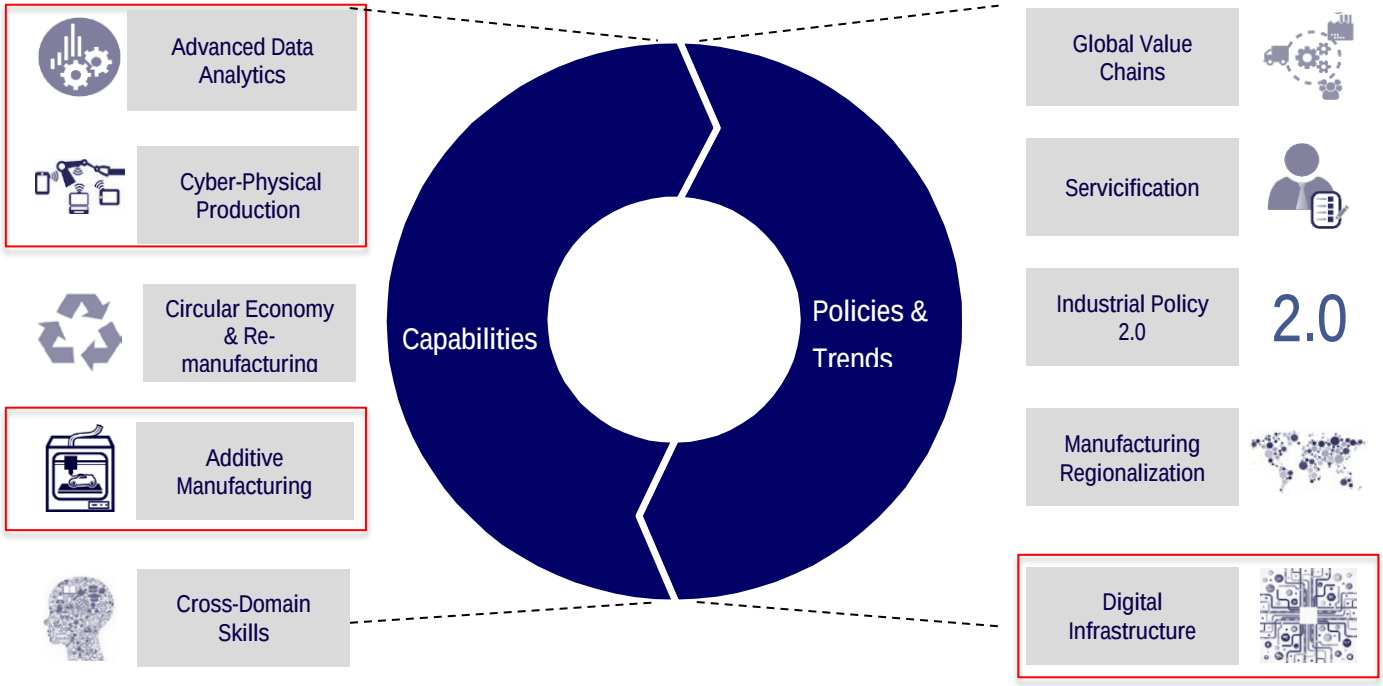
Case 7

# Emerging and Disruptive Technologies for the Future of Manufacturing

Drivers of the Future of Manufacturing




Source: World Economic Forum Global Agenda Council on the Future of Manufacturing, Whiteshield Partners framing

| Energy-based Economies | Least Developed | Developing Economies | Developed or OECD Countries |
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## Executive Summary

# Emerging and Disruptive Technologies for the Future of Manufacturing

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Key facts:

- Technological innovations have transformed the manufacturing industry in the past century.
- The speed of new technology development is rapidly increasing.
- The potential impact of emerging and disruptive technologies on future manufacturing is huge and broad.
- Traditional manufacturing paradigms, operational strategies, system configurations, the labour market, supply networks, etc., will all be transformed.
- Workforce training and skill requirements will also need to change in response to disruptive technological development.

## 1. Evolution of Manufacturing Strategies

Manufacturing technologies have seen revolutionary changes over the last century. Various manufacturing strategies, including mass production, lean manufacturing, flexible manufacturing, agile manufacturing, reconfigurable manufacturing, predictive manufacturing, cyber manufacturing and mass customization, have been introduced to drastically improve productivity, quality, cost and variety. These strategies are realized mostly by enabling technologies such as the Internet of Things, advanced sensors, industrial big data, adaptive machine learning, cyber physical systems, etc.

Rapid advances in material science, artificial intelligence, automation/robotics, optics and mechatronics, among others, are driving transformational change in manufacturing technologies to meet increasingly challenging future demands. Customized functionality, high quality, affordable cost, greater functionality, energy efficiency and environmentally sustainable methods or tools are changing manufacturing.

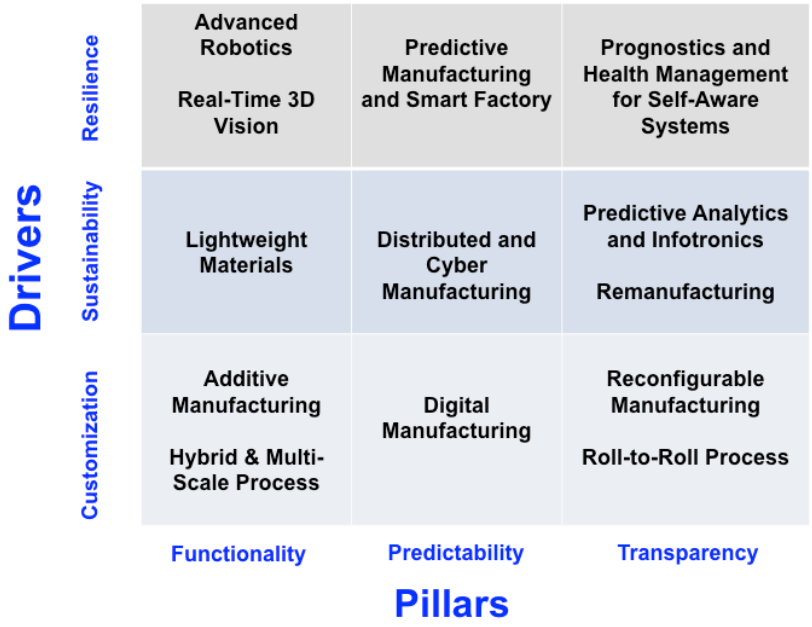
## 2. Emerging and Disruptive Technologies

The following list of emerging and disruptive technologies (in alphabetical order) will likely have significant impact on the manufacturing transformation:

- *Additive manufacturing (3D printing)*: This technology has been under research and development for over 30 years, initially as a rapid prototype tool. The class of materials that can be printed has been expanded greatly, from plastics, paper, ceramics, metals, superalloys, to biomaterials. Developments in additive manufacturing will likely create new applications that will have significant impact on traditional manufacturing methods.
- *Advanced robotics*: A primary example of the successful application of industrial robots is in automotive manufacturing, where robots are used extensively in welding, material handling and painting processes. New and advanced robotics will increasingly be used in precision manufacturing and assembly, in semiconductor fabrication, and even in human-robotic cooperative environments beyond manufacturing.
- *Digital manufacturing*: Recent advances in digital design, engineering and simulation are having a transformational impact on manufacturing enterprises. Traditional experiential and experimental approaches to product development, manufacturing process design and validation, factory automation and supply network development are being replaced by highly efficient digital thread approaches. Digital-Twin technologies will drive new product life-cycle support with smart predictive and prescriptive analytics. Not only might what-if scenarios be evaluated efficiently, but also optimal process conditions can be established digitally without lengthy and costly trial-and-error experiments.
- *Distributed and cybermanufacturing*: The idea of democratization in manufacturing has called for the development of distributed manufacturing strategies, enabled by the DIY “maker movement”, 3D printing technologies, CNC machines and the internet. This promises to transform the traditional labour market, centralized manufacturing hubs, the supply network and the logistics industry. Machine APPs like technologies will be developed with cyberplatforms to create on-demand design and manufacturing.
- *Hybrid processes*: The development of new, advanced materials and the increasing integration of multifunctionalities into a single product have pushed the wide adoption of innovative hybrid manufacturing processes, e.g. the combination of

subtractive and additive manufacturing processes, the use of electro-chemical-thermal-mechanical-optic (multi-physics) manufacturing processes, etc.

- *Lightweight materials and structures*: The demand for energy-efficient transportation vehicles has driven the rapid adoption of lightweight materials and multimaterial structures for the construction of aero, ground and marine vehicles. These new advanced materials and structures call for the disruptive development of novel manufacturing methods.
- *Multiscale processes*: Many advanced products with complex intrinsic features, such as those used in the aerospace and automotive industries, as well as consumer, electronic and medical device products, require the use of macro-, meso-, micro- and nano-scale manufacturing process methods to produce them. This trend calls for the development of advanced equipment that can handle multiscale manufacturing processes and yet still be productive and cost-effective.
- *Predictive analytics and infotronics for intelligent maintenance systems*: In the era of industrial big data, new development in predictive analytics and infotronics has enabled complex engineering equipment and systems to achieve "near-zero breakdown" performance. The monitoring and prognostic health management capability allows manufacturing firms to develop proactive approaches to address the performance degradation of their systems and equipment.




- *Prognostics and health management for self-aware machines and equipment*: Future manufacturing equipment will have the increasingly more sophisticated capacity to sense its environment, monitor its condition, be aware of its own operating performance drift, and adaptively compensate for any deviation from the ideal performance target. It will also be able to reduce the impact of these uncertainties, and give users the opportunity to proactively implement adjustment solutions to prevent the performance loss of the manufacturing system. These new capacities will greatly enhance manufacturing consistency, quality and resilience.
- *Predictive manufacturing & smart factory*: Leading manufacturing firms are adopting highly automated, IT-driven manufacturing planning, scheduling and production controls. Such factories employ smart machines and equipment that have self-aware capabilities, use vast amounts of industrial big data to evaluate and predict production conditions in real time (e.g. cost, quality, productivity, material supply and market demand), and proactively synchronize factory-level as well as enterprise-level resource requirements.
- *Reconfigurable manufacturing systems*: Modern manufacturing systems are increasingly expensive and yet the product life cycle becomes shorter and shorter due to fierce market competition. This dilemma has motivated many manufacturing firms to look for ways to effectively reuse the capital investment for their manufacturing systems, thus leading to the paradigm of reconfigurable manufacturing.
- *Remanufacturing systems*: The increasing pressure for environmental sustainability has created more opportunities for products to be remanufactured after their typical end of life. A properly designed and operated remanufacturing system will not only address the issue of environmental sustainability, but will also increase economic benefits for the manufacturers as well as consumers, leading to a truly circular economy.
- *Real-time 3D machine vision*: Rapid development in pipeline image processing and advanced optics have created unprecedented new capability for real-time 3D machine vision technologies to be widely adopted for advanced manufacturing process control, assembly verification, and in-process product certification. This also helps to provide real-time guidance for advanced robotics.

- *Roll-to-roll processes*: The demand for the high-throughput production of high-quality products has created the pull for the development of roll-to-roll (R2R) manufacturing processes. Advanced R2R processes can significantly change the way many products are made, such as flexible electronics, battery electrodes and cells, solar cells, thin-films, multilayer ceramic capacitors, or even baby diapers.

## Key Outcomes

The rapid development of emerging and disruptive technologies allows:

- Greater flexibility to produce complex products that are multimaterial, multiscale and multifunctional, and that have extreme performance characteristics
- Greatly reduced time to market through the use of digital modelling and simulation tools to evaluate and plan manufacturing processes, system designs and supply network configurations
- Significantly improved productivity and quality to address the issues of increased labour cost and better return on capital investment
- The highly efficient operation of factory assets by the use of industrial big data and advanced data analytics
- The much improved utilization of material resources and reduced energy consumption
- A sustainable manufacturing paradigm

## Drivers & Enablers


R&D investment by public and private partnerships

Demand for productivity, quality, sustainability

- Disruptive manufacturing technologies
- Increased competitiveness

## Barriers

While these emerging and disruptive technologies are causing significant excitement, the following potential barriers must also be noted:

- Significant R&D investment is needed to develop these technologies. The level of investment required is beyond what the private sector can afford. Therefore, effective public and private partnerships are essential to support the R&D efforts.
- New technology adoption and insertion will take years, during which time the coexistence of legacy manufacturing methods and emerging technologies is expected.
- Future workforce development and training must keep pace with the technology adoption rate. It is likely that operating future manufacturing factories will require different skill sets than those of the current workforce.
- The development of sophisticated disruptive manufacturing technologies may further widen the gaps between advanced and developing countries. It is essential to bridge the gap caused by technological advancements.
- The robustness of emerging and disruptive technologies is expected to improve gradually. False expectations may lead to detrimental effects on the development of these technologies.
- Ultimately, no matter the new technologies, their cost-effectiveness must be addressed if they are to make a real impact on manufacturing industries.