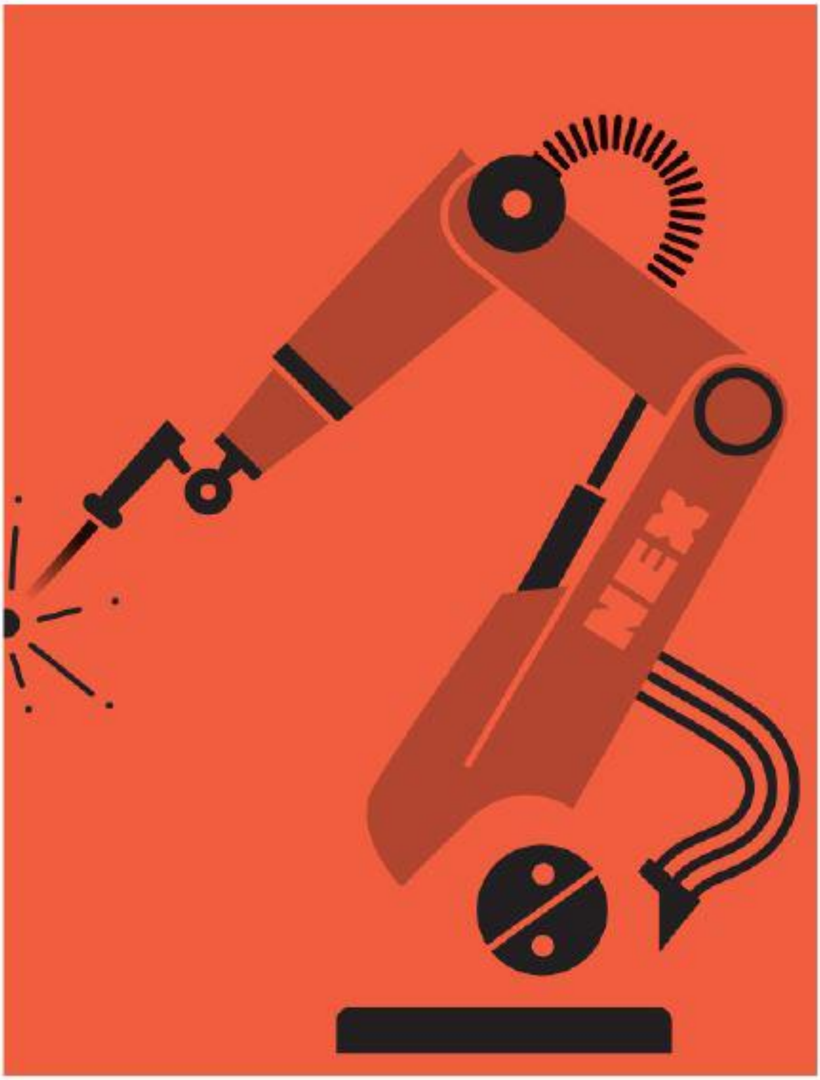

MADE IN NORWAY?

How Robots, 3D-printers and Digitalisation
Bring New Opportunities for Norwegian Industry

Teknologirådet

MADE IN NORWAY?

– HOW ROBOTS, 3D PRINTERS AND DIGITISATION CAN OPEN UP NEW OPPORTUNITIES FOR NORWEGIAN MANUFACTURING

ISBN 978-82-92447-64 – 2 (printed version)
ISBN 978-82-92447-64 – 9 (electronic version)

Published: Oslo, August 2013. English version: October 2014
Cover: Commando Group
Printed by: ILAS Grafisk
Published electronically at: www.teknologiradet.no

PREFACE

Norway has in many ways benefitted from globalisation. Increased global transport and industrial activity have driven up the demand for oil, at the same time as cheap imported goods have reduced price pressures at home.

A concern looming over the horizon is the increasing dichotomy of the Norwegian economy, with its high levels of activity and costs in the oil and gas industry, while onshore manufacturing struggles to stay competitive. What are we going to produce once revenues from fossil fuels decline, particularly since certain aspects of manufacturing are increasingly the preserve of low-cost countries in the east?

This report from the Norwegian Board of Technology is devoted to a new wave of advanced technologies which can offer new manufacturing opportunities to countries like Norway. A new generation of smart industrial robots can produce more quickly, more flexibly and with greater precision. 3D printers are lowering the threshold for design and product development and opening up new niche markets. Generally we are seeing a digitisation of manufacturing which may be well-suited to a small, open economy with high wage costs and high levels of digital competence.

How can Norway best grasp the opportunities to reconstruct “Made in Norway” as a trademark? We have taken a closer look at the steps other western industrial nations are taking in this direction, like the Obama administration’s “Advanced Manufacturing Partnership”, Germany’s “Industrie 4.0” and Denmark’s “Produktivitetkommission”.

The work of the Norwegian Board of Technology on this report has been led by project leader Jon Fixdal (siv. ing. and dr. polit.). During the course of our work we received a lot of good input, including during two open meetings involving speakers from the world of design, architecture, the furniture and shipbuilding industries, robotics and information technology. We would also like to express our thanks to the many individuals with expert knowledge both at home and abroad with whom we have been in direct contact.

Tore Tennøe
Director of the Norwegian Board of Technology

CONTENTS

SUMMARY

There is increasing concern about the growing dichotomy of the Norwegian economy. The oil sector contributes to our high cost levels, whereas many businesses outside this sector are struggling to remain competitive and keep production going. However, a strong manufacturing base outside of the oil and gas sector is important to ensure we have "several legs to stand on", and it will be crucial once our oil and gas revenues begin to decline.

NEW TECHNOLOGY OFFERS GREATER FLEXIBILITY OF PRODUCTION

A wide range of increasingly advanced manufacturing technologies are now emerging. They will change basic assumptions about how products are designed and manufactured, and they will re-dictate the terms governing who can successfully engage in manufacturing and where such production can be based.

- A new generation of industrial robots is currently under development. They are able to produce more quickly, more flexibly and with greater precision. They are extremely reliable and can work in close proximity with people without endangering the latter.
  Baxter is an example of this kind of robot. He has a "head" with a big display, two arms and a body. It does not take long to instruct him in

how to perform new tasks. This can be done by moving the arms in the desired movement pattern. The arms have integrated motors which mean they easily respond to the movements they are made to make. Baxter finds it easy to recognise a new object. All you need to do is hold it up in front of one of the robot's cameras, which are fitted on each arm, the front of the "head" and in his chest area.

- 3D printers construct objects layer by layer in a single piece. Using digital files, they can easily construct highly complex geometric figures, which would be almost impossible to construct in any other way. 3D printers are already a powerful resource in design and product development processes. The technology is also being tested out on production of a range of items, including car bodies, aircraft engine components, prosthetics, buildings and a variety of consumer products. Development is progressing quickly, and there is reason to believe that 3D printers will be an increasingly advanced form of manufacturing technology, and that this technology will be integrated in more established product development and production processes.
- We are seeing a marked increase in digitisation in manufacturing, with more seamless integration of design, product development and production. It will be easier for all involved to exchange information. This is due to enormous improvements in available computing power, the possibility of storing almost unlimited quantities of data, ever-improving infrastructure for data exchange and extremely rapid development in the software available.

THE DEMANDS ON MANUFACTURING IN HIGH-COST COUNTRIES ARE BECOMING MORE SEVERE

Technological development is making the demands on manufacturing in high-cost countries like Norway more severe. We need to produce goods with higher knowledge content, and production itself needs to be increasingly automated and flexible. This will be a pre-requisite of being able to produce cost-effectively and respond quickly to market changes. The requirements in terms of competencies and expertise of those working within manufacturing will change. There will be an increase in the need for staff with high levels of digital competence. This will be crucial if we are to benefit from modern manufacturing technology.

GLOBALISATION CAN BE REVERSED

One of the consequences of this technological development is that a number of businesses in high-cost countries are relocating production home from low-cost countries like China. The technology means that wage costs as a proportion of total production costs are reduced. “Home” production also results in better quality control and a reduction in shipping periods to customers, as well as making it easier to respond quickly to changes in demand. Moreover, development of a product presupposes an understanding of how the product is to be produced. Outsourcing production to low-cost countries can therefore be to the detriment of a company’s capacity for innovation.

Production which is brought back to high-cost countries has to be cost-effective. This therefore contributes to more intensive competition between manufacturers in high-cost countries. It will stimulate the development of new manufacturing technology capable of making production still more efficient.

THE 2013 WHITE PAPER ON INDUSTRIAL POLICY – IMPORTANT, BUT AMBIGUOUS

The most up-to-date review of Norwegian industrial policy is contained in the presentation of the 2013 white paper on industrial and business policy to the Norwegian parliament.[1] The report was entitled “Mangfold av vinnere” (An abundance of winners) and was issued on 7 June 2013. In the report, the government points to the need for proactive use of manufacturing technology and the importance this has for productivity and the ability to compete.

The significance of automation is highlighted, and the report to some extent discusses the importance of digital resources, but there is no discussion of the importance of the digitisation process which is happening within manufacturing. The potential of 3D printers is not dealt with at all. The technological focus of the report appears somewhat limited in terms of how we in Norway are to be able to derive the full potential from using more advanced technology and what the authorities can do to support such a development.

---

[1] The white paper was withdrawn in the fall of 2013 (after the publication of this NBT report) due to the change in administration following the Parliamentary elections in September the same year. The new administration has not launched a new white paper on industrial policy, but they have established a productivity commission and launched a white paper on research and higher education highlighting advanced manufacturing as a prioritized area towards 2025.

The report is at pains to emphasise the importance of investing in areas where we have particular strengths. It mentions in particular shipping and associated industries, energy, environment, travel and tourism, off-shore industries, ICT and healthcare. At the same time it emphasises the point that Norway has a lot of companies which are global leaders in the technology and engineering field. These supply tailored high-tech products in areas like micro-electronics, the defence industry and automotive components.

On the other hand, the government also points out that many of the companies which will support the economy in 20 years' time have not yet been set up. The report therefore appears somewhat ambivalent in terms of what industries we are to invest in for the future.

It is worth noting that some of the businesses in Norway which lead the way in terms of deploying new technology cannot automatically be categorised as belonging to any of the areas cited as those in which Norway particularly excels. Manufacturing of furniture, agricultural equipment, automotive and aircraft components and water heaters are examples of this. The report lacks a more in-depth analysis of which policy measures would be relevant for maintaining and promoting the expertise and production capacity at these businesses.

LEADING INDUSTRIAL COUNTRIES ARE RENEWING THEIR INDUSTRY POLICIES

There is no doubt that Norwegian authorities can learn from their counterparts in countries like the US, the UK, Germany and Denmark. These appear to be more in tune with the development which is driving future manufacturing, and the opportunities and challenges this raises. Industrial policy enjoys a high profile on the political agenda. The importance of greater automation in production is emphasised, and the US, the UK and Germany have all made conscious efforts to investigate the potential of 3D printers and build up expertise in their use and additive manufacturing. The measures include:

- Research projects in a number of areas, including the use of 3D printers, more automation in production, new value chains and how the new technologies may impact on productivity.

- Foresight project on future manufacturing.
- Drawing up strategies for future manufacturing.
- Setting up competence centres for using 3D printers and other advanced manufacturing technology.

SECURING THE FUTURE OF NORWEGIAN MANUFACTURING

If Norway is to be a leading, innovative, dynamic and knowledge-based economy within prioritised areas, we have to be up-to-date in technological development and continually on the lookout for new knowledge. We need a better knowledge base for a policy for future advanced manufacturing. In order to promote the development of future manufacturing, the Norwegian Board of Technology is therefore of the view that Norwegian authorities should consider the following measures:

A best practice analysis. Several Norwegian industrial firms use advanced manufacturing technology. How can we learn from companies like OZO Hotwater, Ekornes, Kværneland, Kleven Industrier AS and GKN Aerospace Norway AS? How do they use advanced manufacturing technology and what significance does the technology have in making them competitive? How do they renew their knowledge of manufacturing technology? What demands does the use of advanced technology make on engineers, management, production scheduling, etc.?

A broad survey of Norwegian manufacturing in general. We need a broader insight into current use of production technology in Norwegian manufacturing. Such an analysis should survey the following:

- The use of automated production within Norwegian manufacturing.
- The potential for streamlining production using increased automation.
- The extent to which 3D printers and modern ICT are integrated in Norwegian manufacturing companies' product development and production processes.
- The companies' plans with respect to upgrading their machine plant and increasing their use of new and more advanced manufacturing technology.

- The needs of these companies in terms of updating their knowledge on how to use modern manufacturing technology.
- The main barriers, in the view of the companies, to their becoming world leaders in the use of advanced manufacturing technology within their particular field/sector.

A foresight project. The project should analyse the potential course of development in advanced manufacturing in the years ahead. What will drive this development in future? What opportunities and challenges does it present? Such an analysis will be important due to the rapid rate of technological change. Just focusing on the current situation entails the risk that any measures or policy development we undertake will not look far enough into the future.

Stimulating greater cooperation between research, manufacturing and government authorities. The purpose of this will be to increase our expertise in advanced manufacturing, make companies more competitive and create the best possible conditions for growth for new and smaller businesses as well. Knowledge transfer and exchange of experience between manufacturing companies which use advanced manufacturing to differing degrees and come from different industry sectors will be important. It will be equally important for manufacturing to communicate its identified knowledge gaps to research centres, and for the latter to disseminate the results of their research to the former. A further objective will be to identify those areas in particular need of state support.

Boosting digital competence in manufacturing. Industrial workers of the future will have to have a high level of digital competence if they are to be able to keep abreast of the most advanced manufacturing technologies. We need to get ready for this. The objective behind boosting digital competence is to ensure that industrial workers have the necessary expertise. This boost in competence should be directed at the education system and industrial workers currently in work, in equal measure. Educational and training establishments should be able to offer training in the use of 3D printers, advanced robots and advanced digital control systems, as well as ways in which digital resources can create new business models. This kind of boost will also aim to stimulate more individuals to want to work in design, product development and manufacturing.

A research strategy. We need an up-to-date knowledge base for developing future manufacturing. This will involve a number of things, including having the necessary knowledge about new technology and new types of manufacturing and value chains. An assessment of our own innovation or research programmes should be included in the survey. The strategy should draw on the results obtained from analysing the current state of manufacturing in Norway.

A FUTURE FOR NORWEGIAN MANUFACTURING

There is increasing concern about the growing dichotomy of the Norwegian economy. In Norway, the oil sector contributes to the country's high cost levels, whereas a large number of businesses outside this sector are struggling to remain competitive and productive.[2] High wage and cost levels are a major contributory factor to this latter problem. It will be unfortunate if the oil and gas industry becomes over-dominant. We need "several legs to stand on", both because that in itself brings security and because the revenues from the oil and gas industry will at some point start to decline.[3]

No one can with any certainty say what we will live off "after the oil runs out". It is highly likely that expertise from the oil and gas sectors and from other established industrial activity will play a role in Norwegian manufacturing in the future. But new areas of economic activity may also emerge, driven by the development in comparatively new technology areas, such as IT or nanotechnology, or by disruptive changes.

[2] See for instance Industry Policy Report 2013 (Report to the Storting 39 (2012–2013)), Financial Markets Report 2011 (Report to the Storting 24 (2011–2012)) or Federation of Norwegian Industries Business Trend Report 2013.

[3] This is also highlighted in the Perspective Report (Report to the Storting 12 (2012–2013)).

NEW TECHNOLOGY – NEW INDUSTRY

Production of goods and services will continue to be one of the main foundations of industrialised societies. It provides jobs, wages for employees and tax revenues for the authorities. The factory is also a laboratory for developing new ideas and forms of production. Equally, we know that economic growth and the ability to remain competitive require innovation. New products have to be developed, and product quality and the efficiency of production processes have to be continuously improved.

Currently a number of factors which impact on what is produced and where and how it is produced are undergoing changes which are in some cases wide-ranging. New technology like 3D printers and more advanced industrial robots are making it possible to produce more quickly and with greater precision. Increasing digitisation of manufacturing is bringing a sea change to the possibilities for interaction and information exchange between designers, product developers, production workers, administration and customers. As a result, new business models are emerging.

Here in Norway, we are certainly not being left high and dry. We have some exciting businesses like OZO Hotwater, Kværneland and Kleven Industrier AS. We also have some exciting research initiatives like SFI Norman, a centre for research-driven innovation which is carrying out interdisciplinary research on the next generation of production technicians.[4] This is a good starting point for further investment.

THE NEW INDUSTRIAL POLICY

Many countries have been severely hit by economic recessions and are working hard to counteract growing unemployment and create new jobs. The US and Denmark are two examples. In order to improve competitive edge and secure employment, the authorities in a number of countries are attempting to streamline manufacturing and stimulate companies into relocating production back home from low-cost countries, a process known as “homeshoring”. They are also investing heavily in developing and bringing on line more advanced manufacturing technology, such as more advanced robots and 3D printers.

[4] www.sfinorman.no.

In parallel with the work of government authorities aimed at securing jobs, companies are finding that relocation of production to low-cost countries ("outsourcing") can have a definite downside. Among other things, it can lead to deterioration in production and design competence, make quality control more difficult and result in long supply lines. It also makes it more difficult to respond quickly to changes in demand. There is a definite tendency for more and more people to seek out products suited to their specific needs and preferences, as well as for trends and fashions to change more frequently.

NORWAY WILL BE AFFECTED

The development now underway affects most industrialised countries and a wide range of companies. Norway is no exception, and the development represents both a challenge and an opportunity. The challenge resides in the fact that when foreign competitors manufacture products more efficiently and which are better suited to the customer, this puts greater pressure on Norwegian companies to streamline their own production. The high cost levels found in Norway add further to the need to streamline production.

For Norwegian companies which manage to keep up with this development, it will represent an opportunity to streamline their production, create new value chains, increase their earnings and capture new market shares.

The development of new manufacturing technology, changes in demand and a new understanding of where and how manufacturing can and should be undertaken will dictate the terms governing the manufacturing of the future. It will also alter the balance of international competition. It is therefore important to closely follow the development of this technology, understand the forces which will drive it in future and what importance it may have for manufacturing in Norway and for Norwegian industrial policy. That is the subject of this report.

STRUCTURE OF THE REPORT

The report is structured as follows. In Chapter 2 we look at important features of the technological development within manufacturing. The main focus is on increasing automation, the increasing use of 3D printers and digitisation. Chapter 3 focuses on what makes companies bring their production home from low-cost countries and the consequences this can have for what is produced and how. This is followed in Chapter 4 by a review of the new report to the Norwegian parliament on industrial and business policy – “Et mangfold av vinnere” (An abundance of winners). Then we will provide some examples of the work being undertaken in the US, the UK, Germany and Denmark (focusing mainly on the first three) to safeguard future manufacturing. This is followed by a brief discussion about what Norway stands to learn from these countries, before concluding the report with a proposal as to what the Norwegian authorities should do to make proper provision for future manufacturing in Norway.

A NEW INDUSTRIAL REVOLUTION?

Technology is important in most production processes. Whether these involve extraction of natural resources, refinement of raw materials or the production of manufactured products for the business or consumer market, technology is used in the processes.

Technological development will in future be driven by the search for new and better products and by efforts to improve productivity. This development is often incremental, but now and then there are big leaps, at which point talk of a revolution is justified. The invention of the steam engine, the assembly line and the Internet are all examples of this.

In what follows, we will focus on three areas of technology which are important for the kind of development we are now seeing in the field of manufacturing:

- The emergence of a new generation of industrial robots
- Developments in the field of 3D printers
- The increasing digitisation of manufacturing.

2.1 NEW INDUSTRIAL ROBOTS

A robot is a machine which has been programmed to move along three axes so as to perform defined work tasks. Today robots are used in many different sectors, such as agriculture, fisheries, packing/distribution, pharmacy, health, the oil and gas industry, as well as in discrete manufacturing, e.g. cars and electronic components. Robots are also beginning to make inroads into the domestic goods market, in forms such as lawn mowers, vacuum cleaners and robots which can crawl along roof gutters to remove leaves and other rubbish.

The first robot was created in 1937, using mainly Meccano parts and a simple electronic motor.[5] The first industrial robot appeared in 1959. It weighed two tonnes and could be operated to an accuracy of 2.5 tenths of a millimetre.[6]

Currently, around 1.1 million industrial robots are in use throughout the world. Since 2005 between 105,000 and 170,000 new industrial robots have entered service each year. Car production has seen the biggest expansion in their application, with around 80% of all production now automated due to their use. South Korea, Japan and Germany – three major car-producing nations – have the most industrial robots per man-hour in manufacturing.[7] Statistics of the International Federation of Robotics for 2012 show that the number of industrial robots per employee in manufacturing in Norway is lower than the average for the organisation's member countries, and also below countries like Denmark and Sweden (we will have more to say on robots in Norwegian manufacturing on page 15):[8]

- South Korea and Japan: approximately 350
- Average for member countries: 55
- Denmark and Sweden: approximately 150
- Norway: approximately 40

[5] Wikipedia/Meccano Magazine (1938).
[6] International Federation of Robotics (2012a). The robot's accuracy is stated as being "1/10,000 of an inch".
[7] International Federation of Robotics (2012b).
[8] International Federation of Robotics (2012b). All figures relate to the number of robots per 10,000 employees in manufacturing.

Robots have been in use for many years and improvements are continually being made. Nowadays there are many different kinds of robot, ranging from those specially designed to only handle a couple of kilos to those which can lift up to a tonne. They are extremely reliable. At the same time, we are witnessing the appearance of a new generation of robots which are:

- more precise, allowing them to perform more difficult tasks, deliver higher quality and repeat the same movement patterns a greater number of times with less risk of deviation.
- lighter, so that they need less space and are easier to deploy.
- more flexible, allowing them to perform a greater number of different work tasks.
- easier to program.
- equipped with better sensors which make them safer, so that they can work to a greater degree side by side with people.

Robots' ability to "learn" is also being improved, together with the software that controls them. They are able to carry out their intended tasks even better. This capacity for improvement is closely linked to the great progress made in programming and computing capacity, which again is an important component of the increasing digitisation of manufacturing (cf. Chapter 2.3).

An example of the new type of robot is Baxter, developed by the iRobot company in the USA.[9] The robot has a "head" with a big display, two arms and a body. It does not take long to instruct him in how to perform new tasks.[10] This can be done by moving the arms in the desired movement pattern and combining this with selecting one of the pre-programmed movement patterns on displays fitted to each arm. Even though the arms are big and heavy, they are easy to move, because the integrated motors make the arms respond to the movements they are made to make. To get Baxter to recognise a new object, you can hold it up in front of one of the robot's cameras, which are fitted on each arm, the front of the "head" and in his chest area.

[8] See www.rethinkrobotics.com.
[10] According to iRobot, the robot can be reprogrammed "within minutes".

In what follows, we will mainly focus on the use of robots in discrete manufacturing.[11] Here robots may be used for e.g. welding, drilling, milling, punching, painting and assembly of various components in a given sequence (e.g. a car).

WHY USE INDUSTRIAL ROBOTS?

The use of robots in manufacturing can have many benefits:

Streamlining of production processes: Modern robots can work faster and with greater precision, generally 24 hours a day. One robot will be able to replace many people if the same tasks would otherwise have been performed manually. This means that more units can be produced in a shorter time and at lower cost.

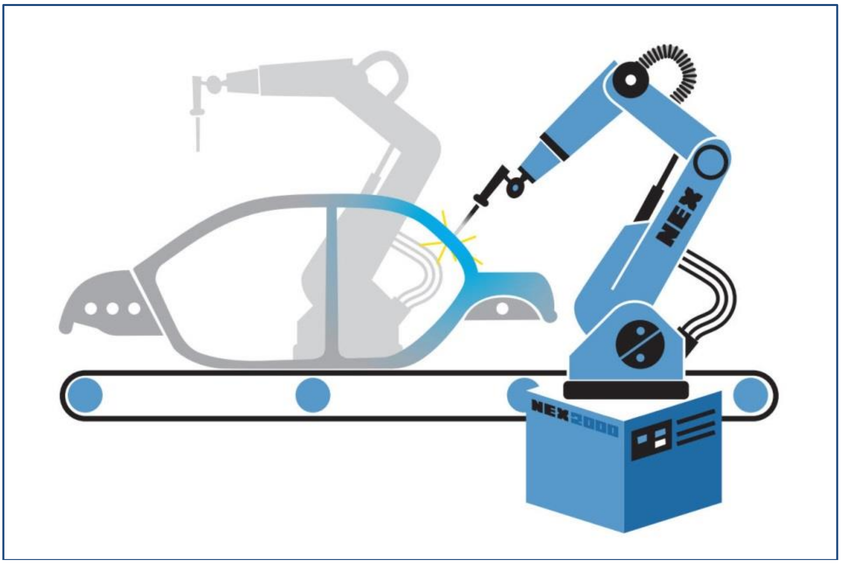

Figure 1: Modern industrial robots can work quickly, precisely and very reliably.

By way of illustration, let us take this example from Norwegian furniture manufacturer Ekornes. The company produces up to 1,500 chairs a day, split

[11] This means we will be disregarding robots designed for use in the home. The examples we will be referring to below are mainly associated with production processes within mechanical engineering, but many of the arguments will also apply to a large degree to other sectors, such as the production of food items and the pharmaceuticals industry.

into around 400 different versions, involving different control options, seat height, design, fabric and colour options, for instance.[12] The combination of a large number of manufactured units and the huge range of versions imposes demanding requirements on the production process. By automating the early part of the process where the basic components are assembled, the human input is focused on implementing the variations.

Reduction in the use of resources: A reduction in the use of resources results in reduced costs, as well as potentially impacting on companies' environment/climate profile (see also Chapter 3.2). Automating the production process can contribute to that. This may be illustrated using an example from the manufacture of car roofs. The roofs are large pieces of metal, which are often punched out from an even larger piece of metal. One of the side-effects of this process is a lot of "off-cuts", i.e. material which will be left lying around and for which there is no other use in car production. New industrial robots give us the option of being able to split the roof into several parts, which are stamped from the same piece of metal before being welded together to make a complete roof. By splitting the roof up into smaller parts, it is easier to utilise a larger proportion of the raw stamping material. This reduces the amount of off-cuts as well as the total amount of material used.

Improved quality: Manufacturing often has to meet very high quality requirements, based either on customer wishes, government authority requirements or international standards. An example of this is the welding of hulls in modern shipbuilding. The quality requirements are so strict that it is extremely challenging for even an experienced welder to weld to a satisfactory standard. For a modern robot welding system the task will be a lot easier, and it can perform it time after time with the same degree of precision and quality (see also the box overleaf).[13]

Reduced risk: Robots can be used for processes which are too dangerous for people to perform. These may be processes which involve high levels of heat or chemicals, for instance, or where there is a danger of coming into contact with moving parts within the product or the production process. From this perspec-

[12] Personal correspondence with the Ekornes furniture company.
[13] Based on personal correspondence with Kleven Industrier AS, as well as Teknisk Ukeblad of 23 January 2012 and the 28 May 2013 issue of the magazine PåSpissen.

tive, the use of robots may be seen as a measure which promotes HSE (health, safety and the environment).

CONSEQUENCES OF INCREASING AUTOMATION

Increasing use of robots impacts on the content of and the general conditions governing manufacturing. Firstly, the need for people to carry out production work decreases as automation increases. This means that even though robots can contribute to maintaining industrial activity which would otherwise be threatened with closure or relocation, it is far from clear that employment could be kept at the same level. If production volumes are kept constant, increased automation can reduce staffing needs in the production processes themselves. In the worst-case scenario, we may well have to face "technological unemployment".[14] If we want to maintain employment in parallel with increasing automation, production volumes will presumably therefore have to increase. The fear of unemployment of this type may well be overstated, however. Increasing automation will result in a need for new types of expertise, in areas linked to logistics, programming and robot control, to name but three.

[14] Brynjolfson and McAfee (2012).

Robot welding systems at Kleven Industrier AS
Kleven Industrier AS is based in the Norwegian municipality of Ullstein. The company produces advanced sea-going vessels for the oil and gas industry, among others. For a time the company had its hulls made in a low-cost country, but has now started to produce the hulls as modules which are welded together at its own shipyard in Norway.

One of the main reasons for this is that the company sees a need for employees with all-round competencies in shipbuilding. The best way to achieve this is for them to have control of larger areas of the production process. The result is better quality, speedy construction and therefore fewer faults and delays.

The company has also invested in new robot welding systems. The robots are extremely precise, can work 24 hours a day and are very quick. A trial carried out by the company showed that an ordinary robot welding system can weld at 0.5–0.7 metres a minute. The new robot welding systems can weld at 2.0–2.7 metres a minute. By comparison, a person will weld at a rate of around 25 cm a minute. By using the new robots, two operators will be able to replace around 20 welders.

Automation also contributes to a decrease in the proportion of total production costs represented by wages costs. This means there is a lot less to be saved by relocating production to a low-cost country (see also Chapter 3), and it may become easier to retain and develop manufacturing in a high-cost country like Norway.

Increasing automation will change the type of expertise needed within manufacturing. There will be a greater need for people who can program, monitor and control the new machines. The need for operators of the traditional types of machine used in production will decline. Instead of standing in the production hall handling and monitoring the machine itself, staff will be in a control room monitoring computers which keep the production process running properly.[15] We can envisage a development where industrial workers move from being the people who themselves process materials and assemble them into the intended products to being rather like an air traffic controller (see Figure 2).

[15] An illustration of what future manufacturing will look like can be found at www.terotech.no/138/fremtidens-fabrikk-volvo-aero-norge.

Automation will also impact on the balance of international competition. When foreign competitors increase automation levels in their manufacturing processes, thus cutting their own costs, Norwegian companies will have to further streamline their own production processes if they are to retain their competitive edge. Automation in other countries thus becomes an important driving force for automation in Norwegian companies.

Industrial robots will not eliminate people from production processes, but they will alter staffing needs and the type of expertise demanded and will have an impact on the cost structure of the processes.

AUTOMATION IN NORWEGIAN MANUFACTURING

As already mentioned, the statistics provided by the International Federation of Robotics (IFR) indicate that Norwegian manufacturing deploys a lower than average number of robots. We are also below Sweden and Denmark in the table. These both have around 150 robots per 10,000 manufacturing employees, while Norway has barely 40.[16] New sales in Sweden are running at around 900–1000 robots a year; in Norway the figure is 80–120.[17]

However, several Norwegian companies have highly automated production processes. The furniture industry has a high number of robots, and Norwegian companies also use robots for the production of equipment for the oil and gas sector and agriculture, as well as automotive and aircraft components and water heaters. Many of these have highly advanced production processes.

The reason for Norway having fewer industrial robots than many other countries is probably complex. To some degree it is due to the limited areas of manufacturing where automation can play a role. Equally, automating production requires time and long-term competence development. From this perspective, the fact that we are a relatively young industrialised nation may have something to answer for, and

[16] International Federation of Robotics (2012).
[17] Information provided by James Anders Fox, KUKA Systems.

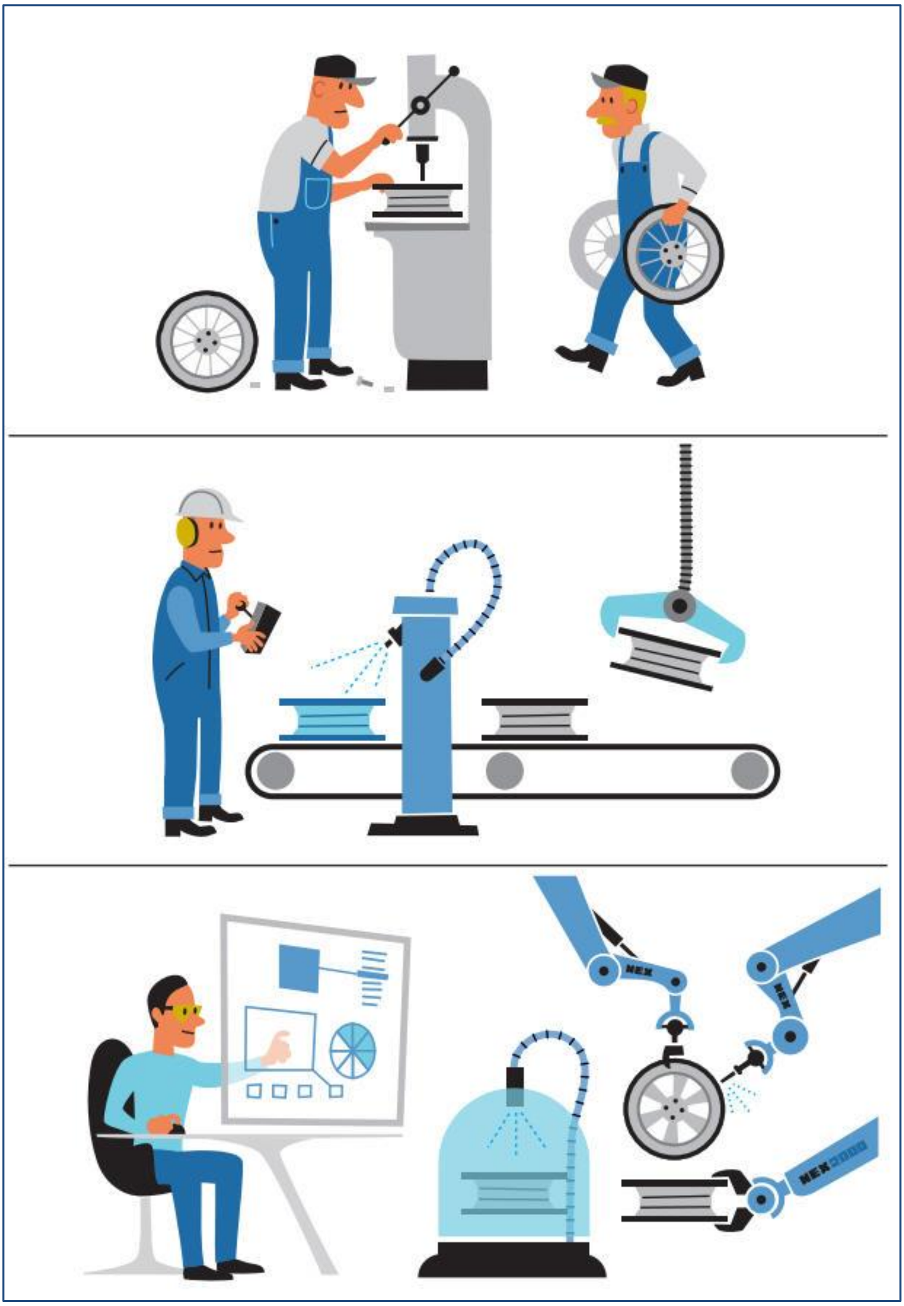

Figure 2: Industrial work is in a process of continuous development. Machines have increasingly replaced manual work. In future, workers will be like air traffic controllers.

compared to many other countries we have had a limited amount of time to build up skills and expertise.

High cost levels in the Norwegian economy make it challenging to retain manufacturing here. These can make it difficult to take a long-term view. It is also a question of whether we as owners have among our ranks actors with a sufficiently long-term perspective, or whether, on the other hand, the costs involved in running a manufacturing company in Norway may make it more worthwhile to sell promising businesses to foreign buyers rather than developing their potential by keeping them in Norwegian hands.

It is not however clear whether the relatively low level of automated production represents a weakness in current Norwegian manufacturing. If those companies which want to benefit from automating their production have actually done so, we can see that the problem is not an urgent one. But if we look further into the future and assume that Norway will have to increase her manufacturing as oil and gas revenues decline, a lack of automation will be a distinct hindrance (we will return to this in Chapter 4.2).

2.2 3D PRINTERS

A 3D printer is a machine which constructs three-dimensional objects from a computer-aided drawing. The items are constructed layer by layer as a single piece, instead of being assembled from different components. The CAD drawing is created either by scanning a physical object or by having a designer draw it. 3D printing is also referred to as “additive manufacturing” and “rapid prototyping”.[18]

The first 3D printers appeared in the early 1980s. The technique was called stereolithography and used lasers to cure added layers of a light-sensitive liquid polymer (photopolymer). Nowadays 3D printers can be split into three main groups. Liquid-based models, to which stereolithography belongs, use UV light to cure added layers of a photosensitive liquid. Extrusion-based ma-

[18] The terminology is still evolving, but 3D printing is the term which looks to become established in general parlance. “Rapid prototyping” can also cover other techniques such as milling.

chines press a heated plastic material through a narrow nozzle, the material being fused together with the previous layer. In powder-based machines a powder solution is cured using laser. Printing of an object can take from a few minutes to many hours, depending on the item's complexity and the technique used.

The most common material for use in 3D printers is plastic. Other possibilities are plastic/polymer mixes, ceramic materials and various metals. There are materials where the end product is completely non-elastic and materials where end products are elastic. What material is used depends on the properties required of the finished model and the type of 3D printing used. The cheapest 3D printers use plastic.

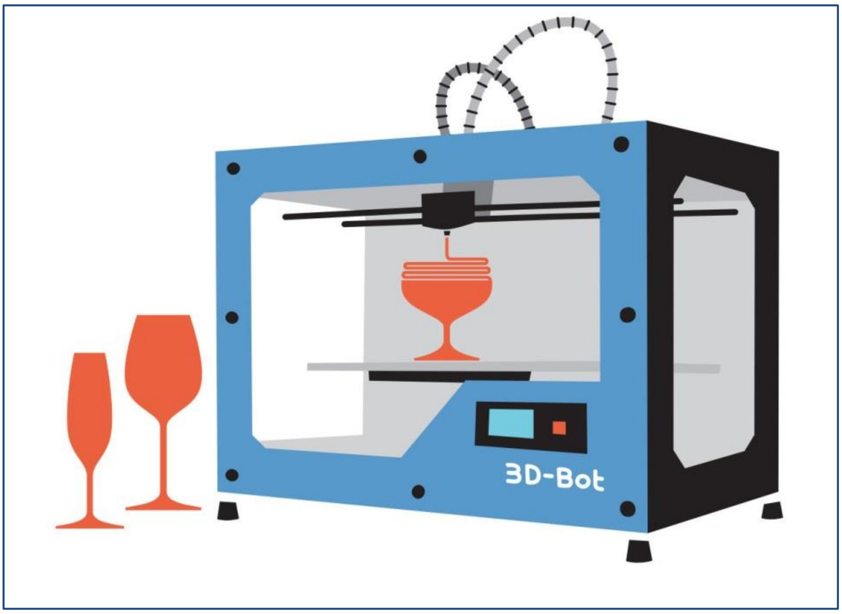

Figure 3: 3D printers construct objects layer on layer in a single piece.

AVAILABILITY AND EXTENT OF USE

3D printers are commercially available in various sizes and qualities, ranging in price from a few thousand to six or seven million Norwegian kroner. More expensive machines can construct larger objects, with greater precision, and the options for combining materials and colours are better.

In recent years the choice of relatively cheap 3D printers has grown considerably, and there are more than 60 different models. The number of printers sold on the Norwegian domestic market has increased tenfold in three years, from 1,900 in 2009 to around 6,900 in 2010 and around 35,000 in 2012.[19]

Many Norwegian firms use 3D printers. Examples are architect offices, furniture manufacturers, design offices and model building workshops which assist customers with product development and industrial design.

APPLICATIONS

3D printers have many applications. The applications which have been most evident so far may be divided into three main groups:

Construction of prototypes: Prototypes can be extremely useful for testing the form and function of a product, making it easy to compare different concepts, whether the item in question is a tool, an item of furniture or a mechanical component. If the prototype has to be modified, this can be done relatively easily by making adjustments to the drawing and printing a new one. This can result in a significant reduction in cost and time compared to more traditional model construction where models are built by hand. Card, paper and modelling scalpels are replaced by a PC and 3D printer.

Visualisation of physical objects: Visualisation is important in e.g. product development processes, architecture and marketing. Cooperation and product development are often easier if the starting point is a physical object rather than a drawing. The visualisation principle of “grab it to get it” is an important and useful one. Many 3D printers can also print in several colours. The colours can be used for a number of purposes, including to highlight the forces an object will be subject to and the stresses this will cause.

Production of specialised end products: One example is a specially adapted hearing aid based on a cast taken of the patient’s auditory canal; an-

[19] Wohlers (2013).

other is prosthetics. Printing of spare parts is a further possibility. The US armed forces see this as an interesting option for forces operating a long way from home.

Applications of and trials involving 3D printers are however developing at a tremendous rate. The list of products already created using 3D printers (or where these have been used in getting production underway) is long and is getting longer by the day. Here are some examples:

- Urbee is a two-seater hybrid car with 3D printed bodywork.[20]
- A Dutch firm of architects plans to build a house with the aid of a 6 metre high 3D printer during the course of the current year.[21] Another company is developing technology for 3D printing of buildings using concrete.[22]
- An American firm is using 3D images of a patient's body (e.g. their one remaining leg) as the starting point for 3D printing of unique, specially customised prosthetics which result in a very symmetrical appearance.[23]
- Rolls Royce has obtained support from the EU to research into the potential use of 3D printers in the production of aircraft engine components. The intention is to minimise the use of materials.[24]
- The Defence Distributed company in Texas, USA has built the world's first 3D printed pistol. It was discharged for the first time in April this year.[25] The developer had permission to build the pistol, and the drawings were made available on the Internet. Four days later the pistol drawings had accumulated more than 100,000 hits. A bill has already been proposed in the US congress to ban all 3D printed weapons.[26]
- Model aircraft,[27] guitars,[28] dresses,[29] and bicycles[30] are other examples.

---

[20] www.urbee.net.
[21] www.dezen.com.
[22] www.contourcrafting.com.
[23] www.bespokeinnovation.com.
[24] lib.bioinfo.pl/projects/view/22292.
[25] www.defdist.com.
[26] www.govtrack.us/congress/bills/113/hr1474/text.
[27] www.newscientist.com.
[28] www.cubify.com.
[29] www.psfk.com.
[30] www.eads.com.

Research is also ongoing into printing electronics and food. For instance, researchers at Princeton University in the USA have printed an ear prosthetic with integrated electronics.[31] Research is also being undertaken into printing of chemical substances, for use in the medical field, for instance.[32] These types of use present new technological challenges, including how to print several types of material at the same time and how biological materials can be used in a printer.

The list above also shows that the use of 3D printers is already spreading to many different sectors. It is reasonable to assume that this trend will help further improve the technology, resulting in still more new applications. Overall, this all goes to support the thesis that 3D printers will be an increasingly common tool in manufacturing in the years to come.

UNIQUE PRODUCTS AND MOBILE FACTORIES

3D printers can have several advantages over more traditional methods of fabricating different types of models and objects. First of all, 3D printers are able to produce highly complex geometric shapes which would be almost inconceivable using other technologies (see the illustration in Figure 4). With a precision down to 0.1–0.2 millimetres, extremely small geometric details can be generated with a high degree of accuracy.

3D printers also have the potential for creating objects which are completely unique ("one of a kind"). Whether the object is drawn completely from scratch or modifications are made to an existing data file, it is possible to make a product which is fully customised to the individual user's needs and wishes. Artificial legs are an example.

A third advantage of 3D printers is that they open up the possibility of distributed manufacturing and mobile factories. Many 3D printers take up less space than a dishwasher. It is in principle possible to undertake production wherever you want, as long as you have access to a PC and a 3D printer. Seen in this light, the increased use of 3D printers, along with new business models based partly on use of this technology (see below), represents a kind of democratisation of the manufacturing sector. Anyone at all can in principle be a designer and

[31] Mannoor et al. (2013).
[32] See for instance www.chem.gla.ac.uk/cronin/.

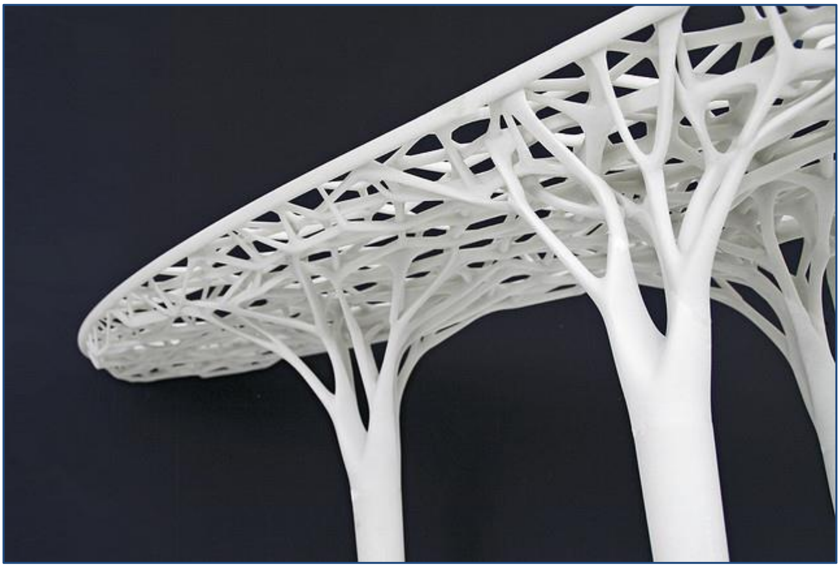

Figure 4: 3D printers can construct geometrically highly complex models. The illustration shows an extract from “The Trabecula Bench”. The bench is 36 cm in height with a length of 180 cm, and the bench’s structure is based on that of bird bone.

manufacturer, simply by setting up a production process in their garage, cellar or kitchen. In principle, it is irrelevant whether you live in Oslo or in Otta, in London or in Lillehammer.

The combination of the possibility of being able to easily produce unique customised products and the possibility of anyone at all being able to produce whatever they want means that 3D printers can help break down the standardisation on which mass production is based. It is this combination which gives the technology its particular potency and which makes one ask whether we may not after all be in the throes of a revolution.

CHALLENGES FOR THEIR FURTHER EXPANSION

3D printers can make production cheaper and more easily accessible to everyone. We can all become our own designer. The potential is massive. Will 3D printers be able to change how we produce things, just like the PC changed the way information is processed?

One challenge relates to so-called “multi-material” processes. A lot of modern products are made up of different types of material, e.g. plastics, metals and fabrics. This is true of everything from relatively simple products, like running shoes, to more complex ones, such as smartphones. This complexity makes the products difficult to manufacture in a simple machine. Nowadays there are 3D printers which can use several materials in the same process, but these relate mainly to different types of plastic/polymer. Printing can also be done using other materials, such as metal and wood, including by mixing these with various types of plastic, but multi-material functionality will have to be improved before printing of really complex products becomes a realistic option.[33]

Another challenge relates to something which is highlighted as a major benefit of 3D printers – the manufacture of products specially adapted to the customer’s needs. This kind of customisation requires either that you design the product yourself or you modify an existing data file. Both of these require a certain level of competence in design and IT. It is therefore far from certain that “anyone” will be able to benefit fully from a 3D printer. On the other hand, there is reason to believe that software will be more user-friendly and 3D printers easier to use, so that the threshold for utilising the technology will be lower (this is related to digitisation of manufacturing, see Chapter 2.3).

Production for higher-volume sales may also be a challenge. This kind of use of 3D printers assumes that the technology can print quickly and cheaply enough to compete with more established manufacturing technologies. Many of the established technologies are however highly sophisticated and fast, and as a result there has been a significant drop in production costs per manufactured unit. It may be useful to draw a parallel with the printing of text on paper. If relatively few copies are needed, a printer of the type found in most workplaces suffices. If, however larger print runs are required, it is quicker and often cheaper to have the document printed at a professional printer’s. 3D printers are a young technology, and the potential of this technology for mass production remains to be seen. At the moment it is too slow for higher-volume production, but it is not certain that this will not be an important area of use for 3D printers.

[33] The Shapeways company prints in metal by printing layer on layer with a certain type of glue on a bed of metal powder. In this way a metal object is built up.

Another potential limitation may be the material properties and mechanical characteristics of the products. Can objects be printed so that they are strong enough to withstand long-term use?

The use of 3D printers can increase the potential for low-volume production. The “tailoring” of products to customer requirements and niche market production can be economically viable. These markets have been referred to as “the long tail” (see Figure 5)[34]. While much of today’s mass production has its economic justification in high volumes of more or less identical products and excludes production of specialised products in low volumes (the long, flat “tail” in the figure), 3D printers will in principle be able to make production of this type economically viable. This assumes of course that they can be used to manufacture products of sufficiently good quality.

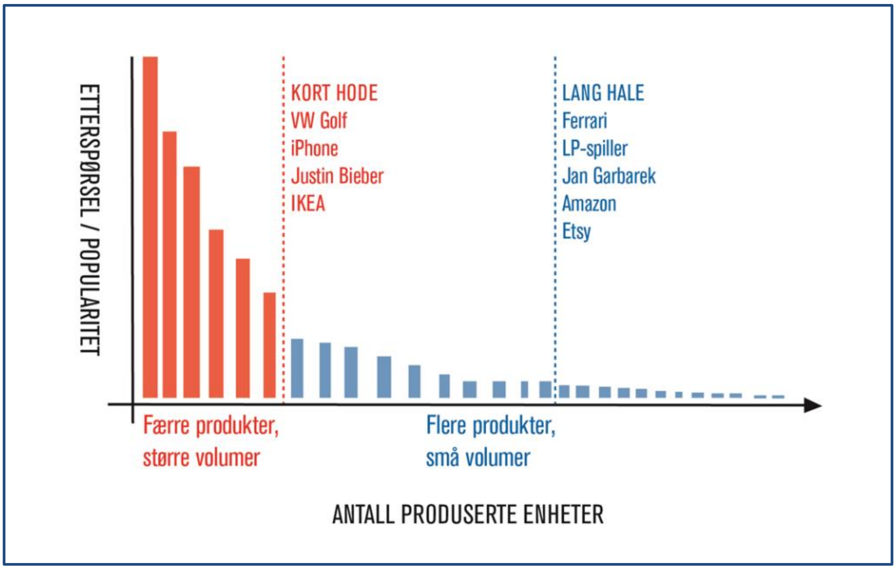

Figure 5: The “long tail” illustrates the fact that there are many products for which there is low demand. New technology can make these economically more viable to manufacture.

[34] Anderson (2006).

Each year the Gartner company creates an overview of emerging technologies and the expectations made of them. The result is presented in what is termed the "emerging technologies hype cycle".[35] In the figure for 2012, 3D printing is at the very top of the curve, on what is called the "peak of inflated expectations" (see Figure 6). This means that 3D printing is seen as a technology for which many have great (possibly too great) expectations, and where it will normally take several years before the real potential of the technology is understood and its most useful applications identified. For 3D printing, in 2012 Gartner estimated that this would take between five and 10 years.

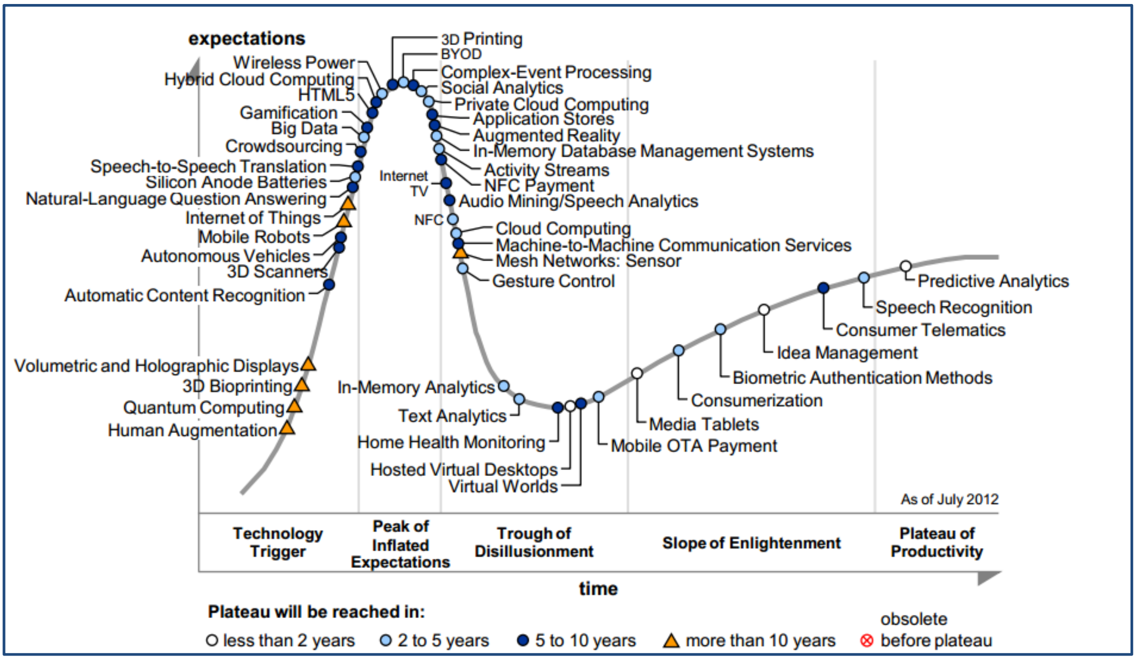

Figure 6: Gartner's "Technological hype curve". The curve indicates that great expectations are made of 3D printing.

One of those with great faith in the potential of 3D printers is the American Chris Anderson. Formerly editor of "Wired" magazine, in his book "Makers –

35 www.gartner.com.

the new industrial revolution”[36], he argues that 3D printers, together with other technologies and digitisation of manufacturing (see below), are in the process of creating a revolution.

Anderson is of the view that a new culture of cooperation between those involved in design and development processes is unfolding. Digital resources are being used a lot more actively in design and product development, and at the same time a cultural norm is evolving for sharing design and working with others online. In addition, common design file standards make it possible to send files to production sites/businesses so that the new item can be manufactured.

Anderson believes that this will lead to the major industrial actors no longer just competing with each other, but also with a sizeable number of very small competitors who can develop an idea into a commercial product in a very short time. The number of such actors is rapidly increasing. He sees this way of thinking and sharing designs as more than just an effective method for innovation. He calls it “... a belief system as powerful as democracy or capitalism for its adherents”. He draws a parallel with the Internet and the way this has altered how we communicate with each other and how we retrieve and convey information.

Nevertheless, there is some disagreement as to the exact importance of 3D printers for the further development of manufacturing. There is little doubt that it is a very useful tool for visualisation and model building, and the technology is already well-developed and has been deployed for this purpose by a number of actors. Exciting too are the many trials being undertaken in use of the technology in e.g. house building and complicated production processes, such as aircraft engine component manufacture.

The big “disruptive” potential of 3D printers is however mainly linked to their potential for allowing anyone at all to be able produce whatever they want, and for allowing printing of complex objects (multiple materials, advanced functionality) in one piece. This potential is not yet realised, and it is not clear how long it will take before this (possibly) happens.

[36] Anderson (2012).

In the short to medium term, in all major respects 3D printers will therefore be a supplement to, rather than a replacement for traditional production processes. It is also possible that they will so remain, and that 3D printers will not to any serious extent dislodge manufacturing technology which is more established. Nevertheless, there is no doubt that use of 3D printers is spreading all the time to new types of product (cf. the list on page 27) and that development is progressing fast. In some cases it is big major manufacturing players which are researching use of the technology, like Rolls Royce and the European Aeronautic Defence and Space Company (responsible inter alia for Airbus), and development has the support of government authorities in countries like the US, the UK and Germany (see Chapter 3).

There is therefore reason to believe that 3D printers will be an increasingly widespread and advanced form of manufacturing technology, and that this technology will be integrated in established product development and production processes in an increasing number of new ways.

2.3 DIGITISED MANUFACTURING

At one time, different contributors to product development processes had their own allotted role, with separate models and tools. Now we are seeing more seamless integration of design, product development and production. Different actors can work using the same data model as their starting point. Cooperation is made easier and can progress quicker. The complexity of design and product development processes can be reduced.

Underlying this development are enormous increases in available computing power, the possibility of storing almost unlimited quantities of data, ever-improving infrastructure for data exchange and extremely rapid development in the software available.

The digitisation of manufacturing revolves around what we may term “digital objects”. These are data packages which describe the shape, material and fabrication of a physical object. If these digital objects are shared by an increasing number of people, at the same time as an increasing number of people can modify the content and implement it in new objects, the general conditions governing manufacturing will undergo significant change. The extent and rate of this change process is uncertain, but there is no doubt it represents something completely new as against traditional manufacturing.

Developments in the field of industrial robots and 3D printers are thus part of a greater development where an increasing proportion of product development and production processes are being digitised.

FROM "CONNECTED" TO "HYPERCONNECTED"?

Digitisation of manufacturing is part of a much greater social transformation in which digitisation plays a key role. In 2005, Thomas Friedmann wrote a book entitled "The world is flat".[37] In his book he pointed out how the world was already at that time in the process of becoming digitally connected, so that more and more people were able to interact, work together and compete, more or less irrespective of their location.

In an article in the New York Times which appeared in January this year, Friedmann mentions that when he wrote that book, things like Facebook, Twitter, cloud computing, 4G broadband, big data, Skype, and smartphones and apps for these were just about non-existent, or at least in their very infancy.[38] In other words, in barely 10 years we have witnessed a revolution in the possibilities for digital communication and production. Friedmann believes we have gone from being "connected" to being what he terms "hyperconnected".

The development Friedmann describes also impacts on what is produced and how it is produced. Within manufacturing we will see increasingly seamless integration of companies, individuals and services in digital networks. All products will get a unique identity, history and traceability. Increasing digitisation will impact on how work in manufacturing is organised in the production hall, supply chains and product development, as well as in sales and marketing. It will also affect training and competence needs, as well as the situation with regard to competition.

---

[37] Friedmann (2005).
[38] Friedmann (2013).

The most competitive businesses will be the ones which are most inquisitive and willing to learn, capable of working out how new technology and the new network opportunities can best be exploited. There are no signs that this trend will be reversed; on the contrary. We will see similar developments in just about all sectors, such as health, education and public services.

NEW BUSINESS MODELS – CROWDSOURCING

New manufacturing technologies, digitisation of manufacturing, and the growing culture of cooperating with others and sharing designs over the Internet all contribute to the growth of new business models, so-called "crowdsourcing" (see also Figure 7).

The website DesignCrowd is an example. Using this site you can submit a proposal for a new design, e.g. for a new product, a new logo or a new website. You describe what you want to achieve with the project and how much you are willing to pay to get help with the design.

DesignCrowd has signed up a whole bunch of designers, and the specific design challenge is then sent out to them. Those who so wish respond to the design task in point. The client selects which of these they want to proceed with, and a dialogue is initiated between client and the chosen designers about enhancing the draft designs. Once the client has chosen their design (and therefore their designer), DesignCrowd pays the money to the designer as for a usual commission. If you are not happy with the result, you get your money back. This is how design and product development processes can be made accessible for a lot more people than would at one time have been the case. People no longer want to depend on belonging to a bigger company to realise their ideas.

Another example is the Quirky company in New York.[39] Anyone can send in an idea for a new product. This may be e.g. various types of kitchen item (bowls, cutlery, etc.), covers for mobile phones or laptop cases, or various fittings to keep cables tidy or some other item of equipment at home or in the workplace. Once Quirky has received a design proposal, it is sent via the Internet to a pool of designers for evaluation as to how best to realise the idea in question. Quirky then assesses whether the idea is worth proceeding with. If

[39] See www.quirky.com. Examples of similar companies are i.materialize and Sculpteo.

it is, the product goes through a process for refining its design and functionality before it goes into production.

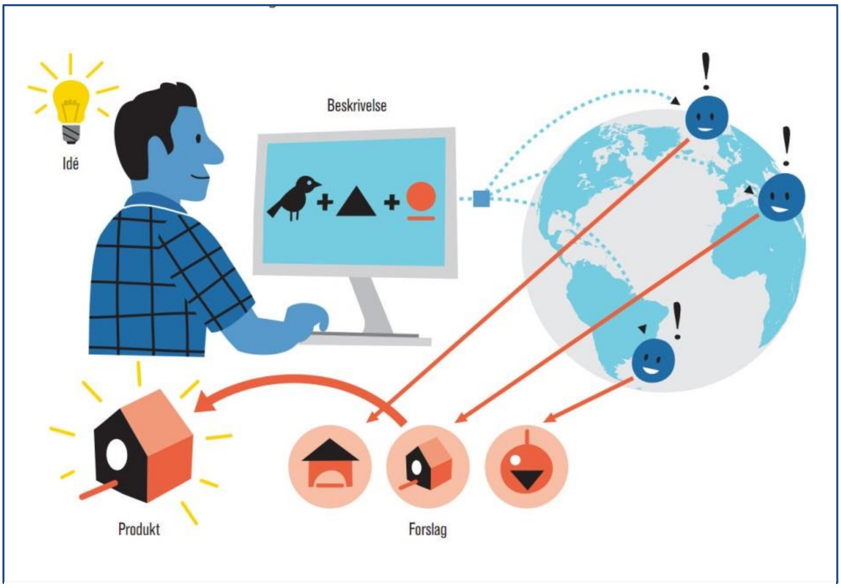

Figure 7: Crowdsourcing makes it possible to realise ideas by drawing on resources more or less drawn from across the globe.

Quirky uses 3D printers in the product development process, whereas actual production takes place in a more traditional production facility. The product is sold through Quirky's own online shop or via other channels. The sales revenues are shared between the founder, Quirky and the others involved in the project. The type of business and cooperation model which companies like Quirky and DesignCrowd represent would not have been possible without the Internet.

2.4 TECHNOLOGY DEVELOPMENT – MORE THAN ROBOTS AND 3D PRINTERS

The development of 3D printers and more advanced industrial robots, as well as the digitisation of manufacturing, run in parallel with developments in other technological fields which are of significance for manufacturing. In materials technology, new composite materials are being developed, delivering a number of benefits, including significantly better weight/strength ratios. Composite materials are replacing metals in a number of fields, including the transport sector (road vehicles, ships and boats, aircraft), building and construction and the defence industry.

Developments in nanotechnology will also impact on manufacturing. Designing material and product characteristics from an atomic level opens up completely new possibilities. For instance, there are medical nano biosensors which can detect proteins at individual molecule level, resulting in a massive improvement in the effectiveness of medical tests. Graphene is a remarkably strong, extremely thin material which has the thickness of a single atom. It is also an excellent conductor.

In the longer term, developments in nano and biotechnology will impact on what is produced and how it is produced, and these technologies will fuse together with 3D printing technology. Attempts to combine the two are already being made. The first 3D printed "nano car" was printed at the Vienna University of Technology in Austria last year (see Figure 8).[40] The length of the car was equal to four times the width of a human hair, and it was constructed by having a laser irradiate molecules in a photosensitive liquid.

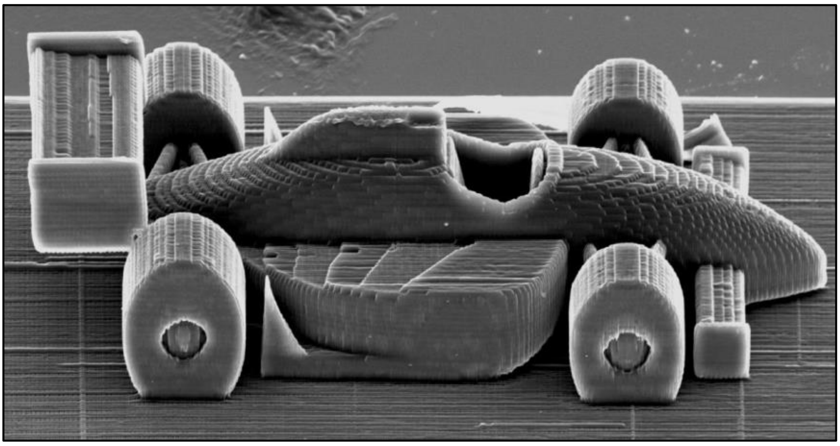

Figure 8: A "nano car" printed by two lasers irradiating molecules in a photosensitive liquid. The length of the car is equal to four times the width of a human hair. Photograph courtesy of the Vienna University of Technology, Austria.

[40] amt.tuwien.ac.at/projekte/2pp/.

Developments in materials, bio and nanotechnology have ripple effects in other technology areas. These are all reasons to believe that these developments will also contribute to more advanced manufacturing technologies and processes in the years ahead.

2.5 EVOLUTION OR REVOLUTION?

How can we best understand the development of more advanced industrial robots, increased use of 3D printers, digitisation of manufacturing and the growth of new business models? There is little doubt that we are seeing the outlines of fundamental changes in manufacturing:

1. Firstly, we have a development in terms of the machines used in production processes. Initially we had manually operated machines where the operator shaped and assembled the requisite components into a product. Then we got computer-controlled machines which can process raw materials and (to some degree) assemble these into end products. Now we are seeing the emergence of 3D printers, which construct products from scratch, and robots, which contribute to production processes which are increasingly fully automated.

2. Key competences are changing. Initially we needed trained operators for the machines. Then we needed people who could program the computers, and now we see a growing need for designers and people who can program and control the computers which control industrial robots and 3D printers.

3. Distribution channels are changing. It will no longer be the case that products are produced in a factory hall and forwarded from there via various distribution chains to the customer. 3D printers open up the possibility of "anyone" being either able to print their own object or order it from a company which does the printing for such customers.

4. There is a lowering of the threshold for using manufacturing technology. Nowadays in principle anyone can buy their own 3D printer. At the same

time, industrial robots are becoming easier to program; eventually we will probably be able to program them from smartphones.

5. New cultures for sharing design information are emerging, together with new companies which specialise in manufacturing more highly tailored products in lower quantities.

To what extent this development should be called a revolution or an evolution is open to discussion. There is little doubt however that we are seeing the outlines of a fundamental change in how things are manufactured, where they can be manufactured and who is able to do the manufacturing. Manufacturing is becoming more flexible and it will be to a much greater degree “bottom up”. Not least in importance is the fact that these fundamental changes are all happening at the same time. This trend is likely to continue in the years to come.

IS GLOBALISATION GOING INTO REVERSE?

The last ten years have witnessed a lot of companies move their production to low-cost countries, and in particular to China. The reasons for this have been obvious. The access to cheap labour yielded significant cost savings. Now, however, the trend is in the process of being reversed.

3.1 IS OUTSOURCING OUTDATED?

In March 2012, Jeffrey Immelt, CEO of General Electric (GE), wrote an article in the Harvard Business Review. In it he explained how, since 2008, GE has been consciously working to reverse a 30-year trend of relocating production to low-cost countries. In the company's estimation "outsourcing was quickly becoming mostly outdated as a business model for GE Appliances".[41]

Along similar lines to GE, a number of businesses have in recent years started to bring home production which previously had been outsourced to low-cost countries, a process known as homeshoring (see Figure 8). The scope is massive. 37% of US companies with annual turnover in excess of a billion dollars

[41] Harvard Business Review, no. 3, 2012.

are planning on or considering homeshoring their production from China.[42] There are several reasons why production in low-cost countries is no longer so attractive.

LESS SAVINGS

The cost savings to be had from manufacturing in China and other low-cost countries are decreasing. Wage costs in China are increasing a lot faster than in many western countries. According to the Boston Consulting Group, the wage costs for factory workers in China in 2000 were 3% of what they were in the US; by 2015 they are expected to be 17% of US levels.[43]

In addition, electricity costs in China are on the increase, as is the cost of buying land to set up manufacturing plants. The same is true of the costs of shipping finished products from China to the markets. When this is considered in the light of the fact that wage costs represent a steadily decreasing proportion of the total costs of bringing a product to the customer (cf. Chapter 2), it is clear that there is less to be saved in relocating production to low-cost countries.

Long supply lines and shipping distances also have their drawbacks. It is a drain on resources to deal with potential problems in the supply chain when the problem arises several thousands of kilometres from company headquarters. When production is homeshored, the shipping and supply process is shorter, and it is easier to intervene where this becomes necessary. A similar challenge is involved when changes have to be communicated along the supply chain. It is more difficult to communicate precisely and quickly with people who are a long way away and where there is the additional complication of a potential language barrier.

THE FACTORY AS LABORATORY

There is a growing recognition that retaining manufacturing competence is important for renewal and innovation. Companies which themselves have first-hand manufacturing competence find it easier to come up with new ideas and turn them into commercial products. Outsourcing of production can thus

---

[42] Boston Consulting Group, Press Release, 20 April 2012.
[43] Boston Consulting Group (2011).

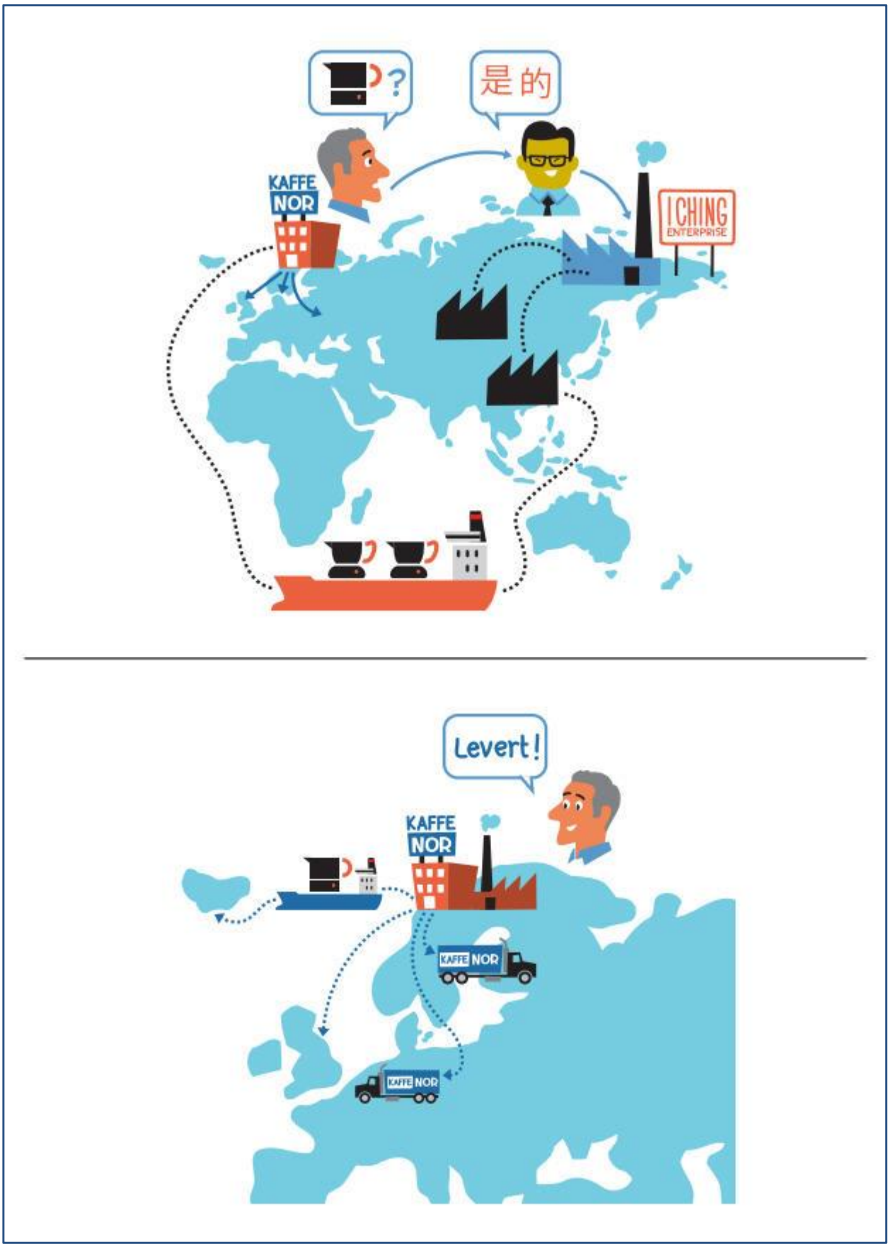

Figure 8: Homeshoring. By homeshoring production from low-cost countries, costs can be reduced, product control improved and lead times to customers reduced.

weaken a company's own ability to innovate and, over time, threaten its continued existence.

Equally, we are seeing that proximity of production to design/product development is also important. It facilitates more in-depth dialogue about challenges and opportunities in both areas, as well as a better understanding of the process which leads from initial idea to commercial product. An example is GE's homeshoring of production of water heaters from China to the US (see the text box over the page).[44] It would seem that the need for such proximity increases the more technologically advanced the products in question are.

MARKET VICINITY INCREASINGLY IMPORTANT

Demand for more specially tailored products is on the increase, be these goods produced in very small volumes, or e.g. running shoes designed to a customer's own specifications.[45] At the same time, trends and fashions change quickly. This means that production in lower volumes which can adapt quickly to new trends will be more important. However, as already mentioned, many of the benefits of locating production in low-cost countries relate to high-volume production with few or no different versions of the same product (e.g. production of one million identical running shoes). On the other hand, long distances to the production locations make it more difficult to respond quickly to new trends.

Increasing demand for specially tailored products and more rapidly changing trends make proximity of the production process to market a definite advantage. It allows companies to respond quicker to new demand.

Equally, it is clear that product development requires access to capital from actors who know the market and who believe they have adequate insight into the production process. If the market is the domestic one, but production is located a long way away, it can be more challenging to get investors to commit.

[44] The Atlantic Magazine, December 2012.
[45] Many sports shoe manufacturers offer this kind of tailored customisation; see e.g. www.nike.com/us/en_us/c/nikeid.

The factory as laboratory

A few years ago, General Electrics (GE) developed a water heater. Development, planning and design was undertaken in the US, but production were outsourced to China, because it was thought this might result in significant savings.

The heater structure involved a number of copper pipes which had to be welded together. The quality of the end product was very much dependent on the quality of the welding. Head office in the US found they had little control over production in China, and hence over end quality.

Having seen how cost savings relating to production in China were in the process of declining, GE decided to homeshore production to the US. However, the company then immediately noticed that the product was less user-friendly than they had wished and that production was a complicated process. At the same time, the company realised that they had not manufactured water heaters in the US for many years. The relevant expertise had almost been lost.

A new team was set up consisting of designers, engineers, production technicians and sales and marketing representatives. According to GE, the outcome was that the entire heater was rebuilt from scratch, using 5% less in the way of materials, making it more user-friendly and to an improved design. A completely new production line was also set up just to produce this heater, and new manufacturing expertise was built up with it.

The time it took to ship the heater to market was also massively reduced. When production was located in China, it could take five weeks from end of manufacture of the product to it being shipped by sea to the US and cleared by customs for dispatch to retailers. Now the heater is ready for dispatch from GE’s own warehouse 30 minutes after end of manufacture.

Outsourcing also conceals an increased risk of copycat manufacturing. Copying of products is widespread. Outsourcing production increases the risk of companies in the country where production is located copying the product in question.

In sum, there are therefore many factors linked to the location of the production process which argue for having it near the domestic market and close to the product development processes. This does not mean that production will not continue to take place in China and other low-cost countries, but increasingly it will be high-volume production where the work still requires high levels of human resource input.

AUTOMATION IN LOW-COST COUNTRIES AS WELL

Cheap manual labour will continue to be an important resource for China, India and other low-cost countries. But at the same time, we are witnessing increasing automation in these countries as well. The company Foxcon is an example. It is one of the world's largest electronic equipment manufacturers and has 1.3 million employees, most of them in China. In 2011 the company announced it was planning to replace part of its workforce with up to a million robots within three years.[46]

Figures from the International Federation of Robotics (IFR) indicate that Foxcon's initiative is part of a bigger trend. In 2011, for instance, 22,577 industrial robots were sold to China. In absolute terms this is on a par with the US and South Korea (which are the countries most robots are sold to), but it is easily the biggest in terms of growth. In its report for 2011, the IRF states the following:

> *"In 2011, 22,577 industrial robots were sold to the People's Republic of China, 51% more than in 2010. With the exception of 2009, the Chinese robots market surged in recent years. Between 2006 and 2011, the annual supply quadrupled. In the 50 years of the history of industrial robots there is no other country with such a dynamic growth of robot installations in such a short period of time. It is a question of time when China will become the largest robot market in the world."*

A significant part of high-tech automated production in China will probably be directed at markets in China and nearby markets in Asia, but some will also be directed at Europe. There is little reason to believe that this development will

[46] See for instance www.theverge.com. How far implementation of this has progressed is however unclear.

not have some potential impact on the international balance of competition in the same way that China's general economic growth has had.

The question could be asked whether automation of manufacturing in low-cost countries might not result in a *new* wave of outsourcing of manufacturing from high-cost countries. The answer is that this will not necessarily be the case. Because automation in high-cost countries reduces wage costs as a proportion of total costs, outsourcing of production will not be so attractive, even if, seen in isolation, it may well be slightly cheaper to produce things in low-cost countries.

3.2 REQUIREMENTS FOR MORE ENERGY AND RESOURCE-EFFICIENT MANUFACTURING

Manufacturing is the transformation of raw materials into a finished product. It needs energy and access to raw materials. Resource-efficiency will probably become increasingly important in coming years.

A growing population will mean that the available energy resources will have to be split between more people. This means we will have to manufacture in a more energy-efficient manner. At the same time, a growing population, where an increasing number of people will have to be lifted out of poverty, means that more people will want products of different kinds. This will contribute further to the streamlining of production processes.

An increasing emphasis on the environment and climate will also reinforce the need for production processes and technologies which are increasingly resource-efficient. Businesses which keep their carbon footprint as low as possible will acquire a competitive advantage. This will apply to all links in the process, from production of raw materials to processing these to form a finished product, to shipment to the customer.

A gradual reduction in access to important materials will favour processes which use a smaller quantity of material, as well as those which are able to switch to new materials which are more easily accessible in larger quantities.

At the same time, there may be reason to believe that we in a low-carbon economy[47] will have an ever increasing need for technologically advanced products. These may for example take the following forms:

- Technology which has a low carbon imprint in use (means of transport, machines of various kinds, etc.)
- Technology which can make the use of energy more efficient in various processes, such as electronics or software which can be used to control industrial processes.
- Technology for the production of renewable energy.

Overall we will therefore get a trend towards production processes which make the same products but with fewer material resources and lower levels of energy consumption, and which will manage to use materials which are easily accessible. In this scenario, more effective robots, as well as robots and 3D printers which reduce overall use of materials will be of interest.

These "requirements" will contribute to the development of new manufacturing technologies. The need for more energy-efficient production and the need for production which is more automated may therefore be said to be mutually supportive, contributing to one and the same technological development.

[47] By low-carbon economy we understand an economy where a company's competitive standing, business opportunities, costs and reputation are to a large extent affected by the carbon footprint of its activity. See the Norwegian Board of Technology (2009).

NORWAY AND DEVELOP-MENTS AT AN INTER-NATIONAL LEVEL

New industrial robots, 3D printers and the digitisation of manufacturing provide a new setting for manufacturing, altering the balance of international competition. New business models are in the process of changing the way products are developed and who can do the developing. Homeshoring of manufacturing from low-cost countries contributes to further streamlining of production and stimulates the development of technology which can also contribute to this.

In what follows, we will look at the consequences this might have for Norway, how the relevant issues are dealt with in the new report to the Norwegian parliament on industrial and business policy, and what Norway can learn from other countries.

4.1 CONSEQUENCES AND OPPORTUNITIES FOR NORWAY

The technological development outlined above serves to highlight the requirements which will have to be met by manufacturing in high-cost countries like Norway in order for it to be competitive. On the other hand, this development represents both an opportunity and a challenge for Norway.

CLEAR REQUIREMENTS FOR MANUFACTURING IN HIGH-COST COUNTRIES

The development outlined in Chapters 2 and 3 above allows us to identify five requirements which future Norwegian manufacturing has to meet:

1. All products should be of the highest possible quality and have the greatest possible knowledge content. This will be crucial if they are to be competitive.
2. Automated, flexible production. This will be a pre-requisite of being able to produce cost-effectively and respond quickly to market changes.
3. Use of advanced manufacturing technology. To remain competitive over the long term, the very latest in available manufacturing technology will have to be deployed.
4. High levels of digital competence. To be able to exploit modern manufacturing technology to the full, there will be a greater need for digital competence, for welders, designers and production schedulers, as well as for others involved in product development and production processes.
5. Production which is more resource and energy-efficient. This will be a pre-requisite of being able to be competitive in a low-carbon economy.

In-depth knowledge of the most advanced manufacturing technologies is also important for innovation performance. If we want to innovate, we have to properly understand how the products are produced. When manufacturing technologies are being developed, knowledge about them must also be developed accordingly. If we do not develop products which can be produced using modern technology, the competition will leave us behind.

In addition, we are seeing the outlines of a future where competitive advantage will be increasingly dynamic due to technological development and the mobility of capital. It is far from certain that the manufacturing of the future will derive from established manufacturing activity to the same degree it once did. If we are aware of the new manufacturing technologies and see the potential of new markets, new activities and areas of activity may emerge.

AN OPPORTUNITY AND A CHALLENGE FOR NORWAY

The five requirements for the manufacturing of tomorrow represent both an opportunity and a challenge for Norway.

- Automated and knowledge-intensive manufacturing is an opportunity for Norway. This is the kind of production where we have a chance of competing internationally. Our population has high skills levels. If we get onboard early and run with the development, we can strengthen our onshore manufacturing base outside of the oil and gas hub. We need this, both because of our need for “several legs to stand on”, and because we will be increasingly dependent on the manufacturing in question once our oil revenues start declining.

- It may well be a challenge to develop a strong onshore manufacturing base given that our oil and gas industry is so strong, employment at such high levels and the Norwegian economy running so incredibly well.

But the strength of the Norwegian economy must not become a convenient excuse to put off developing an industrial policy for tomorrow. Rather, we need an active policy which will make best provision for Norwegian businesses to be able to utilise modern manufacturing technologies and for Norway to be properly armed to engage in the struggle for market share.

4.2 REPORT TO THE NORWEGIAN PARLIAMENT ON INDUSTRIAL AND BUSINESS POLICY 2013

The most up-to-date review of Norwegian industrial policy is contained in the presentation of the new report on industrial and business policy to the Norwegian parliament.[48] The report was entitled "Mangfold av vinnere" (An abundance of winners) and was published on 7 June 2013.[49] It touches on several of the issues discussed above. Nevertheless, the report gives a somewhat ambiguous impression in terms of exactly which industries and types of activity we should be investing it. Moreover, it lacks a proper analysis as to how advanced manufacturing technology can contribute to ensuring Norwegian manufacturing is properly equipped to deal with the future. We will investigate this further.

WHERE ARE TOMORROW'S WINNERS?

The aim of the government is for Norway to become a leading, innovative, dynamic and knowledge-based economy. This is meant to happen in those areas where we have the natural pre-requisites, competence and expertise to achieve this, and where we have already developed leading hubs and technology environments.[50] On previous occasions, the government has indicated energy, the environment, travel and tourism, and the off-shore and shipping industries as strategic areas for its industrial and business policy. In this new Industry Policy Report, ICT and healthcare have also been highlighted.

At the same time it emphasises the point that Norway has a lot of companies which are global leaders in the technology and engineering field. These supply tailored high-tech products in areas like micro-electronics, the defence industry and automotive components.

A question which immediately emerges is whether the winners of tomorrow will not in fact be from outside the major strategic areas,[51] and whether these

[48] Report to the Storting 39 (2012–2013).
[49] The report was withdrawn in the fall of 2013 due to the change in administration following the Parliamentary elections in September the same year.
[50] Report to the Storting 39 (2012–2013); see for instance pp. 9, 12 and 99.
[51] We have here in mind shipping and associated industries, energy, environment, travel and tourism, off-shore industries, ICT and healthcare.

areas will not rather tend to spring up from small, technology-heavy firms or new start-ups.

Many of the businesses in Norway which are most proactively engaged in the use of new technology cannot be automatically categorised as belonging to sectors where Norway may be said to have a particular advantage. Furniture, agricultural equipment and automotive and aircraft component manufacture, as well as that of water heaters are examples of this.

In its Industry Policy Report, the government points out that many of the companies which are to be the bedrocks of the economy in 20 years' time have still not been set up. "Today's firms will be outcompeted by new ones, which will replace them, contributing to higher productivity and increased profitability" (p. 14).[52] This is consistent with the analyses in Chapters 2 and 3 above, a main point of which was that new technology can change basic assumptions as to which areas of industry might be competitive in the future.

To ensure Norwegian manufacturing is technology-heavy and future-oriented, it is extremely important that we retain and develop the necessary skills and expertise for those high-tech businesses which are not in sectors where Norway has a particular edge. Too one-sided a focus on industries which are already strong might well be a pitfall. The new Industry Policy Report however does not contain a more in-depth analysis of what the importance of high-tech businesses might be for the ongoing development of Norwegian manufacturing. The report gives a somewhat ambiguous impression in terms of exactly which industries and types of activity we should be investing it. It would also have been desirable to have had a more in-depth analysis of which policy measures would be relevant for maintaining and promoting the expertise and production capacity at these businesses.

HOW ARE WE TO PROMOTE PROACTIVE USE OF TECHNOLOGY?

In the Industry Policy Report, the government emphasises the importance of having a proactive approach to the use of new technology. This will be crucial for ensuring Norwegian industry can retain a competitive manufacturing base and that Norwegian businesses can only be competitive by virtue of the quality of their products and services. It points out that new technology, new ways of

[52] The quotes have been translated from Norwegian by the NBT

working and new production processes mean that many work tasks are becoming more advanced and knowledge-intensive.

The Industry Policy Report brings out the value of automation and that increased use of robots can make mass production possible in a high-cost country as well.

> *"With a proactive approach to the use of new technology, an overall assessment, covering, inter alia, freight costs, control of the supply chain and an established skills base at home, may mean that companies will find it profitable to homeshore their production." ("Med en offensiv tilnærming til bruk av ny teknologi kan en samlet vurdering som omfatter blant annet fraktkostnader, kontroll i forsyningskjeden og en etablert kompetansebase hjemme, gjøre at bedriftene finner det lønnsomt å flytte produksjonen hjem.")*[53]

The report thus deals with aspects of the issues we have addressed above. This is to its credit, but the report does not provide a more detailed assessment of how automation can contribute to ensuring Norwegian industry is properly set up for the future or how Norwegian government authorities intend to promote increased use of automation. Nor does the report mention even in passing 3D printers and the significance these may have for development of production processes.

As far as the importance of digitisation is concerned, mention is made of the general importance of ICT in improving productivity and developing business processes. The importance of ICT in the development of sensors and robotics, for instance, is highlighted, as is the need for specialist competence linked to the development and use of ICT, and the government gives notice of its intention to propose an R&D strategy for ICT.

It is to its credit that the government is exercised by the importance ICT has for other industries. Nevertheless, the report gives the impression that its main focus is on ICT as an industry in itself. This is substantiated by the fact that the report does not discuss the fundamental importance digitisation has had and will continue to have for manufacturing, as we discussed in Chapter 2

[53] Report to the Storting 39 (2012–2013), p. 144.

above. Nor does the report discuss the potential of the kind of new business models exemplified by Quirky and DesignCrowd. It would have been good to have had a more in-depth analysis of these issues. Analyses of this kind should be included in the promised R&D strategy for ICT.

The point is made in the report that the ways in which we and our competitors approach technology may result in both the growth and downfall of individual firms and of entire industries. This is consistent with our arguments set out in Chapter 4.1 above. The report also stresses that the Norwegian technology, supply and engineering industry is dependent on continuous improvement in levels of competence and adaptation. "The switch to manufacture of high-tech products is largely a result of a successful switch from traditional engineering towards manufacture of niche products." (p. 24). The report then goes on to stress that the retention and development of technological competence will be crucial for this kind of manufacturing. This accords with our own analysis.

The Industry Policy Report still lacks a more in-depth analysis of how the necessary technological competence can be provided. The importance of a good policy implementation system is highlighted,[54] but the report could be more specific as to how Norwegian authorities are to help ensure that companies will in future have the requisite competence in modern manufacturing technology and systems.

A more in-depth account would have also been welcome into how Norwegian authorities see the connection between innovation performance and production competence, and how use of new manufacturing technology will impact on this relationship (cf. the arguments on p. 48 above).

If Norway is to be a leading, innovative, dynamic and knowledge-based economy within prioritised areas, we have to be up-to-date in technological development and continually on the lookout for new knowledge. Even though the Industry Policy Report does to some extent cover the topics discussed in Chapters 2 and 3 above, ensuring Norway has an advanced manufacturing base fit for future purposes does not appear to be a main priority for the gov-

[54] The report points to a number of different policy instruments, such as User-driven Research based Innovation (Brukerstyrt innovasjonsarena (BIA)) from the Research Council of Norway, the Skattefunn Tax Incentive Scheme from Innovation Norway and contributions from the Industrial Development Corporation of Norway (SIVA).

ernment. On some points, the report points in the right direction, but it should have contained a more in-depth analysis of how we in Norway are to be able to derive the full potential to be had from using more advanced technology within manufacturing, and what the authorities can do to support such a development.

In the Industry Policy Report, the government is at pains to stress that it is anxious to learn from the policy developments which are taking place at an international level. Nevertheless, the report contains neither an analysis of international developments in this area, nor an analysis of what measures the authorities in other countries are taking to ensure they have the best possible skills and expertise and a manufacturing base which is best equipped for the future. We will see that the authorities in the relevant leading countries demonstrate greater awareness of and a systematic approach to how to create a manufacturing base which is best equipped for the future.

4.3 WHAT ARE OTHER COUNTRIES DOING?

A study of what is being done in the US, the UK, Germany and Denmark indicates that these have put industrial policy high up on the agenda and are taking extensive steps to learn more about the opportunities and challenges of the new approach to manufacturing.

USA

In his state of the union address of January 2013, President Obama put industrial policy to the top of the political agenda. He linked the increasing tendency of American companies to homeshore their manufacturing with developments within new manufacturing technologies and the work on securing and creating jobs:

> *"Our first priority is making America a magnet for new jobs and manufacturing. After shedding jobs for more than 10 years, our manufacturers have added about 500,000 jobs over the past three. ... There are things we can do, right now, to accelerate this trend. Last year, we created our first manufacturing innovation institute*

in Youngstown, Ohio. A once-shuttered warehouse is now a state-of-the art lab where new workers are mastering the 3D printing that has the potential to revolutionize the way we make almost everything. … I'm announcing the launch of three more of these manufacturing hubs… And I ask this Congress to help create a network of fifteen of these hubs and guarantee that the next revolution in manufacturing is Made in America." [55]

The backdrop to Obama's speech is clear. The US lost 41% of employment in manufacturing from its peak in 1979 to reaching rock bottom in December 2009.[56] The downward trend was particularly severe in the period from 2000 to 2009, when 31.2% of the jobs in manufacturing disappeared. For all that, it is still a very important sector, employing about 11.5 million.[57] Work on retaining and creating more new jobs is high on the political agenda in the US.

The Obama administration has a comprehensive plan for simulating the development of manufacturing in the US, aiming to make the US into a magnet for new jobs:[58]

- To make American manufacturing more competitive and accelerate innovation in manufacturing technology and processes, one billion dollars has been approved for 2014 for the network of 15 innovation centres for manufacturing.[59]

- The "Advanced Manufacturing Partnership " (AMP) is being set up.[60] This is a national initiative to get manufacturing, universities and national agencies to cooperate on strategic investments in new technology so as to create what are referred to as "high-quality manufacturing jobs" and to make US companies more competitive on global markets. AMP was set up in the context of a special investigation

[55] www.whitehouse.gov/state-of-the-union-2013.
[56] Helper, Kruger and Wial (2012). "Manufacturing" here comprises the production of a wide range of products, including tobacco, textiles, paper products, chemical substances, mechanical equipment, furniture, white goods, etc. A full list is available from the US Bureau of Labor Statistics.
[57] US Bureau of Labor Statistics (2013a).
[58] See www.whitehouse.gov for a factsheet on Obama's plan to make the US into a "magnet for new jobs".
[59] Budget of the United States Government, Fiscal Year 2014, p. 8.
[60] www1.eere.energy.gov/manufacturing/amp/.

which underscored the importance of improving technologies, products and processes throughout US manufacturing.[61]

- Increased federal support for research and developed directed at innovative and advanced technologies for use within manufacturing.

- Establishing a fund to support local high schools in their work on training/providing further training for industrial workers for jobs within advanced manufacturing.

- Bringing in tax reductions for manufacturing companies so as to stimulate innovation and investments in the US.

- Several measures for small and medium-sized businesses to encourage them to take on new staff and grow.[62]

- Measures to reduce trade barriers and open up new markets for products produced in the US.

It is interesting that the Obama administration links the emergence of new technology so explicitly with work on creating more jobs and the potential to be world leaders in manufacturing.

Obama's new industrial policy must also be seen in the context of the development outlined in Chapters 2 and 3 above, i.e. US companies' increasing interest in homeshoring production from low-cost countries. US companies are way ahead in developing new business models based on crowdsourcing, and companies in the US are right at the centre of the development of new industrial robots, 3D printers, and not least the digitisation which is increasingly becoming a feature of manufacturing.

It is reasonable to assume that the recent course of US policy and manufacturing will contribute to the technological development described above gaining in momentum in the years ahead.

---

[61] President's Council of Advisors on Science and Technology (2012).
[62] A brief account of the American Jobs Act is provided at www.whitehouse.gov.

UK

In 2011, the UK government launched its “Plan for Growth”. The plan is intended to be an important means for counteracting further reductions in employment and for maintaining the welfare of the nation.[63] The strategy highlights “advanced manufacturing” as one of eight sectors in which it is particularly important to remove any barriers to growth. At the same time, it emphasises that future growth in the sector is entirely dependent on UK firms being able to design and produce “high-value products”. It also draws attention to the importance new machine plant and software has had for development within the sector. Subsequently, a number of initiatives have been undertaken, including the following:

- “The Advanced Manufacturing Supply Chain Initiative”[64] was established in 2011 to support innovative projects linked to the development of improved supply lines for advanced manufacturing. 125 million pounds were approved in 2011 and 120 million in 2015.

- The “Future of Manufacturing” project is a foresight project which is managed by the government’s “Foresight” programme.[65] The project is intended to look at manufacturing between now and 2050 and investigate global trends and the driving factors of development within the sector.

- The Technology Strategy Board is a public body for promoting innovation. “High value manufacturing” is one of its priority areas. The aim is to ensure that advanced manufacturing can be a driver of economic growth in the UK.[66]

In October last year, the UK government also launched a seven-million pound research programme on “innovation in additive manufacturing”. At the programme launch, the Minister for Universities and Science had the following to say:

---

[63] Department for Business, Innovation and Skills (2011).
[64] www.innovateuk.org.
[65] www.bis.gov.uk/foresight/our-work/projects.
[66] www.innovateuk.org.

"3D printing technologies offer huge potential for UK businesses to compete successfully by embracing radically different manufacturing techniques that could be applied across a wide variety of global market sectors, from aerospace to jewellery.

We believe this new investment will help UK companies make the step change necessary to reach new markets and gain competitive advantage. Building on £20 million of previous Technology Strategy Board support for additive manufacturing innovation, it will help secure more of this game-changing high value activity for the UK, driving economic growth and enhancing quality of life."[67]

It is too early to draw any conclusion about the effect the UK measures might have in strengthening manufacturing and delivering the economic growth the government is seeking. There is however little doubt that the UK authorities see strengthening the manufacturing base as an essential part of this work and that they fully realise the significance of the technological development which is currently underway.

GERMANY

Germany is seen by many as in the vanguard of the manufacturing nations: the nation which is the home of automotive brands of the order of Mercedes, Volkswagen, BMW and Opel. On top of this, the country has strengths in electrotechnology, chemical and precision engineering. As stated in Chapter 3, together with South Korea and Japan, Germany leads the world as the country with most industrial robots per employee in manufacturing. The country also has a dozen or so firms developing 3D printers, such as EOS[68] and Concept Laser[69]. Many of these companies are seeing strong growth, e.g. EOS has doubled its turnover over the last three years, now reaching EUR 105 million.

Germany has successfully ridden out the economic crisis, despite the fact that her wage costs in manufacturing are 30% higher than in the US. Employees in manufacturing account for 20% of the total workforce, as against just over 10% in the US.[70]

[67] www.innovateuk.org.
[68] www.eos.info.
[69] www.concept-laser.de.
[70] US Bureau of Labor Statistics (2013b).

German government authorities are completely aware of the new demands on manufacturing and the developments within 3D printing/additive manufacturing. On its webpages the German government has this to say:

> *"There are two trends emerging with regard to the future demands of the market on manufacturing companies. Firstly, consumers want ever more complex products at the lowest possible prices. Short product cycles and wide variety of products require a highly flexible production system. Secondly, there is the increasing involvement of the end user in the development of individual components which are produced at the touch of a button….Additive manufacturing processes such as the 3D laser printer are an outstanding current example of the new possibilities that the photonics toolbox brings to production."* [71]

In order to support the development of 3D printing technology, in March the Federal Ministry of Education and Research approved EUR 30 million (approximately NOK 240 million) for the "Photonic Process Chains" project. The intention here is to consider the use of 3D printers from a broader perspective, involving the entire value chain of the production process. A project has also been initiated to get students interested this field.[72]

The German authorities have also drawn up a strategy for high-tech production in Germany.[73] One of the aims of the strategy is to secure innovation in Germany and make the country more attractive for R&D intensive companies. One of the themes discussed was the concept of "Industri 4.0". The focus here is how to prepare German industry so that it can continue to be a world leader in the years ahead. The final report presents a considered review of how new manufacturing technology, use of the Internet and powerful digital resources will fundamentally change the way in which manufacturing is undertaken in the future.[74] Particular significance is attached to the way in which all phases, from design, via production scheduling, to actual production and sales, will be integrated in a more seamless fashion. We will get an "Internet of machines, people and services" in what the report terms "cyber-physical systems".

[71] The Federal Ministry of Education and Research (BMBF) (2013), www.bmbf.de. The project focuses in particular on the use of light to print metal.
[72] Ibid.
[73] "The High Tech Strategy for Germany", see www.bmbf.de.
[74] German National Academy of Science and Engineering (Acatech) (2013).

Attention is also drawn to the way in which 3D printing and other new manufacturing technologies will make production processes more flexible and create new business models. The customer will become more closely involved in the process, so as to create unique products tailored to the customer's needs:

> *"Industrie 4.0 allows individual, customer-specific criteria to be included in the design, configuration, ordering, planning, manufacture and operation phases and enables last-minute changes to be incorporated. In Industrie 4.0 it is possible to manufacture one-off items and have very low production volumes (batch size of 1) whilst still making a profit."*[75]

The report presents a number of proposals for policy development and further investigative work. These are linked inter alia to competence requirements for industrial workers, the need to establish the necessary digital infrastructure, the establishment of a road map to future manufacturing, and research on what the content and organisation of work in the future should look like. In addition, the authors are exercised by the question of how digitisation of the production process will raise new questions about intellectual property rights, for instance.

In the light of Germany's already strong industrial capacity and innovative strength in manufacturing, there is reason to believe that the German initiative will help accelerate the development of future manufacturing. It is likely to have consequences for both the balance of international competition and technological development.

DENMARK

The Danish government has set up a productivity commission. One of the purposes of the commission is to investigate the causes of Denmark's relatively low growth in productivity since the mid-1990s and to propose measures for improving productivity in a number of fields, including manufacturing.[76] The commission is due to submit its final report before the end of this year, but it has already drawn attention to the importance of automation for growth in

[75] Acatech (2013), p. 15.
[76] Produktivitetskommissionen.dk.

productivity within manufacturing.[77] Based on the commission's mandate, there is reason to believe that this will be discussed in more detail in the final report. This is to be submitted at the end of 2013.

In Denmark too there is concern as to how automation can contribute to retaining competitive edge within manufacturing. The so-called AIM project is studying how much potential increasing automation has for improving the competitive performance of Danish manufacturing companies.[78] The context of the project is the observation that Swedish and German competitors, among others, have significantly higher levels of automation in their manufacturing and that this is leaving Danish companies less competitive.

One of the interim findings of the AIM project is that increased automation would result in a 15% gain in competitive edge for Danish companies.

A SOURCE OF INSPIRATION FOR NORWEGIAN AUTHORITIES

The above is not an exhaustive analysis. It does however give an insight into what is being done in countries which are major competitors for Norwegian manufacturing.

There is no avoiding the impression that government authorities in the US, Germany, the UK and Denmark are more in tune with way in which technological development and global forces will drive manufacturing in future, and the opportunities and challenges this raises.

In these countries, policies for advanced manufacturing are way up on the political agenda, and there is a general concern about the importance advanced manufacturing will have for a country's competitive position. In addition, the US, the UK and Germany have all made conscious efforts to investigate the potential of 3D printers and build up expertise in their use and additive manufacturing. These measures are wide-ranging, but they include:

[77] The Danish Productivity Commission (2013).
[78] www.aim-projekt.dk. AIM stands for Advanced Automation Investment Models. The project is managed inter alia by the Danish Technological Institute, Aalborg University and the Danish Industry Foundation.

- Research projects in a number of areas, including the use of 3D printers, more automation in production, new value chains and how the new technologies may impact on productivity.
- Foresight project on future manufacturing.
- Drawing up strategies for future manufacturing.
- Setting up competence centres for using advanced manufacturing technology.
- Specific support schemes for companies which invest in development and/or use of advanced manufacturing technology.

The approach of these countries to the advanced manufacturing of the future should be an important source of inspiration for government authorities in Norway.

4.4 WHAT SHOULD NORWEGIAN AUTHORITIES BE DOING?

If Norway is to be a leading, innovative, dynamic and knowledge-based economy within prioritised areas, we have to be up-to-date in technological development and continually on the lookout for new knowledge. We need a better knowledge base for a policy for future advanced manufacturing.

The Industry Policy Report has no plan as to how Norwegian industry, Norwegian government authorities or education and training institutions are to address the developments we are seeing. Countries to which we hold ourselves comparable are however in the process of developing such plans. In order to promote the development of future manufacturing, the Norwegian Board of Technology is therefore of the view that Norwegian authorities should consider the following measures:

A best practice analysis. Several Norwegian industrial firms use advanced manufacturing technology. How can we learn from companies like OZO Hotwater, Ekornes, Kværneland, Kleven Industrier AS and GKN Aerospace Norway AS (formerly Volvo Aero Norway)? How do they use advanced manufacturing technology and what significance does the technology have in making them competitive? How do they renew their knowledge of manufacturing technology? What demands does the use of advanced technology make on engineers, management, production scheduling, etc.?

A broad survey of Norwegian manufacturing in general. We need a broader insight into current use of production technology in Norwegian manufacturing. Such an analysis should survey the following:

- The use of automated production within Norwegian manufacturing.
- The potential for streamlining production using increased automation.
- The extent to which 3D printers and modern ICT are integrated in Norwegian manufacturing companies' product development and production processes.
- The companies' plans with respect to upgrading their machine plant and increasing their use of new and more advanced manufacturing technology.
- The needs of these companies in terms of updating their knowledge on how to use modern manufacturing technology.
- The main barriers, in the view of the companies, to their becoming world leaders in the use of advanced manufacturing technology within their particular field/sector.

A foresight project along the lines of "The Future of Manufacturing" project being carried out in the UK. The project should analyse the potential course of development in advanced manufacturing in the years ahead. What will drive this development in future? What opportunities and challenges does it present? Such an analysis will be important due to the rapid rate of technological change. Just focusing on the current situation entails the risk that any measures or policy development we undertake will not look far enough into the future.

Stimulating greater cooperation between research, manufacturing and government authorities, as achieved via the Advanced Manufacturing Partnership in the US. The purpose of this will be to increase our expertise in advanced manufacturing, make companies more competitive and create the best possible conditions for growth for new and smaller businesses as well. Knowledge transfer and exchange of experience between manufacturing companies which use advanced manufacturing to differing degrees and come from different industry sectors will be important. It will be equally important for manufacturing to communicate its identified knowledge gaps to research centres, and for the latter to disseminate the results of their research to the former. A further objective will be to identify those areas in particular need of state support.

Boosting digital competence in manufacturing. Industrial workers of the future will have to have a high level of digital competence if they are to be able to keep abreast of the most advanced manufacturing technologies. The German study "Industrie 4.0" provides a good illustration of this. We have to ensure industrial workers in Norway have the right kind of competence. The objective behind boosting digital competence is to ensure that industrial workers have the necessary expertise. This boost in competence should be directed at the education system and industrial workers currently in work, in equal measure. Educational and training establishments should be able to offer training in the use of 3D printers, advanced robots and advanced digital control systems, as well as ways in which digital resources can create new business models. This kind of boost will also aim to stimulate more individuals to want to work in design, product development and manufacturing.

A research strategy. We need an up-to-date knowledge base for developing future manufacturing. This will involve a number of things, including having the necessary knowledge about new technology and new types of manufacturing and value chains. An assessment of our own innovation or research programmes should be included in the survey. The strategy should draw on the results obtained from analysing the current state of manufacturing in Norway.

LIST OF REFERENCES

DOCUMENTS FROM NATIONAL GOVERNMENT AUTHORITIES

Department for Business, Innovation and Skills (2011): *The Plan for Growth*. London.

Executive Office of the President, President's Council of Advisors on Science and Technology (2012): *Report to the President on capturing domestic competitive advantage in advanced manufacturing*. Washington, DC.

German Federal Ministry of Education and Research (2013): *Photonic process chains – the dawning of a new age in production*. Online publication at www.bmbf.de.

Report to the Storting 39 (2012–2013): *Mangfold av vinnere (An abundance of winners)*. Report to the Storting. Oslo.

Report to the Storting 12 (2012–2013): *The Perspective Report*. Report to the Storting. Oslo.

Report to the Storting 24 (2011–2012): *Financial Markets Report*. Report to the Storting. Oslo.

German National Academy of Science and Engineering (Acatech) (2013): *Securing the future for Garman manufacturing industry – Recommendations for implementing the strategic initiative INDUSTRI 4.0*. Frankfurt.

The White House (2013): *State of the Union 2013*. Washington, DC.

The White House (2013): *The President's Plan to Make America a Magnet for Jobs by Investing in Manufacturing*. Press release, February 13, 2013. Washington, DC.

The White House (2013): *Budget of the U.S. Government, Fiscal Year 2014*. Washington, DC.

The White House (2011): *The American Jobs Act*. Washington, DC.

US Bureau of Labor Statistics (2013a): *Industries at a Glance. Manufacturing*. NAICS 31–33. Washington, DC.

US Bureau of Labor Statistics (2013b): *International Unemployment Rates and Employment Indexes, Seasonally Adjusted, 2009–2013*. Washington, DC.

PUBLICATIONS

Anderson, Chris (2006): *The Long Tail: Why the Future of Business Is Selling Less of More*. New York: Hyperion.

Anderson, Chris (2012): *Makers: The New Industrial Revolution*. New York: Crown Business.

Boston Consulting Group (2012): *Press release*, 20 April. Available at www.bcg.com

Boston Consulting Group (2011): *Made in America, Again*. Available at www.bcg.com

Brynjulfson, Eric and Andrew McAffee (2012): *Race Against The Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*. Digital Frontier Press.

Friedmann, Thomas L. (2005): *The World is Flat. A Brief History of the Twenty-first Century*. Farrar, Straus & Giroux. New York.

Friedmann, Thomas L. (2013): *It's P.Q. and C.Q. as Much as I.Q.* New York Times, 29 January 2013.

Helper, Susan, Timothy Krueger, and Howard Wial (2012): *Why Does Manufacturing Matter? Which Manufacturing Matters? A Policy Framework*. Brookings institute, February 2012, Washington DC.

Immelt, Jeffrey (2012): *On Sparking an American Manufacturing Renewal*. Harvard Business Review, March 2012.

International Federation of Robotics (2012a): *History of Industrial Robots. From the first installation until today*. www.ifr.org.

International Federation of Robotics (2012b): Industrial robots 2012. *Statistics, market analysis, forecasts and case studies*. www.ifr.org.

Mannoor, Manu, Ziwen Jiang, Teena James, Yong Lin Kong, Karen A. Malatesta, Winston O. Soboyejo, Naveen Verma, David H. Gracias, and Michael C. McAlpine (2013): *3D Printed Bionic Ears*. NanoLetters, 1 May 2013. American Chemical Society.

Meccano Magazine (1938): *An automatic block-setting crane. Meccano model controlled by robot unit*. Vol 22, no. 3, March 1938.

The Federation of Norwegian Industries (2013): *Business Trend Report*. Oslo.

PåSpissen (2013): *Backsourcing: Produksjonen hentes hjem*. No. 3, 2013.

The Norwegian Board of Technology (2009): *Plan B. Verdiskaping for lavutslippsøkonomien*. Oslo.

Teknisk ukeblad (2012): *Kleven flytter stålproduksjonen hjem*. Online publication.

The Atlantic (2012): *The Insourcing Boom*. December issue.

Wohlers (2013): *Wohlers Report 2013. Additive Manufacturing and 3D Printing State of the Industry*. Wohlers Associates, Colorado, USA.

WEBSITES REFERRED TO:

Advanced manufacturing partnership, USA:
www1.eere.energy.gov/manufacturing/amp
The AIM project in Denmark: www.aim-projekt.dk
Concept Laser: www.concept-laser.de
Kongsberg TeroTech: www.terotech.no
The productivity commission in Denmark: produktivitetskommissionen.dk
The Advanced Manufacturing Supply Chain Initiative, UK:
www.innovateuk.org
EOS: www.eos.info/en
Foresight UK: www.bis.gov.uk/foresight
Urbee, 3D printed bodywork: www.urbee.net
3D printed house: www.dezen.com
3D printed house in concrete: www.contourcrafting.com
3D printed prosthetic: www.bespokeinnovations.com
3D printing of aircraft engine components: lib.bioinfo.pl/projects/view/22292
3D printed pistol: www.defdist.com
The US bill against 3D printed weapons:
www.govtrack.us/congress/bills/113/hr1474/text
3D printed model plane: www.newscientist.com
3D printed guitar: www.cubify.com
3D printed dress: www.psfk.com
3D printed bicycle: www.eads.com
3D printing of chemical substances: www.chem.gla.ac.uk/cronin/
Nano 3D printing at the Vienna University of Technology, Austria:
amt.tuwien.ac.at/projekte/2pp/
www.sfinorman.no: Centre for Research-based Innovation.
Shapeways: www.shapeways.com
DesignCrowd: www.designcrowd.com