3D Printing: ensuring manufacturing leadership in the 21st century

Public/private partnerships pave the way to become the next global design and manufacturing leader

HP © Copyright 2018

Executive summary

We are in the early days of a 4th Industrial Revolution, a far-reaching analog-to-digital shift that will completely transform the $12 trillion global manufacturing industry.

It will fundamentally change the way we conceive, design, produce, distribute, and consume nearly everything, with enormous impact to jobs, industries, and economies. It's a digital industrial revolution spearheaded by the accelerating growth of 3D printing, and its leaders will be defined by their ability to harness the full power of this truly disruptive technology.

In manufacturing's all-digital near-future, designers will create entirely new categories of products, unconstrained by traditional processes as the line between idea and physical reality erodes. And manufacturers, no longer tethered to overseas factories, will move physically closer to the consumer, shortening supply chains with the newfound ability to custom-produce anything, anytime, anywhere.

Four to 6 trillion (USD) of the global economy will be disrupted and redistributed in the next 10 years due to the accelerating growth of 3D printing, according to a new study conducted by A.T. Kearney.

Jobs will shift around the globe, with manufacturing jobs migrating to places where 3D printing is fully embraced. Countries with strong existing consumer bases will be able to leverage those bases into opportunities for job creation. Countries with strong existing manufacturing economies will need to adopt 3D printing quickly to secure the future growth of their workforces. And the new 3D manufacturing workforce will be one that's skilled-up, tech-savvy, and highly in-demand as it helps to push their nations to the forefront of global technology and innovation leadership.

Those who fail to act will risk securing their share of a historic new wave of value creation across industries and continents. The World Economic Forum has estimated the overall value of the global digital transformation to business and society across all industries at $100 trillion in the next ten years alone.

The 3D printing industry is currently at a technological and economic inflection point that is opening the door to a digital reinvention of the worldwide manufacturing sector, and the countries who act to embrace it now will secure their place at the table of global leadership and innovation for generations to come.

The ability to create, maintain, or revitalize a manufacturing economy. Driving a global shift of this magnitude by leveraging 3D printing technology and applications will rely heavily on public/private partnerships.

Comprehensive government engagement is required for nations to realize the vast economic potential of 3D printing in the fully-digitized new world. It is imperative that federal, state, and local policymakers drive three key policy catalysts to build a successful and sustainable 3D printing ecosystem: Education, Adoption, and Incentives.

Leaders need to focus on creating new educational programs and incentives for engineers to learn 3D design, and to train educators to teach future generations of innovators. By supporting R&D in their own leading educational institutions, countries will foster the growth of broad 3D print capabilities and ecosystems to advance their competitive positions in the global marketplace.

Building incentives to accelerate the adoption of 3D printing, especially at the state and city level, will spur development of a complete 3D ecosystem that will attract manufacturing, create robust new markets, and ensure leadership and prosperity in the 4th Industrial Revolution and beyond.

HP © Copyright 2018

Table of contents

HP © Copyright 2018

HP © Copyright 2018

Background and context: past, present and future of global manufacturing

The global manufacturing sector makes up 16% of the global economy[113]—and is on the verge of being fundamentally transformed by a 4th industrial revolution. 3D printing (frequently called additive manufacturing, which incorporates multiple technologies including 3D printing) is a key element of this global analog-to-digital disruption. It is as transformational to the design, production, and distribution of goods as the computer was for access to information. It will drive the production of goods closer to the consumer, democratizing manufacturing on a worldwide scale and allowing products to mass-customize to match the needs of a growing global consumer base.

Global manufacturing: on the verge of a 4th industrial revolution

The world is on the verge of a 4th industrial revolution that will fundamentally transform manufacturing. New technologies such as artificial intelligence, augmented reality, advanced robotics, and smart devices are blurring the line between the digital and physical worlds, but none more so than 3D printing.

1st industrial revolution: mechanical production

During the late 1700's and early 1800's, the inventions of the steam engine, the power loom, and the telegraph kicked off trends that would have lasting effects on the global economy. The invention of the power loom created the concept of mechanical production and enabled access to textiles; it created a central source of production in villages and communities, building the idea of economies of scale. While this is considered the first mechanical production, it was still relatively decentralized, supporting only local communities. The steam engine created a faster form of transportation and the telegraph enabled cross-geography communications. These began a shift towards globalization and connectivity.[46, 47]

Over the course of the 1st industrial revolution, GDP per capita in the USA increased by 80%, and the population began a steady shift to centralized locations, noted by a 15% reduction in the rural population.[59, 73, 74]

Britain led the first industrial revolution, creating a monopoly on machinery, skilled manufacturing workers, and manufacturing techniques from 1760 to 1830. France was a fast follower, and became an industrial power by 1848, but was unable to catch up to Britain's lead. Much of Eastern Europe fell behind in the 1st revolution and continues to lag behind western Europe in infrastructure and economic value today.

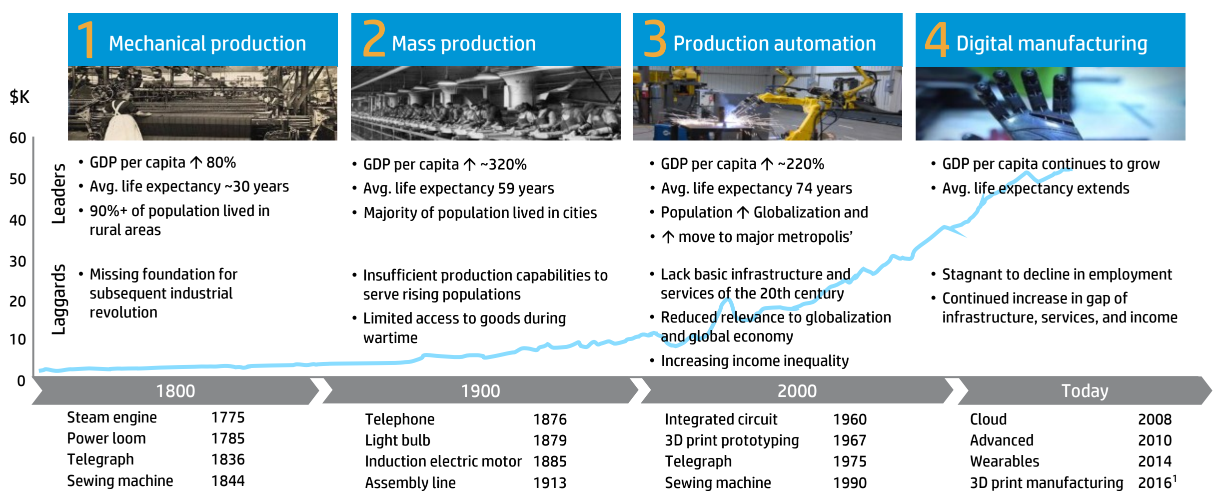


Figure 1: The History of Industrial Revolutions
Source: 2, 6, 59, 74, 105, 114

2nd Industrial revolution: mass production

In the late 1800's development of the telephone continued the trends started by the telegraph. The introduction of the light bulb and the electric motor heralded the ability to use electricity as a source of energy. Finally, the advent of the first assembly line in 1913 by Henry Ford created the concept of "mass production." It reduced the time to build the Model T by 70%, moving from 12 hours to 2 hours and 30 minutes, allowing 10 million Model T's to be built by 1924.[46]

The combination of these technologies drove the USA GDP per capita to increase by a staggering 320%. Life expectancy jumped from 30 to 59 years, and the majority of the population moved to live in major cities, where they could access the goods and services driven by mass manufacturing.[114]

3rd Industrial revolution: production automation

In 1960, the integrated circuit was developed, and the semiconductor industry began to boom, driving the growth of Silicon Valley. Over the subsequent 30 years, inventions such as the personal computer and the internet made access to information commonplace. In the manufacturing sector, what was once done through mechanical forces became an automated process, using computer systems and robotics to automate production processes. It was during this time, in 1981, that 3D printing was invented, but at the time was viewed as a prototyping and design tool, not intended for finished parts.[29]

With these innovative technologies, the global manufacturing sector boomed to where it is today, a $12 trillion (USD) industry accounting for 310 million jobs worldwide. The supply chain became globalized and increasingly complex during the 3rd industrial revolution, as companies began to optimize for cost and shift manufacturing to lower-cost economies.[113]

China became the global leader in manufacturing late in the 3rd industrial revolution based on total economic value, overtaking the US by capitalizing on the shift towards globalization and the lower cost of labor for manufacturing that is not yet fully automated. While the US is still a critical player in the global-value chain, the shift of manufacturing overseas reduced total US manufacturing sector jobs by 30% between 2000 and 2010, and created an employment gap in core manufacturing parts of the country. As China has increased in economic growth, labor costs have started to rise, driving production to even lower labor cost countries.[71] During the 3rd industrial revolution, information, communication, and travel became so accessible that manufacturing could be shifted globally to further leverage economies of scale and low labor costs. In addition, growing economic prosperity increased cost of labor in the leading countries of the 1st and 2nd industrial revolutions. The combined trends drove manufacturers to begin moving production to lower labor cost locations, and the original manufacturing economies in countries such as the US, UK, Germany, and Japan began a decline. As recently as the year 2000, the EU, US, and Japan made up 70% of the global manufacturing value add, which has declined to about 43% today. Meanwhile, China has grown from only 7% of global manufacturing to 24% in 2016.[113]

Each of the past three Industrial Revolutions has driven global growth in manufacturing, GDP growth and improved overall living conditions for the impacted populations. Technologies have driven globalization and centralization of manufacturing to achieve economies of scale. Populations have moved to major cities to allow access to goods and services not available to rural communities, and rural communities have steadily declined in relative prosperity. Countries that have not taken advantage of these revolutions have fallen further behind.

4th Industrial revolution: digital manufacturing and smart production

The recent advent of technologies such as artificial intelligence, augmented reality, advanced robotics, smart devices, and 3D printing are driving a new revolution that is accelerating the shift towards digitalization that began with the 3rd industrial revolution and the dawn of the computer age. During that period, the connection between the digital and physical worlds was limited to a few mechanisms in sparse locations, but now access to that power is being democratized to the level of individual creators and consumers.

Wearables and augmented reality are creating access to information in real time. The Internet of Things is generating user data at unprecedented speeds. Advanced analytics and artificial intelligence are allowing people to act on an abundance of information quickly and decisively. Sensors have digitized the physical world, and now 3D printing is enabling physical output from entirely digital information.

The technologies of the 4th Industrial Revolution are holistically transforming all stages of the traditional product manufacturing lifecycle: design, prototyping, production, distribution, and end of life. The new tools will accelerate the product lifecycle and change the fundamental drivers of the global supply chain structure. A report from the World Economic Forum estimates that the overall economic value of digitization across all industries worldwide will be $100 trillion in the next 10 years alone.[24]

The 4th Industrial Revolution will continue the trend in driving overall economic prosperity and expansion of manufacturing. But with increasing productivity, total jobs may not grow within the manufacturing sector, and the jobs that *are* created will shift to economies leading in manufacturing. Manufacturing will be redistributed closer to the consumer. While there are still cost drivers to re-shore manufacturing to lower cost economies, domestic manufacturing is becoming more feasible due to modern technologies, rising labor costs in traditional lower-cost economies, high international shipping costs, and high risks in the global economy. For example, three major companies in the US (Walmart, Ford, and Boeing) have announced manufacturing facilities that will return 22,000 manufacturing jobs to the US.[87]

There will be winners and losers in this shift. Manufacturers will identify geographies that balance proximity to the consumer, skilled workforce availability, and raw material access with geopolitical factors such as economic incentives, regulatory environment, and risk profile. The geographies selected for manufacturing have a huge opportunity for growth in revenue and jobs.

This slowing shift of manufacturing to low-cost countries is driven by three key elements of the 4th Industrial Revolution:

- An increase in productivity due to technologies like advanced robotics and artificial intelligence
- An ability to produce custom goods any time and any place with 3D printing, increasing the value of proximity to the end customer
- An increased expectation by consumers for fast, convenient, customized service

3D printing is to goods what the personal computer was to information. Manufacturing centers where individuals and entrepreneurs are able to design and manufacture their own unique products and solutions are becoming more accessible in more places. Manufacturing is being broadly democratized, like information was during the 3rd Industrial Revolution, making 3D printing the driver of the new digital revolution and the key to the future of the global manufacturing economy.

HP © Copyright 2018

Global manufacturing sector: key facts

- The global manufacturing sector is:[110]
  - **$12 trillion** US dollars
  - **16%** of the global economy
  - **310 million** jobs worldwide
- Manufacturing in the European Union is 15% of EU total value added
- China has recently become the largest manufacturing hub in the world
- Though the trend has slowed in recent years, manufacturing continues to shift and centralize in regions with lower labor costs
- Consumption continues to grow across the globe in both developed and developing countries

Total global manufacturing sector ($ tn)
Value added

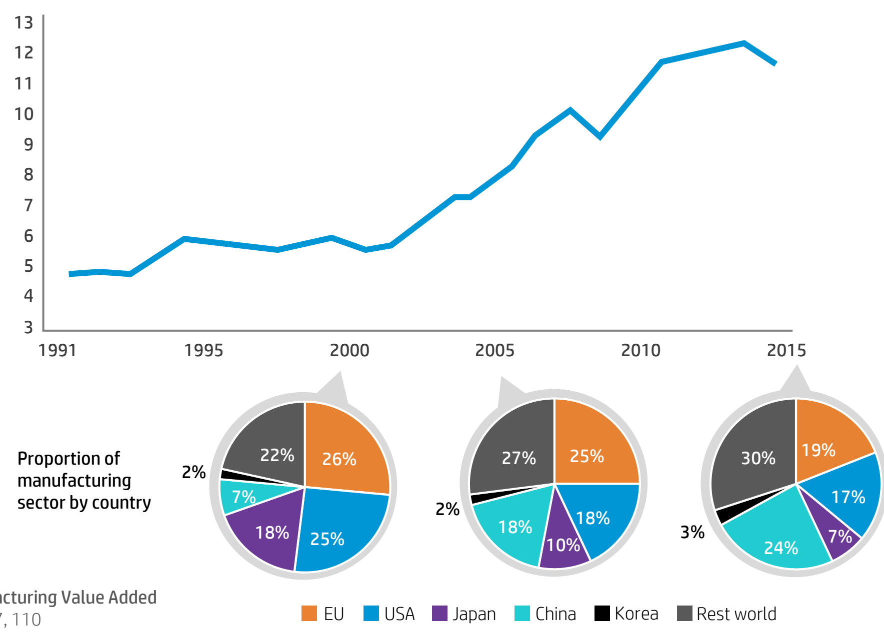


Figure 2: Global Manufacturing Value Added
Sources: World Bank, 97, 110

Manufacturing in the US[97]

- **$2.2T,** or 17% of the global sector
- **12.3 M** direct and 17.1 M indirect jobs
- Every **$1 spent in manufacturing adds $1.81 to the economy**
- The US currently **imports $3 T in goods,** annually

Manufacturing in China[7]

- **$2.9T,** or 24% of the global sector
- **99 M** jobs – 13% of Chinese workers
- China produces the **vast majority** of several major goods**: 90% of PC's**, 80% of air conditioners, 63% of shoes

Manufacturing in the EU[108, 110]

- **$2.3T**, or 19% of the global sector
- **30 M** jobs (direct and indirect)
- **16%** of EU **GDP**
- Germany is the largest manufacturing country in Europe, accounting for 32% of EU total manufacturing output

3D Printing: spearheading the 4th Industrial Revolution

3D printing is the process of adding and bonding layers of material to form a part. This contrasts with traditional manufacturing processes that either mold the finished part all at once (e.g., injection molding or casting) or are subtractive, removing material from a larger bulk to create a finished product (e.g., milling or stamping).

3D printing takes a design file and raw material inputs, and is able to generate a nearly finished part in a matter of hours. Printed parts are not limited by the same constraints as traditional manufacturing, so assembly steps can be removed, fasteners reduced, etc.

3D designs are different from designs in traditional manufacturing. A raw three-dimensional file with information regarding dimensions can be fed directly to the 3D printer. Traditional processes, such as injection molding, are not digitally linked directly to a design file. In addition, the designs for a 3D printer are not constrained by the same barriers as traditional manufacturing processes. For example, injection molding designs typically require a draft angle and seam so that the part can be ejected from the mold. 3D printing processes do not. This is a simplified explanation, but there are many design constraints of traditional processes to which 3D printing is not limited.

3D printing materials also differ from traditional materials, coming in different forms and requiring modified properties to allow bonding. The material used in 3D printing is typically in a wire or powder form, depending on the technology used. Today, the variety of materials for 3D printing is much smaller than that of traditional processes, but this is expected to expand drastically in the coming years, similarly to how plastics are now custom to application in injection molding, and metal properties are custom to application in casting processes.

3D printing was invented in 1967, when the first patent was granted for Method of Producing a 3D Figure by Holography. Since its birth, 3D printing has been seen as a tool for prototyping and design, with limited applications for end products. Within the last five years, the paradigm has shifted. Recent technological breakthroughs position 3D printing to create major disruptions in the coming years:

- Introduction of more and better materials: as more players enter the market, the material

3D Printing 101

How it works

3D Printing is a manufacturing process that creates objects by laying down successive layers of material. Additive manufacturing is also used to describe this, but covers additional processes.

A user can input raw materials and a digital file, and 3D printing outputs a solid, 3-dimensional object, like printers do for 2-dimensional objects.

There are several different technologies for 3D printing production: material jetting, powder bed fusion, photo-polymerization, etc. Each technology is used for different technical requirements including material variety, speeds, quality of finish, etc.

Key terms

- 3D printing – 3-dimensional printing
- Voxel. the voxel is the smallest unit of measure in 3D printing, a volumetric pixel; it is the 3-dimensional equivalent of a pixel

Benefits

- Increase production flexibility (batch size of 1 is possible and economically viable, in cases)
- Speed up design iteration and go-to-market timing
- Allow for distributed production (local manufacturing)
- Allow for optimized designs with reduced design constraints
- Enable fully customized products at a reasonable cost
- Print on demand and limit need for inventory
- Decrease material waste

HP © Copyright 2018

portfolio and variety of printers that can use those materials is increasing

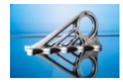
- Increase in printing speed; new printers and new printer technologies, such as the HP Multi Jet Fusion 3D, are breaking down the speed barriers of single laser 3D printing systems
- Improvement in the printer envelope size; engineering enhancements are enabling larger and larger printer envelope sizes
- Enhanced quality of the 3D printed parts; strength and consistency of 3D printed parts are moving closer and closer to traditional counterparts
- Increased level of control. Recent technologies, such as HP's Multi Jet Fusion, can control material and print properties down to the voxel level (3D equivalent of a pixel)

New uses such as dental correction devices and hearing aids have shown the opportunity to use 3D printing to customize products for the masses. New material capabilities such as gold, silver, and even organics have entered the market. 3D printers have also been developed for the maker's movement, and the idea of 3D printers is commonplace.

The entrance of major companies like GE and HP into the 3D printing market have driven capabilities towards "production ready" printers.

3D Printing use cases

Various industries already use 3D printing, both in prototyping and production, and benefit from its advantages.[10, 52, 62]



Aerospace – Airbus Jetliner Parts
3D Printing unlocked an optimized design that uses 90% less raw material, 90% less energy during production and 55% weight reduction

Healthcare & Medical Devices – Hearing Aids
3D Printing unlocked the opportunity to manufacture highly customized hearing aids and to reduce manufacturing steps by 70%

Consumer Products – Loom Dress
3D Printing allowed for complex weave that cannot be achieved through traditional processes, ultimately creating clothing that adapts to human movement and intended functionality

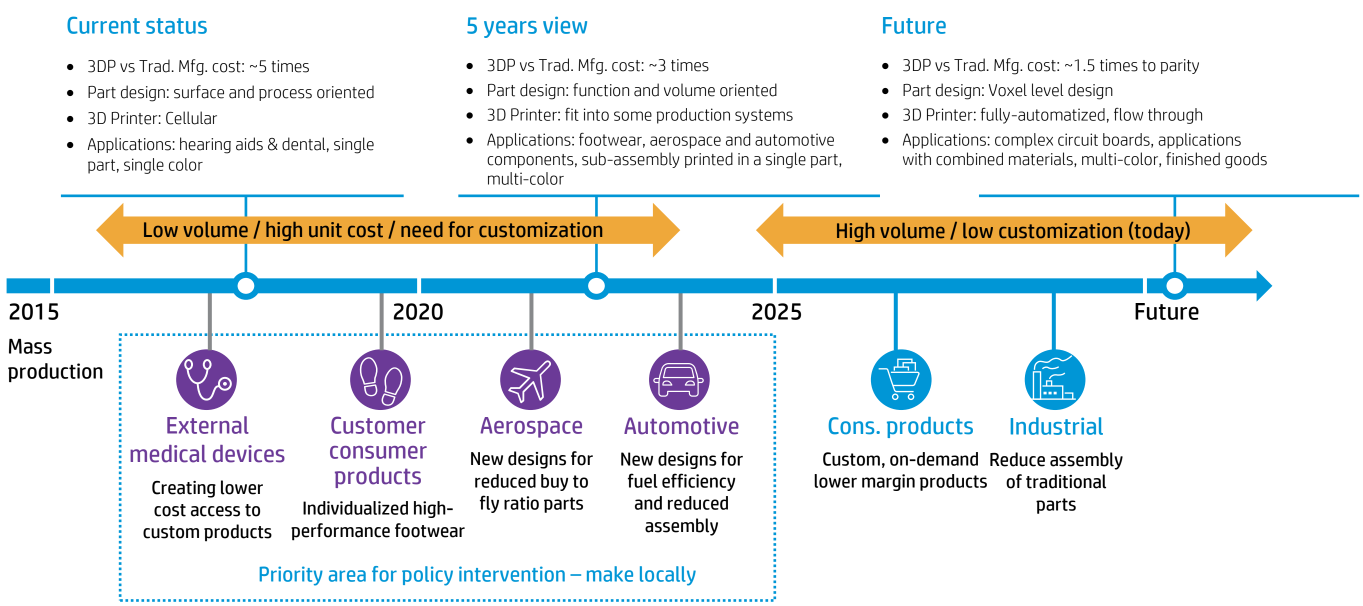


Figure 3: Trends in 3D Printing Technology
Source: A.T. Kearney Analysis

3D printing fundamentally changes how we design, source, make, and deliver products: a transformation within hours, a nearly impossible task with traditional technologies. For example, Smile Direct Club is a new business model for dental correction, fully enabled by 3D printing. The company sends an in-home impressions kit to model the customer's teeth. This is used to develop a 3D printed retainer that helps straighten the smile, all without any dental visits.[29]

In manufacturing, 3D printing is already used to create production tooling and other low-quantity parts; manufacturers can customize to what they need, quickly. Replacement is as easy as reprinting parts. 3D printing in manufacturing will continue to expand and will become pervasive in industries at different rates, driven by technology, maturity, and cost reduction. 3D printing will become a commonplace manufacturing technology alongside more traditional processes like injection molding, forming, and milling.

Currently, 3D printing is most used in industries and applications with low-volume, high-unit cost and the need for customization, where costs of 3D printing are outweighed by the benefits. However, technology improvement has been pushing the limits of the technology and unlocking its use in mass production applications. Uses such as external medical devices, custom consumer products, and aerospace and automotive parts designed for fuel efficiency will become commonplace in the next five to seven years.

Technology maturity is also driving development of a broad 3D ecosystem. The core of the ecosystem is made up of product designers, users, printer manufacturers, material producers, and software providers. Many companies are trying to push expansion of the core. For example, HP has launched an open materials platform to encourage more materials providers into the ecosystem. Other types of players are joining the mix as well; for example, systems integrators are needed to help manufacturers effectively integrate the new 3D printing technologies with existing manufacturing systems. Design software companies also play a role, as existing design software is not able to capitalize on the technological innovations available in the latest 3D printers, such as voxel-level control.

New business models are entering the ecosystem such as service bureaus, which are locally based 3D printing facilities. Local Service bureaus provide access to digital manufacturing methods for entrepreneurs, startups, and small-to-medium businesses to prototype or manufacture new products. Through service bureaus, 3D printing creates lower barriers for entry and greater degrees of manufacturing speed and flexibility.

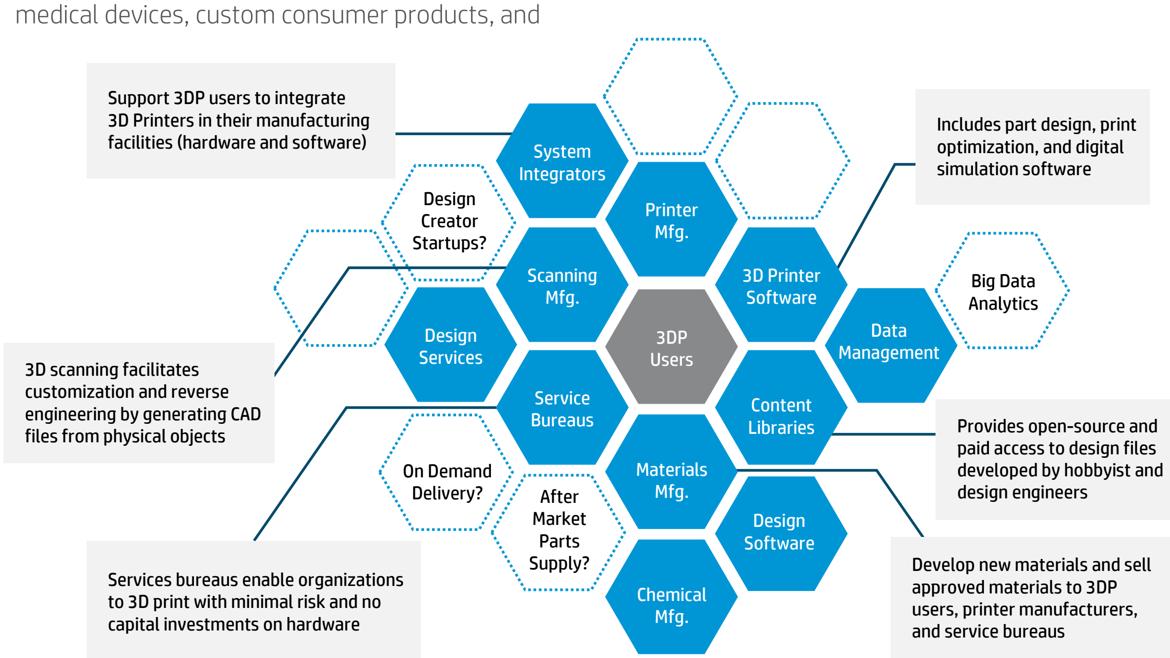


Figure 4: 3D Ecosystem
Source: A.T. Kearney

For example, Forecast 3D is a full-production capable service bureau with 12 HP Multi Jet Fusion 3D printers that can produce 600,000 functional parts in a single week.[91] Historically, access to this level of manufacturing at a viable cost would require the creation of a complex global supply chain; but now it is as easy as a walk down the street. This access to manufacturing in turn enables further innovation in products and business models. Other new business models may be developed as well, such as content libraries, like an iTunes for 3D designs, to store and secure 3D printing designs. There are also opportunities in data management and security, and design services (to help consumers generate a design), etc.

As the ecosystem continues to grow, so does the opportunity that comes with 3D printing.

The future of manufacturing

3D printing will fundamentally change today's complex supply chain, moving manufacturing closer to consumption. The massive supply chain advantages of 3D printing coupled with consumer trends will enable manufacturers to cost effectively serve consumers, closer to where they live.

3D printing enables cost-effective customization. Close interaction with the end customer will be necessary to customize products to meet their needs. Locating manufacturing closer to consumers will allow them to iterate towards the end part; whereas a global supply chain would have large transportation costs that would minimize the ability to test out customizations. The customization needs will be different based on the consumer population; the product for the US consumer will be drastically differentiated from the product for the consumer in India.

3D printing increases go-to-market speed. The time and effort to build complex global supply chains will not keep pace with the increased cycle time of new product launches. The supply base will need to be closer to manufacturing, and various steps of manufacturing will be closer together.

For manufacturers, having 3D printers and raw materials will enable drastic reduction in inventory. Any needed part can be made on demand without waiting for transport time; this efficiency is only enabled if manufacturing is located close to where the part is needed.

3D printing is also reducing the barrier to entry in manufacturing and production of goods, driving a democratization of manufacturing that will fundamentally change entire value chains, from complex global supply to local ecosystems.

The shift closer to consumption and to shorten the supply base will redistribute manufacturing across the globe, but where it will go depends on many factors, including ecosystem development, economic environment, ongoing consumer trends, and, most importantly, which countries act quickly to lead in 3D print manufacturing.

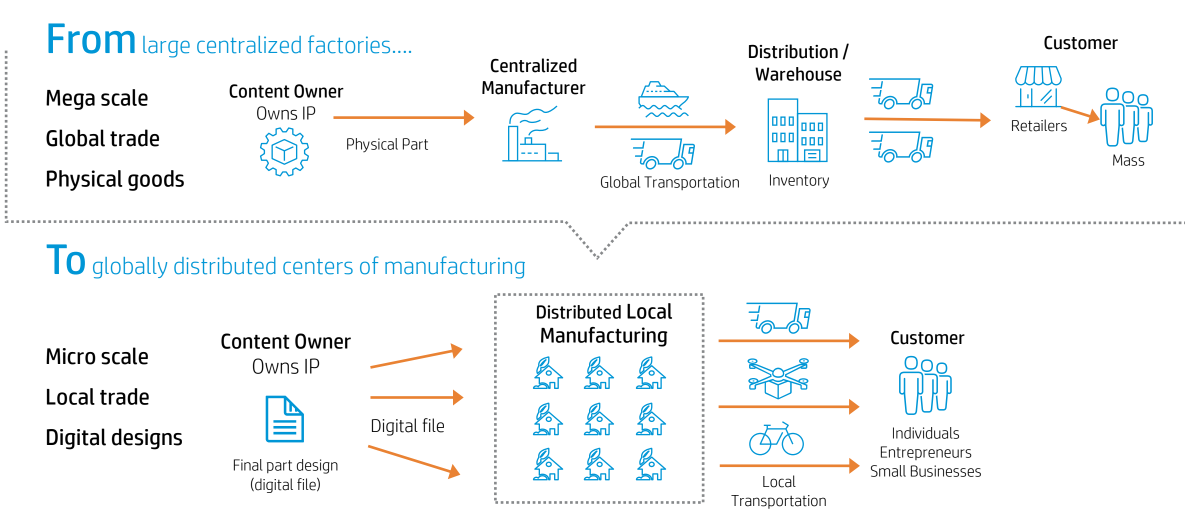


Figure 5: Distributed Manufacturing Supply Chain

HP © Copyright 2018

Opportunities for leaders

3D printing has major implications for leaders across the globe, at all levels. It has the potential to impact many key issues including:

1. Economic value
2. Job creation
3. Education and skills
4. Sustainability
5. Technology advancement
6. Nation defense/security
7. Domestic security

For some of these issues, there is a huge value at play for those leaders that take advantage of the opportunity. According to an A.T. Kearney analysis, 3D printing is poised to disrupt and redistribute $4 to 6 trillion of the global economy in the next five to 10 years, but where that value goes depends entirely on decisions of key leaders in both the public and private sectors. Along with the opportunity, there is a risk for leaders who don't act. Existing manufacturing bases have the potential to shift quickly. The opportunity will go to those who act quickly to build a 3D printing ecosystem; others will struggle to catch up.

Key Issues	Global	Country	State	City	3D Printing Impact	Value at Play
Economic Value	✓	✓	✓	✓	Manufacturing moves closer to consumers, development of new business models, and overall economic disruption	**$4T to 6T**; will be disrupted due to redistributed manufacturing
Jobs		✓	✓	✓	Manufacturing jobs are relocated closer to consumers, new jobs are generated with new business models	Localized manufacturing shifts **Jobs**
Education & Skills		✓	✓	✓	Required skill sets shift up the knowledge curve towards engineering and design	Demand for **higher-skilled labor** increases
Sustainability	✓	✓	✓	✓	Demand and supply can be balanced, closer to 1:1; raw material usage and transportation are reduced	Supply chain is simplified, with **reduced waste**
Technology Advancement		✓	✓		New products can be made that cannot be made with traditional processes; there is increased control at the "voxel level" of design	Groundwork is in place **for Technology advancements**

Key Issues	Global	Country	State	City	3D Printing Impact	Risks of Inaction
National defense/security		✓			Access to supplies on-demand reduces lives risked on supply runs; ability to create new materials and new designs enables technological advantage in security	**National security advantage** goes to countries with 3D printing and technology advancement and on-demand printing
Domestic security		✓	✓	✓	Products can be manufactured more easily and therefore counterfeited more easily	Consumers may access new products without **appropriate controls**: are they safe?

Value at play

3D printing will disrupt global manufacturing and change the fortunes of national economies and workforces. It will have a massive impact for countries, states, and cities, globally. It will create new opportunities for economic growth, job creation, higher-skilled jobs, and a more sustainable future for the global manufacturing industry.

Economic value

3D printing is poised to disrupt $4 to 6 trillion (USD) of the current global economy over the next five to 10 years. This is the segment of the existing economy that has greatest potential to be redistributed across the globe.

The global manufacturing sector is valued at approximately $12 trillion, which accounts for design, production, and distribution of all global goods. There are five key industries that have the greatest potential to be transformed by 3D printing: Heavy Industry, Automotive, Consumer Products, Healthcare and Medical, and Aerospace. These five industries are estimated to account for 76% of the global manufacturing sector, totaling $9 trillion per year of total output. Based on results of a survey by industry experts, 23% to 40% of parts in these industries will be manufactured by 3D printing in the next five to 10 years, meaning $2 to $3 trillion of the global manufacturing sector will likely be impacted by 3D printing in the next five to 10 years.

In addition, assuming a macro-economic multiplier effect to be 1.8 globally, 3D printing will disrupt $4 to 6 trillion of the global economy.[95]

Example: United States opportunity for economic value

The US economy is expected to grow by $600 to 900 B per year in the next 5 to 10 years if they capitalize on 3D printing. The US imports approximately $3 trillion in goods annually. $1.4 trillion of imports are made up of 5 leading industries impacted by 3D printing: Industrials, Automotive, Consumer Products, Healthcare & Medical, and Aerospace. Based on a survey of industry experts, approximately 24 to 40% of parts in these industries will be manufactured by 3D printing in the next 5 to 10 years. This means that for the US, $300 to 500B of what is currently imported, could be manufactured within the US using 3D printing, driving increase in revenue generated within the US.
4, 28, 49, 53, 83, 91, 97, 98, 99, 100, 101

Additionally, in the US for example, every $1 added to the manufacturing sector, generates a $1.8 increase in the total economy due to a cascade of effects of growth in the manufacturing sector, known as the Macroeconomic Multiplier Effect. The effect includes growth in service industries and infrastructure. If $300 to 500B new revenue in manufacturing is generated by the US, the total economic value is $600 to 900B.[94]
(A.T. Kearney Analysis)

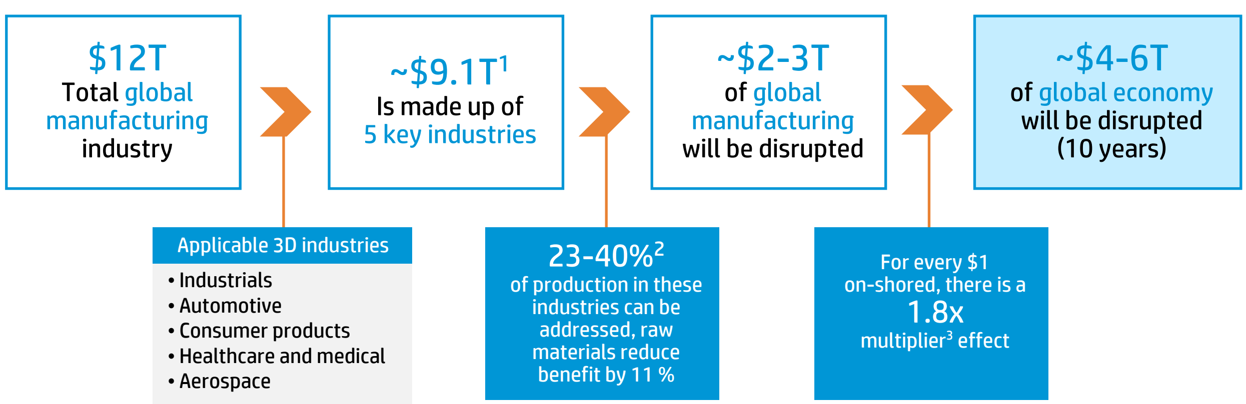


Figure 6: Global Economic Disruption due to 3D Printing
Source: A.T. Kearney Analysis

[1]The macroeconomic multiplier effect varies by geography with estimates ranging between 1.2 and 3.8, therefore 1.8 is used as an estimate to show scale of the impact.

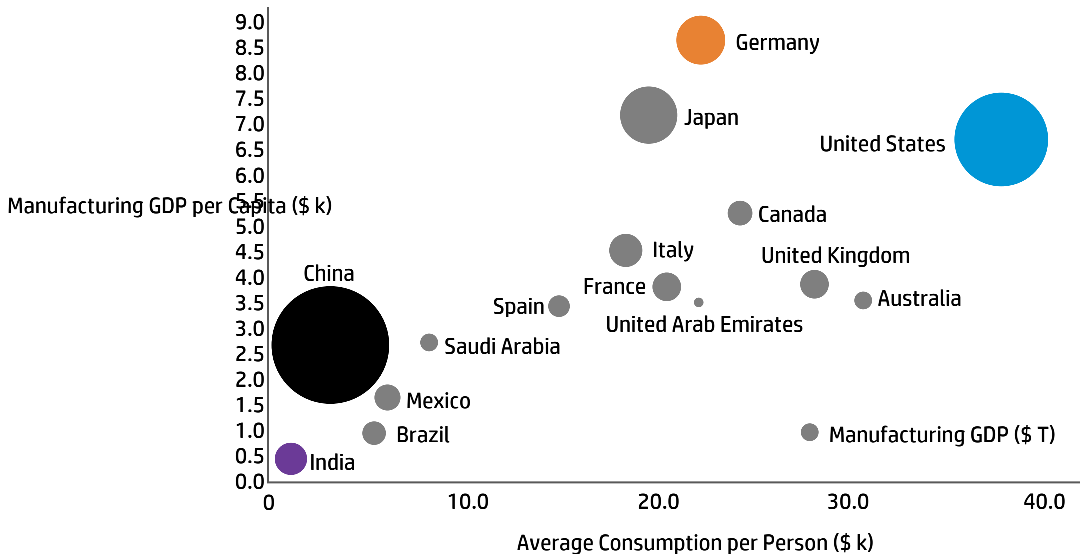


Figure 7: Production vs Consumption by Country (2016, all data in USD)
Sources: A.T. Kearney Analysis; World Bank 2017, 6, 98

Ninety-six percent of the experts from the same survey believe that 3D printing has potential to move manufacturing closer to consumers. (A.T. Kearney Analysis & Survey results)

Various countries are beginning to think through what this massive shift in manufacturing means for them. See Figure 8, which compares consumption versus manufacturing. Countries that have high consumption have an opportunity to grow local manufacturing, while companies that have large manufacturing bases with low consumption need to act quickly to maintain the base.

- China is driving hard to maintain manufacturing competitiveness. They see 3D printing as both an opportunity and a risk to their manufacturing economy, and are investing heavily including $132 million allocated to 3D printing R&D. It is critical for them to remain competitive to maintain the manufacturing export sector. [1, 51]
- India is looking to 3D printing as an opportunity to build manufacturing competitiveness and increase the average income per household through the Make in India initiative. They can leverage 3D printing to better serve the large and varied consumer base, and some see it as a leapfrog opportunity for India to become a manufacturing leader.
- While there are several ongoing initiatives in the United States, such as America Makes, Department of Defense investment, and university and private industry efforts, the US has yet to publicly define an overall national strategy or imperative for 3D printing. However, the US has an opportunity to increase economic output and revitalize the manufacturing economy. Companies in the US can provide the high-consumption populace with more variety and customization of products.
- Germany is targeting 3D printing as a key technology to rebuild the manufacturing competitive advantage.[1]
- Countries like the UAE and Saudi Arabia see 3D printing as an opportunity to leapfrog into the manufacturing sector and serve consumer bases locally. [1, 26, 79]

Many countries have a significant opportunity to revitalize or grow a manufacturing economy and support their local consumer base by acting to build a 3D printing ecosystem that captures the $4 to $6 trillion. Other countries need to accelerate the 3D printing ecosystem to maintain the current manufacturing base. Where the disrupted manufacturing ultimately ends up depends on actions of public and private sector leaders; manufacturing will shift to economies that lead the 3D printing movement.

Jobs

Today, many developed economies are struggling to keep their workforce employed, continuing to strive for higher-value labor. According to the World Economic Forum report on The Future of Jobs, the Fourth Industrial Revolution is expected to decrease low-skilled jobs globally, which will be offset by the creation of new higher-skilled, more lucrative jobs to support new technologies and business models.[24] 3D printing will disrupt the existing manufacturing structure and redistribute jobs across the globe. In this context, 3D printing leadership in the new global economy becomes even more critical; countries that lead development of the 3D ecosystem will capture the influx of new digital manufacturing jobs that will be created in the future, in addition to accelerating development of new business models that define employment opportunities for the future workforce.

The implication of this global job redistribution will vary by economy. There are three key profiles of countries that are best positioned to lead the new employment landscape: Countries that currently have a base in manufacturing, countries that have high consumption, but manufacturing has dropped in recent years, and countries that do not currently have manufacturing but have a consumer base.

Countries that currently have a base in manufacturing will need to act quickly to maintain their workforce. There is a risk that there will be a net job loss if they do not drive the adoption of digital manufacturing ahead of other countries, as those jobs will shift to locations that have taken advantage of the opportunity. Countries like China fall into this category, as they have increased their share of the global manufacturing economy over the years, boosting their economy and employment significantly.

For countries that have high consumption and historically had manufacturing that has been outsourced overseas due to labor costs, there is an opportunity to revitalize the manufacturing sector and bring jobs back to the local economy. Countries such as the US and Germany fall into this category.

For countries that have not historically had a manufacturing base, there is an opportunity to leapfrog into the 4th Industrial Revolution, but it is an uphill battle to create the needed infrastructure and skill sets. Countries such as the UAE fall into this category.

Development of new business models such as 3D printing service bureaus will also create new jobs. For example, the Forecast 3D service bureau in Southern California currently supports 100 employees running a variety of equipment, recently including 12 production-scale 3D printers that allow them to become a manufacturing-scale facility rather than prototyping-focused.[91] The total impact of new business models due to 3D printing is yet to be determined.

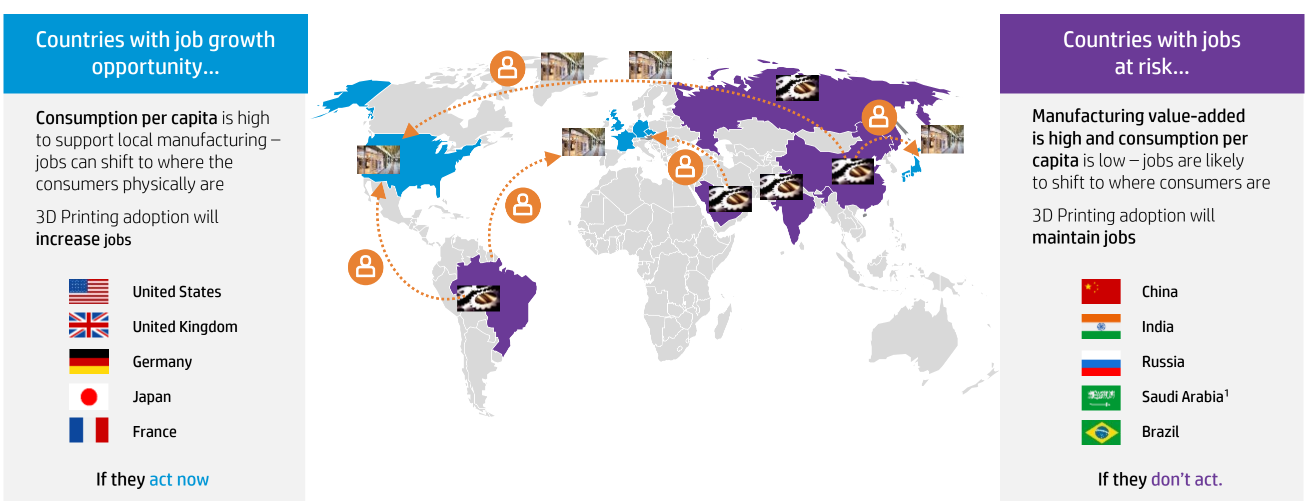


Figure 8: Global Jobs Disruption due to 3D Printing
Source: A.T. Kearney Analysis

Example: US opportunity in manufacturing jobs

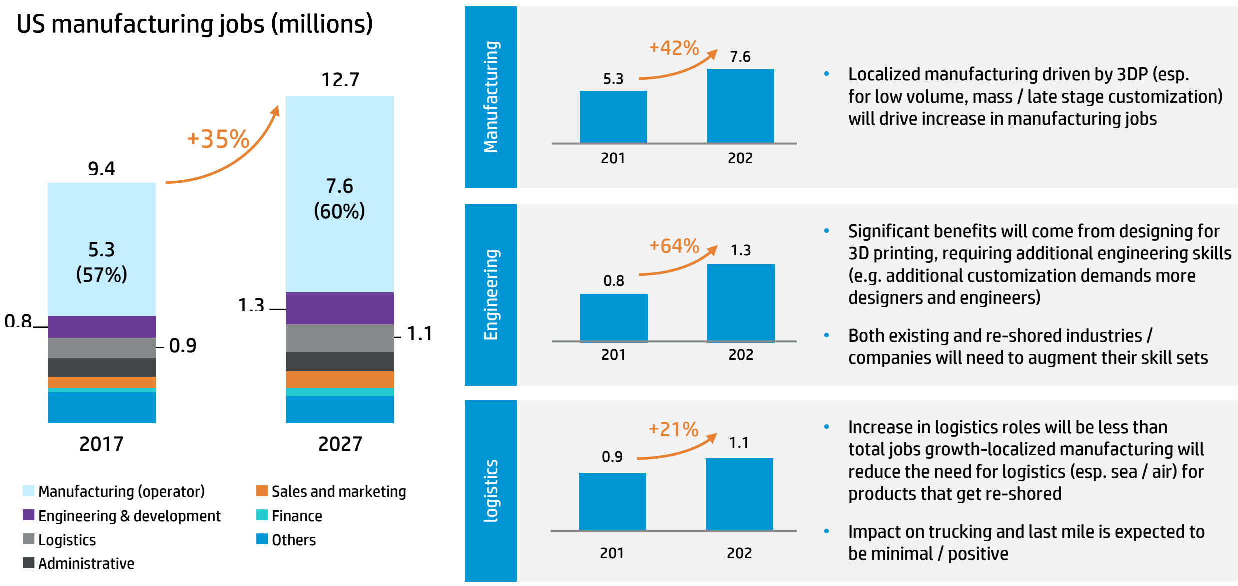


Figure 9: Example – US Change in Job Functions due to 3D Printing
Source: A.T. Kearney Analysis

Within the US, there could be an additional 3 to 5 million jobs in the next 10 years. These are made up of two to three manufacturing sector jobs, and 1 to 2 million jobs created due to the 1.8 x multiplier effect.

Currently, there are 12.4 million jobs in the US manufacturing sector. 2 to 3 million new jobs would mean 20% growth in manufacturing jobs that can be made possible by attracting 3D printing manufacturing business.

The new jobs in the manufacturing sector will be distributed across various types of roles.

The new jobs will be distributed across the industries that come back. If the full value at play is captured, most jobs will fall in the Industrial and Automotive sectors.

In addition, jobs will be created based on the economic multiplier effect. The opportunity for the US is a total of 3 to 5 million jobs, based on a 1.8X multiplier. There are some sources that indicate a multiplier as high as 3.4X; this would mean an additional 7 to 10 million jobs in the US.

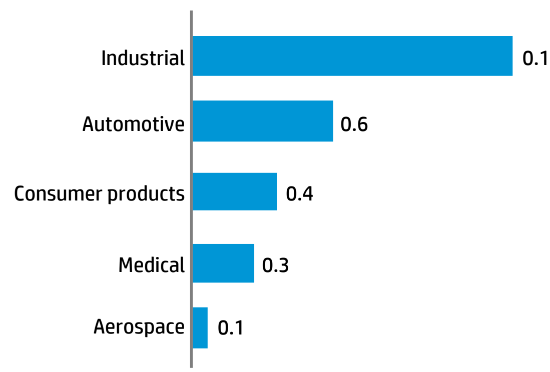


Figure 10: 3D Print Manufacturing Job Concentration
Source: A.T. Kearney Analysis

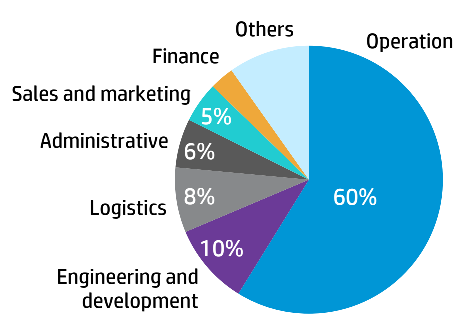


Figure 11: Example – US Manufacturing Job Growth by Industry
Source: A.T. Kearney Analysis

New skill sets

Manufacturing jobs will not only be disrupted, they will also look different from the manufacturing sector jobs of the past. Job functions will be rebalanced with the largest impact on Operations, Engineering, and Logistics functions. In addition, to a change in functional distribution, the skill sets required to execute the operations and engineering roles will change. Finally, new types of jobs will be created, some of which are already evident in the 3D printing industry.

Manufacturing jobs that come back will be rebalanced across functions, with overall growth in concentration within operations roles and engineering, and reduced concentration in logistics roles.

Operations roles are expected to increase slightly in concentration versus total manufacturing jobs, moving from 57% to 60% of total manufacturing sector jobs. This is caused by the need to customize products, which is expected to require increased floor-level support. While operator roles and skill sets will not fundamentally shift from those required to run comparable traditional automated manufacturing equipment, operators will need to be up-skilled to run 3D printing equipment. For example, 3D printing processes can be digitally linked from design through quality control, requiring additional computer user skills. In addition, many 3D printing processes have additional safety considerations, such as laser usage and large amounts of dust, both of which require special training in the manufacturing space. However, in countries with more manual manufacturing roles, operators will require significant up-skilling akin to what would be required to operate any automated production process.

Engineering and design roles are expected to increase in concentration disproportionately to the rest of the manufacturing sector. 3D printing is expected to increase the pace of the product lifecycles, and engineers will be required to design new products, as well as support production of existing products. In addition, engineers and designers will need to learn skill sets that expand beyond the traditional engineering functions across the product lifecycle, blurring the lines between traditional engineering functions.

With a shortened time to market, design engineers will need to help push product through to production – and the distinction between roles will become less clear. Designers will also need to be re-skilled. The design constraints of 3D printing are very different from those of traditional manufacturing processes. Design engineers need to "un-learn" constraints of traditional manufacturing that are no longer constraints for 3D printing, and learn how to "think in 3D" and adapt quickly to the rapidly-changing limits of 3D printing technologies.

Design engineers will learn to "think in 3D"

Manufacturing engineers will also be increasingly expected to support design, and to launch activities. The process flow of manufacturing has the potential to shift fundamentally with 3D printing, and manufacturing engineers will need to evolve the flow of the production floor to adapt to 3D-enabled capabilities, such as mass customization.

Process engineers will need to learn the details of how 3D printer processes operate in order to become process experts, much like injection molding experts today, to support the operations functions during production.

Specialists in engineering functions such as software engineers, simulation specialists, and materials engineers will still be required, but will need to learn additional skill sets for their function in the context of 3D printing.

Logistics roles will be reduced in relative proportion to overall manufacturing sector jobs. With localization of manufacturing, cross-country and global logistics will become less and less of a requirement. Logistics functions will shift to focus on last-mile delivery and customer service.

HP © Copyright 2018

New roles will be created: there is potential for designers that connect closely with consumers, and help them design the product that is right for them. These designers will support customers in creating a product that fits their needs. Updated logistics planning roles will focus on getting tailor-made products to consumers: managing increasing complexity in outbound delivery, closer and closer to the direct-to-consumer model. Individuals may need to fill the role of 3D print "reverse engineers." When 3D printing is used to build replacement parts for items that have no digital equivalent, engineers will be needed to reverse engineer the design. They will also help make modifications to improve designs for the 3D printing process, and for longer-term performance. They will be able to help customers identify materials, dimensions, strength, and other critical properties for any product, then build the digital equivalent so the part can be 3D printed.

Job skills in the 3D Printing world

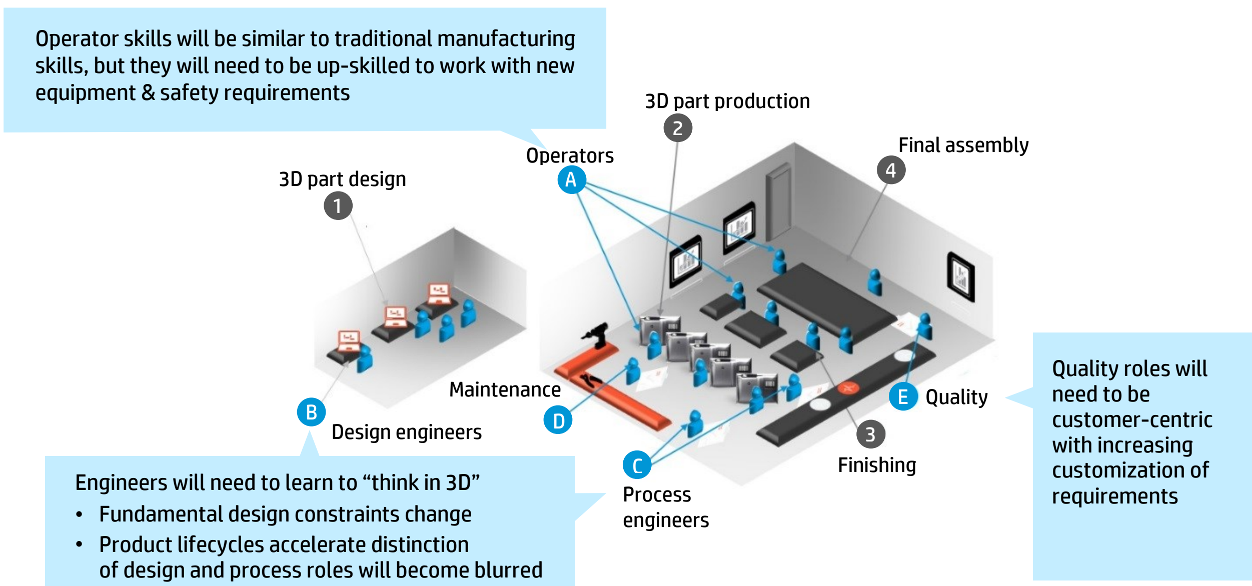
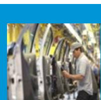


Figure 12: Illustration of 3D Printing Jobs in a Service Bureau



Operators
While skill sets won't substantially change, bringing back overseas jobs will require development of higher-skilled labor

Sample operator steps	Traditional manufacturing (e.g. injection mold)	3D printing	
Insert tooling	✓	✓	Less tooling with 3DP
Adjust process parameters	✓	✓	Different interfaces but similar process
Insert materials	✓	✓	Different material but similar process
Try-out process	✓	✓	-
Handle parts	✓	✓	Part-size dependent, 3DP may need more handling
Inspect parts	✓	✓	-
Conduct additional setups	✓	✓	3DP allows for customization

Design/engineers
Engineers need to learn the new criteria to "design for 3D." Skill sets will need to span the full product lifecycle

Product value chain	Traditional manufacturing (e.g., injection mold)	3D printing	
Ideation			More capable design software
Design			Increase in customization
Prototype			Faster interactions
Validation			-
Process / assembly line development			Less assembly required
Production			Digital connection between design and manufacturing

Figure 13: Job Skill Changes in 3D Print Manufacturing

Design engineer   Specialist engineer[1]   Mfg. engineer

Sustainability

3D printing allows a path to a more sustainable future by localizing and simplifying the supply chain. A model on the sustainability of 3D printing demonstrates that CO_2 emissions could be reduced by 130.5 to 525.5 Mt by 2025, including a 5% reduction in manufacturing emission intensities due to 3D printing. The analysis goes on to state that if 3D printing could be more applicable at higher production volumes, it could theoretically decouple energy and CO_2 emissions from economic activity.[36]

Sustainability benefits of 3D printing occur throughout the value chain from pre-production, to production, inventory, product use, and service.

In pre-production, 3D printing will reduce dramatically the need for tooling, which requires high quantities of energy to be manufactured.

In production, the number of sub-assemblies can be dramatically reduced, reducing overall energy required to mass-produce products.

From an inventory perspective, there will be less material waste as well as reduced logistics. With a local manufacturing process and fast production for customized products, lead times can be drastically reduced, which allows manufacturers to move closer to a 1:1 supply/demand ratio, and reduce scrap created through overproduction. Reduced waste will have a cascade effect, reducing overall supply chain impact on the environment. This effect is a massive opportunity in locations where resources and raw materials are limited or at risk of depletion. Logistics can be reduced due to reduced material flow; logistics will occur for raw materials and finished parts, and logistics of intermediaries will be reduced. As manufacturing moves closer to the end part user, there will also be reduced transportation requirements.

From a product perspective, 3D printing allows new and optimized designs that weigh less, and in cases, can reduce fuel consumption. For example, Renault Trucks use 3D printed engine parts that are 25% lighter, which improves fuel efficiency.

Finally, in service and maintenance, 3D printing enables manufacturing-on-demand, which reduces the need to store parts over a multitude of years, removing the energy required to maintain parts over time.

Overall, 3D printing creates an opportunity to reduce waste and simplify the supply chain, creating an opportunity for a more sustainable future.

1 Jobs and economic growth	2 Pre-production	3 Production	4 Inventory / logistics	5 Product use	6 Service / maintenance
• Not applicable	• Tooling – 3D printing does not require tooling production	• Multi-part assembly – 3D printing is expected to decrease the need for sub-assembly • Allows for ↓ material use (↓scrap)	• Less inventory – ↓Utilities use – Less space required • Inbound logistics – ↓component transportation • Outbound logistics – Localization leads to ↓goods flow	• Less fuel consumption – ↓parts weight and ↑parts efficiency as a result of optimized design (complex designs restricted by Trad. Mfg.	• Part manufacturing on-demand – Printing after-market parts /components on demand reduces the need to store parts for many years and decreases the waste (parts that are never used)
Use cases					
• Not applicable	• Boeing used 3D printing to quickly develop UAV prototypes, eliminating wasteful development cycles and related emissions	• GE uses 3D printing to build fuel nozzles, using fewer materials, reducing manufacturing emissions and energy	• Mercedes-Benz trucks 3D prints and delivers parts from the nearest facility, cutting shipping emissions	• Renault trucks 3D printed engines that have 25% fewer parts and are 25% lighter, improving fuel efficiency	• US Naval Air Systems 3D prints spare parts for old vehicles, removing the need for inventory upkeep emissions and waste

Figure 14: Sustainability Impacts of 3D Printing
Source: A.T. Kearney Analysis, 39, 52, 55, 77

Technology and innovation

3D printing will allow for new designs and products due to the removal of design constraints in traditional manufacturing. There are several examples of innovation already occurring.

Airbus, for example, has parts for jetliners and, more specifically, for the A320. The jetliner parts have a higher strength-to-weight ratio, allowing use of 90% less raw material and 55% reduction in weight. The A320 hinge brackets have an optimized structure for 25% reduction in raw materials and 50% reduction in weight.[52]

A company in Spain, Xkelet, started custom making medical casts in 2014. Custom-printed casts are made with less material and the 3D model is also used to help monitor patient healing. The casts are also more comfortable, enable faster healing, and are waterproof.[14]

Recently, companies have started manufacturing clothing, including suit jackets and dresses, with 3D printers. Printing enables a complex weave called auxetic patterns that cannot be achieved through traditional processing. The clothing can adapt to human movement with increased flexibility and durability.[62]

3D printing is already enabling innovation for both improved efficiency and new product capabilities. As the 3D printing technology itself improves, the innovations will be even greater, moving into increased level control, multiple materials, and even more unique structures.

3D printing will also enable materials to be increasingly customized for purpose. Just as materials in injection molding are blended and fit for purpose, materials for 3D printing will expand to be fit for purpose. The realm of possibilities for 3D printing is even greater because there are more custom applications to solve for, and material properties can be controlled within a design down to the voxel level.

As it advances, 3D printing will be key to technology and innovation leadership for countries, as many other technologies have been in the past. Personal computers, for example, enabled access to information for the masses which scaled innovation on a broad level. As individuals and small business have greater access to manufacturing, they will be empowered to drive further innovation. Countries that have a supportive environment for innovators to gain value within the value chain will experience greater opportunities to advance in technology and innovation leadership through 3D printing.

Figure 15: The First Personal Computer
Source: Wikimedia Commons

Personal computing case study

Technology and innovation chain reaction overview

Computers enabled high-capacity processing and digitized storage—two critical features to enable future revolutions.

Enablers

High-capacity processing: Enabled humans to solve complex problems that were impossible by hand (e.g., rocket launch trajectories, code encryption patterns, etc.)

Key outcomes

Technologies that enable individual access to what is traditionally limited pave the way for greater innovation. Countries leading in these technologies innovate faster, and are able to scale innovation across the entire country.[106]

Risks of inaction

There are also risks to not leading the broad scale introduction of 3D printing. The 3D printing leaders will gain an advantage in national security with the ability to make faster, stronger, lighter tools and access to supplies on demand. Those who are not prepared for the industry to grow also see more domestic risks. As more and more information is transferred rather than goods, and a broader group has access to manufacturing capabilities, there are concerns that people will make things that are unsafe. This could include counterfeit products or otherwise regulated items, such as weapons. Industry leaders and policymakers need to act together to mitigate risks.

National security

Leaders in the 3D printing space will grasp the national security advantage, and those without strong 3D printing capabilities will be at a significant disadvantage. There are three key elements to the national security advantage:

- 3D printing allows manufacture of items that cannot be made with traditional processes
- printing allows these and other items to be printed on-demand and on-location, minimizing supply runs, which is usually a point of weakness in combat zones
- 3D printing can enable access to on-demand manufacturing on ships and submarines, drastically increasing the variety of tools on hand

3D printing is a new tool for militaries that will create an advantage much in the way other technologies have in the past.

During World War II the Enigma Machine, an encryption device for messages that changed daily, made German military missions to attack allied supply ships nearly unstoppable until Alan Turing and his team cracked the code and broke the advantage.[42]

During and post-World War II, development of radar systems began to have a similar advantage. Various countries were able to identify pending enemy attacks, as well as identify the positioning of enemy vehicles to counterattack.[42]

A more modern example are drones, or Unmanned Aerial Vehicles (UAV's), which pushed the United States to unprecedented geographic reach and a military dominance that didn't put soldier's lives at risk. In 2009 the CIA reported that they had killed over half of al-Qaeda's most-wanted targets by using UAV's. Now many other countries have joined the race to rule the skies.[84]

3D printing has already demonstrated the ability to drastically enhance other technologies.

The UK Royal Navy used 3D printing to develop a drone that is cheaper and more durable, a design that was not manufacturable with traditional manufacturing processes. It was tested in January 2017 in Antarctica due to its harsh environmental conditions.[97]

The US recently launched pilots for 3D printed "mini-drone swarms." The drones are so small that they could not be effectively manufactured with traditional processing. The end use is not explicitly stated, but experts agree they will be dropped from the sky to confuse detection systems.[84]

Figure 16: 3D Printed Drone Swarms (Illustrative)

As the technical capabilities of 3D printing expand and material variety increases, the military applications have potential to be far-reaching. 3D print materials, with increased level control, have the potential to bring composites, which have already been used to drive military advantage, to the next level.

In addition to creating things that haven't been made before, 3D printing makes production of these parts, as well as more menial supplies, more accessible. Manufacturing can move on-location for combat zones and military bases. Today the main applications are for replacement parts, but as materials and technologies advance, the opportunities are vast. 3D printing can drastically reduce the number of supply runs to combat zones, which historically have been a point of weakness for most countries. From 2000 to 2011, two-thirds of all U.S. Armed Forces deaths unrelated to war were caused by transportation accidents. With 3D printing, only raw materials would need to be transported, drastically reducing risk to lives.[41, 96]

Domestic security

Preparation is necessary so that adoption does not have unintended consequences. Partnerships between industry and government can drive solutions.

There is risk that, with direct access to on-demand manufacturing, individuals could manufacture goods that are potentially dangerous. The solution to this is partnering with industry leaders to build technical solutions.

For example, in traditional 2D printing, partnerships between large-scale printing companies and the United States government have identified solutions that prevent printing of counterfeit money. This has now become standard in printing technology.[44]

In the pharmaceutical industry across the globe, both industry leaders and policymakers have driven the track-and-trace agenda. Counterfeiting is costly to industry leaders, as their branded goods can be made and sold without them receiving profit. More importantly, if these counterfeit goods cause harm to consumers, the industry will get a bad reputation that can have lasting impact on demand. It is beneficial for industry leaders to identify a technological solution to resolve the issue, and policymakers can support this effort.

Ultimately, supporting technology growth in the production space will allow industry leaders to develop technical solutions. This is mutually beneficial, as designers and 3D print users in industry also want to protect their IP and data from counterfeiting. Technical solutions can support both efforts without inhibiting the technology and all the other benefits that come with it.

Additionally, with transfer of goods shifting to a transfer of data, policymakers should support industry development of technical solutions that drive data security. For example, in the cloud computing space, cloud services are now considered to be more secure than traditional servers, because industry leaders have been able to focus security for the existing risks. In the US, the Central Intelligence Agency has launched a private cloud with Amazon, working closely with them on data security to the extent that other Department of Defense agencies can put data on the cloud as well. Similar solutions can be developed in the 3D space if policymakers are supportive of the industry.[108]

Policymakers need to be sure to work with industry to address these concerns, or they will prevent growth of the industry and the multitude of other opportunities that come with it. The most successful cases of enabling growth of an industry while sufficiently protecting public interest come from public/private partnerships. This enables technical solutions that, ultimately, can be more effective than any regulation.

There are many opportunities for leaders to take advantage of, and there is a risk for those who don’t act to keep up with the industry. 3D printing will disrupt the global economy. It will move jobs and change the skill sets required to work in those jobs. It will drive sustainability and enable further technology and innovation. Those who do not act will miss out on growth, and will be at a national security disadvantage.

The global race is ON

The 3D printing industry is growing rapidly, and is at an inflection point. Leaders across the globe are investing to try to take the lead, because the first movers will capture the opportuinty while followers will fall behind in the 4th industrial revolution.

3D Printing global market

Over the past 28 years, the compound annual growth rate of worldwide 3D printing products and services is 25.9%. For just the past four years, it is 28%. In the past seven years, the total 3D printing market has grown by nearly 5.7 times. The upward shift indicates that the industry is at an inflection point; experts indicate that it is likely to reach at least $18 billion by 2021.[1]

Final part production is expected to further drive annual 3D printing revenues to significantly higher levels as build quality improves and market demand increases.

Seventy percent of the installed base (total number of 3D printers installed globally) is split among five leading countries currently: The United States, China, Japan, Germany, and the United Kingdom.[1]

While these markets are growing, they are not the markets that are growing the most quickly. Markets growing the most quickly are driving growth through government investment.

Global 3D investment activity

China has outpaced overall installed base growth, increasing its share of total installed base by 0.8% in just a year. The Chinese government is aggressively driving the national agenda on 3D printing; they plan to invest $245 million over the next seven years to boost development of 3D printing. The National Additive Manufacturing Innovation Center has allocated $132 million to R&D and applications, or 3D printing. China also has a stated objective to place 3D printers in each one of the approximately 400,000 elementary schools over the next two years. Additionally, they have plans to address IP ownership, and have already implemented patent law that identifies 3D designs as IP, which will enable designers to ensure value capture from designs, incentivizing designers to enter the space.[1]

3D Printing global fact base

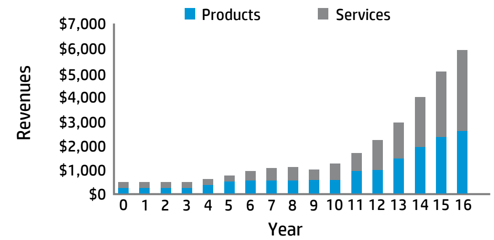


Figure 17: Global Growth in 3D Printer Revenues ($M)
Source: Wohlers Report 2017 [1]

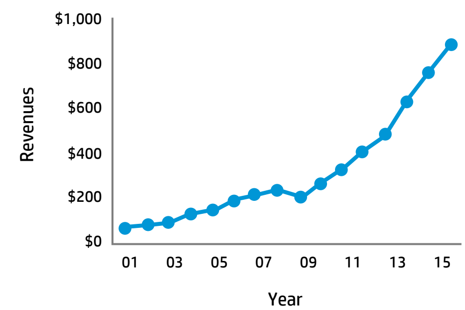


Figure 18: Revenue due to 3D Print Systems Material Sales ($M)
Source: Wohlers Report 2017 [1]

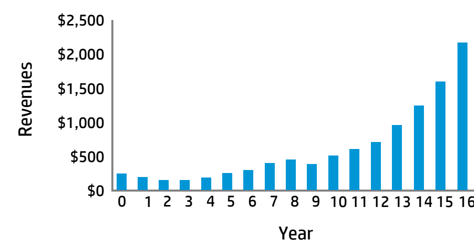


Figure 19: Primary 3D Print Services Revenue ($M)
Source: Wohlers Report 2017 [1]

Key facts

- Over the past 28 years, compound annual growth rate (CAGR) of worldwide 3D printing products & services is 25.9%. For just the past 4 years, CAGR is 28.0%
- In the past 7 years, the total 3D printing market has grown by nearly 5.7 times
- In 2016, revenues from 3D print products, system & product upgrades, and services respectively grew 12.9%, 14.9%, and 21.2% from 2015

Korea has also outpaced global growth, taking an additional 0.5% of the total installed base. Korea's investment is based around the progression of 15 core technologies called the K-Top-10 focus, including smart molds, 3D electronics, biomedical devices, dental products, and medical implants. They have an established R&D roadmap for 3D printing, and are working to expedite regulatory approvals and improve tax incentives for 3D printing.[1]

Other countries are still growing but are losing pace slightly versus the market; the US lost 1% of the share of the total global installed base in just one year. Japan, Germany, and the UK also lost share, but the change was minimal.[1]

The US is investing in 3D Printing, but the long-term strategy is not clear. There is federal funding for university research in 3D printing, as well as National Institutes of Health (NIH) grants for 3D printing. The 2018 Department of Defense draft budget has $13.2 billion allocated to technology and innovation, with a directive to improve 3D printing capabilities.[99]

Germany has a very clearly defined strategy to gain advantage in the broader 4th industrial revolution, of which 3D printing is a key part. The Federal Minister of Transport and Digital Infrastructure has even proposed a government department to drive Industry 4.0. They have also developed the Fraunhofer Research Institution which supports 17 centers for additive manufacturing (3D printing).[1, 51]

The United Kingdom has built a national strategy to promote 3D printing, but Brexit has resulted in some uncertainty in the UK manufacturing sector and innovation leadership. They have placed an emphasis on higher education and training the workforce for 3D printing. [1, 40]

Several countries are not yet on the map, but have started making strides to get there. The UAE for example, has made a public statement that 3D printed artificial limbs will become available by 2025, and that 25% of buildings will be based on 3D printing technology by 2030. They have a very specific roadmap set for the medical sector, and are interested in using 3D printing to become a base of manufacturing to serve local consumers, bypassing the first three industrial revolutions.[26]

3D Printing leaders and fast followers

	Share of Global Installed Base	Change from 2015 to 2016	Planned Gov't Investment Trend	Policies and Investments
US	36.8%	- 1.0	↓	• Established grants for university research on a national level • DoD and NIH have received funding for R&D
China	10.3%	+ 0.8	↑	• National Additive Manufacturing Innovation Center (NAMIC) allocated $132 million to R&D and applications of 3D printing • Goal of 3D printers in all 400,000 elementary schools in two years
Japan	9.2%	- 0.2	↑	• Technology Research Association for Future Additive Manufacturing (TRAFAM), which was initiated in 2014 by Ministry of Economy, Trade, & Industry, will release 3D printing metal systems by September 2017
Germany	8.4%	- 0.2	↑	• Federal Minister of Transport and Digital Infrastructure proposed new government department (Federal Ministry of Digital) to drive Industry 4.0, which covers 3D printing
UK	4.2%	- 0.1	↑	• Government issued funding call of about $5.5 million for 3D printing in 2016 • $24.4 million Manufacture using Advanced Powder Processes Centre focuses on solving technological challenges for powder-based processes, including 3D print • Tax credits and incentives for R&D and digital startups
Korea	3.4%	+ 0.5	↑	• Government established R&D roadmap and is providing national support. • It is also expediting regulatory approvals and introducing tax incentives
Canada	1.9%	0.0	↑	• $8.9 million grant to University of Waterloo will fund a 3D printing lab and overall dedication to additive manufacturing
Taiwan	1.6%	0.0	↑	• Ministry of Science and Technology and Ministry of Economic Affairs are providing funding for AM research and business development
Russia	1.4%	0.0	↓	• Minister of Industry and Trade stated that production of 3D printed aluminum wheels for the automotive industry would be government-supported
Turkey	1.3%	0.0	↓	• Ministry of Development will establish the country's first 3D printing center in collaboration with universities, to assist the aviation and defense industries
Singapore	N/A	N/A	↑	• $9.3 billion of the Research Innovation Enterprise 2020 Plan (RIE2020) budget is for 3D printing to enable engineering development • 2015 National Additive Manufacturing Innovation Cluster (NAMIC) helps companies adopt 3D printing with the aid of Singaporean universities
UAE	N/A	N/A	↑	• Public statements that 25% of buildings will be based on 3D Printing technology by 2030 and 3D printed artificial limbs will be available by 2025

Figure 20: Assessment of 3D Printing Leaders and Key Policies
Source: A.T. Kearney Analysis, Wohlers Report 2017 (1), 82

Example country strategies

China
3D Printing objectives

- **Goal:** World manufacturing power
- **Strategic levers:** R&D and Education
- **Details:**
  - Focus on core research, tech development, and demo applications
  - Using industrial partners and university collaboration

Germany
3D Printing objectives

- **Goal:** Manufacturing leadership
- **Strategic levers:** R&D
- **Details:**
  - Part of larger focus on automation and mass customization
  - Aligned with German emphasis on “Industrie 4.0”

Korea
3D Printing objectives

- **Goal:** Keep pace with global innovation
- **Strategic levers:** R&D and Education
- **Details:**
  - 15 core technologies selected for “K-Top_10” focus: smart molds, 3D electronics, medical implants, etc.

UAE
3D Printing objectives

- **Goal:** Global leader in 3D Printing
- **Strategic levers:** Partnerships
- **Details:**
  - Very specific roadmap set for the medical sector & applications (speed healing process by 40-80%)

Figure 21: Example Country Strategies for 3D Print Policies

HP © Copyright 2018

3D Printing country index

The 3D Printing Country Index, developed by A.T. Kearney, indicates the degree to which a country's governance, capabilities, and economic assets support the adoption of 3D printing. The Index is based on six different dimensions: 3D printing, demand, trade, people, governance, and technology.

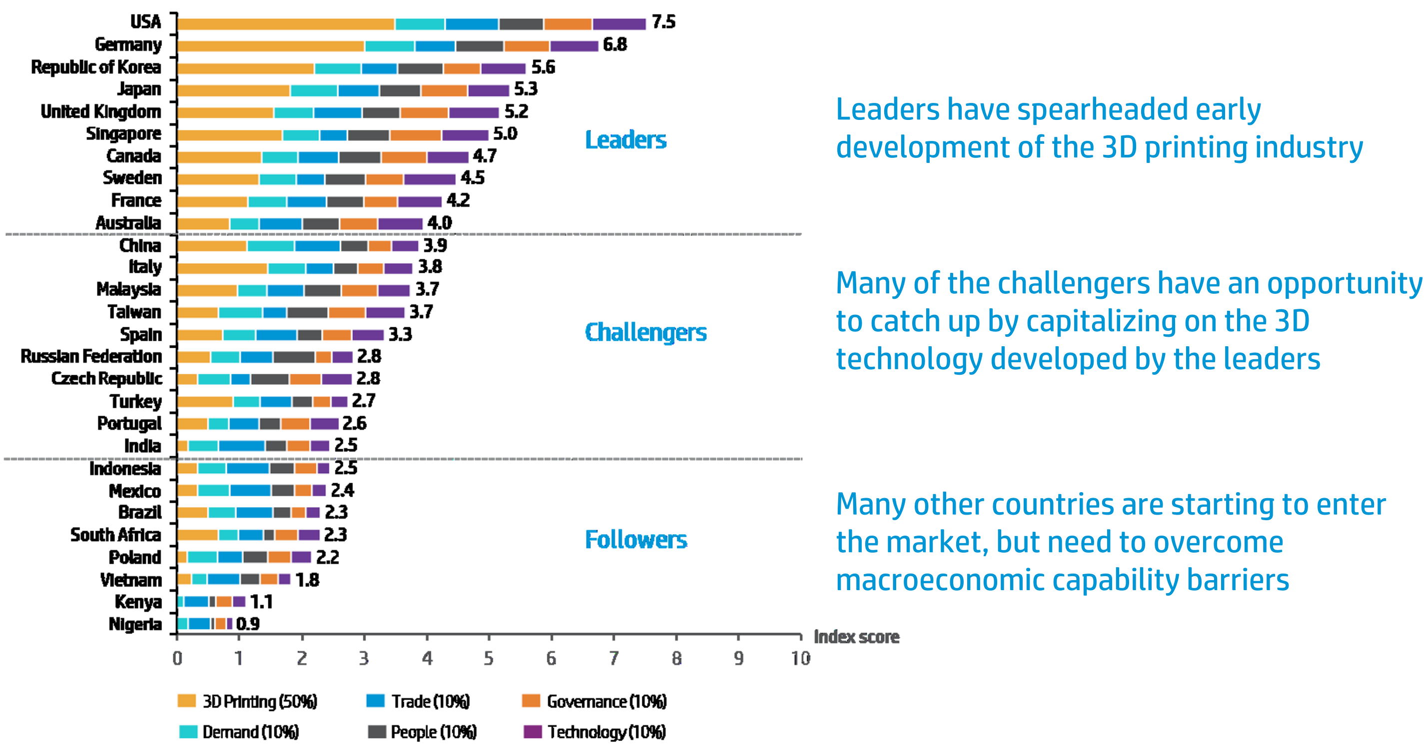


Figure 22: 3D Printing Country Index
Source: A.T. Kearney Analysis

Leaders

The current leaders in the 3D print country index tend to lead in both 3D print-focused capabilities as well as in macroeconomic indicators. The USA is leading due to early-stage 3D printing adoption in the last 30 years, and has developed a significant amount of intellectual property and a supply base of 3D printers. Germany is a close second due to high government engagement with the 3D ecosystem. The German Federal Ministry of Digital is a specific government agency aimed at driving towards and preparing for Industry 4.0, which includes 3D printing as a key technology.

Countries such as Korea, the UK, and Singapore also have focused efforts on 3D printing growth, and a strong base of macroeconomic factors that position them to be competitive.

Challengers

Many challengers have macroeconomic factors that would allow them to excel in 3D printing, but have not yet capitalized on these factors to catch up to the leaders. For example, Taiwan has very strong engineering capability and a demand base for 3D printing, but has not yet capitalized on these to grow the 3D printing ecosystem.

Challengers such as Italy have a strong base today, but are lacking in several macroeconomic factors such as an adaptable and reliable governance structure, and people capabilities such as designers and engineers. Italy is acting to drive 3D printing adoption, mainly in sectors such as jewelry and metal products because they have existing capabilities in these areas, and are using 3D printing as a mechanism to drive manufacturing competitiveness.

Challengers have an opportunity to catch up by capitalizing on the 3D technology developed by the leaders. For example, China is adopting many of the existing technologies in the ecosystem to create 3D printing capability. However, China is lagging in both general secondary education across the population and development of digital skills. China is acting on this today and plans to install 3D printers in all 400,000 elementary schools within two years.

Followers

Most of the followers currently lag in macroeconomic factors to prepare for 3D printing adoption on a broad scale, but can focus in niche areas, such as Italy has done as a challenger.

3D Printing country index year-over-year change

Being a leader today is not sufficient to ensure that a country will benefit from the "first mover" advantages in 3D printing. Countries need to maintain the momentum to the point that 3D printing becomes mainstream in manufacturing in order to fully unlock 3D printing technology potential.

The 3D printing year-over-year change index is a measure of how countries' 3D printing markets and capabilities have changed over time (figure 23).

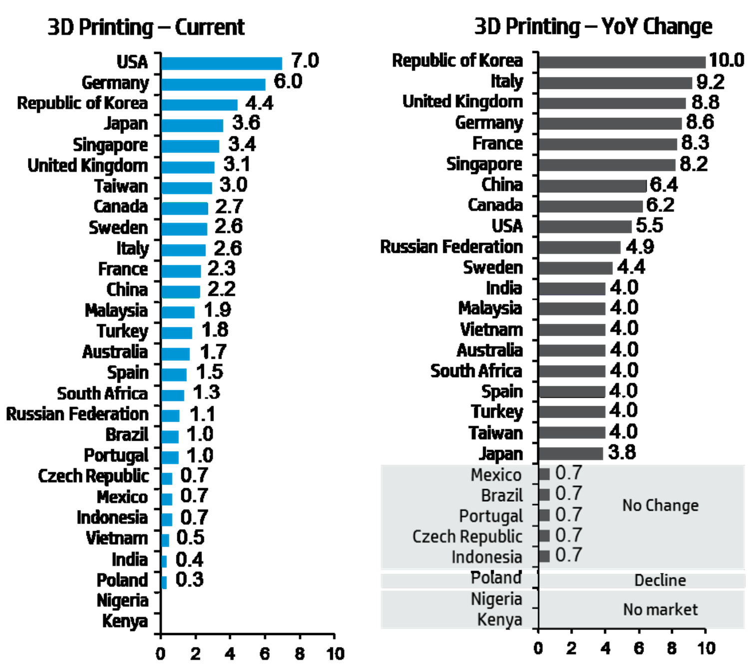
While the US and Germany lead in the current state 3D printing index, Korea and Italy lead the 3D printing year-over-year change. If the trajectory continues, it is likely that Korea will take over the global leadership in 3D printing due to a national, government-led R&D roadmap focused on 3D printing and usage.

Germany is also likely to maintain strong leadership in the space because it has a complete Industry 4.0 strategy that focuses in short-term industrial problem-solving, and in the long-term, expanding material portfolio and machinery capability.

The USA currently leads the 3D printing country index but is at risk of losing this position

USA sales of printers grew by 11% from 2015 to 2016. In the same period, the USA installed base of 3D printers grew by 14%. The USA has an installed base growth rate below the average for leaders in the 3D market.[1]

USA is at risk of losing the lead position



Korea, UK and Germany are accelerating and are poised to take over the lead from the USA within the next 5 years

Japan is on a trajectory to fall behind in the global race

Figure 23: 3D Printing Current state vs Year-over-Year Change
Source: A.T. Kearney Analysis

The USA scored below the leaders' average in 3D printing government engagement, which shows that other countries' governments are more active in shaping the future of 3D printing.

To avert loss of 3D leadership, the US government needs to engage more with the 3D printing ecosystem. While the US has recently engaged more, such as the Department of Defense inclusion of 3D printing as a key capability in the 2018 budget recommendations, US policymakers should consider implementing a broader program of initiatives around digital and 3D design education, 3D adoption, and incentives for companies to adopt 3D printing.

Korea is the benchmark in 3D print government engagement, which is enabling rapid acceleration of the market

Korean unit sales of 3D printers grew by 51% from 2015 to 2016. In the same period, Korea's installed base of 3D printers grew by 37%.[1]

To keep up with worldwide innovation and trends, the Korean government has established a 3D printing roadmap for R&D and is providing national support to execute. This is already reflected in terms of IP creation. Korea has grown more than 300% the number of 3D printing patent applications in the past few years.[1]

Korea is expediting industry regulatory approvals and introducing tax incentives for 3DP

The Korean government is also taking other steps to encourage growth in 3D printing, such as expediting industry regulatory approvals and introducing tax incentives to foster 3D printing adoption.

Italy is investing in 3D printing adoption as a competitive advantage to decrease unemployment

Italy sales of 3D printers grew by 38% from 2015 to 2016. In the same period Italy's installed base of 3D printers grew by 14%.[1]

In Italy, Italian jewelry and metal-products business are the early adopters of 3D printing as a tool to drive competitiveness and create new products that were not possible with traditional manufacturing processes.[92]

Italy is committed to prepare the workforce to 3D printing

Italy is leveraging 3D printing to drive manufacturing competitiveness to reduce its high unemployment rate. The government is focused on preparing the workforce for 3D printing, including dedicated training and education programs at universities and research centers.
Also, Italy has implemented several other multi-disciplinary initiatives to foster 3D printing adoption, such as creation of 3D printing hubs and centers of excellence.[1]

China is focused in driving 3D print adoption, but still lags in 3D print technology advancements and IP

China sales of printers grew by 36% from 2015 to 2016. In the same period, the installed base of 3D printers grew by 27%. However, China has not had any relevant growth in the number of patent applications over the last years.[1]

China must focus on laying the groundwork to develop the required capabilities

China is behind the leaders in education, falling below average metrics such as tertiary degree, secondary education, and the proportion of engineers and designers to the total population. As of now, quality education is available only in the main metropolitan areas. The Chinese government should work on developing 3D printing education at the university level as well as building 3D printing vocational programs across the country to support the workforce preparation for modern technology.

Newcomers are striving to become powerhouses in 3D printing

In addition to Korea, Italy, and the UK, newcomers such as Saudi Arabia and the UAE have been very focused on becoming leaders in 3D printing during the last year, and are expected to show up as strong players in subsequent 3D print indices.

Saudi Arabia signed an agreement to 3D print 1.5M homes in the next five years – contract worth $1.5B

In the past year, the Saudi Arabian government has started to accelerate the development and adoption of 3D printing. In 2017, supported by the Saudi Arabia government, Winsun, a Chinese 3D printing company, signed an agreement worth $1.5 billion with Al Mobty Contracting Company, a Riyadh-based construction company. The agreement is to lease 100 3D printers capable of producing concrete structures.[21]

Saudi Arabia will 3D print 1.5M homes in the next 5 years

Private and public partnerships are powerful enough to accelerate the adoption of new technologies. The Saudi Arabian government has recently become very engaged with the 3D printing ecosystem and is supporting adoption to improve their manufacturing competitiveness.

UAE Government plans to lead in 3D printing and the 4th industrial revolution overall

The UAE government is focused on leading in the 4th industrial revolution, and has defined six strategic pillars to support this goal, including, but not limited to, the creation of the 4th industrial revolution council, the creation of a knowledge-sharing system for new technologies (e.g. think tanks), and the approval of several initiatives at a national level to pilot and explore technologies such as 3D printing.[63]

His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of UAE and Ruler of Dubai, has launched the Dubai 3D Printing Strategy, a unique global initiative that aims to exploit technology for the service of humanity and promote the status of the UAE and Dubai as a leading hub of 3D printing technology by the year 2030.[26]

UAE target is to become a leading hub of 3D printing technology by 2030

High engagement is also reflected in new regulations. Based on Dubai Municipality's regulation, every new building in Dubai will be at least 25% 3D printed, starting from 2019. In addition, Dubai Health Authority has committed to regulating and setting the standards for use of the technology in the health sector, and will explore the use of 3D printed prosthetic limbs, 3D printed teeth, and 3D printed hearing aids in public clinics and hospitals.[26]

Government engagement with the 3D ecosystem is driving year-over-year growth

The countries accelerating to lead in 3D printing have highly engaged governments pushing the capability forward. These governments realize the criticality of 3D printing leadership for the future manufacturing base of the economy.

Success in 3D printing is driven by strong government engagement to build the 3D ecosystem

Countries that have created a national roadmap or strategy for 3D printing and deployed initiatives to foster the technology adoption are leading in year-over-year growth, and are expected to lead in future 3D print country indexes. The most successful strategies to date have focused on education of the workforce, adoption of the technology, and incentives to build the 3D ecosystem.

Implications for leaders

Many countries are going after the opportunity presented by 3D printing. There is $4 to 6 trillion that will be disrupted and potentially redistributed. Countries that don't act will miss out, just as those who lagged in the first three revolutions did.

The first leaders to successfully build the 3D ecosystem will direct the global manufacturing industry of the future. Followers will maintain relevancy, but those that don't act will not.

In addition, first movers will gain the technological advantage and become innovation leaders of the next era. They will build or maintain employment in the workforce, and shift the workforce up the skills ladder. Countries that act to drive 3D printing will reinvigorate industries and create prosperity for the next generation. Countries slow to adapt will miss out on these opportunities and fall behind in the next industrial revolution.

	Jobs and economic growth	• Boost the economy with a strong manufacturing base • Secure jobs and income for the workforce • Reduce reliance on external market
	Technology and innovation leadership	• Lead the next technology boom • Own rights for new technologies and capabilities • Retain top innovation talent
	Relevancy in manufacturing 4.0	• Reinvigorate the manufacturing economy • Define trade structure in the digital world • Create the new vision for the factory of the future
	New business models	• Develop new business models and new sources of growth and revenue • Provide new services to constituents
	Improved sustainability	• Drive the movement towards a sustainable future • Reduce waste and waste management • Rely less on oil and gas through reduced transportation

Figure 24: Advantages for Leaders in 3D Printing
Source: A.T. Kearney Analysis

Securing our manufacturing leadership in core 3D Printing through public/private actions

A coordinated public/private effort is required to create an ecosystem that will allow countries, states, and cities to capitalize on 3D printing. There are several enablers required to develop the 3D printing ecosystem.

Enablers needed for 3D Printing

1. **Design for Additive.** Engineers need new skill sets. Training the next generation will help create the workforce of the future, filling jobs and growing the economy. The new set of capable engineers will drive both innovation and manufacturing in 3D printing as they enter the workforce. Building educational centers, and development or accelerated adoption of 3D curricula in undergraduate engineering programs, will build the skills required to excel in 3D printing.

2. **Awareness and Business Case.** Building awareness will help promote growth and build domestic manufacturing. Many policymakers and business leaders know what 3D printing is, but aren't aware of how to use it, don't know when it is effective, or what value it can drive. Adoption and demonstration of the technology will catalyze the ecosystem.

3. **Transition to New Supply Chains.** Businesses are interested in use of 3D printing. Grants and incentives will create value propositions for businesses to restructure and localize supply chains and manufacturing in addition to using the technology.

4. **Cost per Unit.** Material Price. Adoption and driving increased demand and incentivizing R&D will reduce material cost and enable cost-effective 3D printing in more geographies.

5. **IP and Data Protection.** Ensuring that existing IP ownership and protection frameworks and legislation cover 3D printing designs will incentivize innovative designs and prevent risks to secure 3D print data. When designers have certainty that they will derive value from their designs, they will be motivated to create unique new products that have not been considered in the past. Leaders can also partner with industry to identify technical solutions that increase the ability to manage IP infringement.

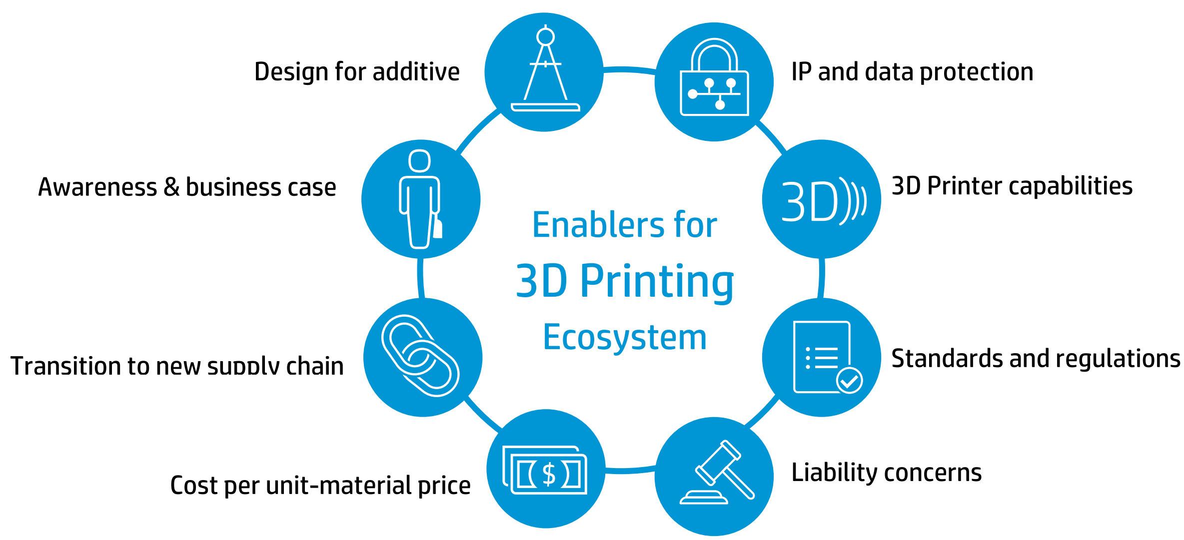


Figure 25: Enablers for 3D Printing Value Capture
Source: A.T. Kearney Analysis

6. **3D Printer Capabilities.** Private industry will strive to improve product capabilities; policymaker focus on education will enable success in industry development.

7. **Standards and Regulations.** Existing regulations are slow to adapt 3D printing, and industry and regulators need to find solutions that accelerate 3D printed products in regulated industries. Regulators will need to respond to the increased pace and create an infrastructure that is able to react quickly. In addition, supporting private efforts to build standards around 3D design file format, data security, and many other standards will enable faster ecosystem growth.

8. **Liability Concerns.** Liability considerations need to be driven by a coordinated public/private effort to ensure an appropriate distribution of responsibilities amongst involved parties. The industry is not yet clear on ownership of elements of the 3D value chain, and the liability that goes with it. Public support for private efforts to clarify the new value chain will enable adoption and development of clarity around liability considerations. Policymakers need to engage and learn about how the 3D printing technology and value chain work in order to appropriately assess liability considerations.

3D Print manufacturing regulatory landscape – US example

Automotive: The US Department of Transportation's National Highway Traffic Safety Administration regulates automotive systems to ensure passenger safety on the road. Regulations are built by systems and sub-systems in vehicles, such as air-brake systems, seating systems, accelerator control systems, etc. For 3D printing, qualification of 3D printed parts to meet existing regulatory requirements is a concern. The DOT needs to work closely with leaders in the automotive industry to provide guidance on revised part qualification processes for 3D printing in order to fully utilize the technology.

Healthcare: The US Food and Drug Administration (FDA) regulates the healthcare and medical device industries. For medical devices, there are three classes of regulation based on the risk to patient. The FDA created guidance on patient-matched device design in 2016 that enables custom products to be built—a key benefit of 3D printing. Manufacturing with 3D printing, however, still has some difficulties: qualification processes are slow, and validating quality consistency is complex for 3D printing. The FDA needs to partner with industry leaders to provide accelerated qualification processes that fully leverage the benefits of 3D printing.

Aerospace: The Federal Aviation Administration (FAA) regulates the aerospace industry based on development stage. Parts are "type certified," meaning the design data meets standards, or "production certified," meaning the physical product matches tested design. In both cases, a significant amount of finished-product testing is required. The FAA has created a roadmap to address 3D printing use in the aerospace industry, but the roadmap is multiple years out. By accelerating this roadmap, the FAA can help industry adapt quickly, and enable 3D print manufacturing leadership.

Catalysts for growth

To seize opportunities in 3D printing, policymakers need to build an ecosystem by acting across three key areas: education, incentives, and adoption. Through pursuing a combination of these policy levers, robust growth of the 3D printing ecosystem and broader capability can emerge. In addition, policymakers need to ensure the legal framework in place is reliable, ready, and not over-burdensome for 3D printing.

There is currently a skills gap in designing for 3D printing, and it will be critical to develop the next generation of native digital product engineers. Promoting education of 3D printing designers will help address this challenge, facilitating the manufacturing workforce of the future. It will be necessary to build the capabilities of engineers to understand and design for 3D printing, as well as to promote research into 3D printing materials to help increase variety and reduce costs.

Policymakers at all levels can take steps to incentivize investment in 3D printing through tax breaks, grants, and other means to help users leverage 3D and promote localization of manufacturing. Tax incentives to promote R&D in 3D printing, including materials research, will enable innovation and ultimately drive down cost barriers and reduce risks for investors in the technology. Taken together, these steps can reduce market entry costs and increase investor confidence, thus growing the market.

A lack of awareness about 3D printing technology is slowing widespread adoption. Showcasing cost-effective business uses through policies geared toward increasing adoption and promotion will help overcome this challenge. Demonstrating the value add of 3D printing will help enhance public understanding of the technology, promote growth, and build a domestic manufacturing presence. Increased awareness will ultimately lead to increased demand in the 3D printing market.

Policymakers also need to ensure that the existing legal framework is reliable for 3D printing and scalable to new technological capabilities. Considerations such as IP protection, regulatory infrastructure, and liability should be reviewed with industry leaders to verify that no gaps exist, or to ensure that any that do exist are resolved in a way that is effective in protecting consumers, developing the 3D ecosystem, and driving growth in the industry.

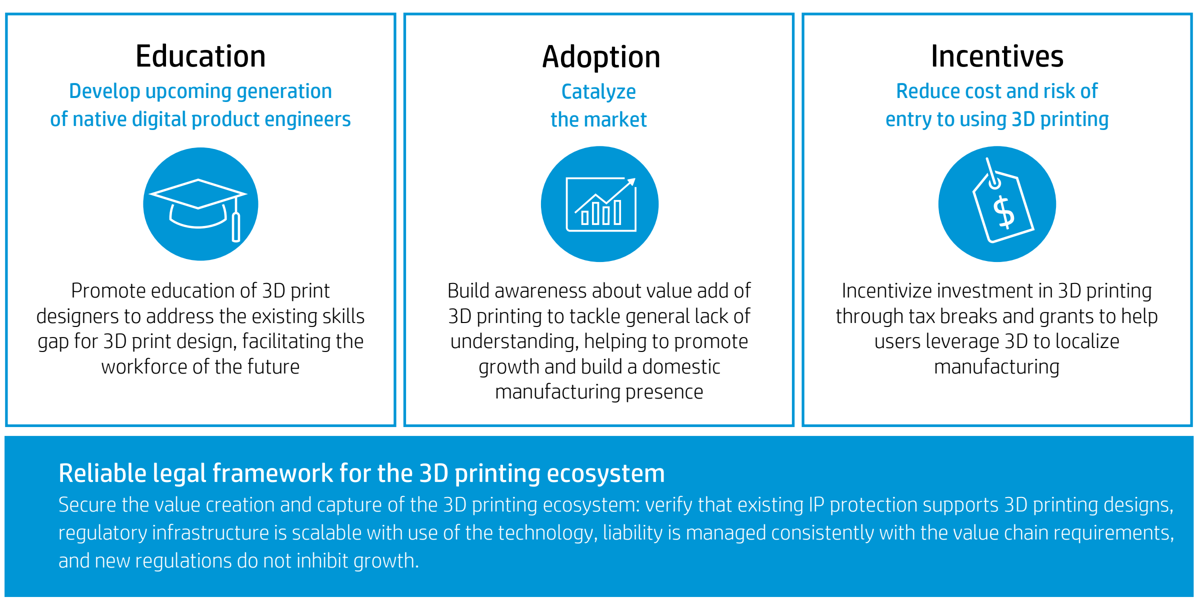


Figure 26: Policy Catalysts for 3D Printing
Source: A.T. Kearney Analysis

Education

Educational efforts need to focus on engineering curricula that will drive the market, which will subsequently pull through blue-collar type manufacturing roles and training. With advances in 3D printing rapidly taking place, there is a growing need for a new set of skills in order for engineers to adequately take advantage of these new technologies. Training the next generation of designers and engineers for 3D will help create the workforce of the future, filling jobs and growing the economy. Policy makers at every level of government have an opportunity to help facilitate the 3D design and engineering workforce of the future through promoting effective educational policies in these areas.

Policies to help grow a 3D ecosystem that effectively links education and training at university, as well as at the vocational level, can help to develop a new generation of native digital product engineers and provide a pipeline for the 3D workforce. Many existing programs focus their curricula around return on investment in the traditional supply chain. Creating new curricula that teach engineers to find cost effective use cases for 3D printing will be essential to accelerating adoption.

Similarly, many manufacturing and mechanical engineering programs teach manufacturing design based on the constraints of traditional processes. By providing comprehensive courses to allow engineers to truly "Design for 3D" using the next generation of tools available will enable them to create innovative designs that have not been previously possible.

Engineers also need hands-on experience with the technology to both learn and research. While many universities have "maker spaces" with small-scale 3D printers, they do not have access to the value and limits of 3D printing technology that would allow manufacturing engineers to understand the end-to-end capabilities and limitations. Policymakers should support mechanisms that allow access to manufacturing-grade 3D printing equipment, for both hands-on learning and research, such as manufacturing training centers and funding for equipment purchase at major universities.

Higher education institutions are often the leaders of fundamental R&D innovations. However, many top-tier institutions today do not have access to industrial-scale 3D printers to enable and stretch the limits of their research. Through stimulating research and increasing access to these tools in strategically targeted universities, these technical barriers can fall, and the overall 3D printing market will be catalyzed. Efforts in each of these areas to train a 3D print-ready engineering workforce of the future and promote new R&D innovations through government funding of university programs are underway in many countries (see sidebar), but there is still much progress to be made.

Key elements

To overcome the current gap in 3D printing education and training, policymakers need to support efforts that help build the capabilities of engineers to understand

Case studies: educational centers of excellence[1, 40, 85]

United Kingdom

The United Kingdom funded £30 million in University 3DP research in 2014 alone. Leading recipients of funding include the University of Nottingham's Centre for AM and Loughborough University's AM Research Group

Singapore

The Singapore Centre for 3D Printing was opened in 2016 at Nanyang Technology University, thanks in part to federal funding from the National Research Foundation. The Centre has the goal of becoming the national centre for excellence for research in 3D printing.

Canada

The University of Waterloo received an $8.9 million government investment in 2017 to build its world-class multi-scale additive manufacturing lab.

United States

In 2017, researchers at the Massachusetts Institute of Technology engineering program designed the Digital Construction Platform, allowing for 3D printing of the basic structure of an entire building.

China

In 2016, Huazhong University unveiled breakthrough research in metal 3D printing that will allow for printing thin-walled parts without excess material.

and properly design for the technology. With greater understanding of the technology and its capabilities, there are not only opportunities to grow the market and increase adoption of the technology, but there are also opportunities to discover new uses for 3D printing. It will also be important to drive materials research in universities to increase the variety of materials available and draw down their costs. Many 3D printing materials remain expensive and serve as barriers to widespread adoption and use of the technology beyond prototyping or small-scale production runs. Promoting R&D of new materials will reveal new material applications, and costs of use can be reduced.

Adoption

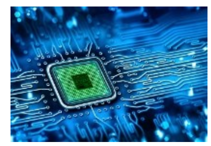
Policies to promote adoption and promotion of 3D printing and additive manufacturing technologies can play a key role in catalyzing market growth. Building awareness about the value add of 3D printing will help overcome the general lack of understanding that currently exists and help to build (or rebuild) a domestic manufacturing presence wherever these policies are pursued. Policymakers at all levels of government can support these efforts by allocating government funds for development of new 3D printing technologies. Similarly, policies that support incubation of 3D printing programs for government use will create the sustained R&D necessary to push the technology mainstream.

Historically, driving demand through government spend spurs market demand and growth. For example, establishing military use of integrated circuits caused early industry growth and production cost reductions in semiconductors (see sidebar). Increased government use of 3D printing technologies, for military applications and elsewhere, will help advance the technology and spur additional market growth.[99]

There are also opportunities to promote adoption of 3D printing technology by favoring small businesses that seek to use the technology. These small businesses make up a disproportionate number of manufacturers. Leveraging existing funding for small-business promotion, or allocating new funds, will not only grow the market, but enable more rapid access to innovation. The use of Small Business Innovation Research grants to promote 3D printing programs in the U.S. is just one example of such an effort.[81,88,89]

Stimulating and incentivizing adoption of technologies in their early stages is key to transforming it and growing its own unique market and consumers. Governments have historically played an outsized role in driving such technology adoption, as evidenced by the U.S. Defense Department's early funding for the ARPANET, which led to the key technological advances that enabled the commercialization of the internet.

Key elements



Adoption case study: semiconductors in the US

Since the Second World War, the United States military has played a unique and critical role in funding new technologies emerging from Silicon Valley. While a range of products emerged as a direct result of government grants and military contracts, the semiconductor represents a central example. From the 1950s to the 1970s, the United States funded 40% of R&D in semiconductors. Military purchases of the product, alongside the extensive government R&D spending, resulted in prices falling at unprecedented rates in the 1960s, making the technology increasingly practical for commercial use. Government investment in the technology boosted industry revenues and growth. Fairchild Semiconductor won its first business through military contracts by creating chips that supported NASA space missions and built Cold War missiles. The growth of the company helped propel it into one of the "founding fathers" of Silicon Valley start-ups.

> Beyond the commercial successes resulting from government investment, the social impact of government investment in the semiconductor has been felt even more widely. The technology forms the foundation of wide-ranging modern electronics, from radios to phones to computers. Without government investment to jumpstart innovation and growth, the technology would have emerged along a much slower trajectory, with broad implications for modern technology and the United States.

Government policies can create demand in the 3D printing market to stimulate broader growth in the manufacturing sector. Policies to incentivize or require government procurement of 3D printing technologies, or efforts to support small business adoption of 3D printers, provide a pair of useful examples. Governments can also drive pilot programs and test cases in 3D printing to encourage competition in the private sector, and help drive the technology to new capabilities and applications. A multipronged approach to policies driving 3D print adoption will likely be most effective for governments interested in growing the domestic 3D print market.

Incentives

Governments can take policy actions to incentivize investment in 3D printing that will encourage companies to build 3D printing and manufactuinrg capabilities in their geography through tax breaks and grants. These steps can help users leverage 3D, and ultimately increase localization of manufacturing, growing the economy and creating jobs. In addition, this will build a base of subject matter expertise that helps to accelerate growth of the broader 3D print ecosystem, leading to economic growth.

More specifically, incorporating tax credits into the operational costs of implementing new technologies improves adoption in that region and creates accessibility for the local constituents. Tax incentives to use 3D printing and localize manufacturing will increase users and further increase related manufacturing jobs.

Attaching tax credits to select product purchases can help attract wary customers and make new technologies competitive. Electric cars in the United States have received a boost in sales as a result of a $7,500 income tax credit on their purchase. Similar incentives for 3D printers would drive demand in an untested market where customers may remain unsure of the new technology.[65]

Efforts to directly link tax credits to research and development for building new technologies can accelerate breakthroughs and enable widespread innovation. Such efforts include Canada's Scientific Research and Experimental Development Tax Incentive Program (SR&ED), which offers a 35% tax credit on qualified investments to attract innovation and drive innovation leadership. Subsidizing R&D efforts for 3D printing and related technologies will enable more organizations to invest in developing the technology, and achieving discoveries crucial to broader national innovation.[37]

Key elements

By building incentives, policymakers will increase 3D printing use in a given geography. Tax credits reduce initial cost barriers to entry while providing annual savings to businesses that grow into 3D.

Case Study: Solar Energy in the United States

In the United States, federal and state subsidies, tax credits, and R&D spending have all been employed to increase solar power production, reduce costs, and decrease reliance on coal, oil, and other highly polluting energy sources. These initiatives created a market that drove wind power to become cost-competitive with all power sources. Wind power capacity has grown 22-fold since 2000, and Wind Turbine Technician is the fastest growing, well-paying job in the US.[16, 20, 37, 86]

HP © Copyright 2018

Federal Tax Credits: The Federal Production Tax Credit (PTC), first established in 1992, is a per-kilowatt-hour tax (kWh) credit for electricity generated using qualified energy resources. The credit can be claimed for a 10-year period once a qualifying facility is placed in service. The PTC has encouraged private sector investment in wind power, and its powerful effect is evident in the dramatic slowdowns in planned wind farms during times when extension of the tax credit has been uncertain. The PTC extension in 2016 is projected to lead to more than 44 gigawatts (GW) of additional installed wind capacity by 2020.[78]

State Renewable Portfolio Standards (RPS): State RPS requirements are legal mandates for state utilities to purchase renewable power. They account for half of all growth in US renewable generating capacity since 2000. Twenty-nine states have renewable portfolio requirements. Wind energy accounts for 61% of RPS additions to date, though solar has taken a larger share in recent years.[78]

Incentives to reduce the cost of training 3D printing machine operators, such as loan forgiveness programs, can help ensure local companies that their machines will be well maintained by local talent. Policies to protect against tariffs on cross-border digital trade can help to reassure investors that they will not be hit with unanticipated costs. Furthermore, incentives aimed at promoting further research and development in 3D printing materials can drive down overall costs while creating opportunities for new innovations that can expand the uses of 3D printing technology.

Ensuring a reliable legal framework

In addition to driving growth of the 3D ecosystem – policymakers need to ensure that the legal framework in the country simultaneously secures the value creation and capture of the 3D value chain, and does not inhibit ecosystem growth. There are four critical pieces:

- Verify that the existing IP framework effectively protects value creation for the designer
- Ensure the regulatory infrastructure is scalable to adapt to democratized manufacturing
- Manage liability concerns consistently with the requirements of the 3D print value chain
- Make sure that new regulations do not inhibit use of the technology

IP Framework: Given that 3D printing designs are a potential revenue source for the designer and can be central to a company's business model, protecting these designs is critical. Protection of 3D design files and digital rights management are a concern for IP rights holders, because the risk of counterfeiting or copying is much higher with 3D printing than for other technologies. 3D printing allows manufacturing anytime and anyplace, and access to manufacturing by a much larger population. Third parties are already working towards better protection of 3D designs. To build a safe and lucrative environment for the 3D ecosystem, governments can support efforts to allay concerns and allow for protections of intellectual property holders and designers in the 3D printing ecosystem. Industry can lead on setting standards for digital rights management. Policymakers can verify that the current IP framework protects 3D printing design and supports industry efforts to combat counterfeiting. This will encourage designers to enter the ecosystem with confidence. It can also enable new business model development, such as 3D design libraries, that will enable further economic growth. A good example of evolving IP policy is the United States Digital Millennium Copyright Act, passed in 1998, which supported digital material creation and distribution while protecting against copyright infringement on the internet. This act enabled growth of today's large network of digital sharing platforms such as YouTube.[31, 94]

The existing recourse for IP or copyright infringement should also cover 3D print designs. In addition, policymakers can partner with the 3D ecosystem to provide technical solutions that facilitate recourses on IP infringement.

Regulatory Infrastructure: The new capabilities offered by 3D printing, in addition to the democratization of manufacturing, are likely to strain existing regulatory infrastructures. Currently, many regulations are slow to adapt. Existing regulatory bodies may not have the appropriate manpower or processes in place to adapt alongside the new capabilities and expansion of the manufacturing sector. Regulatory bodies should engage to become educated on the likely changes, and prepare the infrastructure to adapt along with the technologies.

Liability Concerns: Because 3D printing is likely to change the value chain and the players in the manufacturing ecosystem, it raises some concerns about liability management. It is critical that liability concerns be managed with respect to the requirements of the value chain, and that the 3D ecosystem is aligned to a consistent liability structure. Legislators should work closely with 3D ecosystem leaders across the entire value chain to define a liability framework that protects both the consumer, and ecosystem growth.

Regulations: Many leaders across the globe are not familiar with 3D printing, its capabilities, and its limitations, and there may be a tendency to regulate against perceived risks. It is critical that policymakers engage and educate themselves early, so that they can work with the 3D ecosystem as it grows to prevent introduction of risks, as opposed to regulating risks after they arise. Industry leaders can help drive technical solutions that prevent risks before they are introduced to the consumer, without bogging down industry growth.

Overall, policymakers need to assess the existing legal framework to ensure that it supports a strong 3D printing ecosystem, or risk being left behind.

Policymaker actions

To grow the 3D printing ecosystem, policymakers at the federal, state, and local levels need to take several actions. The policies below provide a snapshot of high-value actions that promote growth, create jobs, and encourage innovation in 3D printing. Through actions and initiatives within each key policy lever, education, incentives, adoption/promotion and IP protection, policymakers will deliver a diversified, effective strategy to promote the 3D printing ecosystem that will propel their countries, states, and cities to manufacturing leadership.

Federal governments have great opportunities to effect significant and wide-ranging changes in a country's 3D printing landscape. The ability to provide sizable educational funding, enact fiscal policies at a national level, and act as the largest potential customer for 3D printing technology make the federal government uniquely powerful in driving the growth of the 3D ecosystem.

State governments can play an influential role in attracting industry, shaping educational initiatives and setting fiscal policies that can have a major impact on the 3D printing market. Through supporting R&D funding, offering special tax breaks and credits, and via direct purchases of 3D printed parts, states can serve a key role as a nexus among industry, universities, and government.

Cities can play an important role in implementing policies that facilitate 3D printing facilities and operations. Through providing funding for local workforce training, enacting favorable zoning laws, and creating additional local tax incentives, cities can provide industry a home to do business and innovate.

Federal policy actions

	Public/Private Partnership Objectives	Policymakers		
		Federal	State	Local
Education	University educational initiatives and curricula, and make training grants available for continuing education	✓	✓	✓
	R&D funding in leading research universities to research 3D printing and materials	✓	✓	✓
Adoption	Government procurement policies mandating 3D printing part purchases	✓		
	Preferential treatment of small businesses using 3D printing in existing SBA programs	✓		
	Direct government funding for test cases for 3D printing in the private sector and purchase of 3D-printed parts		✓	✓
	Beneficial zoning laws, including classifying 3D printing as “light manufacturing”			✓
Incentives	Tax incentives for companies using 3D printers to localize manufacturing to offset investment costs (equipment purchase, qualification, etc.)	✓	✓	✓
	Tariff protection related to cross-border digital	✓		
	Training dollars for 3D print redesign and 3D print operation		✓	✓
	Tax incentives for companies driving R&D in 3D print materials	✓	✓	
Legal Framework	Ensure existing legal framework supports 3D printing adoption and requirements: existing IP legislation covers 3D printing, liability concerns are mitigated based on value chain requirements, and Regulatory infrastructure is adaptable to 3D printing	✓		

Figure 27: Objectives for Public/Private Partnerships and Policies

At the federal level, there are several actions needed to grow the 3D printing and advanced manufacturing environment. Expanding domestic manufacturing has positive implications for both job creation and GDP growth, but to be successful, certain key policy levers need to be applied. Leaders should pursue actions using four key policy levers: education, adoption, promotion, and incentives. In addition, they can ensure existing policies protect the value capture in the ecosystem, such as IP legislation.

Education

Through leveraging their extensive resources, federal governments have the power to play leading roles in developing the upcoming generation of native digital product engineers. Through key initiatives and funding opportunities, federal governments can help build capabilities of engineers to understand and design for 3D printing, and help drive materials research to increase variety and reduce materials cost. Two key high-value policy actions include:

- promoting university educational initiatives and curricula, and making training grants available; and
- funding R&D in leading research universities to research 3D printing and materials.

Federal governments are traditionally the largest funders of both training grants and R&D initiatives for research universities, and can apply these efforts to bolster 3D printing. In the United States, federal agencies invested $141 billion in R&D projects in 2017, while an agency such as the National Institutes of Health, for example, provided $785 million in training grant funding for nearly 16,000 research scientists in 2016. Other countries, including the United Kingdom, Germany, Singapore, as well as the United States, have provided federal funding specifically for additive manufacturing educational centers of excellence. Federal governments that pursue these policies can help grow the 3D printing market and create a steady pipeline of talent for the engineering workforce of the future.[67, 104]

Adoption

To catalyze the 3D printing market and create demand to stimulate overall manufacturing sector growth, federal governments can take a number of steps to promote adoption of 3D printing technologies. Two high-value policy actions include:

- enact government procurement policies that mandate 3D printing part purchases; and
- offer preferential treatment of small businesses using 3D printing in new and existing government programs.

To succeed in the former, countries can partner with industry leaders in 3D printing to first identify the best applications of the technology for government agencies. Findings can be used to help build a legislative mandate to buy and use 3D printed parts in applicable areas (e.g., the U.S. Department of Defense), driving demand for 3D printed products. Public/private sector coordination in these areas will allow for industry to build the 3D printing ecosystem to adequately meet government needs and demands. For example, the 2018 United States Department of Defense military budget includes a $13.2 billion-line item for 3D printing and technological innovation (see roadmap below).[99]

Small businesses make up the clear majority of manufacturers. For example, 98% of U.S. manufacturing firms employ fewer than 500 individuals, this creates an important opportunity for growth in 3D printing, and policies to promote 3D printing adoption among such companies can help take advantage. By requiring that a specific portion of existing funding for small businesses go to those businesses using 3D printing, manufacturing can increasingly be localized, and additional jobs created. Germany's Mittelstand manufacturing companies, for example, include an expansive array of small-to-medium sized companies that often outperform their larger counterparts, averaging profit margins of 7.3% in 2015, compared to 6.3% for the largest German manufacturers. Promoting 3D print adoption grants among these businesses presents a high-value opportunity.[106, 110]

Incentives

To reduce the cost and risk of entry to purchase and use 3D printers and related technologies, states can promote policies to incentivize investment as well as R&D. Three policy actions of high-value include:

- Create tax incentives for companies using 3D printers to localize manufacturing and offset investment costs
- Enact tariff protection related to cross-border digital products and IP
- Create tax incentives for companies driving R&D in 3D print materials

While there are many avenues to promote tax incentives, establishing a government advisory board on the future of manufacturing at the federal level is a tactic that can yield lasting results. The group can examine existing incentives and propose changes as needed to stoke 3D printing growth. Adding 3D printers to the information technology agreement at the World Trade Organization will help ensure that the technology receives the same protections as other technologies.[48, 49]

Building a country roadmap: US Example

	Policy objectives	Assessment of US policies
Education	University educational initiatives and curricula, and make continuing education grants	The United States has helped inform degree programs in additive manufacturing and 3D printing through programs like America Makes; however, funding to drive broader adoption of 3D printing curricula is an open opportunity.[5, 66]
	R&D funding in leading research universities to research 3D printing and materials	The United States has funded 3D printing R&D in academia, and via America Makes, but opportunities remain for the government to expand these activities. [5, 66]
Adoption	Preferential treatment of small businesses using 3DP in existing SBA programs	U.S. government has promoted 3D printing initiatives across a range of agencies and applications through SBIR[88, 89]
	Government procurement policies mandating 3DP part purchases	The Department of Defense has allocated 2018 funding to 3D printing[98]
Incentives	Tax incentives for companies using 3D printers to localize manufacturing to offset investment costs (equipment purchase, qualification, etc.)	While there are other tax incentives, such as Section 199 Manufacturing Credit, there is no current 3D printing specific tax incentive at the federal level.[61]
	Tariff protection related to cross-border digital	Efforts to remove tariffs for 3D printing and materials, as well as to set rules for 3D printing in the WTO, have not yet been established, but are currently underway.
	Tax incentives for companies driving R&D in 3D print materials	The existing R&D tax credit may be applied to 3D printing related activities.

Figure 28: Assessment of US Policies in support of 3D Printing

Actions to close policy gaps

Education: Expand training grants and R&D funding to research universities; grow partnership with America Makes to improve quality and reach of 3D printer education programs.

Adoption:

- Develop a longer-term strategy for 3D printing procurement at the federal level; include longer-term spend allocations in the Department of Defense budget
- Allocate specific Small Business Innovation Research funds towards companies using 3D printing

Incentives:

- Develop an incentives package that supports R&D and use of 3D printing in manufacturing, potentially through creation of a Congressional Commission. Consider policies such as tax reductions on revenue generated from 3D printing, or for repatriated manufacturing.
- Support World Trade Organization (WTO) adoption of 3D printing under the Information Technology Agreement, providing tariff protections for 3D printers and 3D printing material

Legal Framework: Partner with industry leaders to ensure that the existing legal framework provides IP protection for printing, and that the regulatory infrastructure is able to adapt with changing technologies

State policy actions

State governments will play a critical role in building successful ecosystems and coordinating efforts to prepare their constituents for the imminent changes coming from 3D printing—and to harness the benefits. Government leaders should pursue actions using three key policy levers: education, adoption/promotion, and incentives.

Education

Establishing a pipeline of qualified engineers to understand and design for 3D printing through educational initiatives at Universities, while also promoting materials research to increase variety and reduce materials costs will provide states with a differentiated advantage as the 3D printing market grows. Two high-value policy actions include:

- develop university educational initiatives and curricula, and make continuing education training grants available; and
- promote R&D funding in leading research universities to research 3D printing and materials.

In driving toward the former, states have an opportunity to build an educational ecosystem around 3D printing. This includes creating 3D printing curricula in engineering programs, promoting 3D printing research in universities, and hands-on experience with 3D printers, as well as through allocating funding for training grants. State universities already receive extensive funding from state governments. For example, Penn State received $224.8 million for the 2015-2016 school year, specifically appropriating $2 million for its College of Technology in Williamsport. Targeting such line items to 3D print specific programs, such as Penn State's new Master of Science in Additive Manufacturing at the Center for Innovative Materials Processing, represents a high-value opportunity for 3D print education investment. [72]

For the latter, states should assess existing funding for grants and identify opportunities to reallocate or provide additional funds for 3D printing R&D. This can include initiatives to improve ease of access to funding opportunities through web portals and other

NORSK TITANIUM

Case study: Norsk Titanium and New York

In October 2015, New York State announced plans to invest $125 million to build the world's first industrial-scale 3D printing facility as part of a public/private partnership deal with Norway's Norsk Titanium AS. The deal is expected to promote technological advancement in 3D Printing while also bringing new jobs to the region.

The state will use the $125 million investment to buy 40 of Norsk Titanium's industrial-scale 3D printers, and build the company a state-of-the-art factory in Plattsburgh, NY. Norsk will lease and operate the printers and facility from the state. Facility construction is projected to begin in spring 2017.

State goals: New York is seeking to develop a high-tech corridor between New York City and Montreal. This investment will promote R&D and production while bringing significant tax revenue return to NY taxpayers.

Local goals: In addition to putting Plattsburgh on the ground level for the future of manufacturing, the initiative is expected to employ 400 people at the white-collar and technician levels. Norsk is projecting that 80 to 90% of its employees will be locally trained.

Norsk Titanium goals: Norsk wanted a base in the U.S., given the country's role as an aerospace leader. Plattsburgh was chosen because of its workforce training plan, with a new Institute for Advanced Manufacturing opened for the Fall 2017 semester at Clinton Community College, and Clarkson University providing expertise for new R&D in 3D Printing technology and applications.

The Norsk Titanium-New York State deal provides an example of a new model for public/private partnerships in which the taxpayer serves as an investor in cutting-edge technologies.[68, 69, 70]

vehicles. The State of New York's extensive investment deal with Norsk Titanium (see sidebar) is an example that has led to new 3D print R&D opportunities at nearby Clarkson University. In Canada, provinces routinely contribute to University research and innovation efforts to advance innovative technologies. For example, in September 2016, Ontario's Ministry of Research, Innovation and Science gave $3.6 million to support 29 research projects, including 21 at the University of Waterloo. [8, 64, 68, 69, 70, 75]

Incentives

At the State level, there are further opportunities to reduce the cost and risk of entry to the purchase and use of 3D printers and related technologies. High-value policy actions include:

- tax incentives for companies using 3D printers to localize manufacturing to offset investment costs;
- training dollars for 3D print redesign and 3D print operation; and
- tax incentives for companies driving R&D in 3D print materials.

For the former, states will need to undertake an assessment of current tax policies, specifically examining existing technology incentives and identifying opportunities to include 3D printing equipment purchases. Regarding R&D tax incentives for 3D print materials, states have opportunities to provide further tax breaks and/or credits for companies working on the development of such materials. States can also reallocate existing training funds or advocate for allocation of new funds in the state budgetary process, to prioritize 3D printing, including design, maintenance, and operations. For example, South Carolina offers extensive business-friendly tax incentives to encourage investment by specific industries, including via the South Carolina Enterprise Program, which provides companies with funds to offset the cost of locating or expanding business facilities in the state.

The state also offers manufacturers locating or expanding in the state a one-time corporate income tax credit up to 2.5% of a company's investment in new production equipment, including 3D printing. In Germany, the State of Bavaria offers extensive funding for companies involved in research of the latest technologies, including 3D printing, through the Bavarian Research and Innovation Agency. Incentives include low-interest loans and non-repayable subsidies. For training, South Carolina offers collaborative industry partnerships to provide customized, high-quality technical training for area workers. Indiana offers similar training incentives through Next Level Jobs Indiana (see roadmap below).[38]

Adoption

State governments can also take proactive measures to encourage manufacturing, and specifically 3D printing technology, within their borders. Policy actions of high value include:

- direct government funding for test cases for 3D printing in the private sector; and
- state purchases of 3D printed parts

For the former, working through state- and regional-level development agencies can provide opportunities to identify pilot programs that could be created for 3D printing. Such pilot programs can create incentives for private sector 3D printing investment and seek to achieve specific breakthroughs using the technology. The State of New York-Norsk Titanium partnership is a shining example of such a pilot program (see sidebar above). For the latter, states can prioritize the purchase of 3D printed parts as part of state government procurement processes, driving market demand for the technology and its products. Such an initiative could be modeled after renewable portfolio standards requiring state utilities to purchase renewable power (see solar case study above).[68, 69, 70]

Building a state roadmap: Indiana example

	Policy objectives	Assessment of US policies
Education	Develop university educational initiatives and curricula, and make continuing education training grants available	Purdue University operates the Center for Advanced Manufacturing Ivy Tech Community College, which has established a 3D printing (additive manufacturing) curriculum, including in-house training with local manufacturing companies
	R&D funding in leading research universities to research 3D printing and materials	Indiana does not currently offer major R&D funding at state universities to promote 3D printing, resulting in state universities primarily leveraging federal funds for such activities. The Center for Additive Manufacturing Research at Indiana University is a silver member of America Makes.
Adoption	Direct government funding for test cases for 3D printing in the private sector and purchase of 3D-printed parts	There are currently no major state-funded 3D printing pilot projects in the private sector, or government incentives for purchase of 3D printed parts.
Incentives	Tax incentives for companies using 3D printers to localize manufacturing to offset investment costs (equipment purchase, qualification, etc.)	While there are other tax incentives, such as state R&D tax credits (see below) that may be applied to 3D printing related activities, there is no current 3D printing specific tax incentives in Indiana.
	Training dollars for 3D print redesign and 3D print operation	Next Level Indiana is a major workforce development program that includes workforce employer training grants, including for 3D printing.
	Tax incentives for companies driving R&D in 3D print materials	The State of Indiana offers two tax incentives to encourage R&D, including a credit against Indiana income tax liability, and sales tax refunds.

Figure 29: Assessment of Indiana Policies in support of 3D Printing. Source: 17, 22, 43, 50, 80

Actions to close policy gaps

Education:

- Extend Purdue funding to revise Mechanical Engineering undergraduate curriculum for Design for 3D
- Increase R&D funding for research universities, such as Indiana University's Center for Additive Manufacturing Research, to explore new printing materials.
- Expand the ecosystem Purdue has begun developing through training funding increases for 3D print redesign and operations, and leveraging existing training programs, such as Next Level Jobs.

Adoption:

Develop test cases or pilot programs to help push 3D printing innovation by leveraging opportunities in existing ecosystems. Collaborate with local companies such as Eli Lilly and Company and Rolls-Royce in building such a program.

Incentives: Sustain support for R&D tax credits and create additional credits for 3D printing-specific initiatives. Introduce tax breaks for companies adopting 3D printing and/or conducting related R&D.

HP © Copyright 2018

Local policy actions

By creating a receptive environment, cities can capitalize on the localization of manufacturing through local governance. City leaders should pursue actions using three key policy levers: education, adoption/promotion, and incentives.

Education

Cities can help grow the future engineering workforce through higher educational initiatives, including those at vocational and community colleges. A high-value policy action includes:

- Promoting higher educational initiatives and curricula, and making continuing education training grants available

Local governments can play a role in the education space by assessing existing funding for training grants, and identifying opportunities to reallocate or provide additional funds for 3D printing-related education at vocational or community colleges. Funds can be aimed at schools with additive manufacturing centers of excellence or 3D printing programs in place. For the city of Greenville in South Carolina for example, the Center for Manufacturing Innovation at Greenville Technical College would be an ideal target (see roadmap below). Cities can also partner with the local 3D printing industry to encourage the creation of such community college programs to create a workforce pipeline. The Institute for Advanced Manufacturing at Clinton Community College is another example, and will serve as a pipeline for talent to Norsk Titanium.[15, 18, 38, 45]

Adoption

City and local governments can catalyze the 3D printing market and create demand to stimulate overall manufacturing-sector growth via policy action. Key policy initiatives include:

- removal of sales tax on 3D printed parts; and
- beneficial zoning laws, including classifying 3D printing as “light manufacturing.”

City councils and local governments can move to eliminate local sales taxes, if they are present, on 3D printed parts to help promote purchase of such goods, and drive industry growth. Cities can consult with relevant stakeholders, including industry and relevant local manufacturing groups, to establish special zoning provisions based on reasoned analysis of the 3D printing industrial footprint. Such zones provide opportunities for industry investment in 3D printing manufacturing centers, promoting the local economy and creating new jobs. For example, the city of Denver in Colorado offers Enterprise Zone tax credits for businesses conducting R&D on new technologies (3% on the increase in such expenditures) to incentivize this activity in designated areas. The city of Dubai in the United Arab Emirates is seeking to become a leading hub in 3D printing technology, and has created new municipality regulations requiring that all new buildings be 25% 3D- printed by the year 2030.[20]

Incentives

As at the federal and state level, cities can provide incentives to reduce the cost and risk of entry to purchase and use 3D printers and related technologies. Policy actions of high value include:

- tax incentives for companies using 3D printers to localize manufacturing to offset investment costs; and
- training dollars for 3D print redesign and 3D print operation.

Cities can assess current tax policies around technology incentives, and around opportunities to add provisions that promote investments in 3D. Cities can also promote training by exploring opportunities to reallocate existing training funds, or create new ones focused specifically on 3D printing redesign and operation. For example, Incodema3D, a 3D manufacturing company, received a property tax abatement from Tompkins County’s Industrial Development Agency as an incentive to build its new facility in Freeville, NY. The city of Brisbane in Australia provides incentives to support small-to-medium businesses involved in 3DP in conjunction with the Chamber of Commerce & Industry Queensland. Creat3d Brisbane, a 3D printer hub, enables small-to- medium businesses to access 3DP at no or minimal costs.[13]

Building a state roadmap: Greenville, South Carolina example

	Policy objectives	Assessment of US policies
Education	Higher educational initiatives and curricula, and make continuing education training grants available	The Center for Manufacturing Innovation offers vocational education in 3D printing and additive manufacturing.
Adoption	Direct government funding for test cases for 3D printing in the private sector and purchase of 3D-printed parts	Although GE has recently launched an advanced manufacturing center, the city of Greenville has had limited direct involvement in setting up pilot programs.
Incentives	Tax incentives for companies using 3D printers to localize manufacturing to offset investment costs (equipment purchase, qualification, etc.)	While there are other tax incentives, such as state R&D tax credits (see below) that may be applied to 3DP-related activities, there is no current 3DP-specific tax incentive in South Carolina.
	Beneficial zoning laws, including classifying 3DP as "light manufacturing"	The City of Greenville Economic Development Office has changed rules to provide a three-year abatement of the City business license fee for new corporate offices, manufacturing, R&D, and high-tech companies.
	Training dollars for 3D print Redesign and 3D print operation	While Clemson University has invested in the Clemson Advanced Manufacturing and Materials Processing Laboratory, funding specific for 3DP training has not yet been established at the city level.

Figure 30: Assessment of Greenville, SC Policies in support of 3D Printing. Source: 15, 18, 23, 38, 45

Actions to close policy gaps

Education: Promote higher education related to 3DP in Greenville via expansion of the Center for Manufacturing Innovation's vocational educational programs in 3D printing and additive manufacturing. Deepen partnerships with local industry players, such as GE, to ensure a sustainable workforce pipeline.

Adoption:

- Greenville should partner with local industry leaders such as BMW, Michelin, Bosch, and Lockheed Martin, as well as 3D printing companies, to further develop the 3D printing ecosystem for manufacturing
- Work through the City of Greenville Economic Development Council to accelerate creation of special 3D print zones and classify 3D printing as "light manufacturing." Expand existing three-year abatement of the City business license fee for new corporate offices, manufacturing, R&D, and high-tech companies to five years for 3D printing companies

Incentives:

- Ensure funding for training in 3D print redesign and 3D print operation by leveraging the Greenville Economic Development Corporation. Reallocate existing city funds or create new funding streams for training at area vocational schools, such as Greenville Technical College.
- Grow tax incentives to promote 3D printing via the Greenville Area Development Corporation. Promote and expand existing property tax incentives (five-year statutory abatement; fee-in-lieu-of-tax arrangements) for companies investing in the city, with additional benefits for 3D Printing businesses.

HP © Copyright 2018

A vision for the future

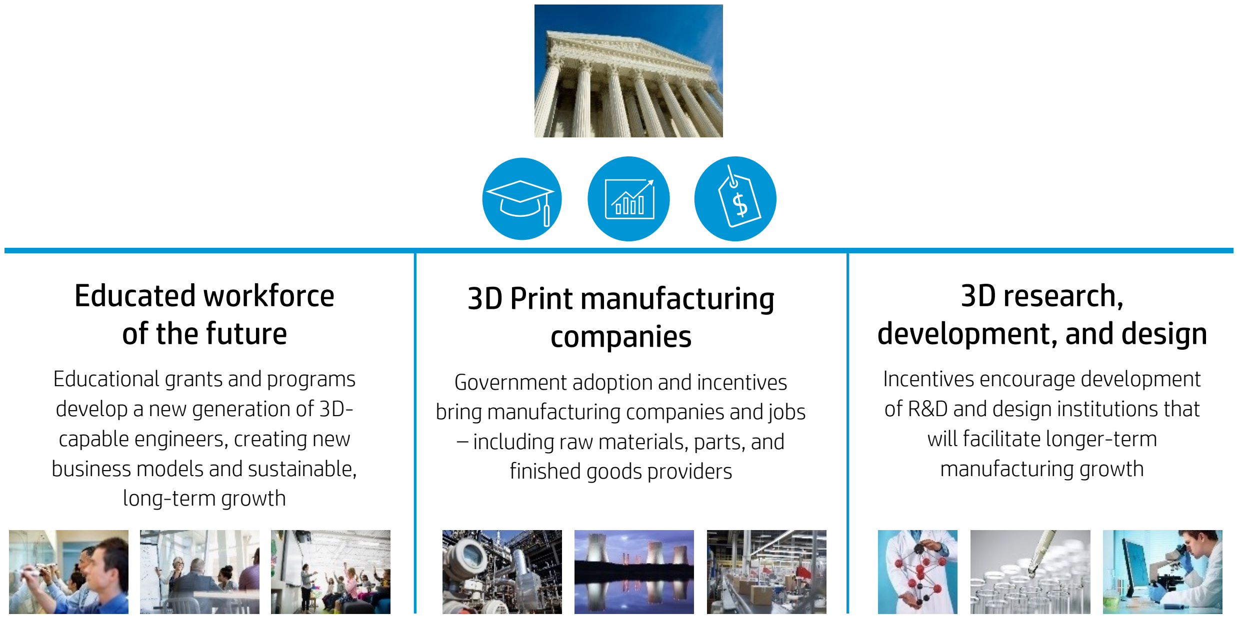


Figure 31: Illustrative Vision for Successful 3D Printing Ecosystem

Conclusion: A call to action

3D printing will fundamentally change the manufacturing industry. $4 to 6 trillion (USD) of the global economy will be disrupted in the next five to 10 years, shifting economic value and jobs across the globe. And leadership in the new digital manufacturing economy will depend on comprehensive government engagement.

Federal, State and Local policymakers need to drive policies across Education, Adoption, and Incentives to develop and grow the 3D ecosystem.

Leaders need to focus on educational programs for engineers to prepare the workforce of the future to design for 3D. Additionally, supporting R&D in leading educational institutions will help to build the broader 3D print capability and ecosystem.

Adoption of 3D printing by federal governments will not only enable new capabilities, it will stimulate the market and broader growth of the ecosystem, leading to development of a strong 3D manufacturing base. Leaders can also support adoption of the technology by supporting small businesses in developing these capabilities.

Building incentives, especially at the state and city levels, to attract the use of 3D printing will accelerate development of a complete 3D ecosystem and capability, and attract more manufacturing, jobs, and economic growth to a geography.

Leaders also need to ensure that their existing legal and policy frameworks are reliable in supporting the 3D ecosystem, and make changes wherever needed.

In this historic global transformation, leaders who fail to move now risk leaving their share of trillions of dollars in newly-created market value on the table. Now is the time for nations to take the steps needed to build a robust and comprehensive 3D printing ecosystem that will ensure leadership in the 4th Industrial Revolution, and the world's hyper-connected, always-on, fully-digital future.

Appendix 1: About the study

A.T. Kearney used a quantitative analysis and survey data to assess the total impact of 3D printing on US imports. This was then extrapolated to a global scale. Overall, the research aims to answer the impact on the following three dimensions:

1. Economic Value: 3D print enables growth in the local economy
2. Jobs Localization: 3D print increases jobs through re-shoring manufacturing
3. Job Skills Shift: 3D print jobs will require different skills—shift across job skills

The model uses data derived from the U.S. Bureau of Labor Statistics and Bureau of Economic Analysis for GDP calculations. The key hypothesis underlying the model is: 3D printing can be used as a source of competitive advantage to localize (and on-shore) manufacturing. The model does not quantify the impact of new business models/products on economic growth or jobs due to 3D printing adoption, which could be a significant upside contributor in the future.

Research methodology

The following steps were taken to derive the economic value:

1. Input: the total U.S. annual imports for industries most applicable to 3D printing (Industrials, Consumer Products, Automotive, Healthcare and Medical, and Aerospace)
2. Assess imports that could be on-shored or localized with 3D printing based on survey input for 3D printing applicability by industry.
3. Use macro-economic multiplier effect of 1.8X to quantify the cascade effect of value add to the economy, based on research by the National Association of Manufacturers.[95]
4. In this model, $600-900 billion is the total economic value identified for the United States.

The following steps were taken to quantify the impact on total jobs created through 3D printing in the US example:

1. Inputs: Total US manufacturing jobs for industries most applicable to 3D printing (Industrials, Consumer Products, Automotive, Healthcare and Medical, and Aerospace); economic value from previously mentioned analysis
2. Assumed that number of jobs per economic value in the US remains equal to the current value in the US, in order to calculate the number of jobs created due to $600 to 900 billion in economic value calculations.
3. The resulting additional jobs created through 3D printing and on-shoring of manufacturing is 3 to 5 million.

The following steps were used to quantify the jobs skill shift:

1. Input: the US manufacturing jobs distribution across the five applicable industries (Industrials, Consumer Products, Automotive, Healthcare and Medical, and Aerospace)
2. Calculated the change on jobs distribution by role, based on inputs from a survey that quantified the expected impact.

Survey methodology

A survey was used to quantify the applicability of 3D printing on selected industries. Research Now, an award-winning global digital data collection company with more than 20 years' experience, was engaged to run this survey.

The survey targeted industry leaders and experts in the five key industries (Industrials, Consumer Products, Automotive, Healthcare and Medical, and Aerospace) that were objects of this study. The survey's qualification questions ensured selection of only respondents with relevant knowledge and expertise in 3D printing. Thus, 26% of the pool candidates qualified, resulting in 112 respondents completing the survey, which were used as inputs in the analysis.

HP © Copyright 2018

Appendix 2: Bibliography

1. "3D Printing and Additive Manufacturing State of the Industry." Wohler's Report 2017. N.p., n.d. Web.
2. "A Brief History of 3D Printing." T.Rowe Price Connections (n.d.): n. pag. Web.
3. "Advanced Manufacturing Sciences Institute." MSU Denver, msudenver.edu/advanced-manufacturing/.
4. "Aerospace Cost Breakdown." Annual Review 2015 IATA ANNUAL REVIEW, www.iata.org/about/Documents/iata-annual-review-2015.pdf.
5. America Makes, "Lousiana State University College of Engineering, Department of Mechanical and Industrial Engineering." America Makes, https://www.americamakes.us/lsu/
6. "Average Consumption." Global Consumption Database, The World Bank, data.worldbank.org/indicator/NE.CON.TOTL.CD.
7. Badkar, Mamta. "10 Mind-Boggling Facts About China's Massive Manufacturing Sector." Business Insider, 1 Aug. 2013, www.businessinsider.com/chinese-manufacturing-stats-versus-rest-of-the-world-2013-8#china-makes-more-than-seven-times-as-many-pair-of-shoes-per-person-as-the-rest-of-the-world-6.
8. Benedict. "Canada's University of Waterloo Building One of World's Largest Academic 3D Printing Facilities." 3ders.org. N.p., n.d. Web.
9. Bensoussan, Hannah. "The History of 3D Printing: From the 80s to Today." 3D Printing Blog: Tutorials, News, Trends and Resources | Sculpteo. N.p., n.d. Web.
10. Black, Sara. "A Growing Trend: 3D Printing of Aerospace Tooling." CompositesWorld, 01 July 2015. Web.
11. Bolt, J. and J. L. van Zanden (2014). The Maddison Project: collaborative research on historical national accounts. The Economic History Review, 67 (3): 627–651. (when referring to underlying methodology and main results)
12. Brooks, Robert, "More AM Funding Awarded for Metalcasting Projects." Foundry Management and Technology, 3 February 2014, http://www.foundrymag.com/moldscores/more-am-funding-awarded-metalcasting-projects
13. "Incentives," Brisbane City Council, August 2016, https://www.brisbane.qld.gov.au/sites/default/files/20160805-urban-renewal-brisbane-brisbane-city-centre-an-open-city-part2.pdf
14. Brown, Bruce. "Xkelet 3D Printed Casts [video]." Health Tech Insider. N.p., 01 Feb. 2017. Web.
15. "Business Assistance." Greenville, SC - Official Website, www.greenvillesc.gov/324/Business-Assistance.
16. "Business Energy Investment Tax Credit (ITC)." Department of Energy, energy.gov/savings/business-energy-investment-tax-credit-itc.
17. "CAMRI." INDIANA UNIVERSITY - PURDUE UNIVERSITY INDIANAPOLIS, www.iu.edu/~camri/home.php.
18. "Center for Manufacturing Innovation." Greenville Technical College, gvltec.edu/indexcmi.html.
19. Chandler, David L., "3-D printing offers new approach to making buildings." MIT News, 26 April 2017. http://news.mit.edu/2017/3-d-printing-buildings-0426
20. Choose Colorado, "Enterprise Zone Tax Credits." Choose Colorado,
21. Clarke, Corey, "Winsun to lease concreted 3D printers to Saudi Arabia in Billion Dollar construction deal", 21 March 2017.
22. Conexus Indiana, conexusindiana.com/.
23. "Clemson Advanced Manufacturing & Materials Processing Laboratory." CAMMP Lab, cecas.clemson.edu/~hongc/.
24. Davidson, Gillian, and T.V. Narendran. World Economic Forum Digital Transformation Initiative: Mining and Metals Industry. World Economic Forum, Jan. 2017, reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-mining-and-metals-industry-slideshare.pdf.
25. Denardi, Kate. "San Jose Looks to Digital Infrastructure to 'Future-Proof' the City." MeriTalk, 10 May 2017, meritalkslg.com/articles/san-jose-looks-to-digital-infrastructure-to-future-proof-the-city/.
26. "Dubai 3D Printing Strategy," Dubai Future Foundation, Government of Dubai,
27. Dubai Future Foundation, "Making Dubai the worlds *[sic]* 3D printing Hub", http://www.dubaifuture.gov.ae/our-initiatives/dubai-3d-printing-strategy/
28. Economics and Statistics Department. "Plastic Resins in the United States." American Chemistry Council, www.packaginggraphics.net/plasticResinInformation/Plastics-Report.pdf.
29. Editors, DE. "History of 3D Printing Timeline." Digital Engineering, 29 Apr. 2016, www.digitaleng.news/de/history-of-3d-printing-timeline/.
30. Enkhardt, Sandra, "German Parliament approves incentives for tenants' solar power supply." PV Magazine, 30 June 2017, https://www.pv-magazine.com/2017/06/30/german-parliament-approves-incentives-for-tenants-solar-power-supply/
31. "Enquiries into Intellectual Property's Economic Impact." OECD (n.d.): n. pag. Web.
32. "Facts and Figures." Berkeley Engineering. N.p., 13 Feb. 2017. Web.
33. "Final Consumption Expenditure." Files, data.worldbank.org/indicator/NE.CON.TOTL.CD.
34. Fisker, Simon. "Sculpto+: The World's Most User-friendly Desktop 3D Printer." Kickstarter. N.p., n.d. Web.
35. "Fraunhofer Additive Manufacturing Alliance." Fraunhofer Generativ, www.generativ.fraunhofer.de/en.html.
36. Gebler, Malte, Anton J.M. Schoot Uiterkamp, and Cindy Visser. "A global sustainability perspective on 3D printing technologies." Energy Policy 74 (2014) 158–167. Energy Policy, Volume 85, October 2015, Pages 511

37. Government of Canada, "Scientific Research and Experimental Development Tax Incentive Program." Government of Canada, https://www.canada.ca/en/revenue-agency/services/scientific-research-experimental-development-tax-incentive-program.html

38. "Greenville, South Carolina Sales Tax – Avalara – Tax Rates." TaxRates.com, www.taxrates.com/state-rates/south-carolina/cities/greenville/.

39. Grunewald, Scott. "3D Printing Will Help Mercedes-Benz Trucks Deliver Thousands of Replacement Parts On Demand." 3D Printingrint.com | The Voice of 3D Printing / Additive Manufacturing. N.p., 14 July 2016. Web.

40. Hague, Richard, Phil Reeves, and Sophie Jones. "Mapping UK Research and Innovation in Additive Manufacturing." Government of United Kingdom, February 2016, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/505246/CO307_Mapping_UK_Accessible.pdf

41. Helman, Christopher. "For U.S. Military, More Oil Means More Death." Forbes, 12 Nov. 2009, www.forbes.com/2009/11/12/fuel-military-afghanistan-iraq-business-energy-military.html.

42. "History of Enigma." Enigma History. N.p., n.d. Web.

43. "Holcomb Rolls Out 'Next Level Jobs' Initiative With 2 Programs to Help Meet Current Workforce Demand." Indiana State Government Website, 14 Aug. 2017, calendar.in.gov/site/gov/event/holcomb-rolls-out-next-level-jobs-initiative-with-2-programs-to-help-meet-current-workforce-demand/.

44. "Illegal, Immoral, and Here to Stay: Counterfeiting and the 3D Printing Revolution." Wired, Conde Nast, 6 Aug. 2015, www.wired.com/insights/2015/02/illegal-immoral-and-here-to-stay-counterfeiting-and-the-3d-printing-revolution/.

45. "Incentives: Greenville Area Development Corporation (GADC)." The Greenville Area Development Corporation (GADC), www.greenvilleeconomicdevelopment.com/incentives.php

46. Industrial Revolution Facts & Worksheets: https://kidskonnect.com - KidsKonnect, June 5, 2017

47. "Industrial Revolution." Encyclopædia Britannica, Inc., 2 May 2017, www.britannica.com/event/Industrial-Revolution. Accessed 29 Sept. 2017.

48. "Information Technology Agreement." World Trade Organization, www.wto.org/english/tratop_e/inftec_e/inftec_e.htm.

49. "International Trade - Current Account Balance Forecast - OECD Data." OECD Database, data.oecd.org/trade/current-account-balance-forecast.htm.

50. Ivy Tech Community College of Indiana. "Advanced Automation and Robotics Technology." Ivy Tech Community College of Indiana, www.ivytech.edu/advanced-automation-robotics/

51. Jackson, Beau, Rushabh Haria, Corey Clarke, Michael Petch, The Future of 3D Printing, Tanveer Khorajiya, and Katie Armstrong. "German Minister Announces Plan to Take the Lead in the New Digital Era of Manufacturing." 3D Printing Industry. N.p., 15 Sept. 2017. Web.

52. Jordan, Claudia. "The Companies Benchmark Eco-Design Attributes of Investment Casting and DMLS™ Additive Manufacturing (AM)." EOS and Airbus Group Innovations Team on Aerospace Sustainability Study for Industrial 3D Printing, 5 Feb. 2014, www.eos.info/eos_airbusgroupinnovationteam_aerospace_sustainability_study.

53. Kallstrom, Henry. "Raw Materials – the Biggest Cost Driver in the Auto Industry." Market Realist, 5 February 2015, marketrealist.com/2015/02/raw-materials-biggest-cost-driver-auto-industry/

54. Koslow, Tyler, et al. "Counterfeit Products." All3D Printing, 18 Sept. 2017, all3D Printing.com/.

55. LaMonica, Martin. "GE Will Make Jet Part with Additive Manufacturing." MIT Technology Review, 09 Dec. 2015. Web.

56. Lomas, Natasha. "BioBots Is A 3D Printer for Living Cells." TechCrunch, 04 May 2015. Web.

57. Long, Tony. "Feb. 26, 1935: Radar, the Invention That Saved Britain." Wired. Conde Nast, 03 June 2017. Web.

58. Lonjon, Capucine. "3D Printing History: From Rapid Prototyping to Additive Fabrication." 3D Printing Blog: Tutorials, News, Trends and Resources | Sculpteo. N.p., 14 June 2017. Web.

59. Maddison Project, http://www.ggdc.net/maddison/maddison-project/home.htm, 2013 version.

60. "Making a success of the energy transition: On the Road to a secure, clean, and affordable energy supply." Federal Ministry of Economic Affairs and Energy, Germany, 31 July 2015, http://www.bmwi.de/Redaktion/EN/Publikationen/making-a-success-of-the-energy-transition.html

61. Merrick, Melissa, and Rex Miller. "What is the Section 199 Deduction?" Greenwalt CPAs, 21 Oct. 2010, greenwaltcpas.com/2010/10/what-is-the-section-199-deduction/.

62. Millsaps, Bridget. "2017 Red Dot Award Winner Sees 3D Printing as Future of Fashion." 3D Printingrint.com | The Voice of 3D Printing / Additive Manufacturing. N.p., 14 Aug. 2017. Web.

63. Millsaps, Bridget, "UAE Government Plans to Lead in 3D Printing and The Fourth Industrial Revolution Overall," 17 November 2016.

64. Millsaps, Bridget Butler. "Industrial 3D Printing Advances in Canada: University of Waterloo Receives $8.9 million Government Investment for World-Class Multi-Scale Additive Manufacturing Lab." 3DPrint.com, 26 May 2017, https://3dprint.com/175945/university-of-waterloo-3d-printing/

65. Mitchell, Russ. "Should California spend $3 billion to help people buy electric cars?" Los Angeles Times, Los Angeles Times, 26 Aug. 2017, www.latimes.com/business/la-fi-hy-electric-vehicle-subsidies-20170828-htmlstory.html.

66. "National Additive Manufacturing Innovation Institute." America Makes, www.americamakes.us/.

67. National Science Foundation, "Federal Obligations and Outlays for Research and Development, by agency: FYs 2015-17." National Science Foundation, https://ncsesdata.nsf.gov/fedfunds/2015/html/FFS2015_DST_004.html

68. "New York state to build large-Scale 3D printing plant-sources." Reuters, Thomson Reuters, 5 Oct. 2015, www.reuters.com/article/norsk-titanium-usa-idUSL1N1211UT20151005.

69. "Norsk Titanium Ramping Up Production." Mountain Lake PBS, 13 Apr. 2017, mountainlake.org/norst-titanium-ramping-up-production/.

70. "Norsk Titanium to Build World's First Industrial-Scale Aerospace Additive Manufacturing Plant in New York." Norsk Titanium, 11 July 2016, www.norsktitanium.com/norsk-titanium-to-build-worlds-first-industrial-scale-aerospace-additive-manufacturing-plant-in-new-york/

71. "Occupational Employment Statistics." OES Database, www.bls.gov/oes/.

72. Penn State News, "Penn State's 2015-2016 Appropriations Released." Penn State, 23 March 2016, http://news.psu.edu/story/399516/2016/03/23/budget/penn-states-2015-16-appropriations-released

73. "Population, Total." The World Bank, data.worldbank.org/indicator/SP.POP.TOTL

74. "Population: 1790 to 1990." U.S Rural and Urban. www.census.gov/population/censusdata/table-4.pdf

75. "Province gives $3.6M to Waterloo regional researchers," CBCNEWS, 31 August 2016. http://www.cbc.ca/news/canada/kitchener-waterloo/region-researchers-province-funding-3-million-1.3743326

76. Q Country 103.7 WQNY, "Ithaca Company gets property tax breaks in 3D printing venture." Q Country 103.7, http://1037qcountry.com/news/025520-ithaca-company-gets-property-tax-breaks/

77. "Renault Trucks Using 3D Printers to Make Lighter, More Efficient Engines." 3ders.org. N.p., n.d. Web.

78. "Renewable Electricity Production Tax Credit (PTC)." Department of Energy, energy.gov/savings/renewable-electricity-production-tax-credit-ptc.

79. Report, Staff. "UAE Aims to Be Global Hub for 3D Printing." Gulfnews, 27 Apr. 2016. Web.

80. "Research & Development Incentives." Indiana State Government Website, www.iedc.in.gov/incentives/r-d-tax-credit/home.

81. "Research and Development - Manufacturing Tax Tips." Internal Revenue Service, www.irs.gov/businesses/small-businesses-self-employed/research-and-development-manufacturing-tax-tips.

82. "Research and innovation funding." Bavarian Research and Innovation Agency, Bavarian State Ministry of Economic Affairs and Media, Energy and Technology. https://www.research-innovation-bavaria.de/service/research-and-innovation-funding/

83. "Retail Apparel Industry Profitability." Retail Apparel Industry Profitability by Quarter, Gross, Operating and Net Margin from 2 Q 2017, csimarket.com/Industry/industry_Profitability_Ratios.php?ind=1301.

84. Robertson, Nic. "How Robot Drones Revolutionized the Face of Warfare." CNN. Cable News Network, n.d. Web.

85. RP Platform, "The UK's Leading 3D Printing Research Institutions." RP Platform, 27 July 2017, https://rpplatform.com/2017/07/27/3d-printing-research-institutions/

86. "Sales and Use Taxes: Exemptions and Exclusions. California Revenue and Taxation Code, Part 1, Division 2." Sacramento, CA, 1991.

87. Sauter, Michael B and Samuel Stebbins. "Manufacturers bringing the most jobs back to America." USA Today, Gannett Satellite Information Network, 23 Apr. 2016, www.usatoday.com/story/money/business/2016/04/23/24-7-wallst-economy-manufacturers-jobs-outsourcing/83406518/. 4th industrial revolution

88. SBIR - STTR, www.sbir.gov/.

89. "SBIR Phase I: High Speed Electrophotographic 3D Printing System." SBIR - STTR, www.sbir.gov/sbirsearch/detail/878915.

90. Scott, Clare. "China Develops New Metal 3D Printing Technology, Combining Old and New Manufacturing Techniques." 3DPrint.com. 25 July 2016, https://3dprint.com/143613/china-metal-3d-printing-tech/

91. Scott, Clare. "Forecast 3D to Begin Offering HP's Multi Jet Fusion 3D Printing Technology to Customers; Materialise Reports on the MJF's Development" 3DPrint.com, 23 Mar 2017, https://3dprint.com/168773/forecast-3d-mjf-materialise/

92. Sher, David, "A Golden Future for 3D Printing in Italy", 24 February 2014.

93. "Steel Imports Reports: United States." Steel Imports Report: United States, www.trade.gov/steel/countries/pdfs/2015/imports-us.pdf.

94. "The Digital Millennium Copyright Act of 1998." Dec. 1998, www.copyright.gov/legislation/dmca.pdf.

95. "Top 20 Facts About Manufacturing." Top 20 Facts About Manufacturing | NAM, www.nam.org/Newsroom/Facts-About-Manufacturing/.

96. Transportation casualties in U.S. Armed Forces, US National Library of Medicine | National Institutes of Health, https://www.ncbi.nlm.nih.gov/pubmed/22694586

97. "U.K. Royal Navy puts 3D-printed drone through its paces in the Antarctic." DigitalTrends.com https://www.digitaltrends.com/cool-tech/royal-navy-drone-antarctic/)

98. "U.S. Total Manufacturing GDP" World Bank National Accounts Data, and OECD National Accounts Data Files, data.worldbank.org/indicator/NY.GDP.MKTP.CD.

99. "US Military budget lays emphasis on 3D Printing technology." 3D Adept, 8 July 2017, 3dadept.com/us-military-budget-lays-emphasis-on-3d-printing-technology/.

100. "United States - OECD Data." OECD Data, data.oecd.org/united-states.htm.

101. United States Congress Bureau of Economic Analysis. "USA GDP by Sector." USA GDP by Sector. www.bea.gov/iTable/index_industry_gdpIndy.cfm.

102. "USA Trade Balance by Industry." UN Comtrade Database, comtrade.un.org/.

103. US Department of Commerce, BEA, Bureau of Economic Analysis. "Bureau of Economic Analysis." BEA International Economics Accounts. .

104. US Department of Health and Human Services, "HHS FY2016 Budget in Brief." Health and Human Services, https://www.hhs.gov/about/budget/budget-in-brief/nih/index.html

105. "US History." UShistory.org, Independence Hall Association, www.ushistory.org/.

106. US Small Business Administration, "Firm Size Data." U.S. Small Business Administration, https://www.sba.gov/advocacy/firm-size-data

107. "Using Technology to Support Education Reform." Department of Education, September 1993, https://www2.ed.gov/pubs/EdReformStudies/TechReforms/chap2g.html

108. Vaughan-Nichols, Steven J. "Is cloud computing secure enough for spies? CIA bets on Amazon." ZDNet, ZDNet, 4 Dec. 2015, www.zdnet.com/article/cloud-computing-secure-enough-for-spies-cia-bets-on-amazon

109. Watters, Audrey. "How Steve Jobs Brought the Apple II to the Classroom." Hack Education, 25 February 2015, http://hackeducation.com/2015/02/25/kids-cant-wait-apple

110. Weber, Winfried W., "Germany's Midsize Manufacturers Outperform Its Industrial Giants." Harvard Business Review, 12 August 2016, https://hbr.org/2016/08/germanys-midsize-manufacturers-outperform-its-industrial-giants

111. Wolfe, Raymond. "Business R&D Performed in the United States Reached $356 Billion in 2015." InfoBrief, www.nsf.gov/statistics/2017/nsf17320/nsf17320.pdf.

112. "Worldwide Manufacturing GDP." UNIDO, https://stat.unido.org/country-profile/SDG/AFG.

113. "Worldwide Manufacturing GDP." World Economic Outlook, www.imf.org/en/Data#data.

114. Zijdeman, Richard; Ribeira da Silva, Filipa. 2015, "Life Expectancy at Birth (Total)", http://hdl.handle.net/10622/LKYT53, IISH Dataverse, V1

HP © Copyright 2018

SARATECH www.saratech.com | 949 481 3267 | info@saratech.com