IVA | Swedish Futures

Advanced Manufacturing

A technical report about complex discrete manufacturing as part of the *Swedish Futures* series

Contents

Foreword

IVA is spearheading the *Swedish Futures* initiative to formulate a vision for Sweden as a leader in technology and innovation by 2035. Since autumn 2025, *Swedish Futures* has brought together stakeholders from academia, industry and the public sector to identify opportunities, challenges and strategic directions for competitiveness and sustainable development.

Among other things, the initiative convenes working groups that quickly and systematically analyse challenges and opportunities in different technology areas and produce highly focused reports. These reports provide an overview of the status quo and outlook for the field under examination and present concrete proposals for action. They also serve as an important foundation for shaping an overarching vision for Sweden in 2035.

This report was written by the working group looking at advanced manufacturing – or Sweden's ability to design, construct and scale complex products and systems. The group's analysis shows that investments into innovation, resilience and collaboration are needed to secure and further develop Sweden's capabilities in this area.

As is the case with all IVA projects, all participants contributed in their personal capacity and not as representatives of the organisations for which they work. The report's analyses, detailed proposals and to-the-point recommendations are based on the experience and knowledge they contributed and the discussions these inputs engendered. The working group endorses the report as a whole, although this does not mean that all members necessarily endorse every formulation.

The working group on complex discrete manufacturing convened from December 2025 to April 2026.

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Summary

The working group believes that Sweden should strengthen its industrial competitiveness through collaboration, more long-term thinking and a holistic view of the entire production system. The focus should not be solely on reducing costs. Instead, Sweden should invest in driving innovation, building resilience, and fostering more sustainable industrial development.

Complex discrete manufacturing is being driven by a rapidly changing environment that demands greater efficiency, more flexibility and new ways of working. Industry is expected to deliver more in less time and collaborate within larger regional structures – while strategies for balancing this speed and the associated risks differ from one country to the next.

As a result, resilience and flexibility are becoming increasingly important, alongside stable supply chains and robust logistics. On top of this, business models are needed that cover the entire product lifecycle and are based on collaboration and trust between stakeholders. There is also a gap between product development and production development that needs to be narrowed through closer integration of these areas and a stronger focus on holistic solutions.

Skills supply and workforce availability are key challenges, as industry needs people with relevant knowledge that is both broad and deep. Digitalisation, AI, electrification, robotics and automation are driving development but require high-quality data and common standards. Circularity is becoming increasingly important as a way of organising entire production processes.

The working group has formulated three recommendations on what Sweden should prioritize to strengthen its competitiveness and sustainability, as well as its own and global security. These recommendations are based on its analysis of Sweden's position in manufacturing, international trends, and key issues related to obstacles and opportunities for Sweden's continued development. They summarize a number of proposals presented in greater detail in the report.

1. Ensure that Sweden becomes better at translating research into industrial applications. This will require the strengthening of industrial expertise and testing environments, as well as investments in research into established production technologies..

2. Strengthen Swedish resilience through the transition to a circular economy. This will require changes to business models, regulations and incentives in manufacturing industry.

3. Increase Swedish innovation capacity by establishing a number of industrial clusters and improving the basic conditions for establishing and operating manufacturing industries throughout the country.

Starting points for focus on complex discrete manufacturing

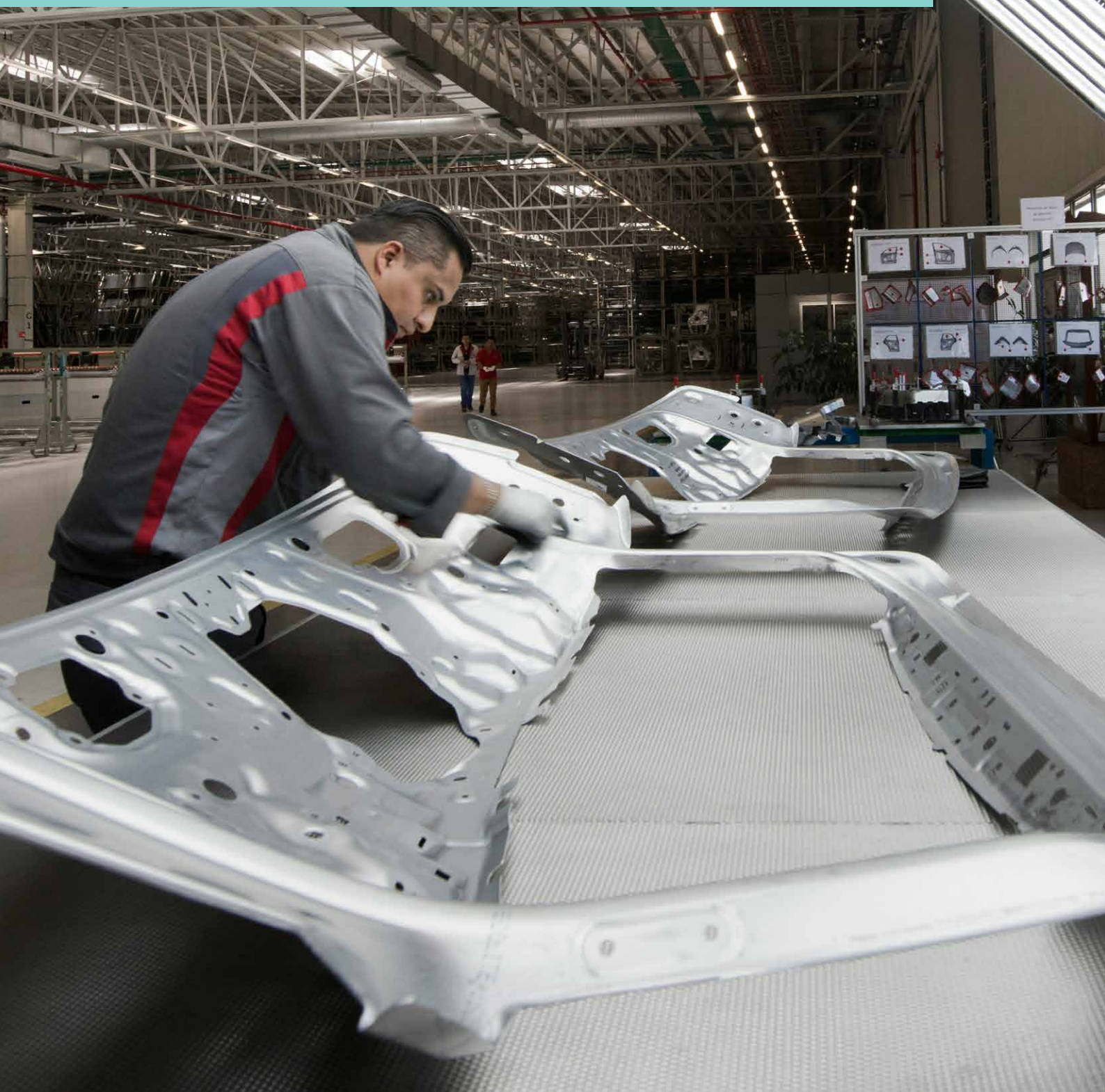
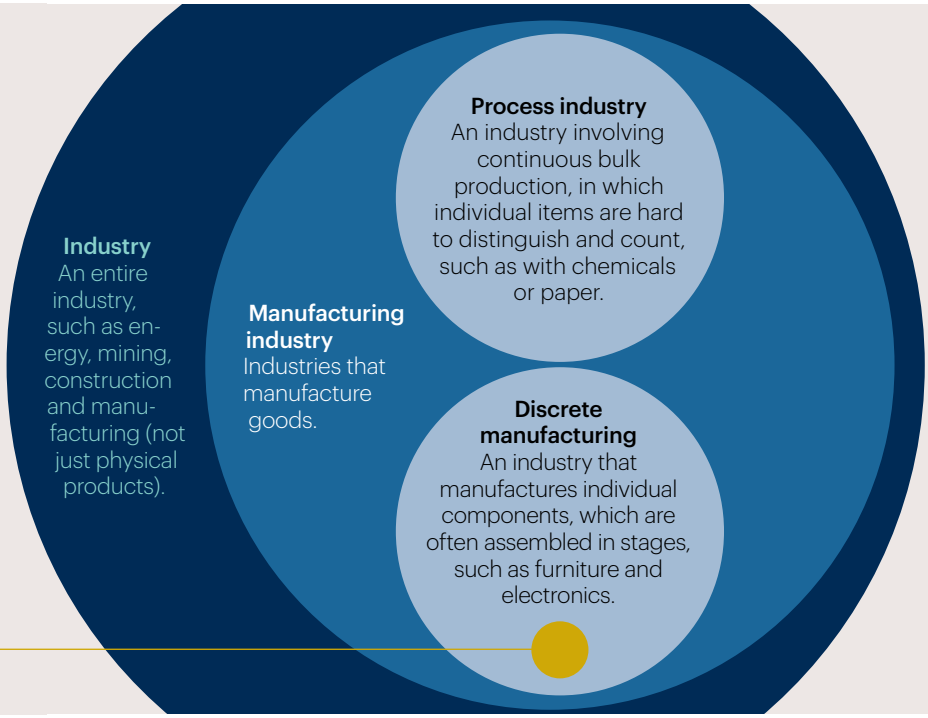


FIGURE 1: Where complex discrete manufacturing stands in relation to industry and the manufacturing sector.



What advanced manufacturing is all about

This report uses the term **complex discrete manufacturing**, which can also be more simply described as **advanced manufacturing**.

Discrete manufacturing is a production process in which individual components are manufactured separately and assembled to make sophisticated products. Each finished product can be identified and counted, unlike bulk outputs from the process industry. Products made using discrete manufacturing include vehicles, electronics and home appliances. Most manufacturers focus on a specific product category, such as cars, mobile phones or dishwashers. Each category often features a wide range of versions and models, and each of these products may consist of thousands of components.

A **complex system** is a system with non-trivial cause-and-effect relationships.[1] In discrete manufacturing, this for example means that there are many variants of each product, that each variant consists of many components, that software and hardware must work together, that there are many rules to observe, that changes in production volume can be costly, and that delivery delays or supply shortages of key material can have major consequences.

The report and its recommendations are tightly focused on complex discrete manufacturing. It does not cover Swedish manufacturing industry more broadly or the country's industry as a whole.

1 Sillitto, H and co-authors (2019). *Systems Engineering and System Definitions*. Version: 1.0. Issued on January 8, 2019. International Council on Systems Engineering (INCOSE).

Starting points for focus on complex discrete manufacturing

TABLE 1: IVA's decision to focus on complex discrete manufacturing is based on eight criteria.

CRITERION	EFFECT ON SWEDISH COMPLEX DISCRETE MANUFACTURING
Global leadership	Success in Swedish complex discrete manufacturing will support export revenues, the trade balance and the tax base. If this industry fails to achieve global leadership, there is a risk that production and corporate headquarters will be relocated abroad
Turnaround (opportunity to reverse current trends)	Much of Swedish industry is long established. Its ability to adapt – for example from internal combustion engines to electrification – will determine whether jobs, supplier networks and skills can be retained in the country.
Positional shift	Sweden has an opportunity is to move towards more advanced parts of the value chain, such as systems, integration and software.
Enabling technology	Many technologies are developed in research environments or at small scale and only become widely used after being industrialised through complex manufacturing and scaled from prototypes to functioning systems.
International dimension	Complex discrete manufacturing in Sweden is almost entirely dependent on global markets, suppliers and collaboration. Swedish actors need to be integrated into global supply chains.
Megatrends	Sweden's industrial strengths, such as electrification, sustainable production and digitalisation, align with global megatrends. Astute positioning will enable Sweden to take a leading role in industries of the future and secure long-term growth.
Geopolitics	Export dependence and specialised production mean that Sweden is exposed to trade barriers, geopolitical conflicts and supply chain disruptions. At the same time, a greater focus on defence and regional production can create new industrial opportunities.
Priority areas	A strong Swedish presence in rapidly growing industrial segments such as defence and green technology will attract capital, research and talent. This will strengthen Sweden's industrial ecosystem and its competitiveness.

Why Sweden needs a more strategic approach

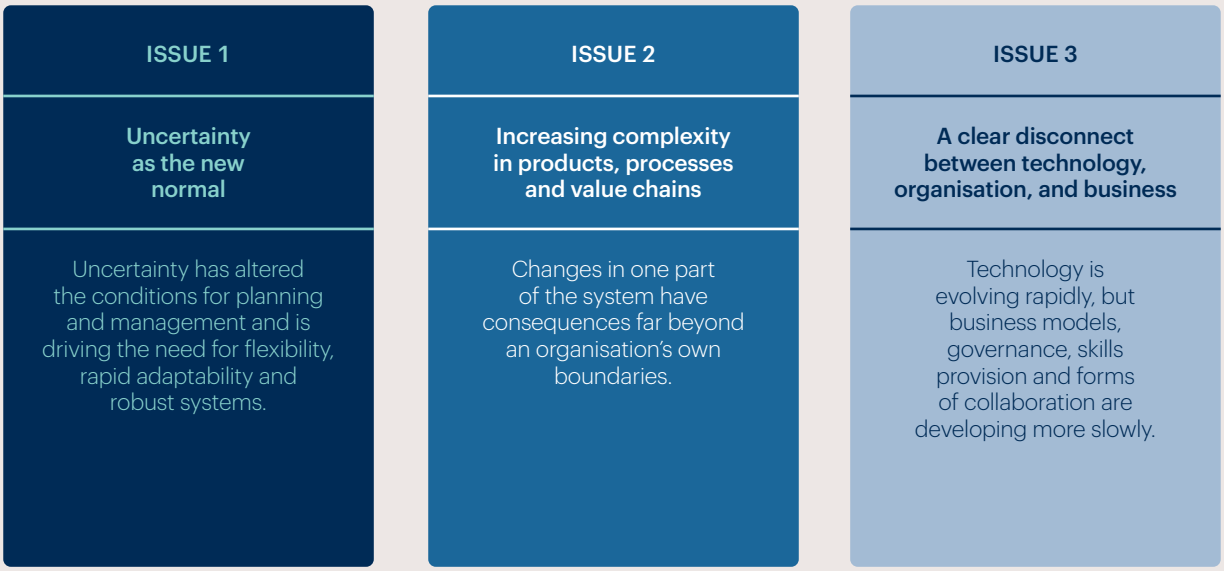
IVA has conducted a data-driven analysis to map Sweden's global position across 48 strategically important technology areas that are crucial for the country's prosperity, economic resilience and national security.[2] Among other things, the analysis revealed that Sweden needs to adopt a more strategic approach to securing its international position. Using eight selection criteria (see Table 1), IVA opted for an in-depth analysis of complex discrete manufacturing to develop proposals for the way forward in this area.

Swedish industry has to contend with several converging structural changes. Geopolitical uncertainty, rapid technological advance and ever stricter sustainability requirements are affecting how products are developed, production is organised, and supply and manufacturing networks function. In this context, the ability to develop, manufacture and scale complex products and systems is a strategic issue that not only influences a country's competitiveness, but also its resilience and security.

2 IVA (2025). *Sveriges position inom strategiskt viktiga tekniker. Investeringsprioriteringar, styrkor och utmaningar.*

Complex discrete manufacturing today

FIGURE 2: Complex discrete manufacturing must deal with three issues: uncertainty, increasing complexity, and technology and business developing at different speeds.



The current situation

Swedish industry is facing the uncertainties of geopolitics, technological advance, changing market conditions and resource issues. To support it in times of change, the government has adopted an industrial strategy that includes investments in research and innovation as well as the development of more efficient permitting processes.[3]

Uncertainty now appears to be the new normal for complex discrete manufacturing. Geopolitical tensions, technological development and changing market dynamics are no longer viewed as temporary exceptions but as fundamental conditions for industrial activity. This has changed the conditions for planning and management, and has increased the need for flexibility, rapid adaptability and robust systems.

The increasing use of complex systems combining hardware, software, data and services is making products and processes more complex and increasing interdependencies among stakeholders. More and more production systems are distributed, automated and dependent on digital

3 Regeringskansliet (2025). *Sveriges industristrategi: för en teknikledande och konkurrenskraftig industri i en ny omvärld*. June 12, 2025.

infrastructure. Complexity means that changes in one part of the system can have consequences far beyond a company's own organisation. Production can be viewed as a system of capabilities rather than an assemblage of technology, creating value through the interaction of companies, policies and expertise. This means that production is not just about machines and technology, but also about how different parts of society interact. Major changes such as globalisation, sustainability, digitalisation and accelerating innovation mean that companies need to develop new production methods and ways of working in more interconnected systems.[4]

The potential of technology is today not always matched by a business's capacity to realise a product's value, highlighting the clear discrepancies between technology, organisation and business. Technological advance is progressing rapidly, but business models, governance, talent acquisition, and collaboration are developing more slowly. This creates friction and risks limiting the use of new technologies and production solutions. Traditional linear approaches to development are no longer sufficient. Instead, industrial development is characterised by rapid change, with solutions being scaled up quickly and value being created in new ways. Companies today are working with shorter planning cycles, faster development and new types of business models.[5]

The key players in complex discrete manufacturing in Sweden are predominantly in the automotive, defence and engineering sectors. Examples of these companies include Scania, Volvo Group, Volvo Cars, ABB, Saab, Sandvik, SKF and Atlas Copco. There are also support structures to nurture new companies in this field, as well as research and development at universities and research institutes.

Nordic, European and international companies play a significant role in Sweden's complex discrete manufacturing sector. They supply critical components that are not produced in Sweden and enable collaboration in advanced technology and the sharing of expertise. Collaboration in the Nordic region centres on telecommunications, energy and defence, while at the European level it focuses on automation, sensors, aviation and aerospace. Globally, collaboration involves innovation together with industrial conglomerates, as well as electronics and automotive companies. The joint development of standards and the advanced production solutions is crucial. The EU, the US and China are the most important markets for Swedish complex discrete manufacturing.

4 World Economic Forum. (2015). *The Future of Manufacturing: Driving Capabilities, Enabling Investments*.

5 Barresi, B. (2024). *Exponential Thinking Social Entrepreneurship*. Medium. Dec 3, 2024.
Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). *Industry 4.0 technologies: Implementation patterns in manufacturing companies*. International Journal of Production Economics, 210, 15–26.

Environment and approaches

Current trends

A changing business environment demands transformation and new strategies

Crisis can create a strong sense of urgency, and both can act as catalysts for change. But, in the long term, they must be replaced with a shared vision of industrial direction and a common understanding that complex production and industrialisation are crucial to Sweden's future.

Manufacturing industry has undergone much consolidation, but the short time-to-market of today's products demands yet more transformation. As time-to-market continues to shorten and uncertainty about supply chains continues to increase, the importance of equipment suppliers is growing. Product lifecycles are also becoming shorter, placing higher demands on production and requiring different production strategies than those previously employed.

Platform strategies require perseverance and long-term planning, particular challenges in a rapidly changing world. The shortening of corporate planning horizons has affected how much industry invests in manufacturing facilities. Swedish companies are accustomed to building production systems with long lifespans. They now face the challenge of quickly developing coherent and adaptable systems that are resilient and foster strong partnerships with local suppliers.

Flexible modular production systems enable companies to adapt quickly. That means they must more carefully monitor the business environment but can also to respond quickly to new demands. One development trend is the shift away from mass production tow flexible production using a common platform. Complex discrete manufacturing is also moving towards more customised and flexible production, replacing traditional mass production with smaller batches and shorter planning horizons. The ability to rapidly adapt to customer-specific needs and to continually revise planning is clearly very different from large-scale and static production methods of the past.[6]

TIME-TO-MARKET

Time-to-market is the time it takes from the conception to the launch of a product. It encompasses several different stages, including development, production and packaging.

Sweden has historically excelled at integrated product and production development within a linear product development model. But today's situation is different. Over are the days in which many industrial employees had a deep understanding of how the machines the operated worked and could engage in detailed discussions with machine suppliers. Swedish companies have lost a great deal of industrial expertise, affecting their ability to assess what suppliers have to offer, for example. Conditions will continue to change in the coming years, particularly with regard to stochastic processes. One consequence of ongoing changes in the external environment will be an increased need for companies to protect themselves against various types of intrusion.

6 Haller, J. and co-authors. *Industry 4.0 advancements in discrete production ramp-ups: a systematic literature review.* J Intell Manuf (2025).

Industry needs to achieve more in less time

There is a clear trend towards more rapid development. This means that industry must adopt new working methods and acquire new skills to achieve more in less time.

There is a growing trend towards close collaboration within cross-functional teams, an approach that Swedish industry has embraced for some time. At the same time, companies' product development organisations are adopting a more open approach, collaborating more with suppliers and sharing data to a greater extent. There is also a great deal of early-stage collaboration with startups and universities. According to experience shared by working group members, German subcontractors are in this regard more advanced than small and medium-sized Swedish suppliers.

Lastly, there is high demand for engineers who have a broad knowledge combined with in-depth expertise in a specific subject. Engineers specialising in complex discrete manufacturing are also expected to understand production and supplier networks, gained through the experience of working in the manufacturing sector (see key issue 5).

In certain areas, a regional capacity is needed

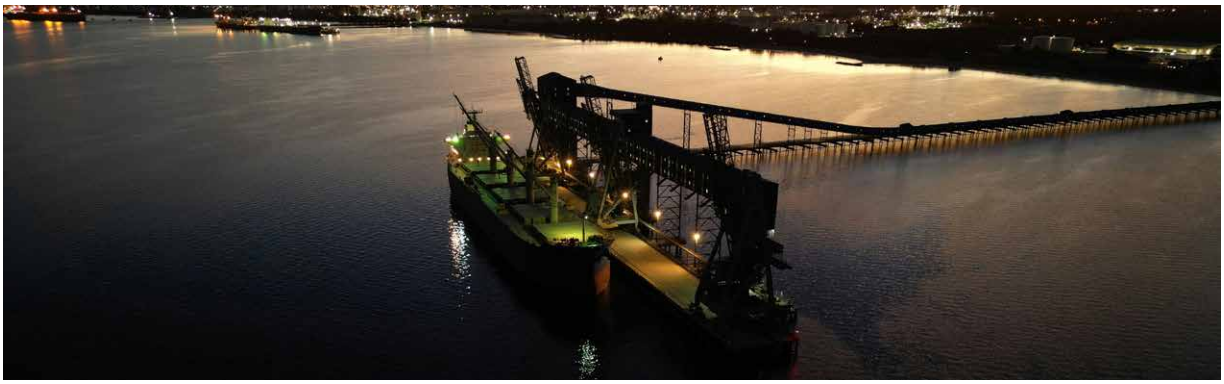
Regarding preparedness and certain other issues, Sweden needs to adopt a European perspective, as it is too small to act alone. At the same time, several European countries rely on Swedish companies for its industrial production and expertise.

Increasing regional production strengthens a country's resilience, partly because there is otherwise a risk that companies will become overly dependent on foreign suppliers. By working within regional ecosystems, companies can extend the lifespan of materials in use, for example, waste materials from one company can be used as input materials in another company's produc-

PLANNING HORIZONS

Over the past 30 years, the stability and duration of planning horizons in production have changed significantly. In the 1980s, production systems were characterised by long lead times, large batches and limited flexibility. Strategic plans often covered 2–3 years, tactical plans 12–18 months, and operational plans 3–6 months, with relatively few adjustments being made. In the 1990s, more structured planning processes shortened strategic planning horizons to 1–2 years, master planning to 6 –12 months and operational planning to 2–3 months, although plans remained relatively fixed and were not updated very often. From the 2000s onward, digitalisation, rolling planning and increasing demand uncertainty shortened planning periods even further. Operational planning today often spans only 2–8 weeks. While strategic plans can still extend over 1–2 years, they are now treated more as guidelines than as fixed decisions. In the 2020s, frequently updated, rolling planning has become the norm in discrete manufacturing in Sweden.

Source: Jonsson, P., Mattsson, S.-A. (2016). *Logistik. Läran om effektiva materialflöden* (3 uppl.). Lund: Studentlitteratur, Jonsson, P., Mattsson, S.-A. (2009). *Manufacturing planning and control: Approaches, context and performance*. London: McGraw-Hill. Svensk Produktionsakademi. (2020). *Svensk produktionsforskning 2020 – Strategi och inriktning*. Göteborg: Svensk Produktionsakademi.



tion process. There is deep and broad industrial capacity in many locations outside Sweden's major cities.

Europe and China have different approaches

Europe and China have adopted different approaches to product variation, lead times and risk management. This affects how companies organise their production and innovation processes.[7] Chinese companies generally prioritise rapid market introduction over initial product optimisation. This enables them to quickly receive feedback from the market and to develop products more iteratively. But such an approach requires a greater willingness to take risks than European companies, which often devote more resources to planning and quality assurance prior to product launches.[8]

Structurally, China is characterised by relatively low product variation and a high degree of standardisation, creating conditions conducive to large-scale production and efficient resource utilisation – and investments quickly translating into profits.[9] In Europe, product variation is generally greater, leading to more flexibility but also more complexity in production systems, which can hinder rapid scaling up of operations.[10] European companies often prioritise quality and reliability over quick product launches, meaning it takes them longer to get feedback from customers using the product to develop an improved next version.

China has pursued a strategic approach through government initiatives such as its five-year plans, focusing on long-term industrial development in areas such as electrification and the supply of critical raw materials. Future investments are being directed towards areas such as semiconductor technology, artificial intelligence and the circular economy.[11]

7 Ernst, Dieter. (2006). *Innovation offshoring: Asia's emerging role in global innovation networks*. East-West Center Special Reports. 10.

8 Williamson, Peter & Yin, Eden. (2014). *Accelerated Innovation: The New Challenge From China*. MIT Sloan Management Review. 55. 27–34.

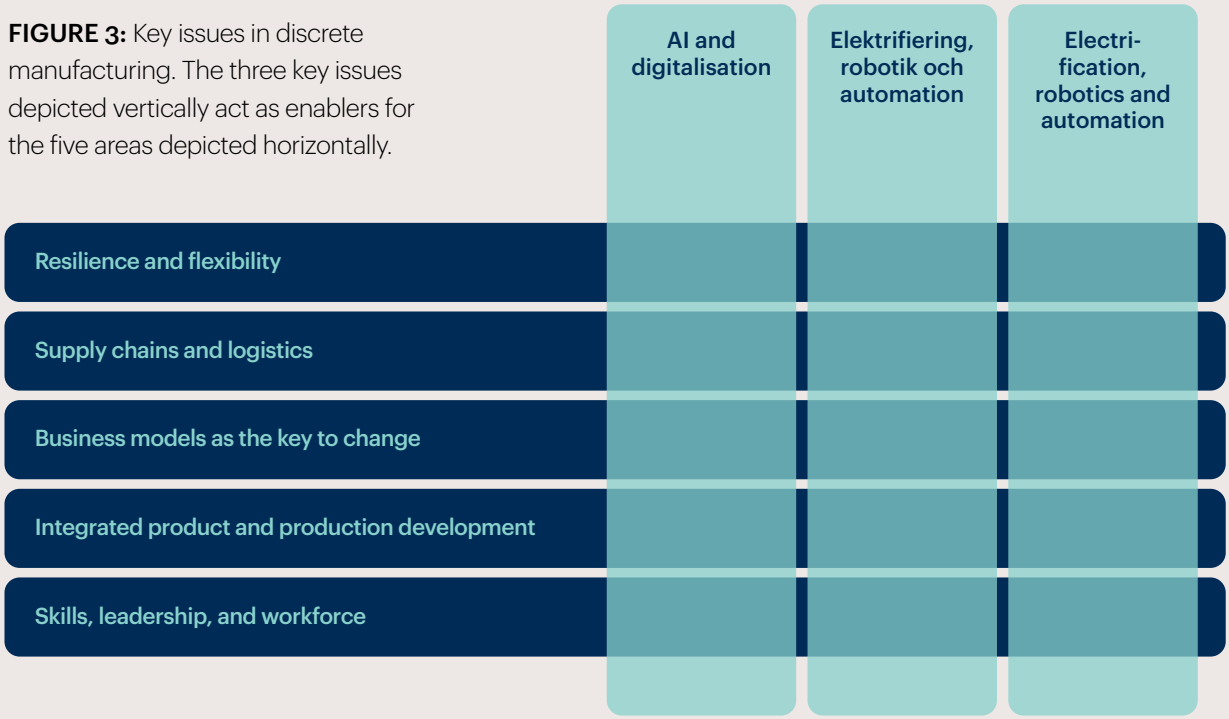
9 Naughton, B. (2007). *The Chinese economy: Transitions and growth*. MIT Press. Zhao, X., Flynn, B. B., & Roth, A. V. (2006). *Decision sciences research in China: A critical review and research agenda*. Decision Sciences, 37(4), 451–496.

10 Trattner, Alexandria & Hvam, Lars & Forza, Cipriano & Hansen, Zaza. (2019). *Product complexity and operational performance: A systematic literature review*. CIRP Journal of Manufacturing Science and Technology. 25.

11 The State Council of the People's Republic of China. (2021). *Outline of the 14th Five-Year Plan (2021–2025) for national economic and social development and long-range objectives for 2035*.

Key issues

FIGURE 3: Key issues in discrete manufacturing. The three key issues depicted vertically act as enablers for the five areas depicted horizontally.



Key issue 1:
Resilience and flexibility

Resilience is an active and developed capability

Resilience refers to a production system's ability to withstand or recover from various types of disruption. In complex discrete manufacturing, resilience must be treated as an actively developed and built-up capability rather than traditional inventory management or redundancy.

For example, resilience reflects the extent to which Swedish companies, their supply chains and partners can quickly scale up production in the event of a crisis. It also concerns the availability of industrial capacity that can be rapidly activated and clearly assigning responsibility for critical but rarely used production capabilities. Resilience also involves companies' controlling their supply chains and building regional ecosystems in which resource flows from local collaborations are integrated into circular systems.

This is particularly evident in the defence industry, a sector in which the need to rapidly increase produc-

tion volumes can arise at short notice. The problem is that it is often unclear how the costs of maintaining such preparedness in peacetime should be borne. The issue of resilience is often linked to questions about the division of responsibility between the state, industry and the market.

Industry developments are driving the need for flexible production systems and organisational structures designed for adaptation rather than stability. This makes resilience a strategic industrial capability that must be built developed deliberately and with a long-term perspective.

Flexibility is about business opportunities, ownership and expertise

Increased uncertainty in the external environment reinforces the need for shorter lead times, flexible production systems that can be reconfigured as needs change, and rapid technical and organisational adaptation. But flexibility cannot be reduced to a technical characteristic of machines or production lines, it also depends on factors such as business opportunities and the ability to implement transitions. A company's flexibility is shaped by investment logic, risk allocation and skills provision, among other things. Short planning horizons limit companies' ability to pursue long-term platform and production strategies.

FLEXIBLE PRODUCTION SYSTEMS

A flexible production system allows production to be modified easily. Manufacturing capacity can be increased or decreased, or the system can be reconfigured, for example, to make different products on the same line.

These developments bring ever-increasing demands for building flexible production systems, as the external environment create ever-greater pressure to realise both more flexibility and speed. This means that companies must carefully plan how to increase production when needed, while controlling investment risk. This requires employees with deep expertise and experience.

The degree of flexibility depends on how investments are made, how risk is distributed, and how expertise is developed and maintained. Rather than being an isolated technical challenge, it becomes a systemic issue as a result.

Key issue 2: Supply chains and logistics

Well-designed logistics chains are a key factor for competitive advantage

Successful companies tend to excel in logistics. Having efficient and well-developed logistics chains is often just as important as the product itself, as they can significantly impact both lead times and costs.

In complex discrete manufacturing, the ability to coordinate numerous suppliers and component flows is essential. Production must be able to adapt quickly to changes and manage disruptions in supply chains. This places high demands on planning and often requires real-time data to ensure that the right parts are in the right place at the right time.

Sweden is vulnerable with regard to access to a number of critical materials used in complex discrete manufacturing. These include rare earth elements such as neodymium for electric motors and magnets, battery metals such as lithium, cobalt, and nickel for electric vehicles, and platinum group metals for catalysts and hydrogen technology. Semiconductor materials such as silicon and gallium, graphite for battery anodes, and tungsten for tools are also essential.

One way for companies to address this vulnerability is to redesign products so they can be manufactured with the most minimal inputs of critical materials possible. Another approach is to develop circular systems that enable re-use and recycling of materials.

Suppliers are critical to supply chains

When companies are reliant on just a few suppliers of components and items, their vulnerability increases, and this can also drive costs higher over time. A supplier that cannot deliver as planned – for example, due to production stoppages or quality issues – can jeopardise an entire production process, leading to delays, costs increases and reduced flexibility.

If an industry depends on a small number of suppliers, these companies have considerable pricing power, which can drive up the cost of critical components and materials. A broader and more diversified supplier base – one for example with sourcing from different countries, varying capacities and different offerings for materials or components – can strengthen the resilience of the supply chain.

Many suppliers of machine tools to Swedish industry operate globally. When they do not have a local presence in Sweden, collaboration with Swedish companies becomes more difficult. This can be problematic, given that machines require close cooperation between their manufacturer and the industry in which they are to be used.

Many small and medium-sized suppliers today have such lean organisations that they struggle to keep pace with technological developments. They are also under intense pressure to deliver quickly. This undermines their ability to engage in any close and interactive collaboration as suppliers to industry.

Suppliers would be more willing to share in the risk of production projects if they received a share of the profits. There are currently few models for the type of close collaboration between manufacturers and suppliers that could create the conditions for joint solutions.

Key issue 3: Business models as the key to change

Business models are changing

Designing business models will be a key issue for complex discrete manufacturing in the future. Since the technical ability to automate, digitise, and streamline production already exists, the crucial question will be how to create, capture, and distribute value along the value chain.

There is a clear trend towards shifting from traditional product sales to services, subscription models, and function-based offerings. Selling

STRATEGIC PARTNERSHIPS

Some examples of strategic partnerships include:

Produktion 2030, a strategic innovation program supported by Vinnova, the Swedish Energy Agency and Formas.

The Advanced Manufacturing Coordination Center (AMCC), which brings together the Swedish armed forces, industry, academia, and the public sector to forge new capabilities in additive manufacturing.

The Strategic Automotive Research and Innovation Program (FFI), a collaboration between the government and the automotive industry to fund research and innovation in road transport.

products as functions or access, rather than as objects, changes the relationship between manufacturers, customers and users. An example of this shift is vehicle manufacturers offering vehicle leasing or "transportation solutions" instead of selling trucks.

This trend strengthens the link between products and production. At the same time, there is increasing demand for data, traceability, legal compliance and long-term partnerships. As companies maintain contact with more and more of their products throughout their entire lifecycle, favourable conditions for circular flows and systems will increasingly arise.

Lifecycle responsibility entails a shift in business logic

When manufacturers take responsibility for the entire lifecycle of their products, the incentives for design, material selection and production planning change. As the link between product and production systems strengthens and the demand for data, traceability and system integration increase, the business model becomes essential for integrating technology, production and product use.

But the greatest obstacles lie not in the technical or business logic, but in legal, liability and governance issues. Lifecycle-based business models require a clear allocation of responsibilities, risks and profits, as well as long-term partnerships between all stakeholders in the value chain (see also key issue 8 – circularity as industrial logic).

Collaboration and trust are needed for successful business models

Successful business models are built on trust between parties, shared incentives, clear risk-sharing and a long-term perspective. The overarching goal is to strengthen Sweden's ability to conceive and scale new technologies and solutions, not to establish new administrative structures.

There are several examples that show how strategic partnerships enabled investment and industrial development that otherwise would not have materialised. Public-private collaboration can be a tool for managing long-term investments and shared risks. time. But it must be designed pragmatically to prevent development projects from becoming mired in bureaucracy.

Key issue 4:
Integrated product and production development

A clear gap in today's system

Complex product development requires close integration between product, production and supplier networks. Software, electronics, and mechanics are today closely intertwined, but organisational structures and working methods are still often developed separately.

Sweden has historically had strong capabilities in developing advanced systems and a way of working characterised by close links between hardware and software development. But today's rapid technological development means shorter lifespans for both products and technical solutions, which places new demands on the design of development processes.

Research is crucial in giving companies the confidence to invest in development. It is also important that this process draws on production expertise early on.

From component to function

The shift from focusing on components to focusing on functions, and from individual products to interconnected systems and services will affect how products are designed, how production is structured, and how suppliers are integrated into these development and production processes.

Subscription- and function-based business models reinforce the importance of integrating machines, processes, and usage, and of viewing products and production as parts of a coherent system rather than as separate areas.

A close link between product and production is needed

A close link between product and production bears fruit when a company has its whole value chain in view from the very beginning. Production cannot be isolated from the other stages of working to create a product.

Business conditions can change rapidly, and product cycles are short, especially when driven by market demands. Integration across the entire value chain is essential; what one stakeholder contributes cannot be separated from the system as a whole. Problems arise when products evolve more quickly than production models can be adapted profitably. This applies both to the design of in-house production processes and the ability to scale them.

As products evolve over time, production must be continuously adapted. But excessively large adjustments can become costly in relation to production volumes. A design that takes the whole lifecycle into account makes later adaptations easier and increases flexibility.

Collaboration is essential for integrated product development

Sweden has a strong tradition of collaboration between business, academia and society as a whole, and Swedish companies have often relied on it to survive and thrive.

Applying such an integrated approach to advanced manufacturing would create real competitive advantage, by bringing together business planners, product designers and customers from

the very beginning of the development process. At its core, this approach is about working methods rather than technological development.

A range of different tools is required to succeed in production: Digitalisation is key to providing access to relevant data; close dialogue between production, and design is essential. When development and production are integrated, companies design better products.

Companies should also involve suppliers earlier in this process, for example, by including machine suppliers in the development phase. This approach also raises useful questions about risk allocation and business models.

Collaboration between different centres of expertise in the value chain is important. For example, representatives from the aftermarket should be involved from the outset to help the creation of circular product flows, such as upgrade, repair, or disassembly of products. Similarly, supplier selection must be carefully considered during the procurement process to increase resilience further along in the value chain.

Key issue 5: Expertise, leadership, and workforce

Companies are investing more and more in digital tools, scenarios, and data-driven decision support systems to help them manage disruptions in supply chains and become more resilient. At the same time, new skills and new ways of organising work are becoming essential.[12]

Expertise in production issues is needed

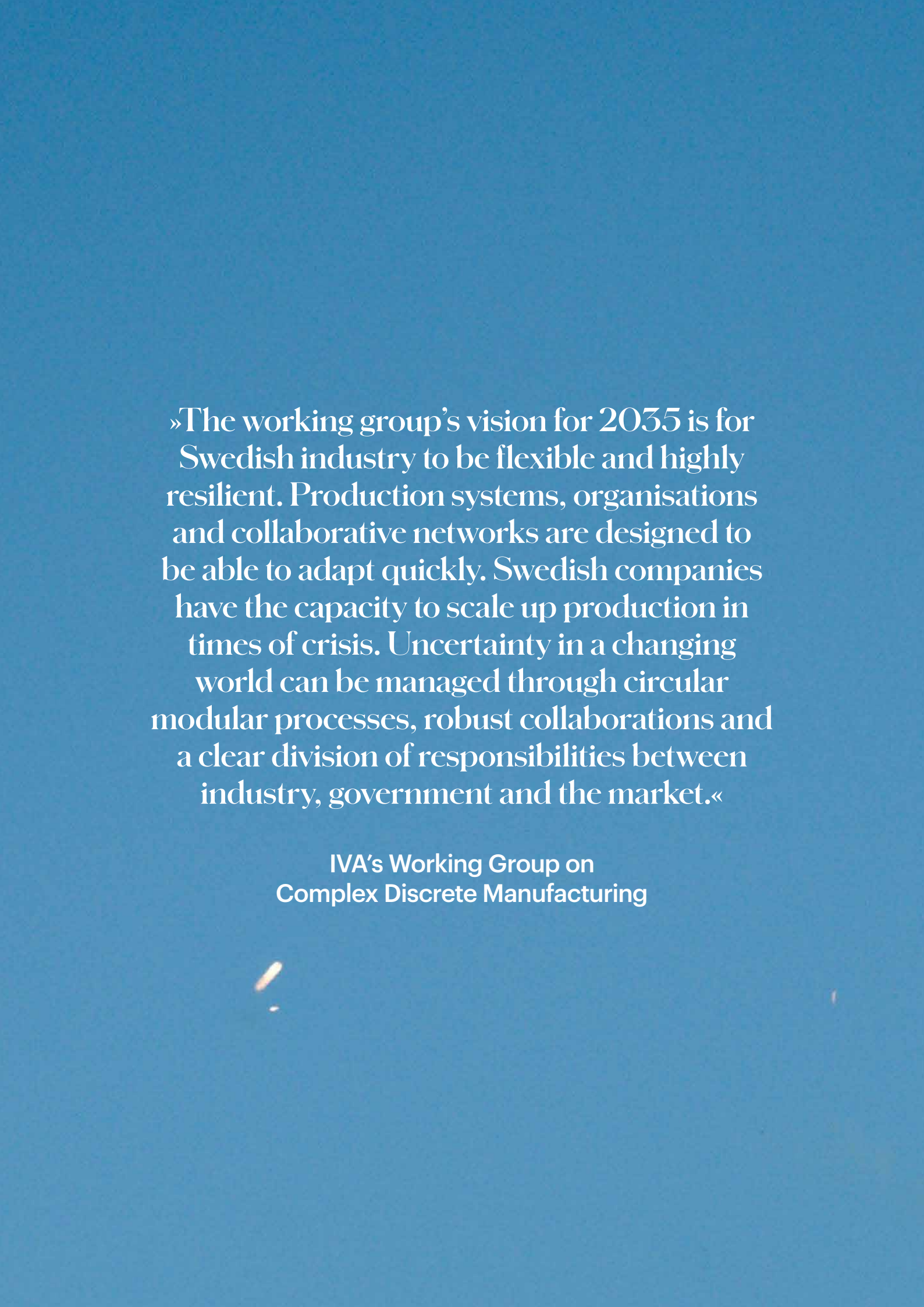
Company executives often lack expertise in production and product engineering expertise. If these perspectives are not part the decision-making process early in the development stage, crucial production-related issues may be introduced too late. There is also a risk that investment decisions will be made without sufficient understanding of the production system, meaning that the potential of new technology cannot be fully realised.

Sweden has many skilled engineers and technicians, but experts with the ability to oversee the entire advanced manufacturing chain are harder to find. Scaling up from development to industrial reality requires broad expertise among management and frontline workers alike. It requires a holistic perspective and an understanding of the entire value chain.

Industry needs people with broad and deep technical knowledge

Engineers need to combine broad knowledge with deep expertise in a specific subject. They

12 Deloitte. (2024). *2024 manufacturing industry outlook*.



»The working group's vision for 2035 is for Swedish industry to be flexible and highly resilient. Production systems, organisations and collaborative networks are designed to be able to adapt quickly. Swedish companies have the capacity to scale up production in times of crisis. Uncertainty in a changing world can be managed through circular modular processes, robust collaborations and a clear division of responsibilities between industry, government and the market.«

IVA's Working Group on
Complex Discrete Manufacturing

URBANISERING

Urbanisation is linked to a dynamic and competitive labour market, which can lead to higher employee turnover in cities than in smaller towns. Entrepreneurship and business activity also tend to be higher in urban areas than in rural ones. A Swedish study of working patterns in urban and rural areas suggests greater mobility within cities than in the countryside.

Source: Bergh, A. and co-authors (2025). *A study of job polarization in Sweden from an urban-rural perspective.* Journal for Labour Market Research, 59(10). Organisation for Economic Co-operation and Development. (2018). *OECD regions and cities at a glance 2018*. OECD Publishing.

also must understand the input and production flows of manufacturing industry. While interest in overarching issues at the system level is growing, one problem is that there is a shortage of people with deep technical knowledge in specific areas.

But rapid developments in AI, automation, and robotics mean that companies are starting to recognise the need to change their employees' skill profiles. For example, assembly workers will need entirely new skills, as their responsibilities will increasingly resemble machining tasks. It is also important to recognise that machine operators today no longer merely perform simple tasks but play a central role in the production process.

Rapid technological development is also changing leadership. Swedish companies generally have fairly non-hierarchical cultures of "flat leadership", which gives them a competitive advantage internationally.

Qualified, competent and diverse workers wanted

The ability to quickly convert market demands into marketable products depends on access to capabilities within the manufacturing ecosystem. A key factor is having access to qualified personnel, from toolmakers to production engineers.

Diversity is integral to Sweden's competitiveness. Having a variety of perspectives creates many advantages. While diversity in ethnicity appears to be on the rise, gender equality is, at best, progressing slowly. The proportion of women in the Swedish manufacturing industry was approximately 18–20 percent at the start of the Millenium, rising to just approximately 20 percent in 2024. This negligible increase over a quarter of a century highlights the urgent need to reduce male dominance in Swedish industry.[13] The country needs to attract more women to technical education programmes.

Sweden also needs to make industrial jobs in both large and small-to-medium-sized companies more attractive. Although they often have lower employee turnover than large companies in large cities, smaller companies in smaller towns offer many job opportunities (see fact box). When developing production expertise, companies must consider the individual willingness and incentives to remain in a particular location. Securing production expertise requires a long-term approach and is often location specific.

13 Statistiska centralbyrån (SCB). *Arbetskraftsundersökningarna (AKU), yrkesregister.*

There is a need for breadth and diversity in education

Although the proportion of women studying engineering disciplines is increasing overall, there are significant differences between programmes (see fact box). But engineers are not the only crucial element of the workforce. Anyone working in production needs good skills and a high-quality education. This is a clear sign that vocational education must be strengthened.

Today's skills shortage is not the result of a lack of educational opportunities, but rather a lack of incentives, time and organisation. To change this, Sweden must create more opportunities for continuing education and encourage learning in the workplace. It should also systematically adopt more flexible and modular forms of education.

There are already many good examples of effective continuing education. The challenge lies in making better use of these structures, for example through more coordination, rather than building entirely new systems. Systems and models for lifelong learning are also needed.

Labour demand is shifting towards people with more versatile skills that promise more adaptability and longer-term employability. At the same time, companies are increasingly taking into account individual motivation, engagement and the sense of contributing to a larger cause.

An important factor influencing young people's educational choices is the opportunity to contribute to something they perceive as meaningful. Many young people want their work to contribute to a better world. But it is not enough for them to simply feel that they are making a difference – they need confirmation from those around them that their work is meaningful.

PROPORTION OF WOMEN ENROLLED IN MASTER'S-LEVEL ENGINEERING PROGRAMMES

The proportion of women enrolled in master's-level engineering programmes in Sweden increased from about 24 percent in the late 1990s to approximately 32 percent in 2023.

Source: Universitetskanslersämbetet. *Jämställdhet i statistiken*. Data retrieved March 28, 2026.

According to a review of thirty engineering disciplines in 2023, the proportion of women ranged from 7 to 69 percent. The proportion of women was highest in structural engineering programmes focused on biotechnology and lowest in electrical engineering BA courses.

Source: Ingenjoren.se/2023/10/23/7-till-69-procent-sa-varierar-andelen-kvinnor-mellan-ingenjorsinriktningarna. Data retrieved March 28, 2026.

High-quality Swedish graduate education

Postgraduate education is strong in Sweden. The system fosters independent and mature individuals who are highly self-motivated and able to continue growing intellectually.

A strong link between industry and academia is crucial, as the system requires both a strong research environment and high levels of expertise. PhD graduates contribute to the system in various ways, for example, by serving as a bridge between academia and industry.

Key issue 6:
AI and digitalisation as enablers

AI is seen as a general-purpose technology that will eventually become integral to all stages of advanced manufacturing. While it is not expected to replace production technology itself, AI has huge potential in providing support, performing simulations, optimising processes, and helping with decision-making.

One recurring risk is that AI development will be driven by stakeholders with limited knowledge of production. This highlights the need for standardised interfaces and a stronger industrial anchoring.

AI has potential as a support tool and as an intelligence-enhancing technology

AI is currently used in a variety of support systems and information management tools. As an intelligence-enhancing technology, AI has become a significant contributor to productivity. While some technologies have undergone a long development process, AI has evolved rapidly. Automation and robotics began transforming manufacturing back in the 1950s, while the changes brought by AI are proceeding much faster. For example, embedded AI components are changing production requirements, making it increasingly important for companies to understand how such products can be manufactured efficiently and at scale.

When used wisely, AI has great potential, particularly when viewed as a support system for optimising production and managing factories more efficiently. For example, it can help small and medium-sized suppliers improve their production and workflows with relative ease.

AI can create significant value in production via the rapid development and testing of various solutions. But for AI to be effective in industry, it must be based on reliable, good-quality data, as well as an understanding of production processes, safety requirements, and real-world decisions. In the short and medium term, the greatest value of AI lies in analysis, optimisation, quality assurance, simulation, and operator support, rather than fully autonomous production.

For example, manually testing all the functions of a car is a protracted task, but AI can simulate and evaluate significantly more alternatives in less time. AI is already being used for control and quality assurance in production. It can also be trained to analyse what products look like with continuing use, enabling the creation of systems that learn to improve reuse and product development over time.

But there are also problems and challenges associated with the use of AI in complex discrete manufacturing. Although the need to recognise vulnerabilities and build resilience is greater than ever, experience shows that companies specialising in AI today have far too little knowledge of the specific conditions and requirements that apply in the manufacturing sector.

Data needs to be standardised and of high quality

The poor quality of available data is a challenge for the application of AI in complex discrete manufacturing. Although manufacturing generates large amounts of data, much of it is difficult to use because it is not standardised.

Although more and more factories are digitally connected, their data is often not used to its full

potential. Changes to structures and working methods will enable companies to derive ever more information from their data, strengthening corporate competitiveness. Companies need to digitise product development to make better use of data in production. They must also drive the integration of product data to ensure that all data is in one place.

Many Swedish companies have their roots in making machine tools. Software and hardware are today tightly integrated and can no longer be developed independently of each other. For example, new software often does not work on older machines because systems are incompatible, use different interfaces and control systems, and because adaptation and testing can be expensive and time-consuming. It is no longer sufficient for a company to develop software tailored at low cost to suit specific production conditions. The industry as a whole needs to undergo a broad transformation.

Data security is a critical capability. Cybersecurity will be a key issue in many areas going forward, yet there is a significant shortage of specialists in industrial cybersecurity.

Key issue 7: Electrification, robotics, and automation as enablers

Electrification

There is a clear trend in the industry towards replacing pneumatic components with electrical solutions to perform repetitive mechanical tasks. For example, cylinders powered by compressed air are being replaced by electric actuators and servo motors. This shift provides companies with greater flexibility and access to more data, as well as reducing maintenance requirements.

But it also changes the way factories are designed, making access to electricity a key part of the production system. This means that electricity supply will become a crucial issue for Sweden's industrial development.

Sweden is well-positioned thanks to its significant hydropower capacity, which enables energy storage and reliable electricity delivery around the clock. This means that industrial production can run continuously, even when demand for electricity fluctuates. Forests also contribute to the energy system, for example through bioenergy or using forestry byproducts as fuel. This creates opportunities for a high degree of self-sufficiency. It also enables Sweden to shift its focus from annual energy consumption to a broader perspective encompassing power demand, grid capacity, connection time, power quality, and price fluctuations.

Access to green electricity can influence where companies choose to locate production. The ability to offer documented fossil-free electricity, for example, through guarantees of origin, provides clear conditions for businesses with high requirements regarding energy provenance. Access to low-cost, fossil-free electricity is crucial for industry. This is particularly true for discrete manufacturing. These industries are often electricity-intensive, using electricity in processes involving motors, variable-frequency drives, robotic cells, or computer-numerically control (CNC) machine tools. Access to electricity is also required for heating

and cooling systems, such as compressors and heat pumps.

Sweden's combination of low electricity prices and almost fossil-free electricity production allows companies to reduce their costs and stabilise them over the long term. In Sweden's highly automated manufacturing system, relatively low electricity prices and high delivery reliability can partly compensate for higher labour costs.

Customers are increasingly demanding low climate impacts, in terms of both emissions from purchased energy and emissions throughout the supply chain, for example, from suppliers and transportation. As Sweden already offers electricity with low emissions and clear provenance, companies can meet these requirements without making extensive additional investments – and avoid future costs linked to emissions.

At the same time, electrification improves companies' ability to measure and track both their own direct emissions from operations and indirect emissions. The latter include emissions from transporting inputs to and outputs from the company, as well as those from customers using a company's products.

The Swedish electricity system is characterised by a combination of energy sources, with controllable hydropower working in tandem with wind, solar, and nuclear power. Hydropower can quickly increase or decrease production to balance out variations from wind and solar power, while nuclear power provides a stable base load. This combination reduces the risk of production disruptions and the need for dedicated reserve capacity, for example, in the form of diesel-powered generators.

This system operates alongside a well-developed district heating system that uses byproducts and waste to deliver heat with high resource efficiency. District heating can also be supplied by combined heat and power plants, which produce electricity and capture the resulting heat. Manufacturing plants can help to balance the system. They can contribute to its flexibility by reducing their consumption when electricity demand is high and shifting energy-intensive processes to other times, as well as increasing consumption when electricity is abundant.

There is a growing trend of treating electrification, automation and software as integrated systems. Electrification replaces traditional energy sources and automation enables hands-free process control, while software ties them together by analysing and optimising performance in real time. This allows electrical systems to be controlled more dynamically, adapting to changes in electricity prices or grid capacity, enabling a more balanced load and more efficient operation. Access to fossil-free electricity is becoming a key factor for an industry characterised by increased automation, digitalisation and electrification.

It could, for example, shift to AI-controlled production, which uses artificial intelligence for sensing, planning, predictive maintenance, quality control and energy optimisation to continuously improve operations. Other examples include using electric furnaces instead of fossil-fuel-powered ones, and advanced robotics. The cost-effectiveness of electricity contributes to a lower cost per unit produced and allows more advanced parts of the value chain to be made domestically. The EU's Carbon Border Adjustment Mechanism is just one example of how climate requirements, trade barriers, and policy instruments linked to emissions are becoming increasingly common across the globe. In such an environment, access to fossil-free electricity is essential for industrial investment, long-term planning, and operational stability.

Robotics and automation

Robotics enables flexible automation that can adapt to changes. Automation can be seen as

more of a commitment to economic efficiency than to manufacturing modernisation. The key question in each case is whether product variations, production volumes, and quality requirements actually justify automation.

Robotics makes the handling of smaller batches, greater product variety and rapid changeovers possible. Furthermore, robotics serves as a new interface between operators, machines and manufacturing software. For example, operators no longer have to be physically present when overseeing their machines. Production can be controlled and monitored remotely in real time. Automation does not replace human labour, but shifts its responsibilities towards tasks such as monitoring, troubleshooting, changeovers, restarts, and improvement efforts.

ROBOT DENSITY IN SWEDISH INDUSTRY

Over the past 20 years, robot density in Swedish industry nearly tripled, rising from 120 robots per 10,000 employees in 2005 to 347 in 2023. Similar trends are evident elsewhere: South Korea rapidly increased its robot density from approximately 500 to over 1,000 robots per 10,000 employees over the same period; China from approximately 120 to 470. Sweden still lags behind the leading Asian countries but leads against Germany and many other European countries.

Source: International Federation of Robotics (2025). *Robot density in the manufacturing industry.*

Developments in robotics are moving towards more flexible systems that can be reprogrammed and used for a wider variety of tasks. These systems can handle greater variation in objects, sequences, and environments. This reduces the need for custom solutions and makes it easier to automate more processes. The robots available in five years will be better suited to integration into production processes and performing tasks currently carried out by humans. Safety is already a fundamental prerequisite today. The next step will be systems capable of perceiving their surroundings, drawing conclusions, and adapting to more varied environments.

Increased standardisation and a reduced need for customised integration is expected to lower the cost of automation in the long run. At the same time, the demand fora quick return on investment may increase. This will affect the viability of many automation projects, especially in uncertain market conditions. Cost trends are driven by two opposing factors. While hardware and standard platforms are becoming cheaper, the largest costs still lie in integration, security, data management, tools, and commissioning. The cost of automation is expected to fall in applications where hardware, software, and integration can be standardised. So the key economic issue will not be the price of the robot itself, but rather the total cost of developing, implementing, securing, adapting, and maintaining an entire automation solution over time.

Sweden is a leader in automation. Even many small companies are highly automated, and automation density – the number of robots per employee – is generally very high. But Sweden has fallen behind countries such as China and South Korea in recent years (see fact box). The strategic value of automation and AI for Swedish industry lies in improving quality, shortening lead times, increasing robustness and strengthening the ability to adapt. It can also make it easier to keep advanced production close to product developers, suppliers, and customers.

The country has relatively limited capacity to deliver automation. This applies not only to the availability of automation equipment, but also to the lack of relevant skills at several levels. While

Sweden generally has a high level of technical expertise, a major push into new industries and advanced manufacturing will make it more difficult for companies to find people with expertise in systems integration, application knowledge, electrical power, software development, cybersecurity, servicing, and operating new applications.

A higher degree of automation can contribute to increased production capacity and enhanced competitiveness. Robotics and automation can offer benefits such as higher quality, shorter lead times, better traceability, increased robustness, and more regionally distributed manufacturing. In highly automated production environments, labour costs will rarely be key competitive factors, with access to production engineering expertise, a strong supplier base, and well-functioning industrial ecosystems proving to be much more important.

Manufacturing industry can learn from the approaches logistics and biotechnology companies have taken to automation. These sectors often developed solutions based on needs that differ from those of the traditional engineering industry, leading to new approaches. Particularly relevant are AI- and perception-driven automation, which allow systems to use data and sensors to make real-time decisions, and autonomous mobile robots in flexible material flows. Working methods for traceability, systematic process verification and data-driven quality assurance could be applied to discrete manufacturing to make production more transparent, robust, and adaptive.

One area of development is the use of automation to improve quality assurance. For example, inline measurement takes real-time measurements while production is running. It provides closed-loop feedback so measurement data can be used to automatically adjust the production process – and pass through AI-based anomaly detection to identify deviations from normal process or quality to quickly detect errors or disruptions.

Key issue 8:
Circularity as an enabler of a new industrial logic

Circularity is not only an environmental goal, but also a means of creating value when resources are limited and supply chains uncertain. As companies become more proficient, their focus should shift from recycling – the most resource-intensive option – to reuse and remanufacturing.

Circularity is linked to product life cycles and business models

The circular economy works best when the product's life cycle can be controlled. To increase circularity on a large scale, several things have to come together: Business structures and contracts must support circular flows and create incentives for value over time. Risks and benefits must be shared between manufacturers, suppliers, service partners, and customers. Products also need to be designed for disassembly, upgrading, and reuse. Standardised modules, traceability and data on product use are crucial. Logistics are part of the solution, as are stable return flows of used products and the capacity for sorting, inspecting and remanufacturing them. This often works best in regional

systems with local collaborations and local supply chains.

The biggest barriers are business models, regulation, and incentives – not technology.

RE-MANUFACTURING

Re-manufacturing is an industrial process in which used products or components are disassembled, cleaned, repaired and tested to restore them to like-new condition. The aim is for remanufactured products to perform as well as, not better than, new products.

Collaboration and new ways of designing products and flows are needed

Circularity only works when it is profitable and all stakeholders involved benefit. The system is based on interdependencies, and value is only created when every part of the chain does its job. This makes collaboration and the sharing of risk and profit crucial. Companies working in circular ecosystems need to strengthen collaboration in and beyond its corporate structure, for example by developing new working methods together with suppliers.

Even actors within different parts of the same company need to collaborate more closely. The includes collaboration between those working on commercial models, product design, procurement, production, supply chains, service and repairs, and refurbishment and restoration.

Circular flows can be difficult to manage industrially. They are often more manual than the processes of the linear economy, which extract raw materials and manufacture products, which will ultimately be discarded as waste. Circularity places demands on design to use sustainable and renewable materials and ensure that all components can be separated when products are no longer used. They must be designed not only to be assembled, but also to be disassembled and upgraded. This requires companies to maintain robust service structures, return systems, and processes for assembly, disassembly, refurbishment and upgrades.

Companies can improve production if they know what went wrong with products that are returned. But they can have a hard time accessing information about quality issues, for example, or any events that transpired during the product's lifespan. If they succeed, companies can streamline their decision-making and improve their production efficiency.

It can also be a challenge to manage products that are manufactured in many different variants. Low volumes and high variation often lead to more manual labour than with standardised products, where manufacturing can be automated to a greater extent.

Restoring a product to its original function is a craft that requires knowledge of various repair methods as well as access to drawings and other information that can provide insight into how the product has been used and has changed over time.

Sweden has several strengths regarding circularity

As a key component of Sweden's energy system, hydropower does more than simply generate electricity. It provides stable and predictable electricity supply, enabling industrial processes to operate continuously. It can also be turned on or off quickly, meaning that production can be adjusted as needed. This makes it possible to integrate hydropower with automated systems and efficiently manage variations in electricity usage. Hydropower also helps to balance the entire electricity system, allowing many stakeholders to safely share the grid and draw power from it.

Forests do not just provide raw materials but constitute a circular resource that can be use in three phases. Forests provide wood, fibre and building materials, as well as residual products, that can then be used to make chemicals or bioenergy. In a third stage, forests provide biogenic carbon from renewable biological sources for use in materials or for carbon capture and storage to achieve negative emissions. But all of these stages require electricity-intensive processing, a stable energy supply, and low climate impact.

Mines and minerals form the foundation of discrete manufacturing because all its products are based on materials extracted from the ground. Sweden's mines are important because they supply the metals and minerals needed for machinery, batteries and electrification. They also have the potential to operate using electricity rather than fossil fuels and are located near areas suitable for industrial development. Combining fossil-free mining and mineral extraction with processing metal recycling can create integrated and circular flows that strengthen Sweden's industrial system.

The way forward

FIGURE 4: The figure depicts the narrative in which Sweden transitions from an economy based on natural resources to a country that is strong and competitive within circular industrial systems.

Current situation	Today, approximately 99 percent of Sweden's electricity production is fossil-free, combining low emissions with electricity prices that are among the lowest in the EU. The electricity system is based on a unique mix of hydropower, nuclear power and renewable production, which delivers both climate performance and stability. This gives Sweden an advantage.
From individual factories to industrial systems	Global competition is no longer decided by individual factories, but by the efficiency and robustness of the entire industrial system. Sweden can shift its focus from individual investments to industrial clusters where energy, materials, heat, and expertise are linked together. In such clusters, electricity is seen not merely as an input but as the backbone of the system. Industrial residual flows (heat, steam, cooling requirements and materials) become resources for other operations.
Natural resources that are not merely exploited	Sweden's traditional areas of strength form the basis for new integrated value chains. Hydropower provides electricity, but also functions as a system tool for stability, regulation and balance. Forests can provide interconnected streams of wood, fibre, chemicals, energy, and residual streams. Mines provide materials for electrification and discrete manufacturing. When Swedish resources are co-located, systemic advantages arise that are difficult to replicate globally. The logic of clusters is about maximising value per resource (not about maximising extraction).
Circularity becomes business, not a pilot project	Many international circular initiatives fail because they remain at the pilot stage. Sweden has the conditions to scale circularity at an industrial level. Electrification and fossil-free electricity are crucial for circular material flows to be sustainable in terms of both climate and business. Circularity thus becomes a cost and competitive strategy, not merely a sustainability ambition.
Organisational model as a competitive advantage	The Swedish model, with flat organisations, trust-based governance, and a strong culture of collaboration, is crucial. Within clusters, stakeholders must dare to depend on one another, share risk, and develop business models iteratively. In Sweden, there is a long tradition of collaboration between industry and energy companies, between the private and public sectors, and between competing players on shared systemic issues. This leads to lower transaction costs, shortens lead times and makes it possible to implement complex solutions in practice, not just on paper.
A systems approach that capitalises on Swedish assets	Overall, this points to the value of not merely investing in specific technologies or individual projects. Instead, there is a need for long-term access to fossil-free and predictable electricity, industrial clusters with strong residual and circular flows, and predictability that enables investments spanning 20–30 years. Sweden should also use its model of cooperation as a strategic asset.
Attractive industrial country	Sweden is an attractive industrial country for investment and innovation over the long term. In the next industrial era, we will not compete on the basis of cheap labour or short-term subsidies. Instead, we will build on a combination of fossil-free and competitive electricity, abundant natural resources, industrial clusters, circular business models and a collaboration-driven organisational culture.

Vision

The working group's vision for 2035 is for Swedish industry to be flexible and highly resilient. Production systems, organisations and collaborative networks are designed to be able to adapt quickly. Swedish companies have the capacity to scale up production in times of crisis. Uncertainty in a changing world can be managed through circular modular processes, robust collaborations and a clear division of responsibilities between industry, government and the market.. Their supply chains are diversified, strategically designed and integrated with product design, reducing dependence on critical materials and individual suppliers. They are also part of regional circular systems.

Business models have evolved from selling hardware to providing service- and function-based offerings. They take responsibility for the entire product lifecycle and forge stronger links between products, production and product use. By 2035,

these models are underpinned by long-term partnerships and mutual trust, and robust mechanisms for sharing risk and value. Product and production development is integrated from the outset, stakeholders along the entire value chain collaborate closely and digital tools enable rapid adaptation to changing requirements.

Digitalisation, AI and automation are fully integrated with industry and are used for simulation, optimisation and decision support based on standardised and abundant data. Electrification and advanced robotics have enhanced productivity and competitiveness, and circularity has become a normal facet of business logic and production, with efficient systems in place for reuse, remanufacturing and resource efficiency. The supply of skills is seen as a key strength for Sweden, with employees having both a broad systemic understanding and deep specialist knowledge. Good jobs, lifelong learning, and more diversity ensure these skills remain available.

With increasing regularity, the government, industry, and energy and defence sectors are planning jointly and testing solutions in pilot projects that can then be scaled up. Rather than optimising their own areas of expertise, stakeholders are prioritising joint solutions that strengthen the system as a whole. In a NATO context, this means that Sweden contributes not only individual capabilities but also coordinated system-level solutions. This comprehensive approach to defence will also strengthen Swedish society. As ever more resources have to be allocated to defence, funding will also increase for investments that strengthen industrial production, expertise, and energy systems. In this way, defence will evolve from being a standalone area to becoming an integrated part of broader industrial and societal development.

This means that, by 2035, Sweden will be able to industrialise new technology and rapidly translate innovations into competitive new products in an ever-changing global context.

Five proposals for strengthening Swedish competitiveness in advanced manufacturing

This section sets out five proposals to boost Sweden's competitiveness in discrete complex manufacturing. These proposals are based on the significant changes currently taking place in Swedish industry. In such a period of rapid change, the ability to develop and manufacture advanced products is crucial not only for Sweden's economic competitiveness, but also for maintaining national security and social cohesion. Against this backdrop, Sweden must

- Strengthen its industrial expertise, innovation and testing environments,
- Boost its resilience through the transition to a circular economy,
- Develop industrial clusters,
- Invest in research into established production technologies,
- Improve conditions for companies coming to and operating in the country.

For each proposal, we describe what measures are needed and which actors should be responsible for implementing them. Our proposals demonstrate how a more coordinated, long-term and system-oriented approach could strengthen Sweden's position in global manufacturing.

Although their impact will unfold at different rates, all five proposals are equally important and implementation should begin immediately. Four of the proposals can produce results within a few years, while the transition to a circular economy is a longer-term effort that may take 15–20 years. All measures need to be initiated as soon as possible to strengthen Sweden's resilience and ensure that we are better equipped in future to handle changes in the geopolitical landscape.

Proposal: Strengthen industrial expertise, innovation and testing environments

Sweden needs to improve its ability to translate research into industrial applications. To do this, it has to strengthen its industrialisation capacity by ensuring access to relevant expertise, and testing and laboratory facilities. By linking advanced research to industrial pilot projects and real-world production environments, Sweden can foster innovation while building the resilience needed in an increasingly uncertain industrial landscape. To maintain competitiveness, Sweden must focus on innovation, quality, and system-level solutions rather than on low costs.

Giving students and professionals access to industry-linked testing, laboratory, and pilot facilities creates a continuous link between theory and practice. This can improve the quality of education and strengthen industry's ability to rapidly convert new discoveries into industrial applications.

Industry needs to rethink its approach to education and show that there are attractive engineering careers in production as well as in management. One way companies can contribute is by integrating education and internships, inspired by examples where students spend time in industry. Certified training programs, industry-focused high schools and combined study-and-work arrangements can strengthen the link between education and the world of work. Establishing this contact early – through internships, part-time jobs, collaboration with guidance counsellors or support for teachers – would increase young people's interest in industry.

Initiatives targeting small and medium-sized enterprises must address these companies' specific challenges. They often operate with limited resources and high operational workloads, and so often shy away from shouldering the risks and difficulties of transformation. To help them, industry should foster ecosystems in which small and medium-sized enterprises can work together with larger players – and risk and value can be shared among stakeholders.

In order to strengthen innovation, test environments and industrial expertise for industrialisation, Sweden needs to make some strategic choices. It cannot be a leader in every technology area and, as a result, it must bundle its resources strategically. Sweden should therefore prioritise technology areas in which it has the greatest potential. Another option is to strike a balance between basic and applied research within research and innovation initiatives. A third choice concerns what balance to strike in a given field between open, researcher-initiated research and more targeted initiatives – as well as who should determine the conditions for such targeted initiatives.

To strengthen expertise, innovation, testing, and industrialisation, Sweden has to:

- **Invest in skills and education** by strengthening the practical components and applied knowledge within engineering programmes, particularly by enhancing expertise in production technology. Higher education institutions offering engineering degrees play a crucial role and need to collaborate closely with industry to ensure that curricula meet industry needs. Such collaboration can be deepened by, for example, including industry representatives on programme boards, where they help shape the content and focus of teaching. Industry can also take greater responsibility

for the supply of skilled labour by actively supporting employees who have not completed a full degree, ensuring that they are given opportunity and time to do so. There are Swedish and international examples of educational models that combine study and work. These more flexible and practice-oriented forms of education can be developed and adapted across different engineering disciplines. Educational models with close links between theory, application and industrial practice are particularly valuable in the field of production.

- **Establish industry-oriented testing and laboratory environments** by bringing universities, industry, research institutes and government agencies together to create settings for experiment, education, and scaling up. All stakeholders will have to collaborate closely.

- **Strengthen the link between research and industry** by creating structures and funding for applied research that cover all forms of research and innovation, including basic and applied research, breakthrough and research-intensive technologies, their application through groundbreaking and often transformative innovation (deep tech), as well as industrial development in production. Government research and innovation funding agencies play a key role, but so do research institutes, universities, and industry.

- **Prioritise strategic research initiatives** by providing funding to fewer, larger, and more long-term initiatives, rather than the emphasis on project-based funding. Government research and innovation-funding agencies are important, but foundations, relevant departments in research institutes, and other funders also play crucial roles.

- **Double government funding for engineering programs** within two legislative terms to ensure the development and operation of teaching laboratories, strengthen ties to industry, and address the long-standing shortfall in public funding.

- **Strengthen small and medium-sized enterprises** through support for technology implementation, skills advancement (such as recruiting new staff and upskilling existing employees) and the development of business models that enable small and medium-sized enterprises to scale up and grow. The government and its relevant agencies need to collaborate with regions and municipalities, industry, and startup- and scaleup-initiatives. Larger companies need to work closely with smaller companies to jointly develop solutions. This collaboration is not driven by external funding, but by the conviction of the larger companies. One way to do this is to create collaborative environments where large and small companies work together on real-world problems. To succeed, initiatives like these must be supported by management and fully integrated into core operations, with a focus on actual needs and concrete solutions.

Improving how research is turned into industrial applications comes in three phases. In the short term of 1–2 years, programmes and testing need to be set up. These will strengthen the links between research and industry over the medium term of 3–5 years.

Over the next two years, representatives from Swedish industry, universities and RISE should develop proposals for national testbeds and labo-

ratory environments, as well as a shared national approach. They should also recommend how Vinnova, the Swedish Agency for Economic and Regional Growth, and the Swedish Energy Agency can adapt their funding programmes. At the same time, existing strategic research areas in production should be reviewed and better aligned with national priorities. A common model for internships in education should be developed, along with a "centre of vocational excellence" covering skills from shop-floor to doctoral level. Steps should also be taken to increase government funding for engineering education and to enable people without a degree to combine work in industry with completing their studies. In parallel, universities, research institutes, and industry should prepare to put upcoming initiatives into practice. Swedish testbeds should also be more clearly integrated into the European innovation system, and the internship model should be gradually introduced in education.

Over the longer term of 5–10 years, these measures should have a real impact on the strength of Swedish industry and the country's supply of skilled workers.

Proposal: Strengthen Swedish resilience through the transition to a circular economy

Swedish manufacturing has to change to help the country transition to a circular economy. The country's competitiveness is based largely on its ability to work efficiently with limited resources combined with a strong culture of collaboration between industry, academia and government. This ability to collaborate is one of Sweden's stand-out strengths. A circular economy creates value not at a single business stage, but in ecosystems of business models that all enable stakeholders to collaborate and share data and risk throughout the entire life cycle.

Sweden has a tradition of collaboration that can be serve as a basis for integrated life-cycle systems linking product design, manufacturing, product use, and remanufacturing. By leveraging their ability to collaborate, Swedish stakeholders can not only reduce resource use and climate impact but also offer greater value to customers. Their collaborative abilities allow them to develop advanced, knowledge-products, particularly in small volumes and closely aligned with customer needs. Rather than simply purchasing a product, customers are buying functionality, accessibility and lifecycle performance. This allows Sweden to stand out in a global marketplace, in which value is increasingly defined by sustainability, transparency and delivery reliability.

The transition to a circular economy presents a strategic opportunity to bolster Sweden's competitiveness and resilience. By developing systems for reuse, remanufacturing and sustainable production, Sweden can take a leading role in complex discrete manufacturing. Access to fossil-free energy and established collaboration structures are crucial assets.

To transition society from a linear to a circular economy, circularity should not primarily be viewed as an environmental issue, but rather as

an industrial and systemic approach to managing resource constraints and uncertainty. Studies show that companies operating in this way can become more competitive, more efficient and better at withstanding disruptions. As the global economy remains largely linear, the challenge for advanced manufacturing is to build circularity into how products are designed, production is planned and the business model is structured – so from the beginning of every product's lifecycle, not as an afterthought at its end.[14]

This requires coordinated policy development so that regulation, incentives and public investment all pull in the same direction. Crucial for this are long-term rules for lifecycle responsibility, standards for traceability and data sharing, as well as economic incentives that make reuse, repair and remanufacturing commercially attractive. Industry needs to be able to transport used products across national borders and view them as valuable materials and resources, not as waste. At the same time, the infrastructure for circular flows – such as collection, sorting and remanufacturing – needs to grow. Such a systemic effort will strengthen environmental and social sustainability. It will also boost resilience by reducing dependence on relatively vulnerable global supply chains, regional supply networks being much more robust.

Strengthening the role of small and medium-sized enterprises in manufacturing supply networks increases the economic sustainability and flexibility of the entire system, while broadening the industrial base and as a result making it more resilient to disruptions.

Research and development must contribute to developing expertise and methods for managing lifecycles. Digital technologies, such as digital twins, product passports and data-driven decision support, can enhance the traceability and management of circular flows. Research is also needed into the systemic challenges, such the creation and distribution of value among stakeholders, the sharing of risk and the industrial scaling of circular systems.

To develop resilient circular manufacturing systems, several strategic decisions must be made. First, standards and rules should be designed to support circular flows. Second, the ability to build sustainable and complex systems should be prioritised over cost competitiveness. Third, Sweden needs to find a balance between national resilience and global integration in manufacturing. For example, it might have to choose between using Swedish suppliers to strengthen domestic industry and resilience or using foreign suppliers to maintain international relations. To strengthen its resilience through transitioning to a circular economy, Sweden has to

- **Establish circular industrial ecosystems** by creating integrated supply systems involving material, energy and data flows. This will create new business opportunities and strengthen supply security, for example by reducing dependence on critical raw materials and increasing reuse and recycling of strategic materials. Swedish industry will be the driving force for this, but the government and its agencies as well as EU institutions will also need to be engaged.

- **Introduce incentives and regulations that strengthen and stimulate circularity** by reviewing producer responsibility, economic instruments and standards. The

14 World Economic Forum. (2025). *Circular transformation of industries*.

primary responsibility lies with the Swedish government and its agencies. They need to collaborate with standardisation bodies and EU stakeholders. At the same time, Sweden needs to advocate for regulations that boost collaboration within the framework of European cooperation and with the United Kingdom, Switzerland, and Norway to simplify cross-border transport and handling of materials.

- **Build infrastructure for circular flows** by investing in collection, sorting, and remanufacturing. The government and its agencies need to collaborate with local stakeholders and industry.

- **Promote circular design and circular business models** by designing for the entire lifecycle. Material selection and processes such as disassembly, reuse and lifespan expansion must be incorporated from the outset. This requires tools that support design for circularity, access to product data and business models based on function, services, or buyback schemes. Swedish industry is in the driving seat, but the government and its agencies also need to be involved.

- **Strengthen expertise in circularity** by investing in research and development that contributes to the understanding and management of entire lifecycles. Public research and innovation funding agencies play a key role, as do foundations and other funding bodies.

- **Strengthen the role of small and medium-sized companies in circular industrial ecosystems** through support structures in the form of test beds, joint pilot projects and standardised solutions for circular business models. Government innovation funding is key, but other funding and support organisations for startups and scaleups are also important.

- Encourage companies to take the "Circularity Leap" by offering them support for their transitions. National initiatives should be designed to receive co-financing from the EU. The Circularity Leap should be coordinated by a national agency, such as the Swedish Agency for Economic and Regional Growth or Vinnova, in close collaboration with other government agencies, such as the Swedish Environmental Protection Agency, the Swedish Energy Agency, Almi, and Business Sweden, as well as industry associations and individual companies.

Developing a circular and resilient manufacturing system can be divided into three phases. In the short term of 1–3 years, the focus should be on pilot projects, the introduction of incentives and the establishment of common standards. Over the next 3–7 years, systems and business models can then be scaled up and brought onstream on a larger scale. Government agencies could take the Circularity Leap to introduce circular procurement processes from 2028, provided that preparatory work, for example about decision-making processes, are completed by 2027.

Over the longer term of 7–15 years, industry should have fully developed and integrated circular lifecycle systems that cover the entire product lifecycle. This involves establishing initiatives for circular product and production development that include subcontractors as active value-creating partners, as well as academia and research institutes contributing methodological support.

Proposal: Develop industrial clusters

In order to realise the potential of circularity and advanced production, Sweden needs strong industrial clusters where energy, infrastructure, expertise and production interact. While access to fossil-free energy and established industrial regions are already a good basis for this, long-term investment and clear priorities are also needed. At the same time, effective permitting processes, robust infrastructure and skilled labour must also be available (see below).

Sweden should develop strong industrial clusters in the manufacturing sector that leverage and reinforce regional and local strengths. In circular and resilient economies the competitiveness of individual factories is a factor of the interconnected industrial systems of which they are a part, integrated production, energy logistics, and expertise. Such clusters become more robust and efficient by allowing material flows and energy to circulate among stakeholders. Companies can share infrastructure for recycling, disassembly, and sorting, and use residual streams as inputs in new production. This approach reduces both transportation costs and climate impact.

For industrial clusters to work well, stable, long-term access to affordable energy is essential, along with connected flows linking sourcing, production, and reuse. Long-term coordination is also needed between industry, energy and infrastructure providers, and public stakeholders.

In practice, the transition is determined not only by technology, energy, and raw materials, but also by how organisations function and collaborate. Industrial clusters are based on actors sharing risks, infrastructure, and sometimes investments, which requires collaboration across company and sector boundaries. For example, this could involve an industry supplying residual heat, an energy supplier distributing it via district heating, and another company using the heat for its manufacturing operations. Local governments need to plan local infrastructure accordingly. All solutions require a long-term perspective, openness and trust among

stakeholders. The Swedish model of strong collaboration between industry, academia and the public sector provides an excellent basis for coordinating investments, expertise and innovation.

Strong industrial clusters in the manufacturing sector can be created by building on established industrial regions with different profiles and areas of strength. Västra Götaland, for example, could be developed further to serve as a hub for the advanced automotive industry and circular mobility-solution providers. Mälardalen could become a hub for digitalised production and system integration. Sundsvall/Timrå, Skellefteå, Piteå, Luleå/Boden and other locations on the Norrland coast have the potential to become a leading cluster for energy-intensive and resource-based industries due to their access to fossil-free energy, raw materials and industrial infrastructure, which could be used to build large-scale circular industrial systems.

Canada's advanced manufacturing clusters are a prime example of how circular-economy principles can be put into practice. They demonstrate how companies, universities and public bodies can collaborate within a given geographic area. This type of collaboration is essential for building long-term production capacity and for strengthening innovation.[15]

Industrial clusters should offer opportunities for education, research and industrial upscaling. Clusters are particularly well-suited to integrating laboratory environments into education.

By linking industrial clusters into a national system, Sweden can create a manufacturing structure that is both integrated and distributed. Integrated clusters strengthen competitiveness and resilience by combining specialisation with flexibility. In doing so, they contribute to innovation, the supply of skilled labour, and long-term resilience. That is why Sweden should

- **Strengthen and develop regions** that already have well-functioning collaboration between stakeholders. The government and its agencies need to collaborate with regions and localities and with industry, particularly companies in the energy, logistics and raw materials sectors.

- **Develop a Swedish financing strategy for industrial clusters** that uses national funds to create and strengthen opportunities offered by the EU for the industrial transition of production. Through programs such as the Innovation Fund and STEP, companies can receive support for clean energy, advanced manufacturing, and digitalisation. This initiative should be led by the Swedish Agency for Economic and Regional Growth or Vinnova in collaboration with other relevant national authorities, regions, municipalities, and industry organisations.

The developing industrial clusters can be divided into three phases. In the short term of 1–3 years, efforts should focus on planning and initial investments. This involves gathering existing expertise in production technology, designating national hubs at selected universities, and establishing clear forms of collaboration between industry, academia, and research institutes.

In the medium term of 3–7 years, the focus should shift to expanding clusters. Capacity and expertise need to be systematically built up in a limited number of regional clusters.

15 OECD (2026). *Next Generation Advanced Manufacturing Cluster (Canada)*. Case study.

In the longer term of 7–15 years, the goal should be several fully developed and integrated clusters. To achieve this, structures have to be consolidated and developed through long-term funding, ongoing updating of priority technology areas, and strong international positioning. The resulting clusters should then function as fully integrated systems closely serving industry needs.

Proposal: Invest in research on established production technologies

Sweden needs to ensure a long-term and coordinated investment in research and development within established production technologies. To avoid fragmentation, designated technical universities should be given clear national responsibility for specific technology areas.

In addition to research, knowledge hubs are needed to support industry by providing education, conducting tests and developing methods. By combining deep expertise with close ties to industrial needs, Sweden will be able to boost critical production capabilities. This structure would enhance the efficiency and quality of existing industries, while also contributing to resilience by ensuring that key technologies and competencies remain available.

One strategic choice would be to focus on a few select regions, rather than dispersing resources across the country and a variety of technology areas. A balance also has to be struck between rapid expansion and long-term sustainability, and decisions must be made about how to divide responsibilities and resources between the national and regional levels. Sweden should

- **Secure a technical skills base anchored in manufacturing.** Several technology areas need to be represented at one or more Swedish universities. Such areas include additive manufacturing, automation, efficient logistics systems, casting, software, sheet metal forming, product and production management, integrated product and production development, cutting, welding and soldering, tool manufacturing, and surface treatment.
- **Strengthen research in a number of technology areas.** Areas that need to be strengthened include AI and digitalisation, circular processes, flexible manufacturing systems, managing shorter product lifecycles, understanding of new complex materials, logistics, and predictive maintenance. Basic research into the use of new technologies in production is also needed.

Higher education institutions offering engineering programmes can play a central role in boosting in collaboration with industry in both areas. Individual institutions could be designated national hubs for specific technology areas, so not all institutions need to cover everything.

In the short term, the focus should be on securing and structuring the research base within established production technologies. This involves mapping existing research, prioritising certain technol-

ogy areas and designating national hubs with clear responsibilities. In parallel, strategic research areas within the manufacturing sector and other existing research initiatives should be coordinated and aligned with a common national focus, in collaboration with industry.

In the medium term, research in the selected technology areas should be strengthened through targeted initiatives and increased funding. The national hubs should be developed further with clear mandates and stronger links to industrial needs, while collaboration between universities, research institutes and companies is deepened.

Research should concentrate on a limited number of promising environments to ensure critical mass and avoid fragmentation.

In the long term, a stable research structure with long-term funding should be established, creating internationally competitive ecosystems in selected production technologies. This will ensure that research is integrated with industrial needs and develops in step with technological and market changes, ensuring ongoing development of expertise and innovation capacity.

Proposal: Improve basic conditions for establishment and operation

Improving the competitiveness of Sweden's manufacturing industry requires structural improvements to rules about founding and running companies in the sector.

Faster and more predictable permitting processes are needed, with shorter lead times are shortened without compromising legal certainty or environmental requirements. In addition, energy production needs to increase. This requires stable regulations and clear incentives to ensure access to competitively priced fossil-free energy that can meet the industry's growing needs. At the same time, strategic investments in logistics and critical infrastructure at the local and regional levels are required to ensure that industrial initiatives can be realised.

To improve the conditions for founding and operating manufacturing companies, Sweden should

- **Invest in social infrastructure** by ensuring that there are well-functioning transport systems, housing, and services in the locations where industry is based and where current and future employees are trained. The government and its relevant authorities need to collaborate with regional and municipal stakeholders to do this.
- **Ensure energy supply** by expanding Swedish output of competitive fossil-free and energy. In addition to actors in the energy sector, the government and responsible authorities need to collaborate with regional and municipal stakeholders to do this.
- **Improve permitting** by making processing faster and more predictable. Responsibility for this rests with the government and its responsible authorities.

In the short term of 1–3 years, the focus should be on rapidly improving implementation, coordination, and efficiency within existing systems. This can be achieved by coordinating transport systems, housing, and services in areas close to industry and education more effectively, planning energy supply more efficiently and ensuring faster connections, and beginning to simplify permitting processes to achieve shorter and more predictable lead times. In the medium term of 3 –7 years, efforts should focus on scaling up, investment and structural improvements.

In the longer term, the goal is to establish fully integrated systems. By 2035 infrastructure, energy supply, and permitting processes should be so robust, fast, and competitive that they support long-term establishment and growth of manufacturing companies in Sweden.

Recommendations

The working group has three recommendations on how Sweden can build its competitiveness, achieve sustainability and boost national and global security. They are based on an analysis of Sweden's position in the manufacturing sector and international trends, as well as a review of key issues identifying obstacles and opportunities for Sweden's continued development. They summarise the proposals and action points described in more detail above. Sweden has to

1. Ensure that it becomes better at translating research into industrial applications. To achieve this, it needs to strengthen expertise and testing environments for industrialisation and invest in research into established production technologies.

2. Strengthen its resilience through the transition to a circular economy. To achieve this, business models, regulations, and incentives within manufacturing industry need to change.

3. Increase its innovation capacity by establishing a number of industrial clusters and improving the basic conditions for establishing and operating manufacturing companies.

Appendix

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