MIT Technology Review
Insights

How adaptive production empowers industry to master a more complex world – while shaping a smarter, more efficient, and resilient future.

# Shaping the future with adaptive production

Produced in partnership with

SIEMENS

## Key takeaways

1. The advanced digitalization and automation technologies used in adaptive production methods allow manufacturers to rapidly adjust to demand fluctuations, customize for local markets, and respond to disruptions. This allows them to address external pressures, become more competitive, and accelerate the shift from globalization to glocalization.

2. If workers are prioritized when designing systems, then adaptive and increasingly self-optimizing production can offer more attractive and accessible job opportunities for a wider workforce, including safer, more meaningful, and strategic work for better pay.

3. Adaptive production can help manufacturers become more sustainable by enhancing efficiencies, providing richer data insights, and driving a change from linear to circular manufacturing.

Adaptive production is more than a technological upgrade: it is a paradigm shift. This new frontier enables the integration of cutting-edge technologies to create an increasingly autonomous environment, where interconnected manufacturing plants go beyond the limits of traditional automation. Artificial intelligence, digital twins, and robotics are among the powerful tools manufacturers are using to create dynamic, intelligent systems that not only perform tasks, but also learn, make decisions, and evolve in real-time.

Taking this kind of adaptive approach can transform a manufacturer's productivity, efficiency, and innovation. But beyond the factory, it also has the potential to deliver society-wide benefits, by bolstering economic growth locally, creating more attractive and accessible employment opportunities, and supporting a sustainability agenda.

As efforts to revive and modernize local manufacturing accelerate in regions around the world, including **North America** and **Europe**, adaptive production could help manufacturers overcome some of their biggest obstacles – firstly, attracting and retaining talent. **Nearly 60% of manufacturers** cited this as their top challenge in a 2024 US-based survey. Highly automated, technology-led adaptive production methods hold new promise for attracting talent to roles that are safer, less repetitive, and better paid. "The ideal scenario is one where AI enhances human capabilities, leads to new task creation, and empowers the people who are most at risk from automation's impact on certain jobs, particularly those without college degrees," says Simon Johnson, co-director of MIT's Shaping the Future of Work Initiative.

Secondly, the digitalization of manufacturing – embedded in the very foundation of adaptive production technologies – allows companies to better address

"The ideal scenario is one where AI enhances human capabilities, leads to new task creation, and empowers the people who are most at risk from automation's impact on certain jobs, particularly those without college degrees."

Simon Johnson, Co-Director, Shaping the Future of Work Initiative, MIT

complex sustainability challenges through process and resource optimization and a better understanding of data. "By integrating these advanced technologies, we gain a more comprehensive picture across the entire production process and product lifecycle," explains Jelena Mitic, head of technology for the Future of Automation at Siemens. "This will provide a much faster and more efficient way to optimize operations and ensure that all the necessary safety and sustainability requirements are met during quality control."

## The drive for glocalization and resilience

The global industrial playbook is being rewritten. Recent disruptions, including the covid-19 pandemic and geopolitical tensions, have exposed the vulnerabilities of centralized supply chains. At the same time, evolving consumer expectations and the accelerating climate crisis demand faster, more sustainable, and regionally tailored production.

Once a fringe idea, glocalization – the practice of conducting business according to both local and global considerations – is emerging as the new default for economic resilience, sustainability, and flexibility in the face of geopolitical uncertainty. Combining the efficiency of global connectivity with the resilience of localized production, glocalization recalibrates industrial priorities, allowing manufacturers to rapidly adjust to regional demand fluctuations, customize products for local markets, and respond to disruptions. Technologies and concepts like digital twins, software-defined automation, and AI-driven production offer the unprecedented adaptability required to support this evolution.

Governments have become powerful drivers for glocalization, recognizing that the success of re- and near-shoring efforts depends on adaptive production. Without the flexibility, efficiency, and scalability that advanced technologies provide, localizing production risks driving up costs and fuels inflationary pressures.

In the European Union, initiatives like the new "**competitiveness compass**," the **European Chips Act**, and policies favoring energy efficiency and circularity aim to strengthen local manufacturing while ensuring alignment with environmental goals. China's "**dual circulation**" strategy seeks to balance domestic self-reliance with global trade. By focusing on automation, AI, and advanced manufacturing, China aims to boost domestic production in key sectors while maintaining its export competitiveness. Meanwhile, India's **National Manufacturing Policy** emphasizes adaptive production as a driver for growth, aiming to boost manufacturing's share of GDP while creating a pipeline of high-value, technology-driven jobs.

These policies underscore a critical realization: the reshoring and near-shoring of industries are not simply about bringing industrial production home; they are about transforming how manufacturing works. Adaptive production technologies make this transformation possible by allowing localized factories to produce

## Reimagining the promise of automation for the 21st century

### Historical lesson

The post-Second World War automation boom wasn't just geared to accelerating production lines; it was about aligning technology with economic and societal needs. Governments and industries invested heavily in infrastructure, creating an environment where technology could scale and deliver broad benefits.

### The present challenge

Adaptive production offers similar scaling and benefit potential, but the focus has shifted from mass production to resilience, sustainability, and customization. In order to rise to today's challenges, which include supply chain disruptions and sustainbility goals, industries are scaling AI technologies like digital twins and software-defined automation.

### A new productivity hypothesis

Adaptive production may not always show up in traditional productivity metrics, but its impact lies in sustaining high operational efficiency amid increasing demands for customization, resilience, and sustainability. By preventing potential productivity losses and enabling industries to adapt without sacrificing competitiveness, it represents a vital shift toward a more agile and future-ready manufacturing paradigm.

with the agility, efficiency, and innovation traditionally associated with globalized systems where the most efficient producers would seize the largest market share.

## The future of work in adaptive, autonomous industries

While some associate automation with job losses, the past shows us its potential to transform the world of work. For example, in the years following the Second World War, mechanized assembly lines and early computing systems reduced the strain of repetitive, manual tasks for blue-collar workers and shifted labor to more skilled, white-collar roles in management and operations. More recently, the invention of the personal computer created an **estimated 15.8 million net jobs** in the US between 1980 and 2017. Today, advanced technologies have the potential to expand the scope of manufacturing jobs and make the industry more attractive and accessible to talent.

**Figure 1: Localizing manufacturing with adaptive production technologies**

How manufacturing is evolving to meet the demands of a changing world

1

### Demographic change

With fewer skilled workers, adaptive production uses AI, robotics, and immersive digital twins to train faster, automate smarter, and support flexible human-machine collaboration—sustaining productivity in aging societies.

2

### Urbanization

To meet urban demand, adaptive production enables space and resource-efficient solutions like vertical farming and modular microfactories, reducing logistics, emissions, and water use while meeting increased productivity demands.

3

### Glocalization

As supply chains fragment, adaptive production leverages standardized digital twins and modular systems to enable "local-for-local" manufacturing—delivering global quality with regional flexibility and faster reconfiguration.

4

### Environmental change and resource efficiency

Adaptive production supports circularity and emissions targets through real-time monitoring, AI-driven optimization, and digital product passports—enabling closed-loop systems that minimize waste and energy consumption.

5

### Digitalization

By combining industrial AI, software-defined automation, and digital twins, adaptive production creates intelligent, connected systems that self- optimize in real time—boosting efficiency, uptime, and responsiveness across the entire value chain.

Source: Compiled by MIT Technology Review Insights, based on data from Siemens, 2025

"Throughout history, we've seen periods of significant automation coupled with the creation of new types of work. Many of those new roles required expertise that commanded higher pay because those skills couldn't be easily replaced," says Johnson. These transformations may not only enhance working conditions but also empower workers with higher wages and career mobility, emphasizing skills and innovation. "Tomorrow's workforce is going to require a growth-oriented mindset. The jobs that are available today are going to be different than the ones in the future, so skills and talents need to be applied differently, and new skills will need to be learned," says Eryn Devola, head of sustainability at Siemens Digital Industries.

The manufacturing workforce has dramatically changed in the last few years. The average tenure of a manufacturing employee has plunged from about 20 years in 2019 to just three years in 2023, according to **LNS Research**. As experienced employees near retirement, the industry is also losing newer talent at a faster rate. A younger, digitally native workforce is **seeking out employment** that offers greater flexibility; learning and career development opportunities; and a safer, more technology-driven working environment.

Adaptive production can help to address some of these challenges, like enhancing workplace safety, for instance. **Advanced sensors** can identify potential hazards and automatically adjust operations if danger is detected, ensuring molten metal is kept away from humans and robotic arms are moving at safe speeds, for example. **Cobots**, or collaborative robots, can take on repetitive tasks to reduce strain-related injuries, and their soft materials and curved designs further mitigate injury risk.

"AI technologies will also help make better decisions, to give targeted assistance and support to the workforce," says Mitic. Humans will still have a central

> "Tomorrow's workforce is going to require a growth-oriented mindset. The jobs that are available today are going to be different than the ones in the future, so skills and talents need to be applied differently, and new skills will need to be learned."
>
> Eryn Devola, Head of Sustainability, Siemens Digital Industries

role to play in the factory of the future, but automated production systems will **allow workers to shift their focus** to more rewarding and meaningful tasks, eliminating the need for involvement in hazardous or tedious work and improving the sector's appeal to a more diverse workforce.

Growing opportunities for higher-skilled, better-paid, and more meaningful work are already changing perceptions of manufacturing work and increasing interest among a wider demographic. "Young entrepreneurs working on software and manufacturing have told me that the interest is absolutely overwhelming, from investors, industry folks, government, and academics," says Jeff Burnstein, president of the Association for Advancing Automation. This interest is reaching young workers and mid-career professionals, looking to apply their skills in new ways, says John Hart, professor of mechanical engineering and director of the Center for Additive and Digital Advanced Production Technologies at MIT. "There's a renewed sense of opportunity, and the importance of re-industrialization is on the public agenda."

## Keeping humans at the center

Realizing the full potential of adaptive production to reshape manufacturing work for the better – creating safer, more meaningful, and more accessible roles – depends on the decisions we make now about how to deploy technologies and how we prioritize the unique strengths of human workers alongside them. "Look at how we've created things throughout history, and how we can be creative, help each other, and contribute

## Microfactories: Localizing manufacturing with adaptive technologies

**Microfactories are redefining manufacturing by combining compact, modular design with cutting-edge adaptive production technologies. These facilities are smaller, more flexible, and more sustainable than traditional factories, making them ideal for localized production. Here are some examples of companies leveraging these technologies:**

**Blendhub: This food production pioneer deploys containerized microfactories close to raw material sources, cutting transportation costs and emissions. Using digital twins, Blendhub optimizes recipes for local ingredients, ensuring consistency across global operations while adapting to regional needs. Its modular design allows rapid setup in underserved areas, fostering local economic growth.**

**Wayout: Wayout's modular water systems combine real-time data analytics and IoT to produce 20,000 liters of clean drinking water daily while minimizing energy use. Adaptive production enables Wayout to replace components as needed without halting operations, ensuring efficiency and continuity in remote or resource-scarce regions.**

**Desert Control: Producing liquid nanoclay to combat desertification, Desert Control's microfactories use process optimization tools to enhance production efficiency while conserving resources. Modular systems allow deployment in regions most affected by soil degradation, ensuring proximity to critical challenges and reducing environmental impact.**

positively to the world. There is a lot of hands-on problem solving and biological interaction with the real world that we do, which will never be replicable by computers," says Johnson.

"People shouldn't lose sight that it's not just about keeping humans 'in the loop;' it's about humans driving the process. Relying too much on a machine is natural when you see how highly competent these machines are; but in doing so, you lose the value of being human," says Johnson.

Mitic agrees that humans remain crucial for complex, high-level engineering tasks. And, if technologies like generative AI take on some of the routine, repetitive work, it could lower the barriers of entry to the industry. "Currently, you need specialized robotic experts to engineer and program the robots," Mitic explains. "But if the programming and engineering artifacts of the robotic system can be generated using AI, with humans overseeing to ensure safety requirements are met, this could make this work much more accessible."

## Designing smarter, sustainable systems

Around the world, industrial activities account for **more than 30% of greenhouse gas emissions**. To meet ambitious sustainability targets, driving greater efficiency, reducing waste, and conserving energy are absolute imperatives for modern manufacturers – and digital technology is essential for doing so.

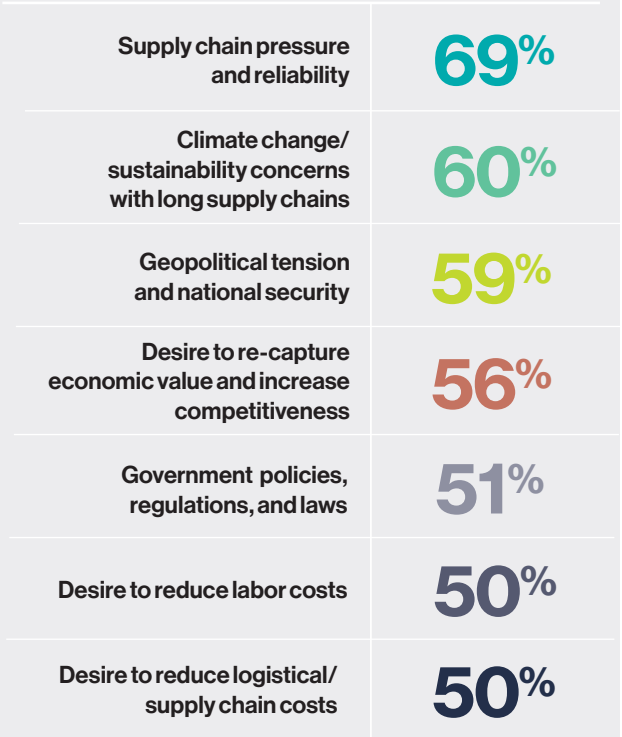
**Advanced analytics** support supply chain visibility by enabling the traceability of raw materials and labor inputs, documenting the chain of custody, and facilitating compliance with regulatory standards. With **digital twins**, manufacturers can model the impacts of products or production processes and anticipate the benefits of making sustainable changes, empowering them to be more ambitious.

Adaptive production is also driving a shift from linear to circular manufacturing. Technologies like additive manufacturing – also known as 3D printing – and digital twins are enabling businesses to extend product lifecycles, reuse resources, and minimize waste. For example, Toolcraft, a German additive manufacturing company, refurbishes worn out machine parts for major consumer goods manufacturers – bringing them back to production lines at around 40% less cost than purchasing new parts.

> "There's a renewed sense of opportunity, and the importance of reindustrialization is on the public agenda."
>
> John Hart, Professor of Mechanical Engineering and Director of the Center for Additive and Digital Advanced Production Technologies, MIT

**Figure 2: Top reasons for reindustrialization strategies and initiatives**

Nearly 70% of companies in Europe and the U.S. identify supply chain resilience as a leading driver of reindustrialization.




Source: Compiled by MIT Technology Review Insights, based on data from Capgemini Research Institute, 2025

The implementation of such technologies at scale demonstrates tangible sustainability benefits. Industrial sites in the World Economic Forum's **Global Lighthouse Initiative** – recognized for their exceptional performance as a result of tech-enabled digital transformation – cut, on average, 30% of material waste and 25% of energy and water consumption. Other benefits include enhanced supply chain resilience, with a 25% to 50% reduction in inventory and a 15% to 30% improvement to on-time delivery.

The tools for environmental transformation are here, but scaling them requires collective action. Legislation like the EU's Corporate Sustainability Reporting Directive (CSRD) may help speed up this process. "The CSRD encourages a more comprehensive approach to sustainability reporting, requiring companies to consider and report on a wider range of environmental and social impacts," says Devola. "This broader scope necessitates more sophisticated data collection, analysis, and reporting tools, highlighting the importance of digital solutions in meeting these new reporting requirements."

## Potential beyond the factory

As momentum for developing adaptive industries builds, it is critical that they are designed in a way that best supports not just economic and productivity targets, but also the needs of society at large. In this way, adaptive production has the potential to deliver solutions to some of society's most pressing challenges, even beyond the factory. "I would like to see automation used to [tackle] major challenges for society: health care, curing cancer and dementia, and dealing with the risks of climate change," says Burnstein. "Can we alleviate hunger through robotics and automation? Can we build inexpensive housing for anybody that needs a place to live? I'm going to continue to be an advocate for the importance of adopting robotics and automation, not just in industry, but everywhere."

## Siemens Kalwa factory: A brownfield transformation

**Siemens has transformed its 50-year-old low-voltage switchgear factory in Kalwa, India, into a sustainable digital enterprise, demonstrating how adaptive production can revolutionize brownfield facilities. By integrating digital twins, IT/OT convergence (the combination of information technology and operational technology systems to enable real-time data exchange), and advanced automation, the factory increased production capacity by 35%, reduced its carbon footprint by 86%, and expanded its product range from 77 to more than 350 variants—all on a single production line. This transformation highlights how adaptive production can help businesses everywhere create jobs and economic value for communities while improving operational sustainability and working toward net-zero goals.**

"I would like to see automation used to tackle major challenges for society: health care, curing cancer and dementia, and dealing with the risks of climate change."

Jeff Burnstein, President, Association for Advancing Automation

"Shaping the future with adaptive production" is an executive briefing paper by MIT Technology Review Insights. Laurel Ruma was the editor of this report, and Nicola Crepaldi was the publisher. MIT Technology Review Insights has independently collected and reported on all findings contained in this paper.

We would like to thank the sponsor, Siemens, as well as the following experts for their time and insights:

**Jeff Burnstein**, president, Association for Advancing Automation

**Eryn Devola**, head of sustainability, Siemens Digital Industries

**John Hart**, professor of mechanical engineering and director of the Center for Advanced Production Technologies, MIT

**Simon Johnson**, co-director of MIT's Shaping the Future of Work Initiative

**Jelena Mitic**, head of technology field "Future of Automation," Siemens

## About MIT Technology Review Insights

MIT Technology Review Insights is the custom publishing division of MIT Technology Review, the world's longest-running technology magazine, backed by the world's foremost technology institution — producing live events and research on the leading technology and business challenges of the day. Insights conducts qualitative and quantitative research and analysis in the US and abroad, and publishes a wide variety of content, including articles, reports, infographics, videos, and podcasts. This content was researched, designed, and written entirely by human writers, editors, analysts, and illustrators. This includes the writing of surveys and collection of data for surveys. AI tools that may have been used were limited to secondary production processes that passed thorough human review.

## From the sponsor

**Siemens AG** is a technology company focused on advancing the backbone of economies and societies through industry, infrastructure, transport, and healthcare. At Siemens, more than 300,000 people work together to create technology with purpose and add real value for customers: from more resource-efficient factories, resilient supply chains, and smarter buildings and grids, to cleaner and more comfortable transportation as well as advanced healthcare. By combining the real and the digital worlds, Siemens empowers its customers to transform their industries and markets, helping them to transform the everyday for billions of people. Today, the company offers the industry's most comprehensive digital twin capabilities and is working to make this the key building block for an immersive, concurrent, persistent, and real-time industrial metaverse.

SIEMENS

**Illustrations**

Cover art and spot illustrations created from Adobe Stock.

**MIT Technology Review Insights**

www.technologyreview.com

insights@technologyreview.com