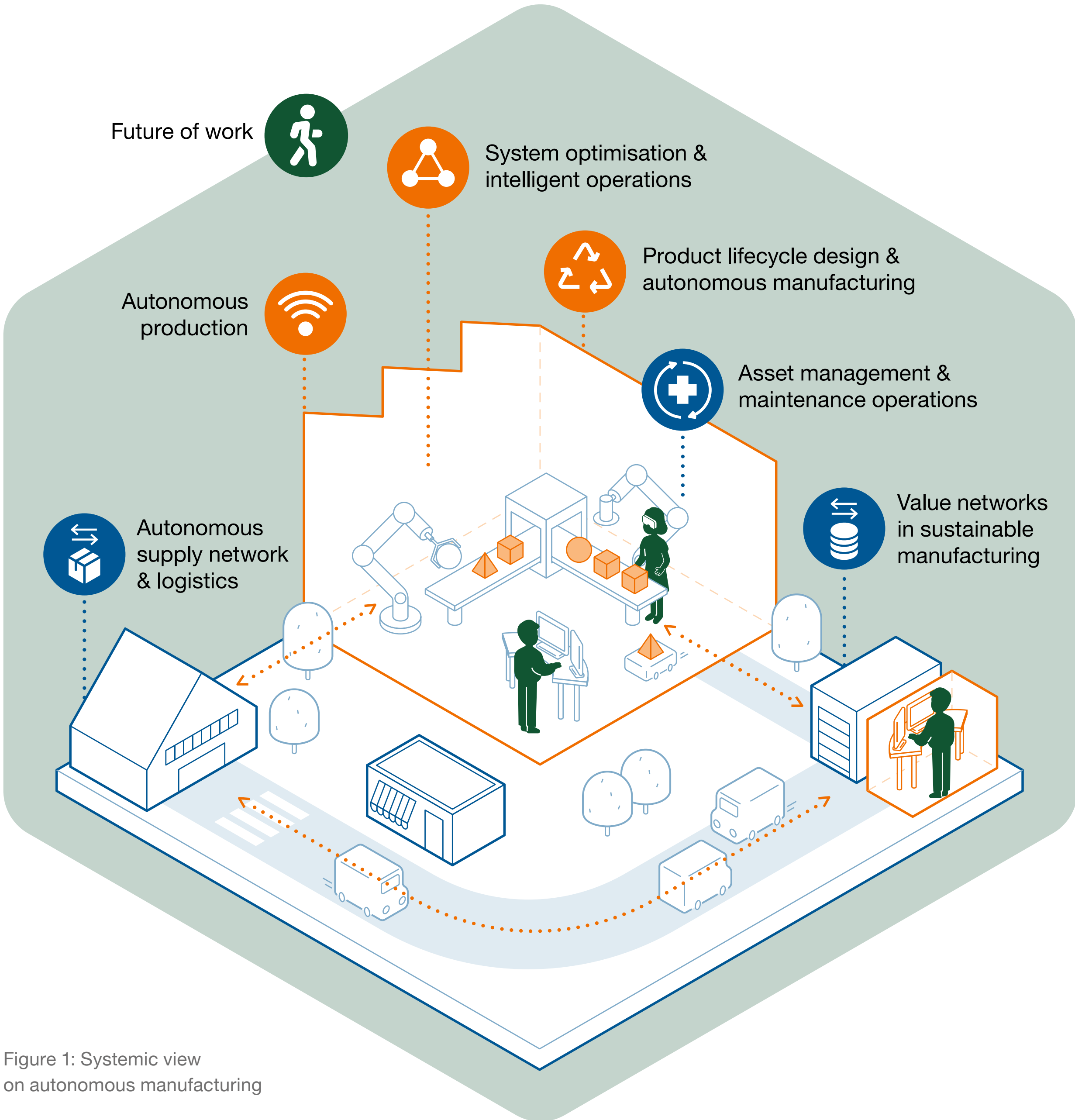

Figure 1: Systemic view on autonomous manufacturing

levels from production to value networks and from individual employees to work communities and customers. The identified levels are presented on page 5 (Figure 1).

With higher levels of autonomy, production expertise no longer relies on a single person. Intelligent learning systems support the sharing of information in the whole work community. Knowledge can be gathered, shared and scaled between manufacturing units, factories, supply networks and product series. This allows faster and more cost-efficient modifications and ramp-ups for new products and their variations. At the same time, customer needs can be identified and shared efficiently, which increases customer loyalty. However, this puts industrial workers in a different position where digital skills are at the core. Autonomy in critical digital competencies and the ability of the workers to deploy technology are essential for the sustainable transformation of industry.

This white paper presents VTT's view on the evolution towards sustainable industries and beyond. Together with about 30 VTT experts from different fields, we have created a vision for the future of manufacturing. The vision has been revised in discussions with selected Finnish manufacturing companies. The purpose of this work is to challenge current thinking and support companies in finding new business opportunities in the transition towards a green, digital, and resilient industry. The focus is on the means that enable systemic change, including business opportunities, operations, human aspects and technologies that pave the way towards sustainability.

2. Drivers and enablers for future sustainable manufacturing

Industry transformation

Manufacturing and industrial technologies are major drivers of societal wealth. In 2019, the manufacturing sector accounted for two million enterprises, €2,078 billion in gross value added, and 32.1 million jobs in the EU-27 area.[7] The European economy is the world's biggest exporter of manufactured goods,[8] thus making it highly dependent on the manufacturing industry and exports. In Finland only, the value of exported goods amounted to almost €69 billion in 2021, with a 21.5 percent increase compared to the previous year.[9]

Europe is a front-runner in manufacturing engineering for highly personalised and complex products and related services, while also being a leading solution provider in production technology, digitalisation, resource efficiency and circular economy implementation. Although Europe's industry is a global technology leader in most manufacturing market segments, retaining this position has constantly been challenged by international competitors. In particular, Europe faces severe competition in mastering industrial data, which is crucial for manufacturing competitiveness. Therefore, investments in manufacturing and digitalisation innovations are a necessity.[10]

The societal impact of manufacturing also lies in added-value jobs that bring well-being and social sustainability for future generations and regions. According to ManuFUTURE 2030 vision,[11] the European manufacturing industry will deliver excellence in solutions, ensuring user satisfaction, high quality and environmental and social sustainability. A human-centric approach must be at the core to attract new workforce and keep current employees. European Commission's manufacturing partnership Made in Europe aims at boosting European manufacturing ecosystems towards global leadership in technology, circular industries and flexibility.[12]

The Fourth Industrial Revolution represents a fundamental change in the way we live and work.[13] This revolution's speed, breadth and depth have forced us to rethink how industries and organisations create value and how societies and people can benefit from innovation. In addition, it improves flexibility, efficiency, integration and customer centricity in the manufacturing industry.

Technological development and societal changes will create a distinct transition path when organisations shift towards higher sustainability and autonomy in manufacturing. The speed of technological change and digitalisation will transform manufacturing work. Both phenomena are necessary to build a sustainable, human-centric and resilient manufacturing industry in Europe, even if it is extremely difficult to depart from old habits and practices. Technology will not be replacing humans, but it will increasingly support human activities and the capability to increase sustainability, effectiveness and value. Below, we introduce a stepwise view that indicates the stage organisations are in their transition. The steps are Integrated, Learning, Intelligent and Autonomous manufacturing (Table 1).[14, 15, 16, 17]

The pandemic and growing geopolitical frictions have highlighted that critical value networks have low resilience. Still, manufacturing relies on global markets and supply networks. The autonomy of European industries has become a priority, and visibility in the end-to-end supply chain is crucial. Companies are striving for multi-sourcing strategies and supplier flexibility. This has resulted in further investments in digital technologies, automation and robotics. Factories can be designed to be easy to set up. Locational flexibility and regional supply networks also allow producing goods closer to customers.

	Integrated manufacturing	Learning manufacturing	Intelligent manufacturing	Autonomous manufacturing
Level of autonomy	Partial automation in clearly defined areas. Data acquisition, analysis and monitoring in isolated systems. Data is shared scarcely.	Cyber-physical systems and digital twins are introduced. Data is increasingly collected and shared within factory and enterprise. AI is used to support decision making.	Intelligent production chains share data and use AI for optimising operations in value chains. Predictive maintenance is put into the practise. Agile and collaborative robots are exploited extensively.	Autonomous operations in all areas of manufacturing. Self-healing and self-learning processes, machines, and components. AI based real-time value network optimisation. Extensive inter-company data sharing with common processes and shared data platforms.
Role of humans	Human labour in specific functions with limited access to data and knowledge. Digital tools are introduced to enhance productivity of work.	Skilled labour in specialist roles. Digital technologies support performance, learning and decision making at work.	Novel technologies are used to empower the work communities. Operators and robots work smoothly together in various and changing tasks.	Human-centric approach is adopted in all levels enabling attractive work, continuous learning and empowerment of work communities. Humans are creative problem-solvers focusing on systemic challenges and ethical concerns.
Industrial cooperation	Companies operate fairly independently with limited sharing of data and resources within networks.	Information exchange with shared digital systems. Common aims and strategies for advancing network-level sustainability.	Agile supply networks that anticipate customer needs and share data against value-based policies and circular economy.	Value networks optimised for circular economy and life-cycle services. Data valorisation brings business benefits for the value networks over life cycle.

Table 1. Transition path towards sustainable and autonomous manufacturing

Key technologies enabling the transformation

Many technologies have been identified as key for shaping sustainable digital transition.[18][19] Robotics, automation and artificial intelligence are at the core of sustainable manufacturing. Robots will become more widespread as technologies mature and prices come down. Modular, multi-use, collaborative and mobile solutions will become more common, which will improve robots' ability to perform multiple tasks. This will lower the threshold for investing in them, even in smaller companies. Robots will be safe and user-friendly with easy programming and the ability to adapt to the individual needs of humans and work communities.

Extended reality technologies enable remote operations, which will be possible in several tasks that now require physical presence. Many manual tasks are already automation assisted but still require human intervention at the site. In the future, human operators can increasingly program and control the robots, or fleets of robots, remotely. Many inspection, control and adjustment tasks can be done remotely with secure real-time network connections and virtual, augmented and mixed reality solutions. In robot operations, motion control with haptic feedback will help the operators.

Artificial Intelligence (AI) will have positive impacts, especially on proactive maintenance, process automation and control and supply network management. It will also reduce costs and improve efficiency, flexibility and safety. Companies will get their products into the market more proactively, faster, with lower prices and

Manufacturing technologies

- New manufacturing technologies enabling sustainable, circular and customised production.
- Manufacturing exploiting green energy and sustainable materials.

Extended reality technologies

- Virtual, augmented and mixed reality, haptic feedback.
- Remote real-time fleet control with secure and fast network connections.

Data

- Digital platforms, standards, rules and agreed procedures for data utilisation.
- Measurement technologies, big data storage and sharing solutions, real-time, distributed analytics and cyber security.

Robotics

- Modularity, multi-use, mobile and smart robots for increasing productivity.
- Safe, user-friendly, collaborative and adaptive human-robot solutions.

Quantum computing

- Development of quantum equipment and algorithms, along with quantum crypto-graphy.
- Quantum computing services for industry.

Artificial Intelligence

- AI algorithms and high-quality data.
- Transparent and ethical use of AI.
- Decision making systems using AI.

better quality. AI can bring additional business value when it is embedded in the products or new services that are offered to users and customers. AI can also anticipate trends in global markets, develop new business models and speed up product development.

Alongside AI and robotics, there is an urgent need for advanced technologies for data storage, analysis and sharing technologies. The heterogeneity of industrial data coming from legacy devices, from various IT systems and from business and customer processes is a challenge for data valorisation. Digital platforms, standards, rules and agreed procedures for data utilisation are needed. In addition, data sharing within the autonomous industry requires real-time, distributed analytics and reliable connectivity where edge and 5G can provide solutions. Cyber security must be ensured throughout the supply network in all operations.

Quantum computing and the advancement of today's supercomputers will enable the modelling and solving of increasingly complex systemic problems in the financial market and industrial processes. Once quantum computers and algorithms mature, their capacity will be extensively used, for example, in processing vast amounts of industrial data, solving cybersecurity challenges, optimising supply networks and designing new materials and products.

In addition to digital technologies, circular strategies strive to use less (primary, scarce, harmful) materials and develop new technologies for remanufacturing, recycling, dismantling and reusing. As renewable and recyclable solutions will be in increasing demand, manufacturing and processes must also change. Thus, the diversity of circular or bio-based materials and recycled components and products entering the production lines is a tremendous challenge to the manufacturing itself. This challenge requires even more advanced digital and autonomous solutions. In the long term, game-changing technologies, such as synthetic biotechnology, which combines engineering principles with biology and utilises natural processes to fabricate materials and products, can revolutionise the production of, for example, pharmaceuticals, fuels, chemicals, textiles, electronics and food. Moreover, sustainable and circular industries are getting electrified and exploring new green energy solutions that replace fossil-based energy sources.

3. VTT's vision for sustainable manufacturing

Scenario for manufacturing in 2035
We took one moment in time (the year 2035) and described what future autonomous factories are like:

In 2035, autonomous factories manufacture green, circular, and highly customised products and optimise resources and operations across value networks. **Humans and machines** work in collaboration, using their unique strengths. Highly **professional individuals** concentrate on systemic and strategic tasks, which can be performed remotely. **Machinery** is largely conscious, self-prognostic and self-healing, not only performing repetitive, dangerous and harmful tasks but also flexibly supporting human operations. **Customisation** is achieved with production lines and supply networks adapting to volatile markets and changing customer needs. **Data is shared in real time** in industrial communities, and manufacturing capacity is offered on-demand to a vast pool of customers. **Factories have minimised their environmental footprint** with extended lifecycles of assets, reduction of material loss and waste, utilisation of sustainable energy and recycled materials and lower logistics footprint. Circular business models and sustainable values are widely adopted.

We built scenarios from six perspectives: role of humans, technological development, customer needs, data sharing, business models and environmental sustainability. These scenarios are described on the next page:

Role of humans:

Creative problem solvers

Future work will be a collaboration between humans and machines. Humans operate functions where their unique cognitive processing capabilities and versatile skill sets are needed to prevent and solve unexpected events and to create solutions for future customer needs. They focus on systemic and strategic tasks and coach robots to perform laborious and non-creative production tasks. People can work remotely, accessing friendly, engaging and intelligent interfaces and systems. Overall, factory work appears meaningful for new generations entering the workforce.

Technological development:

Leaps in digital technology

Significant leaps in crucial digital technologies, such as artificial intelligence and connectivity, along with edge, fog and quantum computing, will allow the development of a high level of automation in factories and their ecosystems. Technological development has enabled conscious, self-prognostic and self-healing machines and processes. Advanced computing and the availability of data drive major innovations in, for example, process optimisation, product and service development and in the transition to carbon neutrality.

Customer needs:

Personalised customer solutions

B-to-B and B-to-C customers expect personalisation, with varying levels of tailoring across product categories. Demand forecasts and agile supply networks will enable customisation and the adjustment of production volumes. Orders based on consumption are automated, data-driven and individually profiled, with a high level of supply chain automation. Mass production still exists in categories where customisation does not create real value for the user, but it becomes rarer as tailoring does not typically increase costs.

Data sharing

Interest-based communities

Data will be shared in industrial communities when sharing serves the interests of the factories. Incentives for sharing can be political, environmental or based on trading. Factory operators, clients and subcontractors jointly develop the required processes. Inter-company data sharing optimises products to meet customer needs. The end-user opt-out possibility is widely offered, but relatively few use it, as life without data sharing would be inconvenient. The legislation supports company collaboration with standardised sharing practices.

Business models

Production capacity on demand

Factory ownership is in the hands of specialist investors offering production spaces flexibly to a vast number of manufacturers. The size of factories varies from small and local units to large factories producing goods efficiently for mass consumption. Brand owners prefer simple processes and contract structures, favouring large production units. Contracts are forged on the fly, as customers order products from the most suitable factories for their needs at a given moment, based on the factories' offerings.

Environmental and social sustainability

Pronounced corporate responsibility

Legislation, customer expectations and proactive industry- and company-level social responsibility decisions drive industrial greening. Companies rather exceed responsibility expectations than reach the minimum requirements. Factories are assessed by the level of environmental friendliness their production can offer. Great emphasis is put on energy sources, workforce and production handprint. Sustainable industrial production carefully considers material use and re-uses and repurposes waste streams as materials. Excellence in manufacturing enables the production of future green products with positive environmental handprint.

Elements of sustainable manufacturing

Developing strategies towards sustainable manufacturing requires understanding the key elements in an increasingly systemic operational environment. This understanding allows organisations to make better decisions and carry them out in operational reality.

Everything will be more connected in future manufacturing. Data and knowledge flow from various digital systems that connect companies, employees, assets and customers in different product lifecycle stages from concept to end product.

Collaboration with the customer and the supply network starts already in the product concept design and planning, looking into sustainable, flexible and optimised production and product customisation and circularity. Machines and digital systems are intelligent; data is distributed and operated mostly autonomously, so people can concentrate on the impact their decisions have on the economic, societal and environmental levels. Digital manufacturing supports on-demand production; it is directly connected to customer warehouses and customer services. Factories' assets management optimises performance and machine downtime. Connected products enable instant usage feedback for design and material improvements.

The infographic on the next page (Figure 2) shows the systemic view on sustainable manufacturing, and it includes six elements where we see disruption and potential for change. In addition, there is a cross-cutting theme, **future of work** that highlights new capabilities and expertise required to reach the vision. Examples of future work tasks are described for each of the presented elements.

Value networks in sustainable manufacturing
Shared data brings full awareness of the demand and supply between the entire value network. Organisations will become more collaborative and operations more autonomous and sustainable. Skilled and connected work communities ensure mitigating risks across operations and business networks and manage the collective agenda to improve the overall system with common practices, strategies and standards.

System optimisation and intelligent operations
Process modelling and optimisation happens on the system platform level in autonomous factories. This enables customisable and optimised operations between different parts of the production sites and supply network. Digital twin architects, for example, are responsible for the delivery and operationalisation of a scalable digital twin framework and driving the continuous assessment and creation of new capabilities.

Asset management and maintenance operations
In autonomous factories, asset management and maintenance operations will evolve from predictive and prescriptive maintenance towards self-conscious and self-healing machines. Predictive maintenance specialists use systems on existing assets, equipment and infrastructure to monitor fleets and predict their individual and collective performance and maintenance needs over time. Mixed reality and mobile robotics solutions will support this process.

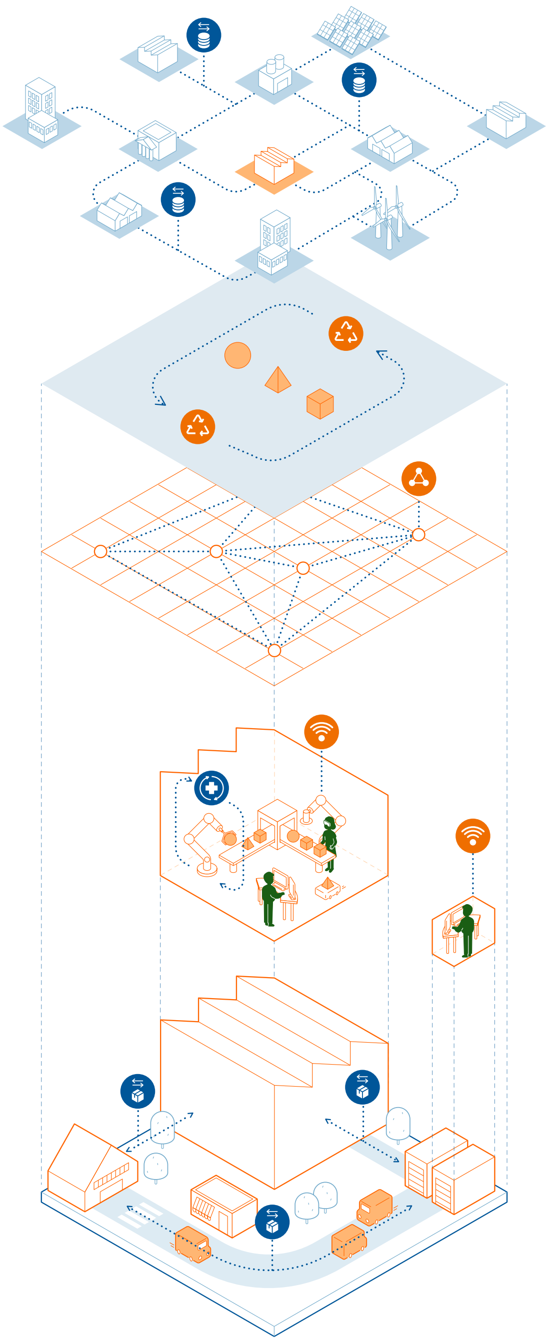

Figure 2: Elements of sustainable manufacturing

Product lifecycle design and autonomous manufacturing
Autonomous factories require that products are designed in collaboration to support circularity and standardised autonomous operations and production. Skilled professionals are responsible for planning and supporting product circularity and sustainability and for refining related parameters in the production planning simulations. The professionals also build maximum reliability, maintainability and data connectivity throughout product lifecycles.

Autonomous production
Autonomous production combined with remote operations can provide efficient, standard quality and adaptability needed in manufacturing. Data-driven manufacturing engineers plan and teach optimal manufacturing methods to robots and systems. Co-designed human-robot collaboration enables smooth on-site and off-site work in multiple locations 24/7.

Autonomous supply network and logistics
Enhanced data processing and connectivity capabilities will enable the overall optimisation and use of autonomous vehicles, machines and operations in logistics. Adaptive digitalised supply networks will support the resilience of manufacturing ecosystems. Fleet managers will monitor logistics to ensure reliable supply in all situations from inbound and warehouse logistics to product delivery. They engage in collaborative planning with a variety of stakeholders in the value network to better optimise operations and logistics.

4. Sustainability benefits and impact

A transition to autonomous manufacturing yields economic, environmental and social benefits for companies.

Economic

- Automated, optimised and more efficient processes across the supply chain.
- Better preparedness to meet different production needs with adaptive systems.
- Improved resource- and cost-efficiency with transparent production processes.
- Prompt and contextual decision-making based on transparent and real-time data.
- Increased effectiveness and economic value with lifecycle and asset management.
- New service and business model innovation with end-to-end system-level optimisation.

Social

- Higher personnel well-being by focusing on workers' individual capabilities, preferences and skills.
- A safer work environment due to machines performing dangerous, harmful and repetitive tasks.
- Empowered individuals with novel technologies to support complex work tasks and proactive decision making.
- Engaging and more attractive work with well-designed work tasks, tools and user interfaces.
- Talented workforce with flexible and creative ways of working.

Environmental

- Handprint of new manufactured, environmentally friendly products will have an enormous impact on green transition.
- Decreased environmental footprint in the whole supply chain level through optimising operational efficiency, energy and raw material use and logistics.
- Less material loss and reduced waste outputs with fast feedback loops in the value networks.
- Extension of the useful life of assets and spare parts with decreased environmental impact.
- More sustainable materials adoption in adjusting the physical facilities of factories.
- Minimised negative environmental impacts while conserving energy and natural resources when on-site components and spare parts are produced.
- Better prediction of emissions to stay within agreed limits and preparing for regulatory changes and a carbon-neutral future.

Examples of transformation impacts

Going beyond the benefits that investments in sustainable manufacturing can bring to businesses, the results of such initiatives can lead to the mitigation of existing challenges, such as:

1. Autonomy increases cost-effective, sustainable manufacturing in Finland

Finland has world-class expertise in digital technologies, such as artificial intelligence, the primary enabler for autonomous manufacturing. Finnish high-tech companies with a well-educated workforce have the necessary knowledge to increase autonomy significantly. This enables the cost-efficient and sustainable manufacturing of a wide variety of goods in Finland.

2. Autonomy helps increase the resilience of industrial production

Industrial resilience includes technological, economic and social aspects. In crises such as trade wars or pandemics, increased technological autonomy in manufacturing lines, factories and supply chains is required to adapt production according to the availability of critical resources. Utilising the same facilities and equipment for producing various goods increases economic resilience by allowing faster response to market volatilities. Social resilience is based on the capability to continuously learn, transform, and use people's skills and competencies. This enables companies to constantly develop and quickly adapt to changing needs and disruptions.

3. Autonomous industry helps solve global sustainability challenges

The manufacturing industry is needed to produce the green and circular products of the future. Thus, sustainable autonomous manufacturing is an enabler of the green transition. At the same time, manufacturing innovations are needed to utilise circular raw materials and industrial side-streams, to increase energy efficiency, use green energy and minimise emissions and waste. The efficient use of resources and raw materials requires autonomously adaptive supply chains and agile production systems and methods.

5. Realising the vision

Bold steps and key investment areas towards sustainable manufacturing

The transition towards sustainable manufacturing is not easy and requires some proactive and bold steps from each stakeholder in the manufacturing ecosystem. These bold steps are summarised below.

Step 1: Adopt shared visions and targets. Companies in manufacturing ecosystems will need to understand what state-of-the-art means in future factories and take smooth but concrete actions towards it. They will need to co-create clear and shared targets and roadmaps on how to optimise processes and operations and leverage proprietary data.

Step 2: Increase data transparency and accuracy throughout product lifecycles. For operations and processes to run smoothly and securely throughout the product/factory lifecycle, shared standard practices, protocols, certifications, data ownership issues, traceability systems and security measures in data collection and utilisation must be adopted in manufacturing ecosystems. This involves an increased dependence on machines, which makes reliability a key issue.

Step 3: Redesign manufacturing processes and lifecycles. Transformation towards autonomous industries requires collaboration and cooperation in redesigning the entire manufacturing lifecycle with autonomous technologies, shared standards and principles. An end-to-end view on product lifecycle will enable maximum capability, capacity and resilience. Improve asset and component lifecycles by actively managing and updating datasets.

Step 4: Redesign products and production. Autonomous production infrastructure is reconfigurable and reusable for different product variations and production methods. Redesign products and factories for autonomous robot operations. Redesign products for hybrid manufacturing technologies where the product shape is not limited and there is a possibility to use unique material combinations. Add intelligence to the products as part of the production process. Ensure product definitions are complete, safe, and precise for machine interpretation and correction.

Step 5: Develop and invest in key capabilities for a sustainable transition. Invest in expertise for minimising the environmental impact of products and production and extend capabilities for remote operations. Increase digital skills of people and their technology acceptance. Develop new ways to reduce people's cognitive load to manage complexity and information flow. Build partnerships and ecosystems, and ensure expertise development and investing in key technologies and solutions throughout the whole production network.

Step 6: Go beyond. Create new products and services that are not possible with more traditional methods and business models. What if the future product is manufactured from the customer's recycled material close to them in just a few days? What if a new company controls the data platform that offers the manufacturing capacity of several factories? What if a worker could monitor and control several factories from their summer cottage using XR technologies through industrial metaverse?

VTT supports companies in taking the right actions towards future sustainable manufacturing
With our holistic understanding of the future of manufacturing and our pool of experts, we want to support our customers with research, development and innovation activities throughout their R&D&I processes – from tackling significant strategic objectives to accelerating the development of an already identified solution concept from our customer's R&D&I portfolio. Throughout the R&D&I process, we support our customers to steer their research and development efforts and resources to a well-grounded and validated path.

We do this by helping answer the key questions: What are the key future opportunities – the problems worth solving – that we should focus our time and resources on? How do we ensure the solutions are future-proof and bring sustainable growth? How should we implement the solutions to create the planned impact?

Our approach is to bring together the best experts from the customer and VTT to explore the challenge at hand and co-create future-proof solutions to move towards future sustainable manufacturing. The working methods and level of outcomes are continuously adjusted based on the customer's goals and needs:

- **Strategic level:** Create visions and clear direction when moving towards future manufacturing (for example, building a roadmap for a carbon-neutral sustainable future)
- **Process level:** Adopt new sustainable and increasingly autonomous processes, systems and working models (for example, improving the human-machine collaboration in production)
- **Operation level:** Adopt new working methods, tools and technologies to shift to sustainable manufacturing (for example, adopting teleoperated virtual and augmented reality solutions in asset maintenance)

As an outcome of this collaboration, our customers get future-proof and sustainable strategies, products, services and user experiences to make sure they stay competitive also in the future.

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References

1 European Commission (2019). Advanced Manufacturing. Accessed in March 2022.

2 Eurostat (2018). Manufacturing Statistics – NACE Rev. 2. Accessed in March 2022.

3 European Commission (2019–2024). A European Green Deal. Accessed in March 2022.

4 Technology Finland (2021). Teknologiateollisuus tarvitsee 10 vuoden sisällä 130 000 uutta osaajaa – Ikääntyvän Suomen osaajapula uhkaa romuttaa digivihreän talouskasvun. Accessed in March 2022.

5 World Economic Forum (2020). The Future of Jobs Report. Accessed in March 2022.

6 Deloitte (2021). 2022 Manufacturing Industry Outlook. Accessed in March 2022.

7 European Commission (2019). Advanced Manufacturing. Accessed in March 2022.

8 European Commission (2018). ManuFUTURE vision 2030. Competitive, Sustainable and Resilient European Manufac-turing. Accessed in March 2022.

9 Finnish Customs (2022). 7.2.2022 Press Release. Accessed in March 2022.

10 European Commission (2021). MADE IN EUROPE. The manufacturing partnership in Horizon Europe – Strategic Research and Innovation Agenda (SRIA). Accessed in March 2022.

11 European Commission (2018). ManuFUTURE Vision 2030. Competitive, Sustainable and Resilient European Manu-facturing. Accessed in March 2022.

12 EFFRA (2021). Made in Europe – State of Play. Accessed in March 2022.

13 World Economic Forum (2021). Fourth Industrial Revolution. Accessed in March 2022.

14 European Commission (2018). ManuFUTURE Vision 2030. Competitive, Sustainable and Resilient European Manufacturing. Accessed in March 2022.

15 DARPA (2017). A DARPA Perspective on Artificial Intelligence – Three Waves of AI. Accessed in March 2022.

16 ConnectedFactories (2019). Autonomous & Smart Factories Pathaway. Supported by the European Commission through the Factories of Future PPP (Grant Agreement Number 873086). Accessed in March 2022.

17 European Commission (2021). Directorate-General for Research and Innovation, Breque, M., De Nul, L., Petridis, A. Industry 5.0: towards a sustainable, human-centric and resilient European industry. Accessed in March 2022.

18 European Commission (2020). Directorate-General for Communications Networks, Content and Technology. Shap-ing the digital transformation in Europe. Accessed in March 2022.

19 PwC (2016). Global Industry 4.0 Survey: Building the digital enterprise. Accessed in March 2022.

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