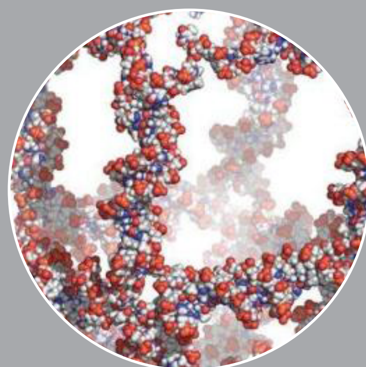
9 DISRUPTIVE TECHNOLOGIES CHANGING THE WORLD

2015 REPORT



PRESCOUTER

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EXECUTIVE SUMMARY

Disruptive Changes

In the past 25 years, modern society has undergone a number of significant changes due to the emergence of new and disruptive technologies. The emergence of the Internet and connected personal computers made it possible for individuals to freely access information and communicate with each other from the comfort of their homes. Companies at the forefront of this trend, such as PC manufacturers, software developers, and upstarts like America Online, saw double, and even triple digit growth.

Simultaneously, companies that failed to anticipate the impact of the Internet were decimated. The U.S. Postal Service has struggled to cope with mounting losses and a 36% reduction in mail volume due to advances like email and paperless billing. Newspapers have undergone a wave of consolidation as free access to information threatens traditional publishing models. Meanwhile the Encyclopedia Britannica survived the American Revolution, two World Wars and the decline of the British Empire, but was unable to compete in a world of Wikipedia. Encyclopedia Britannica went out of print in 2012 after a 244 year run.

Indeed, the only thing that remains constant about technology is the fact that it is constantly changing. Anticipating these changes is a high stakes endeavor - companies that succeed reap great rewards. Those that fail to adapt can quickly fall behind, losing market share, influence and profits. Garmin, one of the first manufacturers of Global Positioning System (GPS) navigation devices, has become synonymous with the technology, and saw revenues increase ten-fold ($105 million to $1.77 billion) over a ten year period. Simultaneously, Rand McNally, a name that had been synonymous with maps since 1856, and filed for bankruptcy in 2003, failed to anticipate both GPS navigation and Internet mapping software.

Looking Forward

In hindsight, it is easy to identify transformative technologies and criticize the business strategies of companies that failed to adapt. Yet, accurately predicting the course of disruptive technologies, as they are being developed, is a much more difficult endeavor. Corporate Research & Development departments may have relationships with local universities, but globalization indicates that innovations are now arising from research labs located in Europe, Asia, and elsewhere.

In order to accurately identify disruptive technologies, PreScouter relied on its network of more than 500 scholars actively performing cutting-edge research in 5 of the 7 continents. Our team of scholars examined thousands of technologies being developed at their universities and beyond. Of these technologies, the scholars selected the 9 most likely to disrupt established business models in the near-term, based on the following criteria:

- **Signs of Economic Success.** Even the most breathtaking innovations have severely limited utility if they remain confined to the laboratory due to high costs or missing infrastructure. Technologies selected in this report have progressed beyond lab-scale validation. They have already shown signs of successful commercialization, and are beginning to enter the marketplace.
- **Interdisciplinary Impact.** While every industry experiences its own 'revolutions', disruptive technologies, such as the Internet or smartphones, impact multiple industries simultaneously, becoming a global phenomena. The technologies detailed here have the potential to transform several industries simultaneously and are not limited in scope to a particular domain.
- **Near-term Consequences.** It goes without saying that by the year 2100, our world will barely resembles the world of today. Yet, it is almost impossible to predict exactly how that world will be different: Remember the predictions of flying cars from the 1950s? Technologies mentioned in this report are on the cusp of major breakthroughs, and are expected to have significant impacts in the next decade.
- **Revolutionary Potential.** While 99% of change is evolution, most companies are able to accurately predict gradual, incremental changes. This report details the 1% of change that is revolutionary and likely to disrupt, rather than extend existing industries. Although these technologies build on existing developments, they are likely to trigger significant changes to business models and practices as they are implemented.

As a result, the following nine technologies were selected based on their potential to disrupt the global marketplace by 2025. A brief summary of each technology follows below, while a more comprehensive overview can be found in the relevant sections of this report.

Big Data

In just two years, mankind generates enough information to fill 67.5 billion DVDs, and the amount of data an individual produces is expected to rapidly increase due to advances in mobile and wearable computing. Decreasing costs of storage have led to a situation where companies can retain vast quantities of data that were previously discarded. Analyzing this data in intelligent ways will enable companies to establish predictive relationships, based on subtle, almost undetectable cues. This will revolutionize the reliability and efficiency of manufacturing processes, targeted advertising, customer service, and medical care. Advances in algorithms and natural language processing will ultimately enable non-technical users to quickly extract valuable information. Because of this, Big Data is expected to be a $50 billion industry by 2017.

Automation & Artificial Intelligence

Artificial intelligence, a technology that has long been associated with robots, is beginning to cross-over into consumer products, and has become a $20.5 billion industry. Virtual assistants like Siri and Cortana have outgrown their gimmicky phase to become legitimately useful tools. Backend AI enables websites to present entirely different storefronts to consumers based on their demonstrated preferences. Coupled with advances in computer vision and the prevalence of smartphones, this technology will lead to major advances in understanding and predicting individual preferences.

Internet of Things

The utility of the Internet for personal computers cannot be overstated, yet millions of devices remain unconnected to the Internet, and require costly and time-consuming status checks, maintenance, and repair. Industrial internet technologies will use low power networking to put all of these devices and components 'online' so that failures can be detected remotely. By 2022, these advances will result in a network of more than 50 billion connected objects. Coupled with advances in Artificial Intelligence, this will ultimately lead to production lines that are able to autonomously route around damaged components, creating smart factories which will contribute $2 trillion in value to the global economy.

Microelectromechanical Systems (MEMS)

Sensors and actuators are critical devices for transferring information between the physical and digital worlds. While early sensors were large, bulky, and prone to failure, advances in miniaturization have led to micro-scale devices that can be combined on a single chip. These MEMS are already revolutionizing medical care and industrial diagnostics, and are poised to lead to rapid advances in haptic control, as accelerometers and gyroscopes are placed in every electronic device a person carries. As smartphones replace entire laboratories of equipment, the $12 billion MEMS market is experiencing annual growth rates of more than 20%.

Nanomaterials

Smaller materials are advantageous for continuing to drive miniaturization, however many substances display dramatically different properties at the nanoscale, making nanomaterials of a complete novel class of materials. Materials like gold and silicon can undergo radical changes in color and fluorescence as surface properties begin to dominate bulk effects. This can extend beyond color, as nanomaterials have been engineering with strengths, conductivities, and thermoelectric properties that are orders of magnitude better than traditional materials. While these effects were typically reported in academic journals, companies are now integrating nanomaterials into actual products. These products have properties that are unmatched by the competition. The global market for nanomaterials has increased by an order of magnitude in the past decade, and is estimated to exceed $25 billion.

Biotechnology

While farmers have been performing some type of genetic engineering for centuries, a detailed understanding of genes and advanced laboratory techniques have enabled agricultural science to extend beyond breeding and crossbreeding. Crops can now be created with extra-species genes to increase salinity tolerance, vitamin content, and drought-resistance, thus saving lives and eradicating hunger. Annual revenue from these crops exceeds $80 billion annually, and continues to grow. Further, these same techniques are poised to make plants and bacteria into micro-manufacturers of energy, drugs, and other useful products.

Terahertz Imaging

The paradigm of sensing has typically mirrored the human body's way of obtaining information. Cameras replicate sight, microphones replicate hearing, and transducers replicate tactility. Terahertz imaging extends sensory capabilities by moving beyond the realm of the human body. By using electromagnetic waves with terahertz frequencies, imaging devices can be designed such that they can penetrate structures and simultaneously provide information about their chemistry. Sensors based on this technology are already being used to enhance path planning in self-driving cars, and to detect previously 'invisible' explosives. The market for THz devices is expected to grow by 35% annually and exceed $500 million by 2021.

Advanced Energy Storage & Generation

As the world's population continues to expand, so too does its need for energy. This demand is coupled with new regulations designed to curb climate change. Advances in supercapacitors and high-capacity batteries are leading to distributed, rather than centralized, models of electricity generation. Advancements in battery technology alone are expected to have an economic impact of more than $415 billion in economic . Further, new legislation has created tremendous financial incentives for "greener" products. Whereas cold fusion power was once regarded as a distant, fantastical idea, there is strong evidence that it could be a viable source of energy in the next decade.

3D Printing

Rapid prototyping has existed for decades, but novel advancements in 3D printing techniques could significantly transform the capability and scope of this emerging technology platform. Commercial 3D printers have dramatically reduced the cost and increased the quality of printed materials. Companies are now using 3D printed parts as finished products rather than internal prototypes. As the cost of 3D printers continues to decrease, distributed manufacturing will arise, as consumers will be able to print parts and materials on-demand in their own homes. As a result, 3D printing is currently a $3.1 billion industry, growing at a rate of 35% annually.

BIG DATA

We have generated over 90% of all data in the last two years alone, and now record and transfer the same amount of information in a single week as we did during an entire year, just a decade ago.

State of the Technology

The volume of global data produced doubles every two years.[1] In 2007, the estimated information content of all human knowledge was 0.3 zetabytes (ZB),[2] less than the amount of data created on the Internet just last year. (For reference, 1 ZB is equivalent to 250 billion DVDs). We have generated over 90% of data in the last two years alone,[3] and now record and transfer the same amount of information in a single week as we did during an entire year, just a decade ago[4]. Last year, the digital universe contained 4.4 ZB. This number is expected to reach 44 ZB by 2020, at which point we will have generated and stored as many digital bits as there are stars in the universe.[5] It is projected that big data will be a $50 billion business by 2017.[6] It is incontrovertible that we are in the midst of a revolution in terms of the quantity and quality of information available for analysis. Big data may play a key role in innovation across nearly every market sector in the foreseeable future.[7] At present, most companies have not exploited big data's disruptive potential regarding how and where they do business.[8]

How much data? [3,5,1]

Unit	Bytes	Comparison
Megabyte (MB)	10^{6}	5 MB: the complete works of Shakespeare
Gigabyte (GB)	10^{9}	20 GB: the complete works of Beethoven in audio
Terabyte (TB)	10^{12}	10 TB: all printed material in the US Library of Congress
Petabyte (PB)	10^{15}	1 PB per second is generated by the CERN LHC
Exabyte (EB)	10^{18}	5 EB: all words ever spoken by human beings
Zettabyte (ZB)	10^{21}	5 ZB: approximate size of the World Wide Web
Yottabyte (YB)	10^{24}	2 YB in state-of-the-art storage would fill the Great Pyramid

1 Putting a Dollar Value on Big Data Insights, Wired, 2013
2 Big Data Universe, CSC
3 Basic Understanding of Big Data, Data Science Central, 2013
4 Eric Schmidt's "5 Exabytes" Quote is a Load of Crap, 2011
5 The Digital Universe of Opportunities: Rich Data and the Increasing Value of the Internet of Things, 2014
6 A Comprehensive List of Big Data Statistics, 2012
7 Big data: The next frontier for innovation, competition, and productivity, 2011
8 Big Data's Five Routes

What makes big data big?

There are three key characteristics that separate big data analytics from current varieties of analytics: volume, velocity and variety.[9]

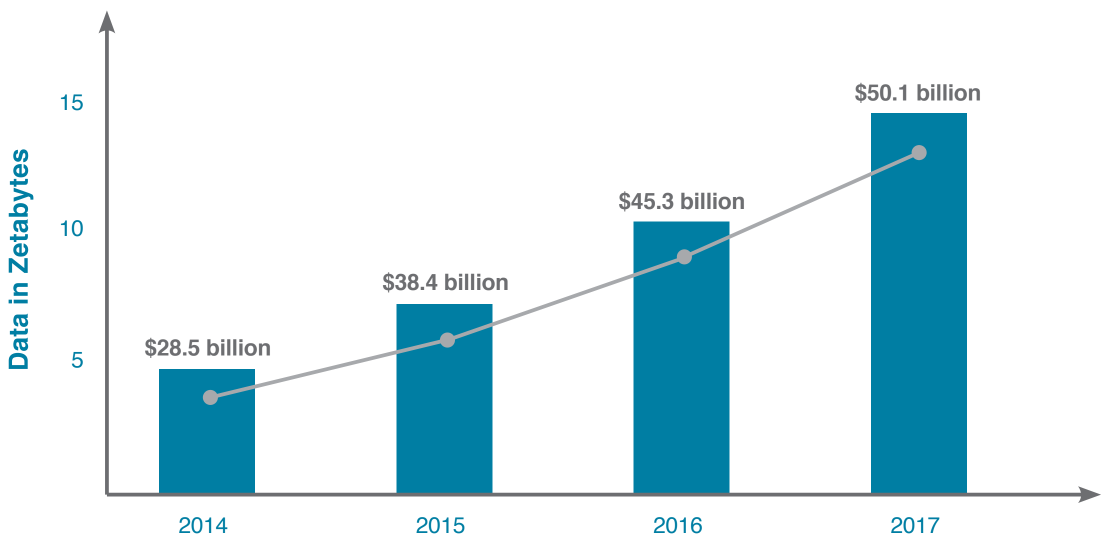
Volume can be seen in the massive amounts of data that organizations such as NASA, Facebook and Google produce each day. This data must be stored, analyzed and processed in order to extract information.

Velocity follows directly from volume: analysis of massive datasets must proceed at much higher speeds and scalabilities than with traditional systems. It is not sufficient to merely acquire large quantities of data: one must also analyze that data in a timely fashion.

Variety refers to the fact that we are generating mostly unstructured data from different sources in different forms, ranging from videos to images to email.[3]

When asked about the biggest challenges faced in dealing with big data, 46% of US retail executives cited volume, 20% listed velocity, and 34% mentioned variety.[10] In short, capabilities must be developed to deal with each of these features of big data.

ESTIMATES FOR THE INCREASE IN TOTAL DATA AND MARKET SIZE FOR BIG DATA VENDORS OVER THE NEXT FOUR YEARS



9 Big Data: The Management Revolution, 2012
10 Big Data: Getting Ready For The 2013 Big Bang, 2013

Big data analytics.

The challenges are not as daunting as they may seem. In terms of volume, data processing and storage costs have decreased over 1,000-fold over the past decade, a trend which promises to continue. Software technologies, such as Hadoop, allow for the processing of massive amounts of distributed, unstructured data,[11] and powerful analytical techniques have made even the most difficult challenges tractable. High-performance analyses can be used for simpler and faster processing of only relevant data, while full datasets can be approached using high-performance data mining, predictive analyses, text mining, forecasting, and optimization, in order to uncover hidden patterns and correlations. In particular, machine learning presents an ideal means to address the fast-paced big data needs of many businesses.[12]

For example, A/B testing (an optimization tool used in marketing that is essentially a randomized experiment with two variables), can provide much more accurate results with improved availability of data. Conversely, big data has enabled the birth of new practices such as crowdsourcing, which involves obtaining services from a large group of people (usually over the Internet), rather than from traditional employees.

Business-centric innovation.

The transformative applications of big data range from innovations that can lead to new revenue streams to insights that can uncover new business models. “Simply put, because of big data, managers can measure, and hence, know much more about their businesses, and directly use that knowledge to improve decision making and performance.”[10]

Five major applications of big data include:

1. generating new business insights,
2. improving core operating processes,
3. enabling faster and better decision making,
4. taking advantage of changing value chains,
5. creating new data-centric businesses.[8]

There is already evidence supporting this viewpoint. Researchers at MIT and McKinsey’s business technology office found that companies that utilized data-driven decision making were, on average, 5% more productive and 6% more profitable than their competitors, and enjoyed measurable increases in stock market valuations.[10]

COMPANIES THAT UTILIZED BIG DATA WERE 5% MORE PRODUCTIVE AND 6% MORE PROFITABLE THAN THEIR COMPETITORS.

11 Big Data: Hadoop, Business Analytics and Beyond, 2014
12 Big Data Analytics, SAS

Applications by sector.

Big data has the potential to disrupt current practices in every sector. Cisco's Internet Business Solutions Group (IBSG) recently laid out a framework for retailers to engage with big data, including the use of high-definition cameras, social media, and mobile devices, to better understand customer preferences, patterns, interests, influences, and demographics. These opportunities could lead to an estimated 54% after-tax operating profit gain, resulting from higher revenues (increased customer traffic, fewer out-of-stocks), higher margins (more profitable product mix, more efficient supply chain), and reduced expenses (more efficient store operations).[13]

In politics, big data has already made headlines due to its successful use by the 2012 Obama presidential campaign. Obama's analysts used the Democrats' historic vote totals in each precinct to identify each of the 69,456,897 voters most likely to have put him in the White House in 2008.[14] They used this information to create the most sophisticated voter list in history, comprising of hundreds of pieces of voting records, political donation histories, and publicly available consumer data, in order to micro-target voters in the 2012 presidential campaign.[15] Additional sectors that would benefit substantially from big data include manufacturing, healthcare, electronics, information, finance, insurance and government.[7]

The following sections illustrate case studies from a few markets where companies have started to use the power of big data to transform their businesses.

13 Big Data in Retailing: Follow the Money!, CisCo Blog, 2013
14 How President Obama's campaign used big data to rally individual voters, Part 1., 2012
15 Democrats push to redeploy Obama's voter database, 2012

Case Studies

Using big data to address specific business problems

Improved operations in manufacturing.

What if a manufacturer could follow the whole supply chain, from the moment every piece of raw material enters the factory to the point where it is shipped out to the customer? Effective use of big data could entail improvements in supply planning and product quality to achieve a transparency that may eliminate uncertainties such as inconsistent component performance and availability.[16] Leaders in the utilization of big data have been able to operate at higher capacities, with operating margins on average 16% higher, and unscheduled downtime 8% lower than their counterparts who are not leveraging big data. They are also able to implement just-in-time manufacturing processes with inventory reductions of up to 50%.[17]

Raytheon Company, a major American defense contractor with $24 billion in revenues, has built a smart factory in Huntsville, AL. If a single screw, in a single missile, fails to complete its full count of turns, an error message flashes, and production is halted until corrective steps can be taken. The technology used by Raytheon, which is dubbed manufacturing execution software (MES), is already being used by several other manufacturers to provide real-time control over multiple steps in the production process.[18]

Improved efficiency in manufacturing.

US manufacturers spend more than $200 billion each year to power their plants.[19] How can big data remove inefficiencies to help streamline operations and save manufacturers money? One example comes from a major pulp mill in Western Canada, which has used predictive analytics to reduce fossil fuel costs by over $500,000/month and electric power imports by $60,000/month. They have used sensors placed on machinery to monitor usage patterns, in order to create early-detection/prediction systems that help avert breakdowns and ensure timely maintenance. Specifically, they employed a predictive header pressure controller, which adjusts boiler loads in order to maintain an appropriate header pressure several minutes into the future. Since the system is predictive, rather than reactive, it prevents response lags that would cause boilers to over-respond, thus reducing thermal stress and efficiently spreading load across multiple boilers to achieve "outstanding header pressure control at substantially reduced fuel costs."[20]

Source: GNU Free Documentation License (top photo)
Source: Raytheon (bottom photo)

16 Manufacturing: Big Data Benefits and Challenges, 2013
17 Smart Manufacturing Whitepaper
18 Putting Big Data To Work
19 Energy Department Takes Major Steps to Increase U.S. Energy Productivity and Manufacturing, 2014
20 Innovations That Could Change the Way You Manufacture, SME

Saving premature babies' lives.

There is huge potential for big data to improve healthcare. 95% of healthcare CEOs are exploring how to better use and manage big data.[21] Creative and effective use of big data to drive efficiency and quality within the US healthcare system could create over $300 billion in value every year, two-thirds of which would result from reducing expenditures by about 8%.[7] One example of the power of big data to improve healthcare outcomes is Project Artemis, which began in 2008 as a collaboration between IBM, the University of Ontario Institute of Technology, and the Hospital for Sick Children in Toronto. These researchers developed software that can use physiological data from premature babies to predict the likelihood of infections and the infants' response to treatment.[22] One out of every eight babies born in the US is premature.[23] One-quarter of these infants contract an infection, and about 10% of these die.[24] Many who survive suffer serious neurological or physiological defects. Project Artemis is capable of processing 1,256 readings per minute, allowing doctors to monitor vital signs in real time, and check changes in conditions.[22] Early on, trends in the data led to the unexpected conclusion that premature babies with more stable heartbeats were more susceptible to infections. Such findings today enable doctors to see early warning signs of infection up to 24 hours sooner, providing a means to intervene earlier "so these babies aren't suffering the same impact of infection."[25] Project Artemis is now being implemented at neonatal units around the globe, which send minute-by-minute readings via the cloud back to the base in Toronto for processing.[24]

BIG DATA ANALYTICS PREDICT LIFE-THREATENING CONDITIONS IN PREMATURE INFANTS TO IMPROVE CARE AT A TORONTO HOSPITAL

21 Global CEO Survey, 2014
22 Achieving Small Miracles from Big Data
23 National Prematurity Awareness Month, CDC
24 The digital doctor will see you now: how big data is saving lives
25 Big data's powerful effect on tiny babies, CNBC, 2013

Better marketing and customer service.

General Motors (GM) implemented major changes involving a heavy focus on big data, in order to become profitable again after resurfacing from Chapter 11 bankruptcy in 2009 (the company reported a net income of $200 million in Q2 of 2014). This thrust is planned to increase in-house IT work from 10% to over 90% by the end of 2015. These plans include a $130 million data center, that runs on Hadoop and already holds 3 PB of data, which consists of product development, procurement, logistics, quality, manufacturing, customer care, sales, marketing, and financial data.[26]

GM has used big data to achieve profitability in several ways. It has improved dealership performance by tracking local demographics, regional differences, and location characteristics. This information is shared with dealers to help them better understand their customers. It is also utilized by GM to compare expected and actual performance of specific dealers.[27] For example, spatial analysis has revealed that customers are willing to drive an extra 2 hours past the most convenient dealer if the extra trip will save them $500, but not nearly so far to get their car serviced. GM has also implemented personalized marketing, creating detailed customer profiles to distinguish between buyers of cars in each price category. Instead of spending money on households that prefer older models or only buy used cars, marketing can "chase those households that buy new cars", resulting in lower spending and higher sales.[28] Finally, GM has used sensors and telematics to build connected cars that can save up to $800 per car (and hopefully prevent another safety scandal), resulting from predictive diagnosis and preventative maintenance.[29]

Using big data to generate new business insights

Outsourcing analytics.

Many companies do not have to develop massive in-house IT capabilities in order to profit from big data. A number of platforms are becoming available that can remove the difficult decisions of how to best implement big data analytics. Teradata has been an early leader in this field. It released the world's first parallel data warehouses in 1984, and was named the global leader in warehousing databases in 2011. Last year, it reported revenues in excess of $2.6 billion.[30] Teradata offers a full suite of analytic data platforms, applications and services to "help companies unify and analyze massive amounts of data, so they can discover more of the things that matter most in the world around them." [31] Their services have been used by Procter & Gamble to create a website for their diaper brand Pampers that offers advice, money-saving coupons or free samples tailored according to each stage of a woman's pregnancy or to each baby's age.[32] Barnes and Noble also leveraged Teradata services to analyze data from over 1,300 stores to determine who their customers are and what they want to read, Cardinal Health did something similar in order to optimize its supply chain to ensure that raw healthcare materials arrive in good condition, precisely when they are needed by patients.[24]

26 GM's Data Strategy Pushed To Center Stage, InformationWeek, 2014
27 Three Use Cases of How General Motors Applies Big Data to Become Profitable Again, BigDataStart-Up
28 How GM uses big data to generate sales, Tech Page One, 2014
29 Could Big Data In Cars Have Saved Mary Barra From Embarrassment In Senate Hearing?, Forbes, 2014
30 Teradata Corporation, wikipedia, 2013
31 Big Data Solutions, Teradata
32 Procter & Gamble uses Teradata cloud analytics for global marketing, CW

Making big data accessible.

Another very promising platform is IBM's recently launched Watson Analytics, a set of cloud-based data analysis tools built around the Watson artificial intelligence technology, which made headlines in 2011 for defeating humans in the *Jeopardy!* challenge.[33] "The company's goal is to make data analytics—and business intelligence based on big data—more accessible to anyone in the enterprise who needs it."[34]

The initial release offers a full range of self-service analytics, such as easy-to-use data refinement, data warehousing services, advanced analysis tools, and data-driven visualizations based on natural language queries, that make it easier for businesses to acquire, prepare, interpret, and present large datasets. Watson Analytics automates steps like data preparation, predictive analysis, and visual storytelling, making it much more accessible for the average businessperson, and reducing the barriers to successfully using big data analytics. Watson has made such large advances in ease-of-use that IBM is marketing it as a tool to serve as a classroom assistant for overworked teachers.[35]

PLATFORMS SUCH AS IBM WATSON ANALYTICS ARE NOW MAKING BIG DATA ACCESSIBLE TO THE AVERAGE BUSINESSPERSON

Source: IBM

33 IBM's Watson Supercomputer Destroys Humans in Jeopardy I Engadget, Youtube, 2011
34 IBM's Watson Makes Easy Work of 'Big Data' Analytics, NewsFactor Network, 2014120009ZE97Q0
35 Watson Could Power 'Tech that Teaches Teachers', EdTech, 2014

Future Directions

Data as a commodity.

We live in the era of data. As 'big data' grows even bigger, it will become increasingly commoditized. The availability of cheap data is opening up opportunities for new discoveries and business models.[36] The case studies in this report have highlighted several ways in which both companies and individuals stand to profit from the use of big data. The potential benefits will be as diverse as the situations to which big data analytics are applied, but the trend toward increasing reliance on data-driven decision-making is clear. Nine out of ten executives feel that their decisions would have been better had all the relevant data been available.[37]

9 out of 10 executives feel that their decisions would have been better had all the relevant data been available.

Technological drivers.

One of the key challenges at present is not how to acquire data, but how to effectively store it. Work on a number of new technologies that can address these concerns is underway. For example, Hewlett Packard (HP) has developed a new architecture, dubbed 'The Machine', which is composed of many clusters of smaller processors and uses optics instead of copper wires to transfer data. HP claims that The Machine will be capable of addressing 160 petabytes of data in 250 nanoseconds, while using 80 times less energy than traditional computers.[38] However, the next game-changer in computer technology is undoubtedly quantum computing. D-Wave claims to have built the world's first commercial quantum computer.[39]

36 The Era of Data, Gartner, 2014
37 The deciding factor: Big Data and decision-making, The Economist, 2012
38 Supercomputer revolution: Meet HP's The Machine – an all-in-one, mega-powerful photonic device, RT, 2014
39 The Quantum Computing Company, D:Wave

Organizational drivers.

The major challenge in capitalizing on big data is a human resource issue. There are too few individuals trained to handle and analyze big data, which may result in a “war for talent” as firms try to outbid each other for data analysts.[37] In addition, organizations will need to structure workflow and incentives congruent with optimal use of big data. Finally, because companies will need to integrate information from multiple sources, incentives must be put into place to enable this practice.[7] At present, 70% of data is generated by individuals,[3] but this balance is expected to shift as organizations begin collecting more data.

A balance between openness and privacy.

Since the launch of the first open-data government websites in 2009 (data.gov and data.gov.uk), open data policies from multiple governments and private entities have continued to follow the trend toward the commoditization of data, by increasing the size of the market.[36] Openness is necessary for big data to realize its full potential, because each analysis is strengthened by the addition of more data points. At the same time, we cannot ignore the implications that this ready flow of information has for privacy and security. Policy-makers must strike the appropriate compromise between protecting the privacy of individuals’ data and allowing for innovation in service delivery and product development based upon that data. In addition, robust security is needed to ensure that both individuals and organizations feel comfortable engaging in big data activities.[40]

The future of big data.

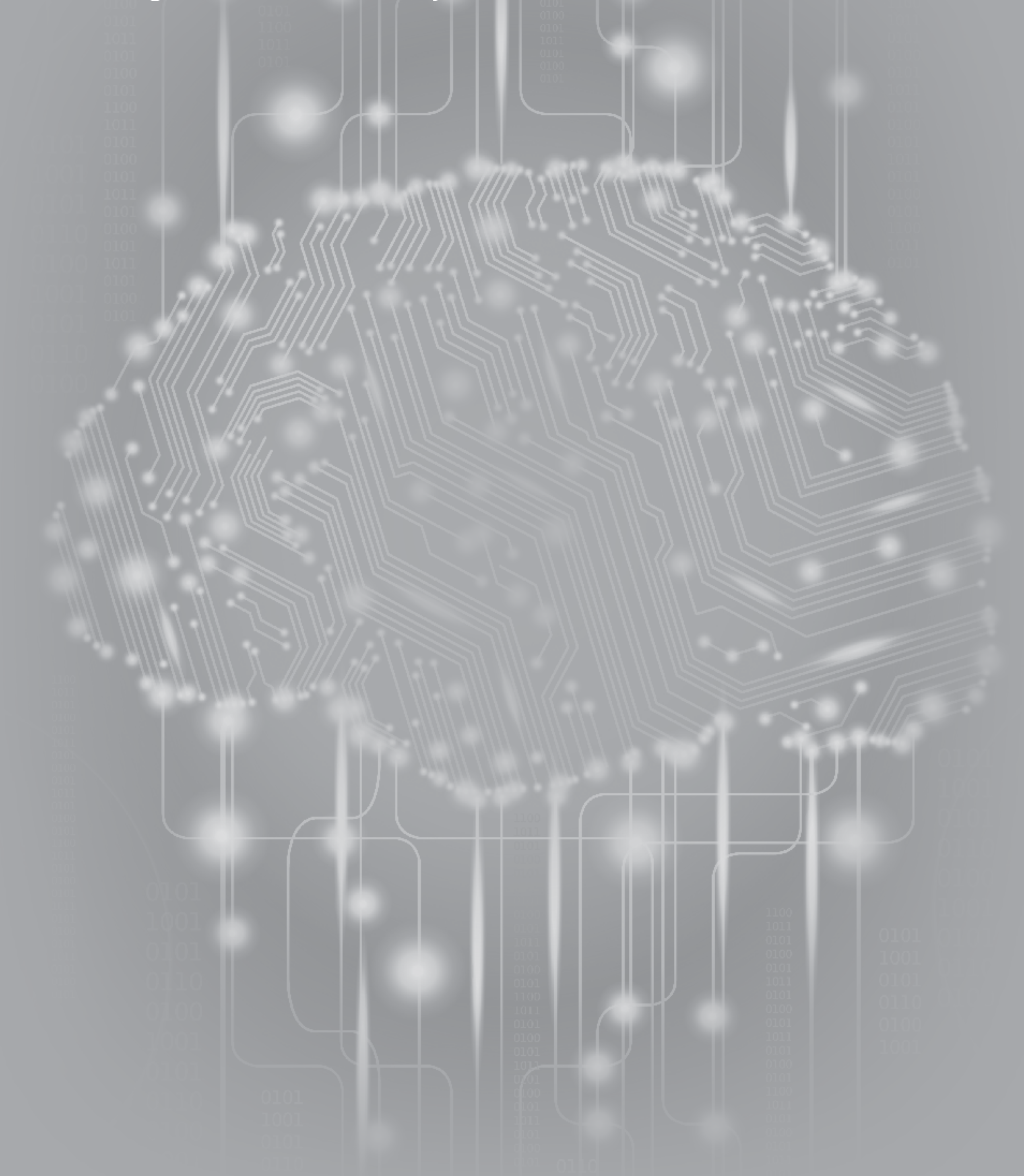
“Big data has a remarkable ability to change the world.”[41] This fast-moving technology will affect all aspects of our lives, especially in business. Big data analytics are routinely uncovering insights that would have remained hidden just a few years ago.[8] The ever-growing amount of information and capabilities to analyze it are enabling many erstwhile impossible activities, including predicting business trends, preventing diseases, and proactively combatting crime.[42] Big data will unlock new sources of economic value for those who can make effective use of it.

Big data analytics are routinely uncovering insights that would have remained hidden just a few years ago.

40 Four trends driving the future of big data, World Economic Forum, 2014
41 Global Information Technology Report 2014, World Economic Forum
42 Data, data everywhere, The Economist, 2010

AUTOMATION / AI

A 2012 study estimated that the market for artificial intelligence will grow at an annual rate of 10.5%, reaching $20.2 billion by 2016.



State of the Technology

As we move further into the 'information age', demands on our time increase, while our physical capabilities do not. Despite our dexterity and intellectual advances, logistical limitations present constraints upon what may be accomplished without artificial aid. Fortunately, current technological advances, both physical and intellectual, are allowing us to bypass our biological limitations and extend beyond our physical abilities. Automation and artificial intelligence (AI) allow us to leverage commands, algorithms, and robotics in order to accomplish tasks in faster, stronger, and more efficient ways.

More than just robots.

While AI has typically been associated with robots and inspired by science fiction, the same concepts that have been used to enable machine learning are being effectively implemented in today's computing systems. AI can enable e-commerce sites to provide personalized recommendations, self-driving cars to make decisions on navigation, and sales teams to quickly hone in on promising leads.

Exponential growth in demand.

As the hardware and software for automation and machine learning develop, so does the number of applications and markets that demand these technologies. Although automated robotic systems have existed for decades, the demand for AI is growing rapidly as it enters new markets in Asia, Europe, and North America. A 2012 study estimated that the market for artificial intelligence will grow at an annual rate of 10.5%, reaching $20.2 billion by 2016.[1] These exponentially growing projections serve as a predictor of the importance of automation and non-sentient learning technologies in today's industrial and commercial markets.

A 2012 study estimated that the market for artificial intelligence will grow at an annual rate of 10.5%, reaching $20.2 billion by 2016.

1 "World Robots to 2016, Study # 2950, 2012

Case Studies

The profit of personalization.

During its infancy, e-commerce was characterized by anonymity and difficulty in tracking and reaching the right demographics. But with the boom of social networking, internet-based communication, and pervasive mobile internet access, consumers are increasingly integrating their personalities and desires into their online profiles. Recent studies have found that 80% of consumers prefer a personalized shopping experience[2], and that 56% of frequent online shoppers are more inclined to make repeat purchases on a website that offers personalized purchase recommendations[3]. Accommodating this reference can be quite profitable: Amazon.com, one of the largest online retailers, uses its "item-to-item collaborative filtering" platform to make future purchase recommendations based on browsing and purchase history. Amazon's profits rose 29% - about $3.7 billion - after introducing its automated personalized recommendation platform.[4] Nordstrom, a brick-and-mortar department store, purchased Trunk Club in 2014 for $350 million in order to acquire a personalized shopping platform.[5]

While shopping is one of the realms that can benefit from personalization, many users rely on the internet for information feeds and content consumption. Gravity, a small startup, has developed a tool called the Interest Graph that received the 2014 DIgiday award for the "Most Disruptive Publishing Technology."6 This Interest Graph automatically analyzes the trending social topics and browsing history of customers, and uses this information to optimize content and suggest links. Within the first 12 months of establishing its innovative platform, Gravity received 1 billion page views, and was acquired by AOL for $90 million in 2014.

AMAZON'S PROFITS ROSE 29% - ABOUT $3.7 BILLION - AFTER INTRODUCING ITS AUTOMATED PERSONALIZED RECOMMENDATION PLATFORM.

2 Brusilovsky, P., A. Kobsa, and W. Nedji, Eds. The Adaptive Web: Methods and Strategies of Web Personalization. Berlin: Springer Verlag, 2007.
3 Freedman, L., "Merchant Views of personalization and lasting customer relationships." Special report, ATO, October 2007.
4 Amazon's recommendation secret, Fortune, 2012
5 Nordstrom to Buy Trunk Club for $350 Million, Hamodia, 2014
6 The Onion, UrbanDaddy Lead Digiday Publishing Awards Finalists, Digiday, 2014

Cost savings.

Automated tools are often employed in settings that require repetitive tasks with little differentiation (for example, installing doors on an automobile frame), while tasks that change over time are delegated to humans. Recently, AI, coupled with machine learning, has acquired the capability to perform more and more complex tasks. In 2012, Singapore General Hospital debuted the Outpatient Pharmacy Automation System, a robotic pharmacy that automatically reads prescriptions and packs medications. This system has cut down waiting time by 50% and increased accuracy to over 99.9%.[7] The automated system frees up the time of 11 workers, who can perform other tasks around the pharmacy. This enables the pharmacy to dispense 1,300 prescriptions a day. Based on successes like this, the market for pharmacy automation technologies is expected to exceed $4.5 billion in 2019.[8]

Mimicking the human eye

For computers and robots to learn and operate in the world, they must be capable of sensing their environment like humans. Thus far, accurately recognizing an object has proven to be an extremely challenging problem for automated systems, despite extensive Defense Advanced Research Projects Agency (DARPA) grants funding this area. Recently, advances in mobile processors and cloud computing have enabled regular smartphones to identify an array of objects. The Amazon Fire phone uses a suite of cameras to obtain a 3D image of a product, which can be automatically linked to a product in Amazon's online store.[9] Neven Vision, a California-based startup that was acquired by Google in 2006, has developed facial recognition software that can run on an ordinary smartphone, enabling biometric authentication.[10] The company is licensing its software to vendors of employee management systems to control building access, as well as to smartphone manufacturers for device encryption keys. Market analysis estimates that the facial recognition market will grow from $1.92 billion in 2013 to $6.5 billion in 2018, a CAGR of 27.7%.[11]

The computer processing power required increases with the complexity of computer vision task at hand. By outfitting a single car with $150K of high-tech equipment, including 360-degree cameras, LIDAR, and high performance computers, Google has created self-driving cars that are able to autonomously avoid cyclists, navigate railroad crossings, and respond to the directives of crossing guards. As of 2014, a single self-driving car had logged more than 700,000 accident free miles, and its capabilities continue to improve.[12] As the costs of processing power decreases, the capabilities of these vehicles will continue to improve, eventually replacing fleets of long-haul trucks, delivery vehicles, and even passenger cars. By 2030, the market for these self-driving cars is expected to exceed $87 billion, with particular growth in the Chinese market.[13]

7 TTSH pharmacy's automated system cuts waiting time for patients, 2014
8 Pharmacy Automation Systems Market Worth $4,566.2 Million by 2019, PRNewswire, 2014
9 Amazon launches Fire phone with dynamic 3D perspective and object scanning, Digital Photography Review, 2014
10 Neven Vision, CrunchBase
11 Facial Recognition Market [Emotion; Thermal; Mobile; Forensic; 2D; 3D; Cloud-based Facial Recognition]: Global Advancements, Emerging Applications, Business Models and Worldwide Market Forecasts and Analysis (2013 – 2018).
12 Google's self-driving car passes 700,000 accident-free miles, can now avoid cyclists, stop at railroad crossings, ExtremeTech, 2014
13 Self-driving Cars Will Be $87 Billion Market by 2030, Spectrum, 2014

Neural Networks

In many ways, computer learning is a lot like human learning. We humans alter our responses to new situations based on our past experiences. For that to happen, we must have 1) sensors for recognizing new situations, 2) memory of past experiences, and 3) a method to process and reconcile our memory with the new sensory information. Neural networks are algorithms by which AI attempts to mimic this process of learning and decision making.

Ward Systems, a manufacturer of neural network software, has seen their NeuroShell software suite used to predict HIV infections, forecast treatment costs, make profitable stock trades, rapidly test genetic sequences, anticipate device failure rates, monitor product quality, and identify chemicals via an artificial nose.[14] Because of their applicability to a variety of industries, the market for neural networks is expected to grow rapidly. Annual increases in market size are expected to top 40% a year and exceed $16.9 billion in 2015.[15]

Infer, Inc. is a 2010 startup that seeks to apply neural networks and machine learning to counter the challenges that sales and marketing teams face on a daily basis. Infer's lead scoring software is able to learn which leads are most likely to result in sales, and helps sales teams to work smarter, rather than harder. Recent data recognizes that 92% of a typical company's sales stem from only 28% of its leads. Infer is able to quickly identify those leads based on data about the demographics and behavior of previous customers. When Box, a cloud service provider, implemented Infer's solutions, it found that its conversion rate of leads into sales more than doubled. Infer raised $10 million in Series A funding on April 23, 2013.[16]

Infer represents only a single example of the power of neural networks. In 2014, venture capital firms invested $160 million in tools for predictive analysis. Furthermore, Salesforce purchased startup RelateIQ for $350 million in order to obtain its machine learning algorithms.[17] Networked Insight, another vendor of neural network algorithms, analyzes more than 560 million social networking posts every day in order to predict consumer demand 3 months ahead of time.

Annual increases in the market for neural networks are expected to top 40% per year and exceed $16.9 billion in 2015.

14 Artificial Intelligence, WSGI
15 Big Blue Makes Big Moves In Big Data, Forbes, 2012
16 Infer provides cloud-based, data-powered business applications
17 Predictive apps are the next frontier of marketing tech (infographic), VB, 2014

Future Directions

With new computing techniques and logarithms on the horizon, automation and artificial intelligence are poised to expand rapidly in the next decade. Innumerable applications exist, and pervasive developments, such as improved object recognition, will be utilized in everything from hand-held devices to robotic avatars. However, in order for this technology to achieve its full impact, development in other fields must occur simultaneously.

Human interfacing and communication

By increasing the ability of technology to better interact with its surroundings, innovations from AI and automation can allow for humans to better interact with society and each other. These technologies also have the capability to mitigate injury in potentially harmful situations, such as from combat or inhabiting inhospitable lands. By learning from an individual's past behavior and preferences, algorithms are also making the consumer experience more efficient and enjoyable for many. However, with this added benefit of personalization, comes a byproduct: growing concern over the loss of privacy. Highly transparent policies for personal data acquisition, as well as easily understood opt-out procedures, will go a long way in alleviating many of these potential concerns.

Retail and customer service

Systems like the automated pharmacy at Singapore General Hospital will improve profits for companies, while simultaneously increasing customer satisfaction. Although such automation seems to be an overly beneficial addition to the business of pharmaceutical dispensary, consumer skepticism on the ability of automatic systems will limit its applicability for other retail sectors. While consumers may be perfectly fine with robots dispensing prepackaged pills and goods, they are wary of automated systems dishing out made-to-order products like food in restaurants. When an online news source reported on a new automated assembly line that produced restaurant hamburgers without the direct assistance of human workers, the top commentator's response was, "Can I get WD-40 with that?" This is a sobering reminder that consumers have enough distrust in automated systems that they still prefer the human touch in consumer fields that require a high level of quality control, such as the food and emergency medical fields.

Machine creativity

As artificial intelligence develops, computers become more equipped to learn new tasks and adapt to novel situations without pre-programming. This will free up human labor, and in the case of brain-interface-based prosthetics for the paralyzed, present a direct replacement of human power. The ability of artificial intelligence systems to learn without direct programming will also expand the market for domestic robots. No longer will a consumer need to have knowledge about conventional computer programming language or techniques in order to train their own personal assistants to help them around the house.

As the applications for AI and automation increase, however, corporations will have to address the issues surrounding consumer trust in using the devices integrated with this technology. Many in the public fear that artificial intelligence will not operate as intended, or attempt to take over the world, as depicted in science fiction. However, AI technology repeatedly proves to be efficacious and beneficial to human society. Negative perception of AI and automation should subside over time.

Source: University of Southern California

INTERNET OF THINGS

It is estimated that over 50 billion objects will be connected to the Internet by 2022.

State of the Technology

Accelerating connectivity.

The past two decades have seen an explosive growth in the ways humans interact with and through machines. The Internet has provided the infrastructure behind this trend, facilitated by increasing uptake of technologies such as personal computers and mobile devices that provide people access to the Internet. To date, the majority of such interactions can be classified as person-to-person (P2P) or person-to-machine (P2M). However, within the last few years, a new paradigm has begun to emerge: machine-to-machine (M2M) connections, wherein devices communicate directly with each other. The advanced connectivity of devices, systems, and services that will arise from the combination of each of these three types of connections, termed the Internet of Things (IoT), is expected to fundamentally impact and change almost every field involving human activity.

Source: Salesforce

What is the IoT?

The IoT refers to the interconnection of uniquely identifiable physical objects accessed through the existing infrastructure of the Internet. These objects contain embedded technology that can sense and communicate internal states or the external environment, which will result in a huge increase in automation by allowing us to "track and count everything, and greatly reduce waste, loss and cost. We would know when things need replacing, repairing or recalling, and whether they were fresh or past their best. The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so."[1]

There are roughly 200 connectable physical objects per person that could one day become part of the IoT. At present, 99.4% of these things are unconnected.[2] It is estimated that over 50 billion objects will be connected to the Internet by 2022.[3] One essential step already underway is the adoption of new Internet Protocol addresses (IPv6) that will have the capacity to uniquely identify each of these objects.[4] Connection of these objects through small-embedded sensors will allow IoT systems to find applications in fields ranging from environmental or healthcare monitoring to infrastructure and energy management.

Value creation.

It is estimated that the IoT could create over $14 trillion in value by 2022,[4] resulting from increased revenues and lower costs. The five main factors that will contribute to this value are:

1. an improved customer experience (26%)
2. reduction of time to market (21%)
3. elimination of waste in the supply chain (19%)
4. cost reduction through better asset utilization (17%), and
5. greater labor efficiencies (17%).

Put differently, two-thirds of this value will arise from industry-specific use cases (e.g., smart grid and connected commercial vehicles), and one-third from cross-industry use cases (e.g., telecommuting and travel avoidance).[4]

An emerging market.

Many instances of the IoT have already been demonstrated. For example, the startup AdhereTech has manufactured a smart pill bottle to ensure that patients take their medications as instructed.[5] The Google Nest smart thermostat works to reduce unnecessary energy usage, saving up to 20% on heating and cooling bills.[6] Retailers can use networked cameras and sensors to detect how customers are engaging with specific products and the store's layout.[7] Moreover, scientists have even used RFID-tagged honeybees to study hive dynamics.[8] The following in-depth case studies illustrate the magnitude of impact that IoT systems can make at home, on the road, and in the office.

1 That 'Internet of Things' Thing, 2009
2 Internet of Things (IoT)
3 Visualization, IBSG
4 Embracing the Internet of Everything To Capture Your Share of $14.4 Trillion, 2013, 01-16
5 AdhereTech, SWPB
6 Nest (Thermostat and Smoke + CO Alarm)
7 An Internet of Things
8 RFID tags on honey bees reveal hive dynamics, 2014

Case Studies

Teaching physical objects to "understand the human".

For the true potential of the IoT to be realized, we must find a way to standardize protocols for interactions between each device, and develop a means of intelligently automating sensing and communications activities. One startup company, Neura, is already working to address each of these challenges in order to make the IoT "all-inclusive and anticipatory."[9] Neura originated from UpWest labs in 2013 and has already secured over $2 million in funding,[10] based on a platform that offers a way for devices to communicate with each other, and helps those devices understand context in order to eventually produce predictive features. Neura's ultimate goal is to build an open platform to connect devices and enable them to blend seamlessly into your daily life by learning and adapting to your lifestyle.[11] For example, the Neura platform could be programmed to turn off the oven after you leave home, prompt your vacuum cleaner to work harder after multiple visitors have gone through, or allow a connected glucometer to access your statistics after exercise.[12]

Intelligent homes.

SmartThings, a startup that received $15.5 million in funding before being acquired by Samsung Electronics in July 2014,[13] is working to realize the idea of a smart home. Their system can automate many daily tasks in the home, and can be controlled from a single app that acts as a hub for all of the technology in the house. SmartThings allows remote access to the home, permitting one to turn off the stove from work or check if the kids have gotten off the school bus[14]. The starter kit, which requires a broadband Internet connection and 15 minutes of self-installation, sells for $199.[15] In the future, it could also come pre-installed in any of Samsung's electronics. Aside from the small price tag, another exciting aspect of the SmartThings platform is its emphasis on a community of developers who create "smart apps" that allow various devices to synchronize and communicate with each other.[16] As more consumers adopt this technology, the developer community will also grow, creating a better experience for all end users. This is an example of how the IoT enables improvements to the current way of doing things through a network of smart, connected, physical objects.

Source: Based on image from Olga Nunes

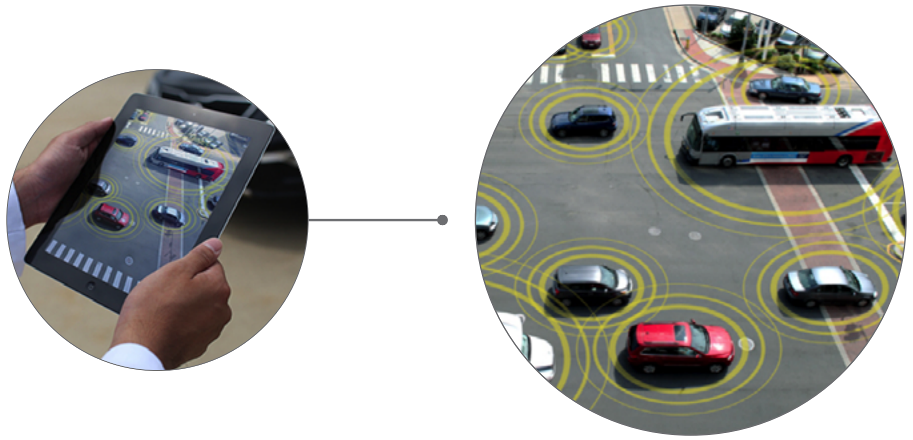
9 Neura gets $2M to bring AI to the internet of things, 2014
10 Internet of Things Leading Company
11 EMPOWER YOUR CONNECTED DEVICES WITH AN UNDERSTANDING OF YOU
12 10 Hot Internet of Things Startups, 2014
13 SmartThings
14 SmartThings
15 Smart Home Starter Kit
16 Samsung Acquires SmartThings, A Fast-Growing Home Automation Startup, 2014

Urban infrastructure optimization.

Smarter infrastructure will enable smarter cities to develop. One way in which the IoT can help accomplish this goal is through optimization of transportation services, such as traffic management, parking, and transit systems. "Intelligent IoT-enabled transportation systems improve capacity, enhance travel experiences and make moving anything safer, securer and more efficient."[17] For example, the city of Toronto has been plagued by congestion along its roadways. In order to improve traffic flow, the Toronto Intelligent Transportation Systems Centre and Testbed, a research initiative spearheaded by the University of Toronto in partnership with nine private organizations and seven public entities,[18] developed a system known as MARLIN-ATSC (Multi-agent Reinforcement Learning for Integrated Network of Adaptive Traffic Signal Controllers). It is composed of smart signals that process traffic information locally. This system uses cameras and "learning" computer chip technology, which can react to shifts in traffic patterns and tune to the timing of traffic signals. Tests results of MARLIN-ATSC have shown a reduction in delays of up to 40%, with travel times cut by 26%.[19] In addition, local law enforcement and emergency services can use information from these sensor networks to rapidly respond to accidents.[17] By alleviating congestion and allowing rapid emergency response to accidents, the IoT can improve capacity of roadways, enhance travel experiences, and increase safety.

National infrastructure optimization.

An alternative approach to leverage the full capabilities of the IoT has been delineated by the US Department of Transportation Intelligent Transportation Systems (ITS). ITS has funded numerous research projects on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, to build a national, multimodal system composed of connected vehicles, infrastructure, and mobile devices (both driver, passenger, and pedestrian).[20] This "connected" transportation system would be both safer and more efficient. The first step in the ITS Strategic Plan is to help reduce crashes by alerting drivers of a nearby vehicle that might pose a threat, such as one that is speeding or merging onto the roadway from a blind spot.[21] According to the National Highway Traffic Safety Administration, V2V and V2I applications could address 80% of unimpaired crashes, and also significantly reduce congestion and improve air quality.[20]



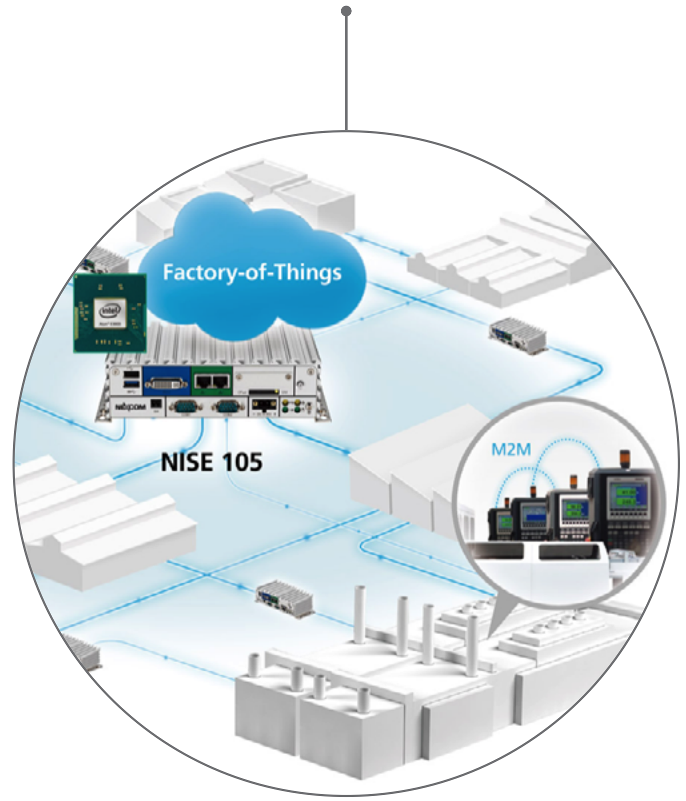
Source: US Department of Transportation

17 Smarter Cities Are Built On The Internet of Things
18 Intelligent Transportation Systems
19 Can 'smart' traffic lights ease Toronto's road congestion?
20 The federal Intelligent Transportation Systems
21 Smart Roads, Smart Vehicles, 2013

Smart factories.

Smart factories represent $2 trillion in added value, arising from capabilities such as i) better sensors, ii) improved connectivity with other machines, iii) more intuitive interfaces with people, iv) the ease of programming intelligent machines, v) efficient adaptation to external conditions, and vi) back-end analytics to integrate labor, capital and technology more effectively.[4] One early example comes from Intel, which already offers Gateway Solutions that extend legacy systems and connect them to next-generation intelligent infrastructure.[22] Intel recently utilized this IoT technology in a collaborative pilot project to generate $9 million in cost savings from their own plant in Penang, Malaysia. Components in a semiconductor manufacturing line were retrofitted with sensors. These components then sent this sensor data to gateway devices before they were processed. Insights from this data resulted in reduced component failures and energy costs, while increasing equipment uptime and productivity. According to Intel Asia-Pacific sales director Philip Cronin, "There's no better place to talk about it than the fact that we did it for ourselves."[23] Others are taking notice: Intel's IoT group achieved $1.8 billion in sales and $550 million in operating income in 2013.[24]

THE NEXCOM NISE 105 HELPS MANUFACTURERS CREATE SMART, IP-BASED FACTORIES BY ENABLING M2M COMMUNICATION



Source: Intel
NexCom NISE 105 for the Product Review

22 The federal Intelligent Transportation Systems
23 Intel pushes factory IoT with $9 million cost savings at plant, 2014
24 Intel's Internet of Things Group Is Highly Profitable, 2014

Connected marketing.

Connected marketing and advertising contribute $2 trillion in value, resulting from unparalleled access into consumer behaviors, preferences, and demographic profiles, as well as from the ability to deliver individually targeted advertisements on any device at the exact time and place where they are expected to produce the greatest impact. By using the IoT, companies will be able to react more quickly to market changes, increase profits by adapting pricing to an individual consumer's situation, and grow revenues by bundling offerings based on a holistic assessment of consumer wants and needs.[4]

Salesforce, which offers the most popular customer relationship management (CRM) tool,[25] and is ranked by Forbes as the most innovative company in America,[26] offers the Salesforce1 Customer Platform. It offers a zoomed-in view of each individual customer so that companies can deliver personalized content across all channels and devices. Existing users of Salesforce1 include Facebook and Microsoft. Salesforce Ventures, the venture capital arm of Salesforce, recently launched a $100 million investment fund for businesses building new mobile apps and connected products tapping into this platform.[27] Salesforce1 can empower a company to grow its addressable market and improve outreach to customers. It hopes to provide a solution for companies to take advantage of a potential shift in organizational behavior from engagement to personalization at scale.[28]

Salesforce recently launched a $100 million investment fund for businesses to tap into Industrial Internet technologies.

25 GROW SALES FASTER WITH THE WORLD'S #1 SALES APP
26 The Ten Most Innovative Companies In America
27 Salesforce launches $100 million dedicated fund for internet of things, 2014
28 Salesforce unveils Salesforce1, a new CRM platform to help companies shift focus to customers

Future Directions

A turning point.

Because the Internet of Things will allow ubiquitous connectivity between real-world devices, it has the potential to change every aspect of our daily routines and operations. Although we are still at the earliest stages of the development of the IoT, 2014 and 2015 are expected to be a tipping point. After six consecutive quarters of negative asset outflows in the IoT arena, growth managers finally began to see increasingly positive returns beginning in Q4 of 2013.[29] In 2013, investors allotted $1.1 billion to IoT startups.[30] By 2017, it is expected that the number of devices connected to the IoT will surpass the number of PCs, smartphones, and tablets.[31] These changes will have dramatic effects on a variety of industries.

Imagine the benefits for manufacturing, when sensors embedded in millions of instruments connect together to ensure that everything runs as planned across the entire value chain. In the public sector, sensor-embedded water pipes, sanitation services, traffic patterns and parking meters can monitor and flag capacity issues and make automatic adjustments in traffic flow and pickup schedules. This "smart infrastructure" could drastically reduce the impact of an unexpected asset failure. Within healthcare, the applications span from the hospital to the home, with one example being a patient-centered home, using ultrasound to monitor home activity in order to detect falls and trigger automatic ambulatory services accordingly.[32]

In 2013, investors allotted $1.1 billion to IoT startups.

Drive to standardization.

One obstacle to the creation of the IoT is the standardization of protocols that allow all devices to interact with each other. Neura is taking one approach to this problem by developing a middleware platform that can communicate between all connected devices. An alternative approach is embodied by Intel's gateway devices, which enable communication between legacy devices. The Industrial Internet Consortium (IIC), which was founded by AT&T, Cisco, GE, Intel, and IBM, is working to accelerate growth of the IoT by working closely with industry leaders to establish interoperability across industrial environments, and increase momentum in the adoption of IoT applications.[33]

29 Here's why the Internet of things just became very interesting, 2014
30 Internet of Things Companies Haul In More than $1 Billion in Venture Capital in 2013, 2014
31 THE INTERNET OF EVERYTHING: 2014 [SLIDE DECK], 2014
32 Accelerating Innovation In Connected, Intelligent Machines And Processes
33 Driving IoT Adoption Through Industry Collaboration

Security and privacy.

One of the most serious concerns regarding the IoT revolves around security. Many devices that currently connect to the Internet have been designed without appropriate consideration of the security challenges. It is likely that new regulations will be necessary to ensure proper implementation of security measures for all networked devices. A related issue involves consumer privacy. When an organization can record and catalogue minute details of a consumer's behavior through a myriad of devices, how does one maintain a sense of privacy? Again, new policy frameworks are necessary to ensure that the power of the IoT is not abused.[3] The IIC is actively working to address these issues, and it is also worth noting that these issues are not new. Visionaries in the early 1990s predicted that the internet would herald the death of privacy; although our definition of online privacy has been refined, this prediction has not (yet) come true.[34]

The next industrial revolution.

Philadelphia's Centennial Exposition of 1876 marked the point of critical mass of the Industrial Revolution. It was the nexus where advanced steam technology, mass production, railroads and telegraphy merged, and foreshadowed the rapid cultural and economic transformation that would sweep through the world in the near future. The exposition led to over 10,000 patents and accelerated the global adoption of the 'American System of Manufacture.' Jim Stogdill, general manager of Radar at O'Reilly Media, has stated that we face the same situation now, in terms of the IoT. "It's really a watershed moment in technology and culture. We're at one of those tipping points of history again, where everything shifts to a different reality"[35] as the physical and the virtual worlds collide. The intersection between Old and New Economies will not be painless, and change may not come easy, but this process is nearly inevitable.[36] Those who embrace this new paradigm will be able to create tremendous value.

34 Privacy integral to future of the Internet of Things, 2014
35 How The Internet Of Things Is More Like The Industrial Revolution Than The Digital Revolution, 2014
36 How the Internet of Things Changes Everything

MEMS

By applying the methods of integrated circuits, MEMS allows the creation of tiny, low cost sensors and actuators. This is analogous to the effect of the transistor on electronics. Where the transistor enabled modern, ubiquitous computing, MEMS enable ubiquitous sensing and smart materials and devices that react to their surroundings.

State of the Technology

The size and cost of a technology define the limits of where it can be feasibly deployed. New techniques for the production of components can revolutionize entire industries. For instance, early computers were huge (the first mass-produced computer was the size of a one-car garage),[1] had limiting computing power, consumed large amounts of power and were very expensive (equivalent to about $7 million per unit in 2014 dollars).[2] Today, for a few hundred dollars you can buy a smartphone which fits in your pocket, runs all day on a battery charge and has five orders of magnitude more computing power. A major driver behind this change was the replacement of large computing elements with smaller elements. Vacuum tubes were replaced by transistors and transistors were replaced by integrated circuits (IC). The same advances in miniaturization can be used to create tiny sensors and actuators, known as microelectromechanical systems or MEMS.[3]

1 The History of the Mainframe Computer
2 Timeline of Computer History
3 MicroElectroMechanical Systems (MEMS), 2001

What are MEMS?

MEMS are tiny (micron-scale) mechanical devices. They are typically built on semiconductor chips using the same techniques as microchip manufacturing. The most common MEMS today are pressure sensors, accelerometers, and gyroscopes, but the possibilities are endless. Just as transistors and integrated circuits (IC) allowed the miniaturization of electronics, MEMS allow the miniaturization of sensors and actuators. Moreover, by using manufacturing techniques taken from the IC industry, MEMS can be manufactured at remarkably low cost. MEMS' small size, low cost and low power requirements contribute to the increasing ubiquity of sensors in our everyday lives.

ACTUAL SIZE
2mm

Medical.

An early example of commercial MEMS technology was IV blood pressure sensors. Prior to the early 1980s, the sensors used to monitor blood pressure in the IV lines of patients in intensive care were reusable, bulky devices that cost over $500 and required sterilization between patients, incurring significant costs and a risk of cross-contamination. These have been replaced with low-cost, disposable MEMS sensors which are delivered pre-calibrated and sterilized at a cost of around $10 per unit.[4] Subsequently, MEMS pressure sensors have become ubiquitous in medicine, measuring vital signs, respiration, intrauterine pressure, pressure within the eye, flow rate in drug infusion pumps and even the pressure inside hospital beds for burn victims.[5] In total, the market for medical pressure sensors was $143.9 million in 2013.[6]

$143.9 million

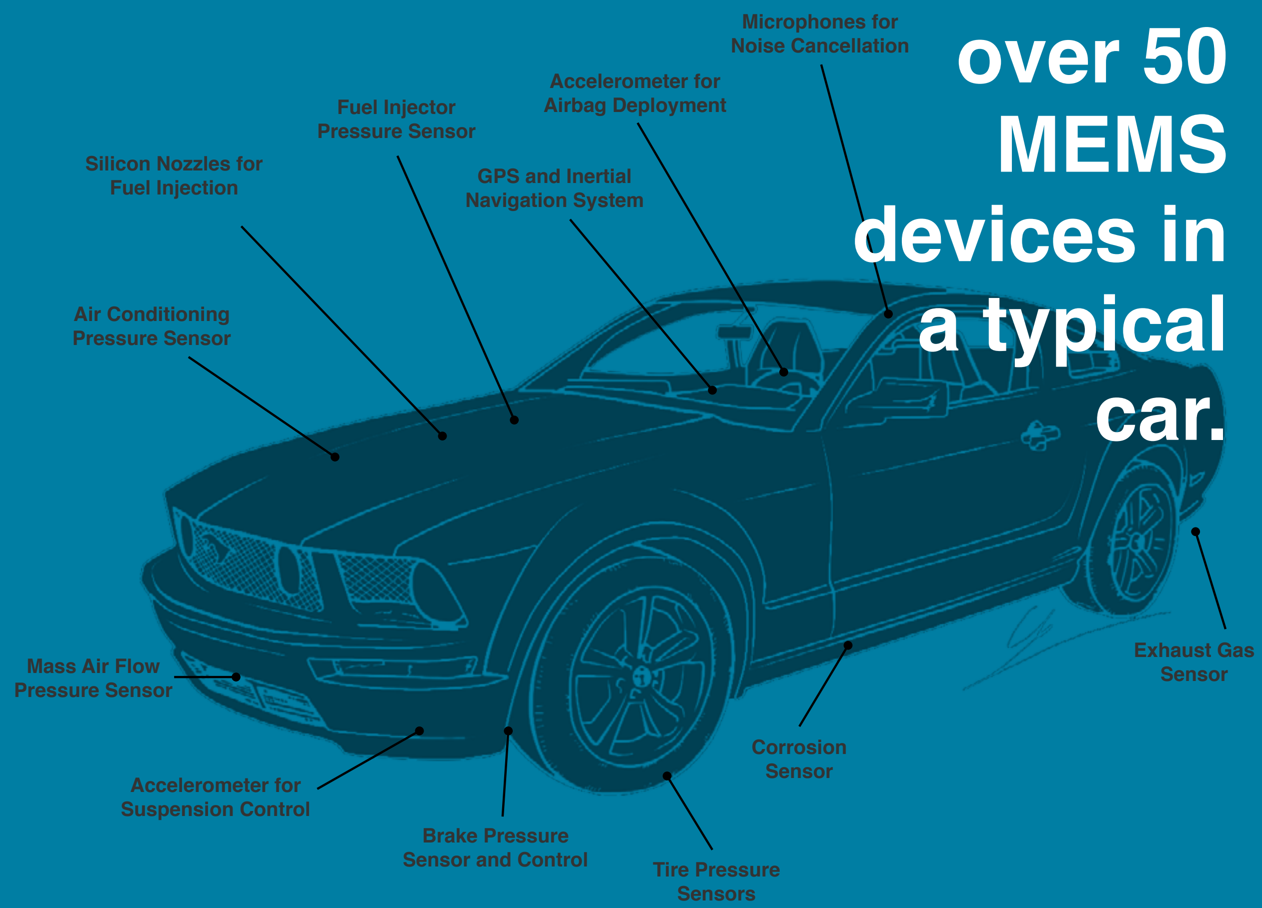
2013 Revenue from Medical Pressure Sensors

4 MEMS and Nanotechnology Applications
5 MEMS and Nanotechnology Exchange
6 Automotive, wireless applications to drive pressure sensors to become top-selling MEMS devices

Automotive.

MEMS devices are also extensively employed in the automotive industry. They have been used to help improve safety, reliability and performance of automobiles, while reducing emissions and increasing gas mileage. An early application of MEMS in the automotive industry was the control of airbags. The first airbags were controlled by g-switches, which relied on a ball and spring to measure acceleration. G-switches were expensive, had reliability problems and returned limited data, which required multiple sensors to distinguish between road roughness and a crash. In contrast, a single MEMS sensor in the center console can detect a crash at much lower cost, with single digit parts per million (ppm) defect rates. Moreover, the systems are capable of robust self-testing to indicate when the data is reliable and when service is required.[7] The use of MEMS sensors played a key role in the widespread adoption of airbags. Today, there are over 50 MEMS devices in a typical car.[8] The market value of MEMS for cars was $2.6 billion in 2013.[9] The applications range from tire pressure sensors to monitors for emissions control. The market for these products is expected to continue to grow.

There are over 50 MEMS devices in a typical car.



7 Automotive MEMS Sensors Are Driving the Automotive Industry, 2002
8 MEMS Markets & Applications, 2012, 01-53
9 Global Automotive Sensors Market with Special Focus on MEMS Sensors, 2014

Mobile computing driving advances.

In recent years, smartphones and tablets have been a major driver of growth and innovation in the MEMS marketplace. MEMS entered this market in the United States in 2007 with the introduction of the iPhone, which contained a three-axis accelerometer. The accelerometer enabled the iPhone to respond to motion (including automatic portrait/landscape rotation) and created the market for tilt controls. By 2012, MEMS for mobile computing had grown to be a $2.2 billion market, with 4.5 billion units sold annually. [10] The use of accelerometers is now pervasive in the smartphone market and additional MEMS devices have been added to increase functionality. By 2013, the Nexus 5 included a six-axis gyroscope, a 3-axis electronic compass, and an additional 2-axis gyroscope for optical image stabilization.[11] Other MEMS found in modern smart phones include bulk acoustic wave (BAW) filters, which reduce signal interference, and MEMS microphones, often multiple per phone.[12] Up and coming applications include pressure sensors for indoor navigation, temperature and humidity sensors to track the weather, MEMS based autofocus for faster camera response.[13] Overall, MEMS are getting cheaper, with unit prices declining by 25-35% in 2012 alone,[14] and manufacturers are integrating more functions into smaller packages, which consume less power.[15]

Market Size.

Over the last ten years, the MEMS market has experienced steady double-digit annual growth in revenues (except for a dip in 2008 due to the global financial crisis).[16] At the same time, price per unit has declined dramatically. For instance, in 1990 there were approximately 1 million MEMS accelerometers sold at an average price of $5. By 2011, 1.9 billion accelerometers were sold for consumer and automotive applications alone and the price had declined to under $1 each. [17] By 2013, the MEMS market was worth $12 billion, up 10.4% from 2012 with a 7% decline in unit price. [18] This trend is expected to continue with a projected compound annual growth rate of 20% leading to 18 billion units to be delivered in 2018, up from 3 billion in 2012.

In 2013, MEMS was a $12 billion market.

10 MEMS for Cell Phones and Tablets 2013 Report by Yole Developpement, 2013
11 MEMS Integration Drives Applications, 2014
12 How MEMS Enable Smartphone Features, 2013
13 MEMS Makers Want to Put Even More Sensors in Smartphones for Total Situational Awareness, 2013
14 MEMS for Cell Phones and Tablets 2013 Report by Yole Developpement, 2013
15 MEMS Integration Drives Applications, 2014
16 Status of the MEMS Industry 2013 Report by Yole Developpement, 2013
17 MEMS Senior Analyst, Yole Developpement, 2012, 01-53
18 Challenged by newcomers proposing low-cost solutions, established MEMS companies must develop new strategies

Case Studies

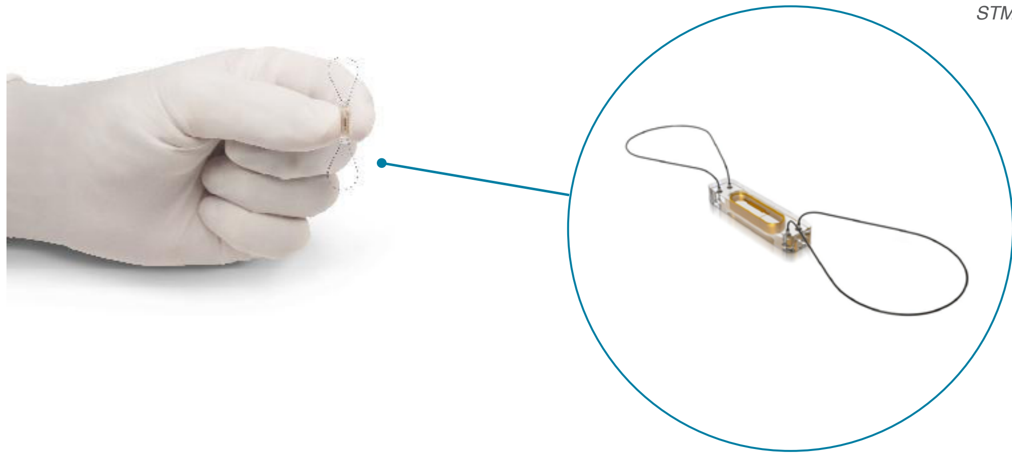
Pressure Sensors.

MEMS pressure sensors can do more than just measure the pressure in your tires. 5.1 million people in the United States suffer from heart failure. However, current methods for managing heart failure leave a lot to be desired. Doctors typically manage heart failure by monitoring symptoms, body weight and blood pressure. Even with daily self-monitoring, 25% of patients are readmitted to the hospital within 30 days and 50% are readmitted within 6 months.[19]

To address this challenge, CardioMEMS,[20] a 2001 startup acquired by St. Jude Medical in 2014 for $435M, developed an implantable device which provides ambulatory pulmonary artery (PA) pressure monitoring. It enables early detection of worsening heart failure and proactive adjustments in medication to improve outcomes. The tiny MEMS pressure sensor is implanted into the pulmonary artery and provides reliable PA pressure monitoring without leads or batteries. Use of the CardioMEMS system reduced subsequent hospitalizations by 37%. Since more than half of the $31 billion spent annually on heart failure is from these hospitalizations, the potential savings are significant. Moreover, patients experienced improved quality of life.[21] The FDA approved the system in May 2014[22] and sales are expected to reach $259 million by 2018.[23]

Other applications of MEMS pressure sensors include monitoring intraocular pressure in glaucoma patients, identifying what floor you are on in a building and a range of applications in the automotive and aerospace industries.

Source: STMicroelectronics, Inc

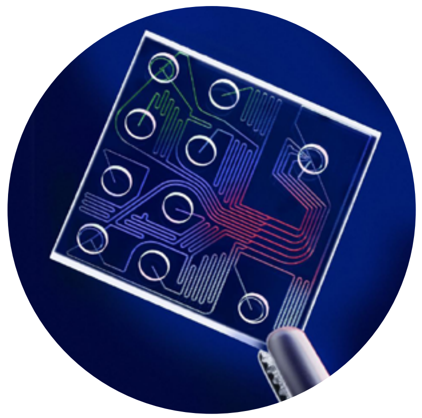


CardioMEMS IMPLANTABLE PRESSURE SENSOR.

Source: Businesswire
Source: St. Jude Medical (inset photo)

19 St. Jude Medical, CardioMEMS
20 ENTREPRENEURS TRANSFORMING HEALTHCARE
21 http://professional.sjm.com/therapies/cardiomems/home
22 Medical Devices, CardioMEMS HF System - P100045
23 St. Jude to acquire CardioMEMS following FDA approval of device, 2014

Microfluidics.



Source: Agilent, Inc.

MEMS can also be used to create a lab-on-a-chip assays using microfluidics, facilitating automation and dramatically reducing the sample size needed to perform tests. One, very successful, example of this approach is the Agilent Bioanalyzer. Agilent has combined microfluidics and automation to create a device with over 70 different applications. It requires 1-4 µL of sample, improves precision and reproducibility and automates previously time-consuming procedures, such as flow cytometry and DNA, RNA, and protein assays. The Bioanalyzer has had a large scientific impact, with over 3500 citations in scientific publications.[24] It has also had a significant impact on Agilent's bottom line, being among the top three products in terms of revenue and revenue growth for Agilent's $500 million genomics group.[25]

Gas Sensors.

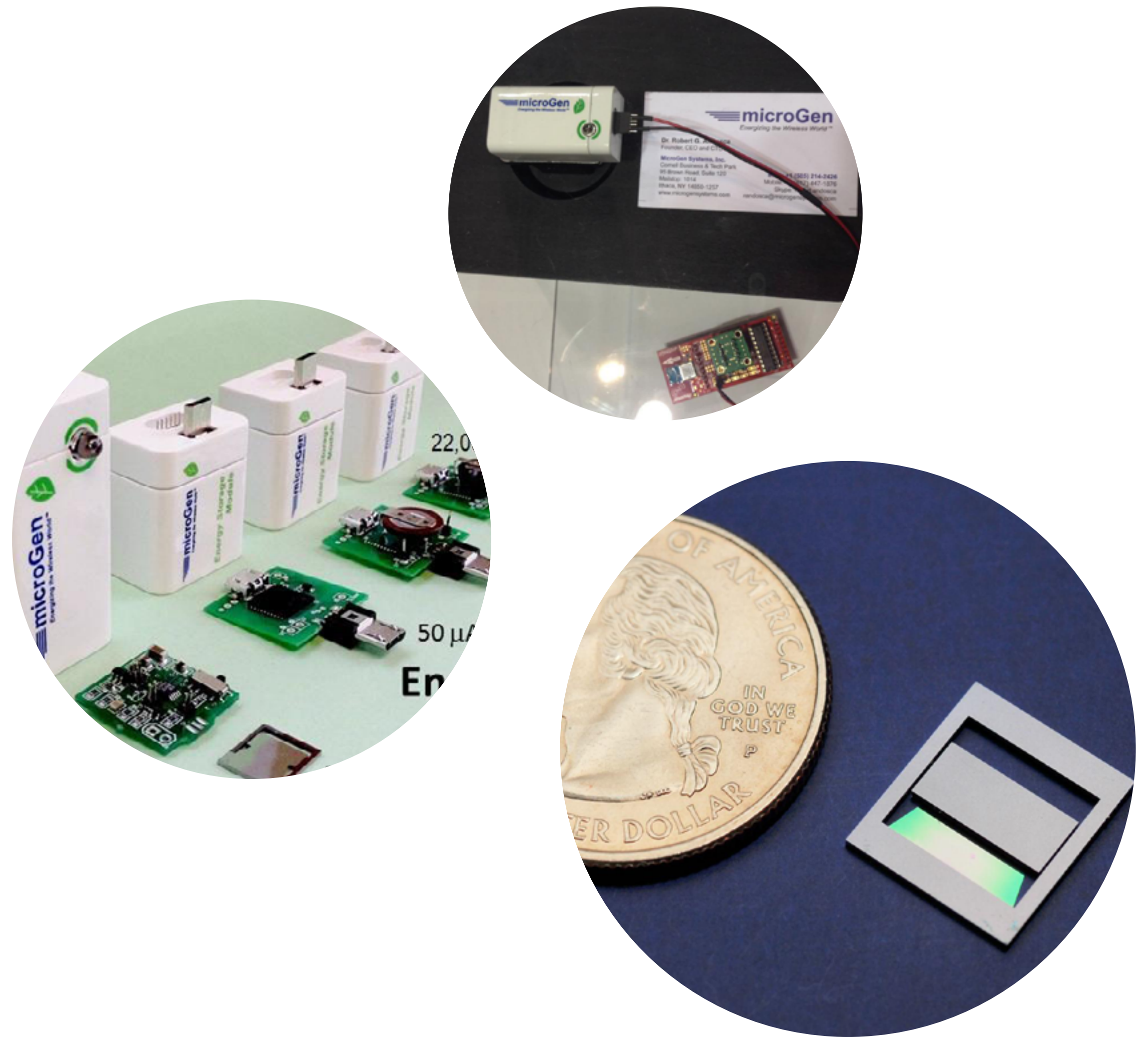
An important new application of MEMS devices is in the detection of various gases. One of the first commercial applications in this area is the detection of methane build-up in oil and gas installations. GasSecure launched their GS01 hydrocarbon gas detectors in 2012. By 2014, they had installed systems for multiple major oil and gas companies both onshore and offshore, in locations ranging from the tropics to the arctic.[26] Where a typical gas detector on the market today uses 3-6 W of power in normal operation, the GS01 uses only 5 mW of power. This allows it to be a truly wireless solution with a battery lifetime of about 2 years.[27] Wireless installation enables the sensors to be placed exactly where they are needed, without the constraints imposed by needing to run cables. When GS01 sensors were installed on the Statoil Gullfaks C platform in the North Sea, they found that not only did the sensors perform as well or better than wired sensors, they took only 5-10% as long to install and had an 80% total cost savings compared to a wired solution.[28] All of this is made possible by the breakthrough MEMS sensor enabling infrared spectroscopy on a chip, which does not need to be recalibrated for the life of the device.[29]

The technology used by GasSecure was developed by the European Space Agency and the Norwegian research organization SINTEF. It can be tuned to detect different gases, which opens up a host of potential applications, including air quality monitoring - "alco-locks" - which prevent drunk drivers from starting their cars[30]. GasSecure's technology could even be used as disposable detectors to measure carbon dioxide in food packaging.[31] Other companies and research organizations have been developing MEMS-based gas sensors as well, including gas chromatography-on-a-chip applications.[32] In all, $2 billion of gas detection equipment is sold annually, and significant new markets could be opened up with the introduction of compact and affordable equipment and sensors

24 Agilent Technologies
25 Agilent 2012 Annual Report
26 GasSecure, GS01
27 Gases & Instrumentation, 2013, 01-19
28 GasSecure educational event in Perth
29 GasSecure, GS01 IR Technology
30 Sharing Technology for Hostile Environments
31 Emerging MEMS Technologies to Watch, 2013, 01-05
32 Miniature Gas Chromatograph Could Help Farmers Detect Crop Diseases Earlier The leader in Nano-Sensor based gas chromatography systems

Energy Harvesting.

One of the main challenges for wireless sensor networks is how to power the sensor nodes. Use of wired power limits the viable locations (and ultimately numbers) of sensor nodes and may preclude gathering essential information. Batteries, on the other hand, need eventual replacement. This is an expensive (and, in some cases, impractical) proposition for networks with large numbers of nodes, some or all of which may be difficult to access. Moreover, batteries are constrained to a limited temperature range. Microgen has developed, and is starting to market, a piezo-MEMS vibrational energy harvester, which converts vibration into electricity. Their devices are the about the size of 9 volt battery and can produce 25-100 µW of electricity at typical industrial vibration levels. While that isn't much, it is enough to support low-powered sensor nodes. In June 2013 at the Sensors Expo and Conference in Rosemont, IL, Linear Systems and Microgen collaborated to set up a fully functional wireless sensor network powered by Microgen's energy harvesting Bolt Power Cells, the first of its kind.[33]



Source: MicroGen, Inc.

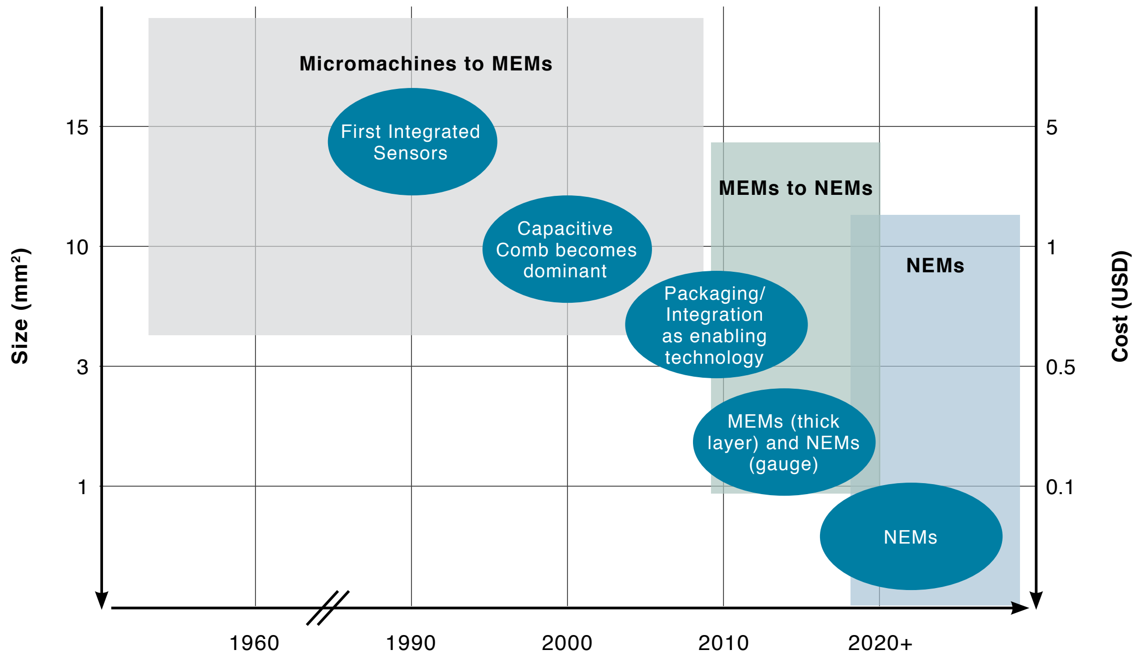
33 MicroGen's Piezo-MEMS Vibration Energy Harvesters Enable Linear Technology SmartMesh IP Wireless Sensor Network, 2013

Future Directions

MEMS have already had a huge impact on our daily lives, enabling objects in our environment (such as our smartphones and cars) to intelligently react to our actions and environmental conditions. Yet, the impact of MEMS is still expected to continue to grow.

Continued miniaturization.

Not only will MEMS continue to increase in number and decrease in price, but they will also continue to decrease in size. The first examples of nanoelectromechanical systems (NEMS) are already on the market, including atomic force microscopes and gas chromatography-on-a-chip.[34] Nanotechnology and MEMS already have important interactions. For instance, airbag accelerometers use self-assembled monolayer coatings (a form of nanotechnology) to prevent performance degradation over time.[35] As MEMS change to NEMS, the unusual properties of nanotechnology will become more important in the design of sensors and actuators.



Source: Adapted from the Yole Report

34 The leader in Nano-Sensor based gas chromatography systems
35 Micro-Electro-Mechanical Systems

Increasing functionality.

MEMS will also continue to increase in functionality. Technologies that have already been demonstrated include sensors that can detect chemical composition and radiation, microflaps which can be used to control aircraft, optical switches and mirrors, micropumps and much more. [36] Also, increasingly, more than one of these functions will be integrated on a single chip, greatly increasing the power of single sensor. By 2025, smartphones may be able to replace Geiger counters, spectrophotometers and entire laboratories full of equipment.

An enabling technology for the Internet of things.

MEMS are ideal for wireless sensor networks due to their small size and low power consumption. Expect them to be a major player in the development of the internet of things, greatly increasing the prevalence of smart objects.

MEMS, energy and the environment.

Not only do MEMS devices generally consume significantly less power than the traditional sensors they replace, they can also be used to harvest energy that would otherwise go to waste (as in the case of Microgen) and eliminate the need for batteries in some cases. MEMS sensors can also play key roles in environmental health monitoring; from indoor air quality issues, to worker protection, to monitoring potential contamination of air and water.

Big potential in medical applications.

MEMS potential in medicine is only beginning to be realized and goes far beyond pressure sensors. Some of the exciting potential applications include point-of-care diagnostic tests which are more accurate than laboratory results; implantable drug delivery systems for better control of diabetes and other drug-dependent conditions; micromachined needles which allow for painless, scar-free injections; and microsurgical tools that allow precise control in delicate surgery.

36 What is MEMS Technology?

Continued importance in mobile computing and automotive markets.

The use of MEMS devices is now well-established in these areas, and it will continue to remain significant. In mobile computing, in particular, expect the steady addition of more functions using tiny, low-cost, MEMS sensors and actuators.

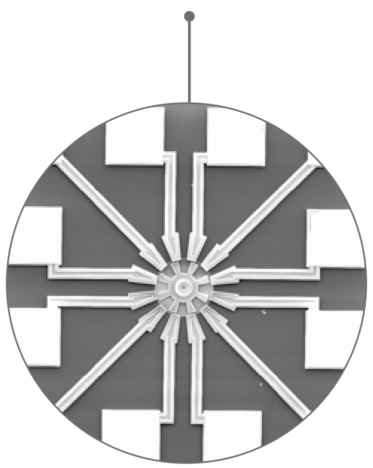
Disposable sensors?

As the cost of MEMS sensors continues to drop, it may become economical to use them in packaging applications, where they have a limited lifespan and a trivial cost.

Challenges to Overcome.

While MEMS devices can pack immense capabilities into tiny, low-cost packages, they have been hindered by a lack of standardization and long development cycles. This has been commonly described as the MEMS law "One product, one process, one package,"[37] and stands in stark contrast with the highly standardized methods used to develop IC chips today. As a result, most of today's MEMS products took multiple decades to develop and commercialize.[38] However, this is changing. Efforts are being made to standardize the process and development times are speeding up. Experts in the field predict that new products could be developed in as few as four years from ideation to commercial product. [39] New technologies, like 3D printing may help as well. Between the development of new MEMS sensors and actuators, and new applications for existing MEMS devices, the role of these miniature sensors in making technology more responsive to its surroundings will only increase over time.

A SURFACE MICROMACHINED ELECTROSTATICALLY-ACTUATED MICROMOTOR FABRICATED BY THE MNX. THIS DEVICE IS AN EXAMPLE OF A MEMS-BASED MICROACTUATOR.

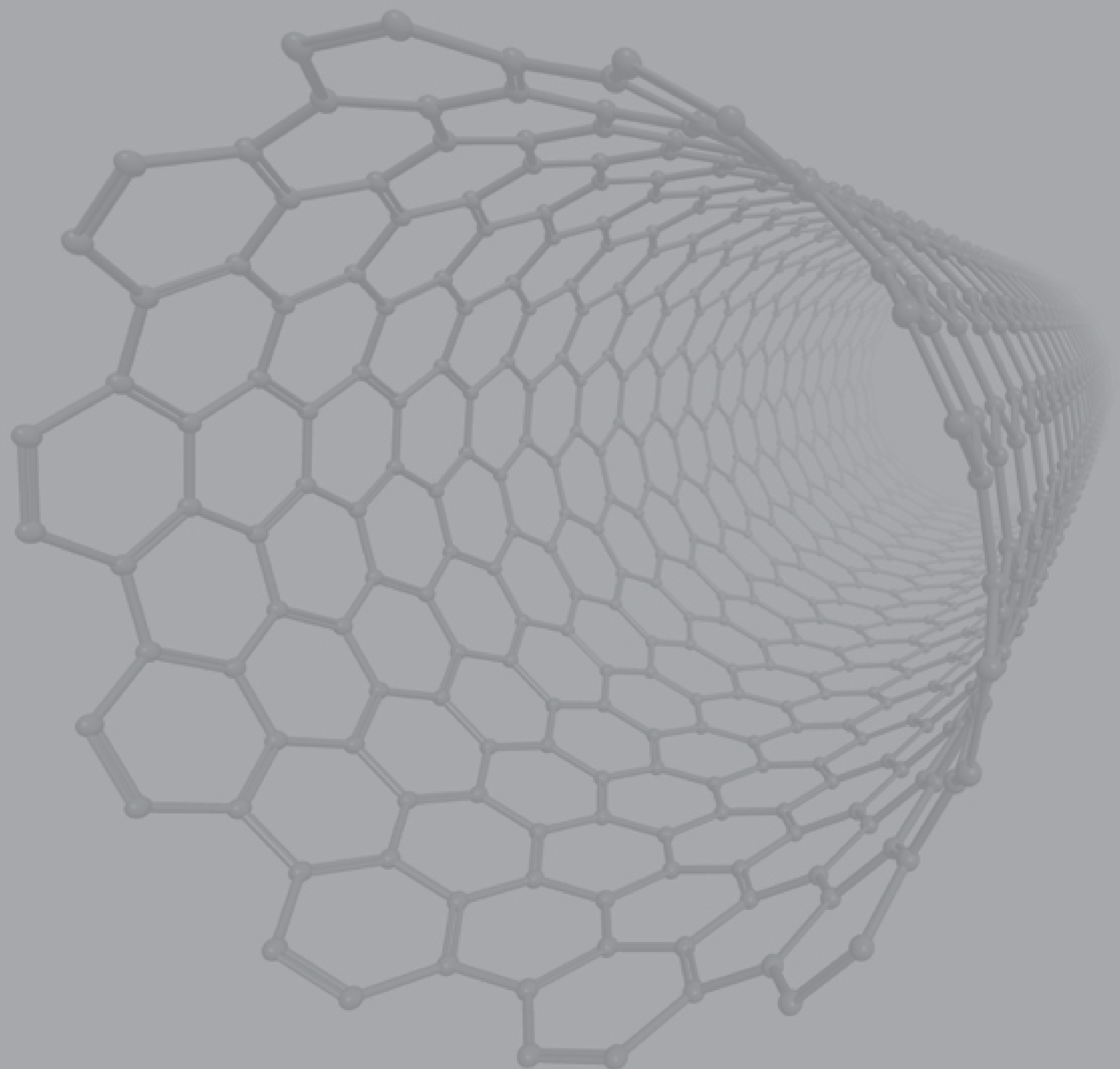


Source: MNX - MEMS and Nanotechnology Exchange

37 MEMS Senior Analyst, Yole Developpement
38 Emergence of a $Trillion MEMS Sensor Market, 2012, 01-22
39 Focus on Wireless Sensor Networks & Energy Harvesting

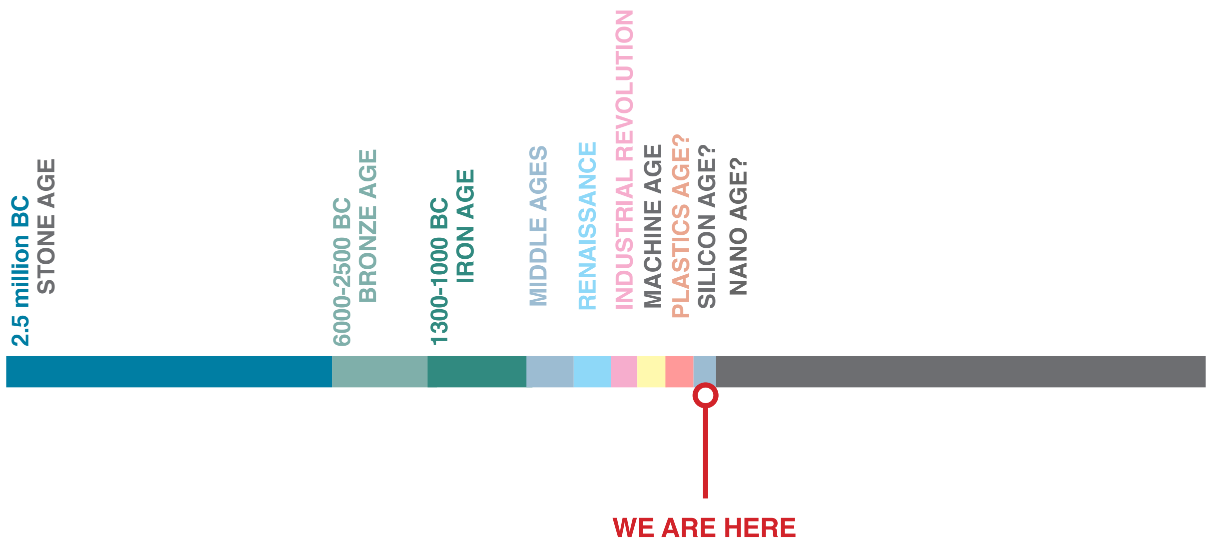
NANOMATERIALS

The properties which emerge at the nanoscale are often a function of size, allowing materials to



State of the Technology

The development of human societies has been defined by the materials we use. For instance, we refer to prehistoric cultures as “stone-age” or “bronze-age”, based on the materials the people of those era learned to work with to create their tools. As humans engineer more complex materials, new ideas and products are developed which move the society forward. For example, the first synthetic plastic, synthesized in 1909, irreversibly transformed human existence, ushering it in an era of lightweight, disposable materials. Like new technologies in the past, nanotechnology is creating a new class of materials that has the potential to transform existing technologies and turn impossible ideas into a reality.



Source: Loughborough University

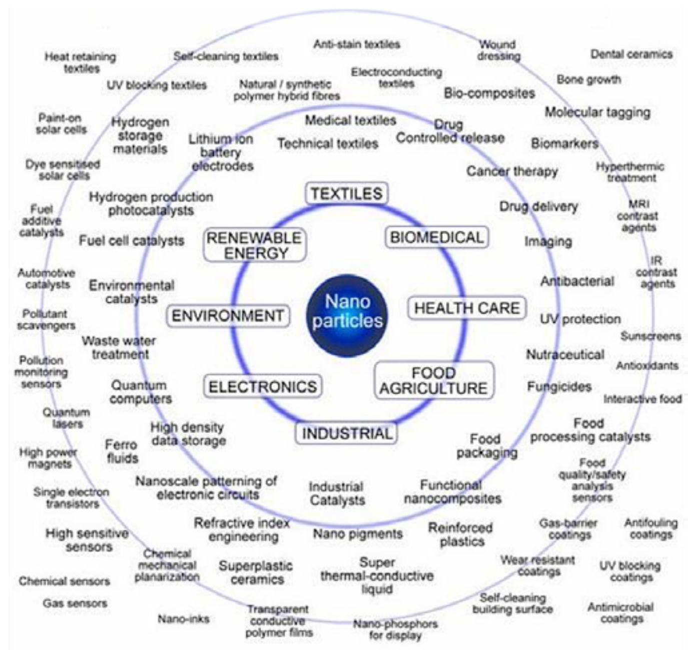
What are Nanomaterials?

Nanomaterials are materials that have at least one dimension between 1-100 nm, which is in the order of the size of individual molecules. At this scale, forces at the surface start to dominate over forces playing at bulk properties, and material properties can dramatically differ from typical bulk behavior. The properties which emerge at the nanoscale are often a function of size, allowing materials to be tuned to produce desired behavior that may not have been previously possible.

Nanoparticles.

Nanoparticles are the simplest nanomaterials to make and as a result, are the most common variety of nanomaterials in commercial production. Nanoparticles are often spherical particles, with varying diameters that exhibit different properties as a function of their size. Gold nanoparticles are seeing an increasing use in commercial applications. If a gold ring is broken up into pieces, its color and other properties remain unchanged. However, if the ring is divided until the pieces have nanoscale sides, the resultant gold nanoparticles possess dramatically different properties than the original ring. Instead of the familiar golden color of gold, gold nanoparticles in solution can produce a brilliant rainbow of different colors with the specific hue dependent on the size of the nanoparticles.

Nanoparticles are being used in products that are already on store shelves. Silver nanoparticles impart antimicrobial properties in everything, from consumer goods to surgical implants.[1] Nanoclay has been incorporated into the undercoating of cars to improve adhesion and corrosion resistance, while surfaces coated with nanodiamond[2] or nanoparticles of cubic boron nitride[3] are exceptionally tough and wear resistant. In food packaging, nanoparticles are used as part of the water based coatings, which can replace wax in board and paper packaging,[4] and can be used to scavenge ethylene gas, increasing the shelf life of produce and flowers.[5]



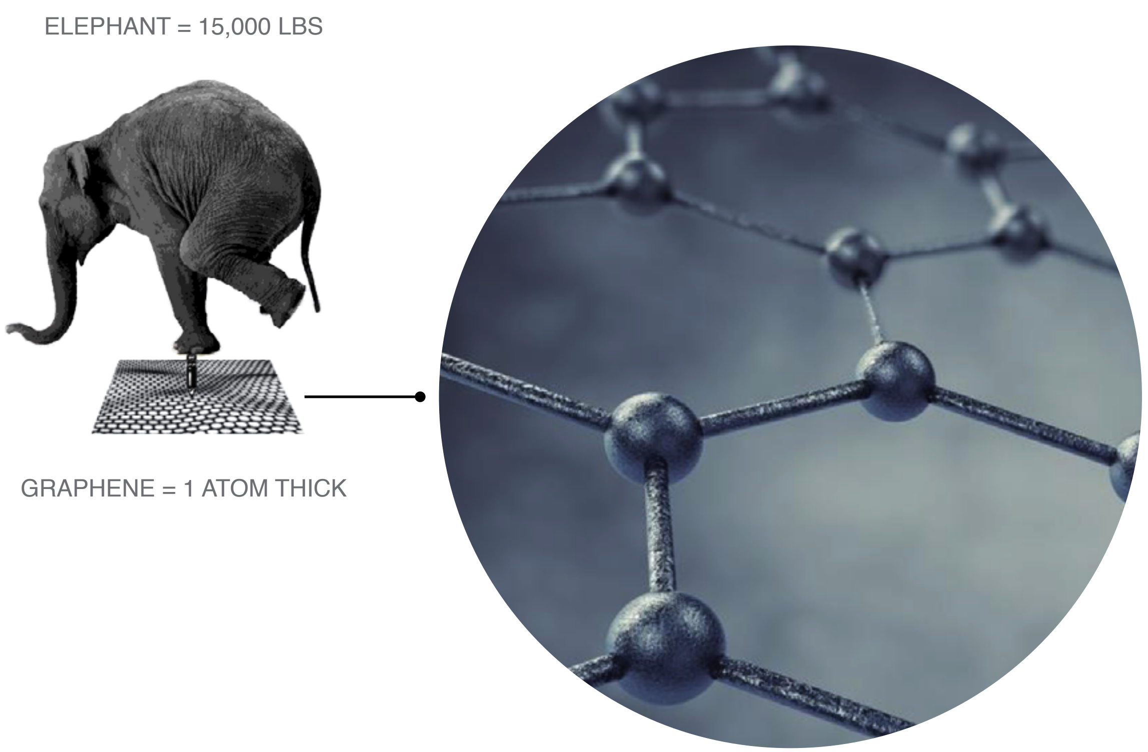
Source: Inderscience

1 Nanotechnology Products and Applications, SilvaGard
2 Nanotechnology Products and Applications, UNCD
3 Nanotechnology Products and Applications, TuffTek
4 Nanotechnology Products and Applications, TopScreen DS13
5 Nanotechnology Products and Applications, GuardIN Fresh

Beyond nanoparticles.

Nanomaterials extend far beyond nanoparticles. One dramatic example to demonstrate the potential of nanomaterials is graphene. Graphene is a two-dimensional sheet of carbon, which was first isolated in 2004 by using scotch tape to peel off layers of pieces of graphite, a common material used in pencil lead and in industrial lubricants.[6]Graphene, sometimes touted as miracle material, possesses amazing properties. It is remarkably strong. One researcher, studying the physical properties of graphene said that “it would take an elephant, balanced on a pencil, to break through a sheet of graphene the thickness of Saran Wrap.”[7]In addition, graphene has exceptional electrical conductivity and interesting optical properties such as the ability to absorb 2.3% of white light, despite being only one atom thick.[8]

To date, applications of graphene and other promising nanomaterials, such as carbon nanotubes, have been limited by the inability to produce them in large volumes at low cost. However, as the following case studies illustrate those barriers are beginning to fall. As the production of a wider range of nanomaterials becomes feasible and economical, their impact will grow in industries ranging from consumer goods, to medicine, to energy.



Source: Extremetech.com

6 Electric Field Effect in Atomically Thin Carbon Films, 2004
7 Columbia Engineers Prove Graphene is the Strongest Material, 2008
8 Graphene

Market Size.

Estimates of world demand for nanomaterials vary widely (from 27 thousand to 11 million tons in 2011 valued anywhere from $2.6 - $25.8 billion)[9]. Despite the widely differing estimates, various sources agree that the demand for nanomaterials is increasing rapidly: it has increased approximately 10 times between 2002 and 2011, and is projected to increase 30% annually thereafter. Moreover, research funding is significant in this field, with $12.6 million in SBIR and STTR grants awarded in 2013, up more than 19% from the previous year. The amount of intellectual property is growing rapidly, as well. Since 1990, the number of patents for nanoparticle products has doubled every two years.[10] Nanomaterials clearly represent a significant and growing market segment with many interesting applications.

Every two years, the number of patents related to nanoparticles doubles.

9 Nanomaterials Production 2002-2016: Production Volumes, Revenues and End User Market Demand, 2011
10 Pollution, R. C. o. E. Novel Materials in the Environment: The case of nanotechnology; Royal Commission on Environmental Pollution: London, 2008; p 156.

Case Studies

An important characteristic of nanomaterials is their dimensionality, i.e., the number of dimensions possessed by the material.In general, materials with lesser number of dimensions are easier to produce. Higher dimensional materials have their own unique properties which make them extremely desirable. In the following case studies, we examine materials from zero-dimensional nanoparticles to three-dimensional aerogels.

Zero Dimensional Technologies – Nanoparticles and Quantum Dots

Nanoparticles.

Some of the most interesting new applications of nanoparticles are in the area of drug delivery. The first nano-drug approved by the FDA was Abraxane, developed by Abraxis in 2005 for the treatment of breast cancer.[11] Abraxane is comprised of a nanoparticle albumin, coated with the chemotherapeutic, paclitaxel. The benefits are two-fold: first, Abraxane is more soluble than pure paclitaxel and does not require the use of toxic detergents. Second, the albumin nanoparticles activate a specific uptake pathway in the cancer cells, thereby selectively targeting tumor sites for uptake of the chemotherapeutic payload.[12] Abraxane's success led to the acquisition of Abraxis by Celgene for $2.9 billion in 2010.[13] Abraxane has subsequently been approved to treat lung cancer and pancreatic cancer, as well.

Source: Celgene

11 Nanotechnology Enables Precise Cancer Targeting, 2010
12 The Abraxane® Story: A Nanoparticle Platform Delivers Improved Anticancer Activity, 2006
13 Celgene to Acquire Abraxis Bioscience in $2.9 Billion Deal, 2010

Source: PlasmaChem

Quantum Dots.

Another promising application of nanoparticles is quantum dots. Quantum dots are semiconductor particles, small enough to confine electrons so that they exhibit quantum mechanical effects. The most noted special properties of quantum dots are their optical properties. They possess highly tunable, light emitting properties in striking colors, making them ideal for LEDs and LCD displays, a market worth $140 billion in 2012. Quantum dot displays have significantly better color than LCD displays while consuming less power.[14] Two companies, QD vision and TCL, brought the first quantum dot TV to market this September at 1/3rd the price of OLED displays, which produce comparable color.[15] Phones and tablets with quantum dot displays are expected to arrive on shelves within the next year.[16] The same properties which allow quantum dots to emit excellent colors, also enable them to convert light into electricity. Therefore,quantum dots show significant promise as a technique to improve photovoltaic technology.[17]

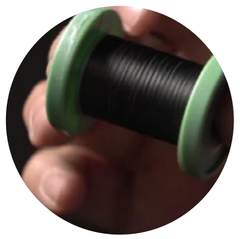
14 Will Quantum Dots Dominate Displays?, 2014
15 OLED Color at 1/3 the Price: QD Vision's Quantum Dots Enable TCL's Launch of 4K UHDTVs with Full-Gamut Color, 2014
16 Samsung, LG to mass produce next-generation Quantum Dot displays this year, 2014
17 New breed of solar cells: Quantum-dot photovoltaics set new record for efficiency in such devices, 2014

One Dimensional Technologies – Carbon Nanotubes and Nanofibers

Carbon Nanotubes.

Not only can nanomaterials help generate electricity, they can also improve transmission as well. Carbon nanotubes have tunable electrical properties (dependent on their structure and size) and in theory can carry 1000 times more electricity than copper wires with the same cross-sectional area.[18] These properties make carbon nanotubes highly desirable with regard to electrical applications. With the development of new manufacturing techniques, carbon nanotube cables have become commercially available for the first time, under the brand name 'Litewire'. Litewire is a direct replacement for copper cable in existing infrastructure and equipment at an equivalent cost. It has a number of highly desirable properties: It is 80% lighter and 20 times stronger than copper and does not expand as it heats up. It is non-corrosive, enabling a longer service life and is hydrophobic, preventing the formation of ice on cables. Moreover, while its electrical properties are equivalent to copper at 60 Hz, they improve exponentially with increasing frequency. In high voltage applications, the Litewire's efficiency increases by 32% to 60% and its low weight makes it ideal for aerospace applications. To put these savings into perspective, the new Boeing 777 airliner would weigh 4000 lbs less if its copper wire were replaced with Litewire. On the basis of its stellar properties, Weatherford International signed a long term contract as the exclusive distributor of Litewire to the Oil and Gas industry, with a forecasted annual revenue of $350 million.

Carbon nanotubes can also be used in a range of other applications. For instance, Hyperion Catalyst produces electrostatically dissipative plastics that prevent electric shocks which can cause fires or damage to sensitive components from passing through. Due to the highly conductive nature of carbon nanotubes, Hyperion Catalyst dopes their polymers with very small quantities of nanotubes, which do not affect the mechanical or surface properties of the plastics.[19] Due to their exceptional strength, carbon nanotubes have also been incorporated into body armor[20] Other types of nanofibers are used for everything, from air and water filtration[21] to trapping bed bugs. [22]



Source: Rice University (left and center photo)
Source: Curtran (right photo)

18 Nanotube Electronics: A flexible approach to mobility, Nature Nanotechnology, 2007, 207-208
19 The Leader in Nanotube Technology
20 AR500 Armor Carbon Nanotube Soft Armor IIIA - Backpack Armor
21 Filters and By-Pass Systems, Air
22 New Fibertrap Technology Stops Bedbugs, Termites, In Their Tracks Fibers and filtration – Advantages Of A New And Advanced Nanofiber Fiber application list

Two Dimensional Technologies – Coatings, Self-Assembled Monolayers and Graphene

Self-Assembled Monolayers.

A form of two-dimensional nanomaterials is the self-assembled monolayers (SAMs), which can be used to alter the properties of surfaces so that they are hydrophobic, oleophobic, waterproof, biocompatible and much more.[23] One example of this is Ultra-Ever-Dry. Introduced in 2013 by UltraTech International, Ultra-Ever Dry is a nanostructured coating that has superhydrophobic and oleophobic properties, enabling it to repel almost any kind of fluid. The demonstration video became a viral sensation shortly after being posted, amassing almost a million hits in just 48 hours.[24] The increased customer demand enabled UltraTech to expand their business model from exclusive B2B sales to products designed for consumers.[25] In 2014, Nissan announced the use of Ultra-Ever Dry to create the world's first self-cleaning car.[26]

Source: Nissan

Graphene.

Another two dimensional nanomaterial is graphene. By many accounts, the first commercial graphene product was a conductive ink, produced by Vorbeck materials. It has been used to produce flexible security tags. Vorbeck is also using graphene to improve battery technology. Recently, the company debuted a flexible battery that can power a cell phone for up to 50 hours, and the Department of Energy recently awarded them a $1.5 million grant for the development of low-cost, fast-charging batteries for hybrid vehicles. Other applications of graphene being developed by Vorbeck include engineered elastomers, touch screens and displays, RFID tags and wearable technology. Their innovation has won them a number of awards including the prestigious R&D 100 award in 2012.[27]

RESEARCHER WORKING WITH A THIN FILM.

23 Waterproof-breathable clothing
Biocompatibility
Optics
MEMS
24 The Official Ultra-Ever Dry Product Video - Superhydrophobic and oleophobic coating, 2013
25 Ultimate Waterproofing Industrial Coatin
26 Nissan develops first "self-cleaning" car prototype, 2014
27 Empowering the Road Warrior, Vorbeck bends batteries

Three Dimensional Technologies – Aerogels

Aerogels.

Aspen Aerogels was founded in 2001 as a producer of thermal insulation materials for the oil and gas industries. It developed a key product based on nanomaterials – an aerogel comprised of a network of silica nanoparticles. In addition to being one of the lightest materials in the world, Pyrogel XT-E is the most effective, high temperature insulation material on the market. As a result, Aspen has seen a nearly 37% annual increase in revenues ($82.1 million in 2013). Aspen's products are used by almost all of the world's largest refining and petrochemical companies. Their products are installed at 30% of the world's refineries.[28]

Not only are aerogels lightweight and fantastic insulators over a very wide range of temperatures (from cryogenic temperatures to 650°C), they are also translucent, completely hydrophobic and insulate even when compressed. This makes them extremely useful in a wide range of applications. Cabot Corporation, another major manufacturer of aerogel products, has a product range which includes insulated skylights, highly insulating coatings, outdoor gear and apparel, and personal care products. In recognition of its large potential impact on the $32.5 billion global insulation market,[29] Cabot received the 2013 ICIS innovation award, in addition to the award for best environmental benefit, for its use of aerogel in building insulation.

AEROGELS LIKE THIS ARE HIGHLY POROUS, LIGHTWEIGHT AND EXCELLENT THERMAL INSULATORS.

Source: NASA

28 Securities and Exchange Commission, 2014
29 Insulation Demand Will Increase By 2018

Future Directions

As manufacturing techniques improve, production of new nanomaterials becomes economically viable. While nanoparticles remain an important part of the field, higher dimensional nanomaterials are becoming more common in the commercial marketplace. Expect these materials to deliver significant improvements in existing technologies and open up new and radical possibilities.

Medicine.

Current nanomaterials can decrease the toxicity and improve the efficacy of drugs. There are even more nanodrugs still in the pipeline. However, the impact of nanomaterials in medicine is not limited to drugs. Nanotechnology can also enable lab quality diagnostics to be performed at the bedside. [30] Combined with MEMS and modern electronics, in the near future nanomaterials will also have the potential to play a part in the making of a device that resembles Star Trek's medical tricorder.

Aerospace.

Nanomaterials' exceptional properties also make them an excellent match for aerospace applications, where weight is a critical factor for feasibility and economics. Engineering challenges such as insulation, conduction or structural strength may be obviated as nanomaterials deliver more functionality with reduced weight compared to conventional alternatives.

Energy.

Nanomaterials may have one of the largest impacts in the energy industry. The pipeline for the improved production, transmission, storage and conservation of energy are hot areas of academic research, and commercial applications are beginning to spin off from these research laboratories. The potential of nanomaterials in this area is just beginning to be tapped. In addition, nanomaterials can contribute to significant energy savings due to weight reductions in automobiles and aircraft.

Personal Electronics.

Electronics will continue to benefit from improved nanomaterials, which will lead to the production of flexible displays with vivid colors,lower energy consumption, more computing power, longer battery life, lighter weight and much more. Eventually, they may even become self-repairing. In addition to this, the use of nanomaterials in electronic devices will benefit consumers while also creating opportunities for differentiation through innovation.

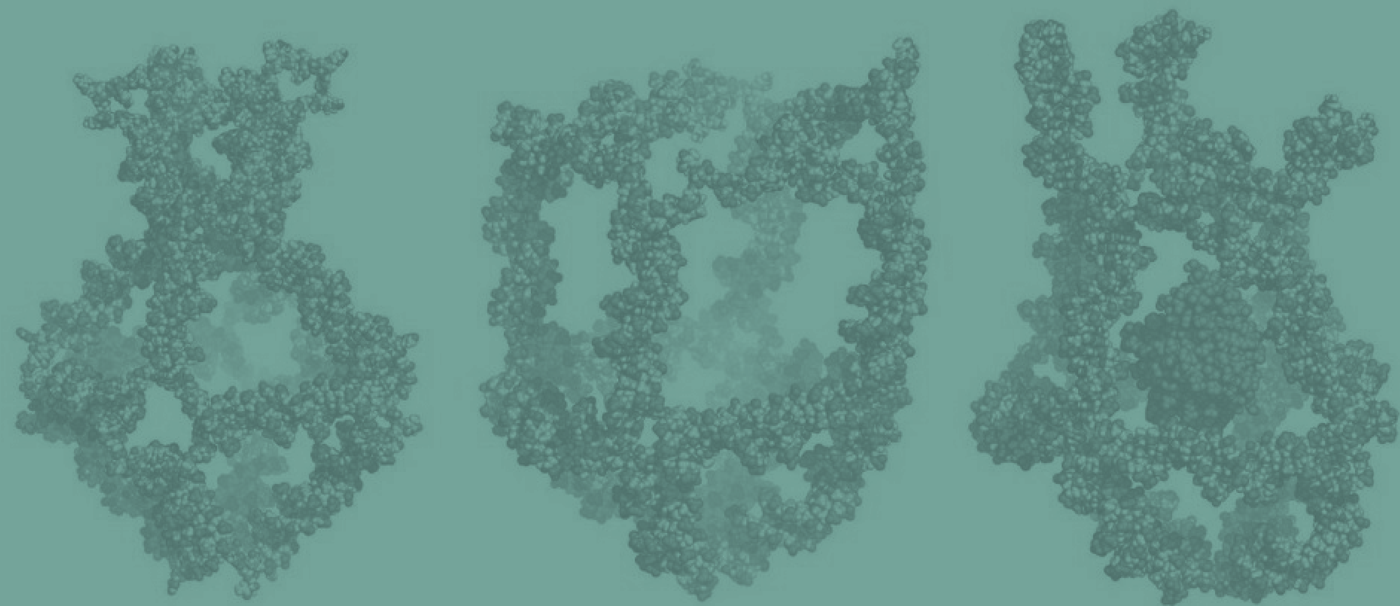
30 A Quantum Leap In Chemical & BioSensor Technology

While nanomaterials have a great potential, there are still a few constraints limiting their widespread commercial use. The first and foremost constraint is scalable production. A ton of nanomaterial can encompass billions and billions of particles which must be produced and transported in a way that prevents agglomeration. A secondary concern is that many nanomaterials are produced alongside undesirable byproducts. Single and multi-wall carbon nanotubes have vastly different properties. Yet, the arc discharge techniques commonly employed to produce them generate a commingled mixture. This necessitates expensive separation and purification steps. Overcoming these challenges to produce industrial quantities of nanomaterials at low cost will be a key factor in determining the success of nanomaterials in broader markets.

Furthermore, the general public has begun to view nanomaterials with skepticism. Many vendors have integrated nanoparticles in a variety of products ranging from socks to dishwashers to toothpastes, without educating the public about toxicity and safety concerns. As a result, products that are labeled as containing nanomaterials are often shunned by consumers. Overcoming such stigmas or branding nanotechnology in a positive, creative way will pave the way for the acceptance and success of next generation of nano-based products.

BIOTECHNOLOGY

Innovations in biotechnology are also paving way for discovering methods by which energy may be produced with reduced (or a beneficial) environmental impact.



State of the Technology

The Earth's human population is estimated to approach 8 billion within the next 10 years, placing unprecedented demands on our ability to provide food, energy, and healthcare to every individual. In order to meet these growing demands, we must learn to utilize our natural resources in new, more efficient ways. It is fitting that we may look to the biological world for these solutions, as it has indeed proven to be one of the richest sources of innovation, with millions of years to refine its designs.

Natural selection, one of the harshest and strongest driving forces toward specialization and improvement, inherently drives new advances for the benefit of efficiency and survival. As humans, we have a long history of co-opting the products of this selective process toward our own objectives.

Since 1996, land for GM crops has grown by 100x, and domestic crop harvests have exceeded $80 billion annually.

What is biotechnology?

Biotechnology refers to the use of organisms and biological systems to create new products or technological applications. Such processes have been utilized throughout the course of human history for diverse markets, from agriculture to medicine. One of the most disruptive human innovations, penicillin, was not synthesized by a chemist. Instead, it was sourced from mold unexpectedly growing on a petri dish in 1928. Since that time, penicillin has saved over 100 million lives, serving as an early testament to the transformative power of biotechnology. Nature had already equipped Penicillium notatum with the ability to kill bacteria, but the tools of biotechnology allowed us to harness that power for our own health and benefit. In that way, scientists co-opted the small mold's antibacterial capabilities, and dramatically altered the course of human progress and health.

Providing for 8 billion people.

One of the most persistent problems addressed by biotechnology is the need to feed and furnish the world's growing population. The conventional selective breeding of plants and animals has served as the cornerstone of modern agriculture for over 10,000 years. However, there is a limitation to these traditional techniques, as they are time consuming, and are hindered by the constraints of breeding compatibility and logistics. Genetic engineering, on the other hand, through the use of the recombinant DNA technology, allows for the precisely controlled insertion or deletion of genes, and for the utilization of genes that are not originally found in a given species.

Much of the research in the biotechnology field focuses on improving crop and animal yield through better genetic engineering techniques. It is estimated that agriculture and agriculture-based technologies contributed $775.8 billion to the U.S. gross domestic product in 2012.[1] Since the first commercial genetically modified (GM) crop was introduced in 1996, land utilization for GM crops has grown 100 fold,[2] with the revenue from GM crop harvests valued near $80 billion annually in the United States alone.[3] The USDA reports that the insertion of foreign insect-repelling genes into corn has allowed for the dramatic 10-fold reduction in the need for chemical crop treatment, saving farmers time and money, as well as increasing viable crop yields and lessening the side effects of chemical insecticide on the environment.[4]

Although the global demand for food is expected to continuously increase with the growing population, the area of arable land is dwindling, primarily due to salinity caused by irrigation. Conventional crop irrigation gradually leads to a buildup of mineral deposits that eventually render the soil unsuitable for crop production. Salinity currently affects up to 20% of irrigated farmland worldwide,[5] and the area of contaminated land continues to increase globally by 25 million acres a year, a surface area almost equal to of the state of Indiana. Scientists are addressing this issue by developing crops with a higher tolerance to salty conditions, and thereby renewing the potential of previously unsuitable croplands.

1 Economic Research Service, Economic Data on Food, Agriculture, and the Rural Economy, "Ag and Food Statistics, Charting the Essentials"
2 ISAAA Brief 44: Global Status of Commercialized Biotech/GM Crops: 2012, Clive James
3 Rob Carlson, Nature Biotechnology 27, 984 (2009)
4 Economic Research Report No. (ERR-162) 60 pp, February 2014
5 The salt of the earth: hazardous for food production, FAO

Environmental benefits in energy production and agriculture

It has been estimated that nearly 25% of potential agricultural production in the United States is lost during the growing, post-harvest, and handling stages.[6] A large majority of this loss stems from pests, decay, or disease – issues that are actively being addressed through biotechnology. Solutions in this sector would not only reduce waste in manpower and dumping agricultural waste into landfills, but have indirect environmental and economic benefits as well. Modern agriculture in the United States requires 10% of the national budget, 50% of available land, and 80% of freshwater consumption. Innovations that lead to even a small reduction in agricultural losses could potentially have a significant impact on gross profit.[7]

In addition to reducing waste, innovations in biotechnology are also paving the way for discovering methods by which energy may be produced with reduced (or beneficial) environmental impact. Current methods of energy production often physically disturb soil and result in carbon emissions that pollute the atmosphere. As the global population grows and the demand for energy, food, and goods increases, biotechnology provides a new generation of innovation that can meet those needs without placing undue stress on the Earth's natural resources.

6 Dana Gunders, "Wasted: How America is Losing Up to 40 Percent of its Food From Farm to Fork to Landfill."
7 NRDC Issue Paper, August 2012 IP: 12-06-B "Wasted: How America is losing up to 40 Percent of Its Food from Farm to Fork to Landfill." NRDC Issue Paper, August 2012 IP: 12-06-B

Case Studies

Farming

Without dramatic changes to farming practices, it will be impossible for food production to keep up with the exploding global population. One way in which scientists are addressing this problem is through genetically altering crops, so that they can grow well under previously inadequate conditions. One company tackling this challenge is a startup called AgBiome. AgBiome secured $17.5 million in Series A funding in 2013. AgBiome's mission is to apply state-of-the-art genomics and screening technologies to identify plant-associated microbes that enhance plant health, pest resistance and yield.[8]

Another player in the farming space is Targeted Growth, Inc., (TGI), founded in 1998. TGI is a crop biotechnology company focusing on developing products with enhanced yield and improved quality for the agriculture industry, as well as the energy sector. "TGI has incorporated modern molecular breeding techniques with targeted genetic adaptations and biotechnology for a comprehensive approach toward optimizing the yield characteristics of plants. TGI's current development programs include enhancements to corn, soybean, canola, rice, and wheat."[9] In early 2013, a division of TGI, Sustainable Oils, that produces renewable jet fuel for the US Navy, with $20 million in revenues, was acquired by Global Clean Energy Holdings, Inc.[10]

Looking ahead, pervasive advances such as the identification of salt-tolerant genes or photosynthesis enhancements allow for the genetic engineering of these traits into a wide range of plant species.

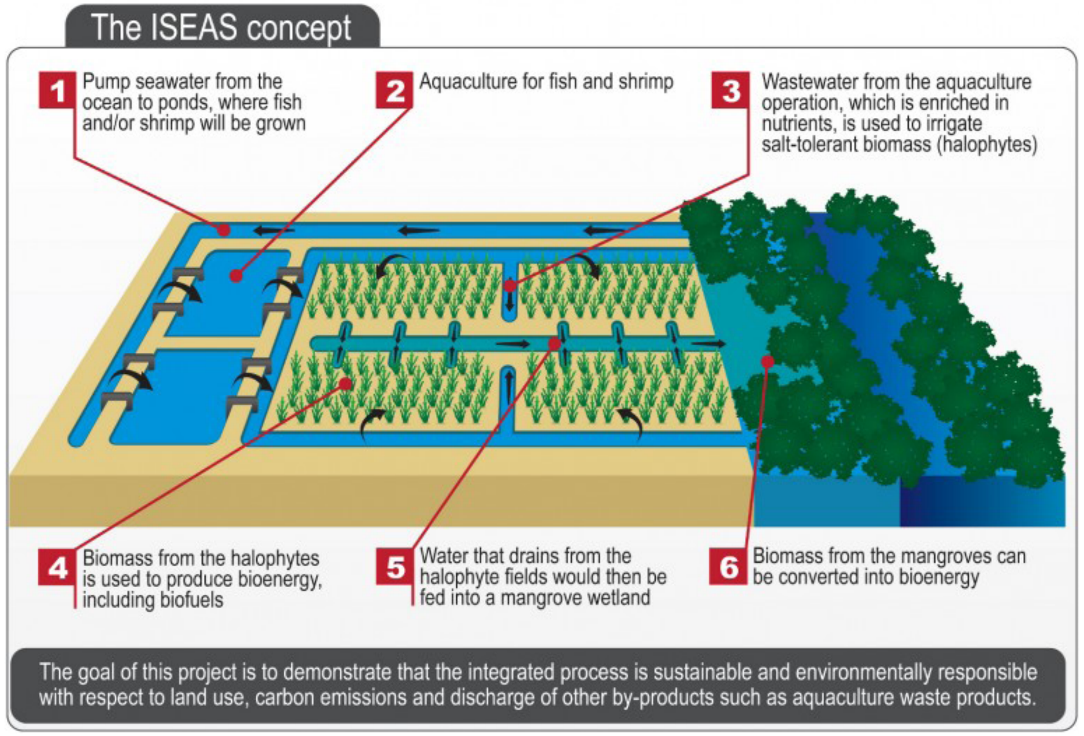
Source: Wisconsin Department of Natural Resources

8 AgBiome, CrunchBase
9 The next generation of agricultural biotechnology, Targeted Growth, Inc.
10 Global Clean Energy Holdings, Inc. Acquires Sustainable Oils, LLC

Pass the Salt.

In an attempt to counteract the loss of farmland caused by irrigation-induced salinity, scientists have, within the last five years, utilized genetic modification and selective breeding to generate salt-tolerant strains of tomato[11] and wheat.[12] Such innovations have increased crop yields in salt-contaminated fields by as much as 25%, and renewed the usability of previously abandoned farmland. New research is pushing the envelope even further, aiming to expand cultivation beyond salt-contaminated land, to extremely high saline conditions such as seawater. Ceres, a startup located in California, announced in 2010 that they have identified a gene that allows crops to withstand higher salt concentrations than ever before, thriving even in untreated water taken from the Pacific Ocean.[13] Such advances would open up the potential use of ocean water or saline-contaminated irrigation water for crop production, and eliminate the need for desalination, which consumes large amounts of energy and raises the cost of water up to $4/gallon. Ceres is incorporating the novel salt-tolerance gene into biofuel grasses (switchgrass, sorghum, and miscanthus), with the goal of planting fields by 2015. When combined with saltwater irrigation, these new “energy grass” varieties will provide an entirely novel source of renewable energy, made possible by the power of genetic engineering.

Salt lover: A salt-tolerant switchgrass plant stays healthy in highly saline soil, unlike its conventional counterpart



Source: The Masdar Institute’s Sustainable Bioenergy Research Consortium
Salicornia for biofuel production

11 Hong-Xia Zhang & Eduardo Blumwald, Nature Biotechnology 19,765–768(1 August 2001)
12 Grain yield of modern wheat on saline soils is improved by ancestral HKT gene. Nature Biotechnology 30:360-364.
13 Energy Crops Growing On Seawater, Ceres

Improving plant efficiency.

Other approaches are bringing together the biological power of different kingdoms, promising to boost the growth power of crops by 36-60%. Researchers at Cornell University and Rothamsted Research have taken genes from cyanobacteria and transplanted them into a proof-of-concept model of tobacco, allowing the plant to produce a bacterial enzyme that catalyzes the conversion of carbon dioxide to sugar more efficiently.[14] The researchers plan to implement this metabolic booster into commercial crops in the next 5-10 years, beginning with potatoes, tomatoes, eggplant, and peppers. This change will allow plants to produce more, thereby increasing yields without consuming more resources or requiring more land.

Biodiesel

The industrial age has been driven by fossil fuels, an unsustainable situation in dire need of alternate solutions. Biofuels are a popular area of research in the sector of renewable fuels, yet current methods rely on land-based crops, such as corn and soybeans, that detract valuable space from food production. A new concept is being developed by the Sustainable Bioenergy Research Consortium (SBRC) at the Masdar Institute of Abu Dhabi[15], using salicornia, an oil-producing plant. Salicornia plants have a naturally high tolerance to salt-water, and produce oil-rich seeds that can be processed into bio jet-fuel. With the airline industry contributing 2.5% to the world’s global emissions, and the aviation industry’s desire to be carbon neutral by 2020, this pro-arid, pro-salinity plant may hold the solution to some of the daunting challenges faced by this industry.[16]

The project has led to collaborations in 2014 with Boeing, Etihad Airways, and Honeywell, who are providing funding and technology for the conversion of the salicornia oil into jet fuels. The remaining plant biomass can then be used as animal feed or burned for energy, adding additional economic value to the process. Test fields of salicornia have been successfully established by the SBRC in Abu Dhabi, utilizing adjacent fish and shrimp farms as a source of natural fertilizer. This concept is estimated to have a similar per-acre biofuel yield as soybeans, while sparing the use of valuable farmland and freshwater, and emitting 50-80% less carbon than fossil fuels.

Source: Boeing
Product Review

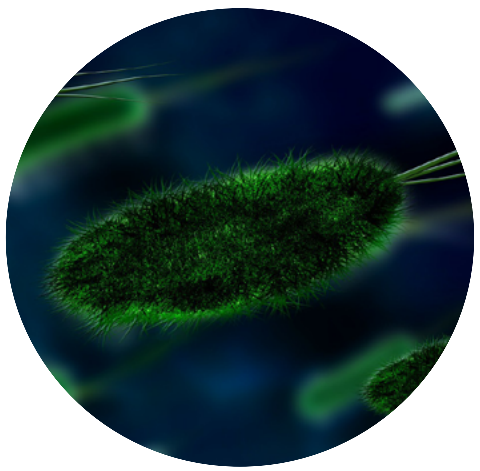
14 “A faster Rubisco with potential to increase photosynthesis in crops.” Nature 513, 547-550, September 2014
15 Sustainable Bioenergy Research Consortium
16 At SXSW Eco: Creating Jet Biofuel from Saltwater Tolerant Plants, Silicon Hills News, 2014

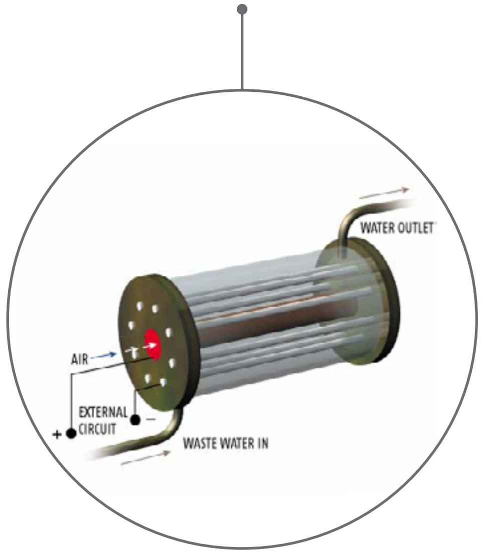
Energy

Carbon emissions are not the only detriment associated with fossil fuels. Current production processes involve drilling and extraction from the Earth: processes which require pipes, waste pits, and the clearing and destruction of land. Professor John Love, of the University of Exeter, and the Shell Corporation are working to co-develop a biotechnology solution to produce “fossil” fuels that can be easily produced by humans. In 2013, these scientists developed a strain of E. coli that generated diesel that is indistinguishable from conventional diesel.[17] This has an added advantage over current biofuels, which are not completely compatible with common combustion engines. “Commercialization is the goal,” says Love. “Having Shell as a partner keeps us focused on that goal.”[18]

In 2012, Dr. Orianna Bretschger demonstrated a microbial fuel cell (MFC), which uses raw sewage and modified bacteria for energy production. Dr. Bretschger, currently at the J. Craig Venter Institute in San Diego, has developed a MFC driven by genetically modified bacteria that were able to metabolize hydrocarbons in the sewage, and convert 13% of the available energy to electricity.[19] Scientists at Oregon State University and Korea National Open University have pursued similar innovations, producing a microbial fuel cell capable of generating several times the energy required for the normal processing of wastewater, with no additional greenhouse emissions.[20] Currently, conventional methods of wastewater treatment use about 2% of the US energy supply, and cost $25 million per year. MFCs would mitigate that expense, generate an additional renewable energy stream, while treating sewage.

BACTERIAL FUEL CELL TO GENERATE ELECTRICITY FROM SEWAGE, PENNSYLVANIA STATE UNIVERSITY, 2004





Source: Pixabay, public use (left photo)
Source: Pennsylvania State University (right photo)
Product Review

17 Howard et. al., PNAS April 22, 2013, “Synthesis of customized petroleum-replica fuel molecules by targeted modification of free fatty acid pools in Escherichia coli.”
18 Drop-in biofuels from microorganisms, 2012
19 Presentation at the American Chemical Society in San Diego, Dr. Orianna Bretschger, J. Craig Institute in San Diego.
20 Fan et al., Energy Environ. Sci. 2012, 5, 8273-8280

Pharmaceuticals

The pharmaceutical industry is primed for biotechnology to serve as a disruptive element. In 2012, the global pharmaceutical market was estimated at $962 billion, with 5.3% CAGR within the US over the next several years.[21] Yet, the cost of drug research is around $4 billion for every drug that’s approved (including all previously failed drugs). Finding novel methods to screen, validate and scale a drug is a high priority in order to cut down the cost of drug research.[22]

Planning for success. Bioleap, a $5 million Series-A venture-backed 2010 startup, is a molecule discovery and design company driven by next-generation computational fragment-based molecule design (CFBMD) technology, which quickly predicts binding affinity based on thermodynamic principles.[23] Their goal is to eliminate the need for expensive high-throughput screening or synthetic experimentation for compound lead optimization screening.

Work smarter not harder. Another hurdle addressed by biotechnology is the scalability of a complex molecule, such as the life-saving anti-malarial drug component artemisinin, conventionally derived from the wormwood plant. Malaria is treatable, but infects 200 million people, and kills more than half a million people every year due to lack of low-cost pharmaceuticals. In April 2013, the biotechnology company Amyris and the pharmaceutical company Sanofi partnered for the first large-scale synthetic production of artemisinin.[24] The team is inserting the necessary genes for the compound’s production into fast-growing bread yeast. Sanofi expects to make about 50–60 tons of artemisinin this year, enough to cover a third of the global demand.[25] The project was funded by $53.3 million in grants from the Bill & Melinda Gates foundation, will dramatically cut the cost of malaria treatments, and enable treatment of 150 million more malaria patients by the end of 2014.

Drug Delivery made simple. Biological components are not only being used to make drugs, but also to deliver them in more efficient ways. Recently, Professor Shawn Douglas at Duke University constructed a proof-of-concept prototype for the controlled delivery of enzymes to cells, using encapsulation in synthetic DNA-based structures called “DNA Nanocages.”[26] In a biological system, DNA functions by specifically binding proteins and by forming 3-dimensional structures based on the specific sequence of nucleotide bases. Scientists have co-opted these properties to develop a nanoscale DNA capsule that specifically binds to an enzyme of interest, and then releases its load in a temperature-dependent manner. Although currently in the proof-of-concept stage, this type of drug delivery system could be used to home enzymes and drugs to specific cell types, enabling precise therapies that would be used to target cancers and gene deficiency disorders.

21 Total Unaudited and Audited Global Pharmaceutical Market By Region/2012 - 2017, imshealth
22 50 Jaw-Dropping Pharmaceutical, Biotech, and Life Science Statistics, 2013
23 Better Drugs By Design, BioLeap
24 “High-level semi-synthetic production of the potent antimalarial artemisinin,” Nature, 496, 528-532, April 2013
25 Sanofi launches malaria drug production, 2013
26 “Temperature-controlled encapsulation and release of an active enzyme in the cavity of a self-assembled DNA Nanocage.” ACS Nano, 2013, 7(11), pp 9724-9734.

Future Directions

New technologies that utilize the power of living organisms will have a transformative effect in food production, energy sectors, and medicine within the next decade. The innovative power of biotechnology, however, comes paired with concerns regarding the safety and control of technologies that rely on living and biological systems. Much of the public concern centers on biotechnology that will come into direct contact with consumers, specifically, genetically modified crops and pharmaceuticals. These issues of safety to humans and the environment must be adequately addressed in order to facilitate the successful use of biotechnologies.

Labeling of GM foods

The economic benefit of genetically modified crops, particularly in the United States, is clear. According to the USDA's National Agricultural Statistics Service, genetically modified technology has increased agricultural income by $43 billion between 1996 and 2011, and the value of biotech crops stood at $115 billion in 2012.[27] Even in light of this information, a notable segment of popular opinion opposes GM farming, perhaps due to its noticeable contrast with traditional breeding techniques. Particularly when it pertains to food products, consumers are pushing for greater transparency in packaging labels that indicate the presence of genetically modified plant derivatives. On average, about half of US consumers currently support or are undecided about consuming GM food products.[28] Therefore, transparent GM food labels may not dramatically affect profits, but may instead facilitate the acceptance of biotechnology by empowering consumer knowledge and power.

27 GMO Opposition Creates Uncertainty for Farmers! BIOtechNow, 2014
28 "Public Sentiment About Genetically Modified Food", 2001

Pandora's Box

The unintended dispersal of GM organisms and the resulting interaction with endogenous species is another concern that requires addressing. This problem pertains primarily to GM organisms that reproduce and disseminate rapidly and easily, such as viruses, bacteria, and pollinating plants. In biomedical research, a field that has utilized modified viral vectors for decades, the method to prevent such dissemination involves incorporation of a so-called "kill-switch" through which the modified viruses are rendered incapable of replication, and therefore incapable of spreading past the cell culture dish.

Several strategies have been introduced as methods to prevent "transgene transfer," or the transfer of genes from GM crops to wild or non-GM relatives. One approach takes advantage of the presence of genetic material present in plastids, a major plant organelle. While the nuclear genetic material is disseminated by pollen, genetically modified material in the plastids are only passed on through the female plant, and not capable of being spread over significant distances. This is particularly beneficial for the production of fruits and vegetables, as the produce contains the transgene, while the pollen does not. This technology was first introduced in 2002, and through its development, is helping to bring genetically engineered agriculture into a new era. Termed plastid-transformed plants, or transplastomic plants, the technology has the additional benefit of being able to deliver high dosages of foreign genes, because plastid genomes are present in multiple copies - up to 10,000 in each plant cell. This trait has been used to allow transgenic proteins to comprise up to 46% of total leaf proteins.[29] Since the early 2000's, research has progressed on the methods to stably insert transgenes into specific locations within the plastid genome. The process has been experimentally applied to crops such as cabbage, lettuce, potatoes, cotton, rice and soybean, and has the potential to elevate the safety and flexibility of GM crops in the approaching decade.

An alternative method of controlling undesirable gene flow from GM organisms is to install a "kill-switch" gene along with the genes of interest. Such a method has been developed for GM corn. In 2013, scientists from the Zhejiang University in China introduced a new strain of GM corn that contains genes that render it resistant to glyphosates, but sensitive to nicosulfuron - the exact opposite of conventional corn crops.[30] In this way, corn plants contaminated with the GM genes were easily killed by nicosulfuron, presenting a method for the control of unwanted gene transfer.

29 De Cosa B, Moar W, Lee SB, Miller M, Daniell H (2001) Overexpression of the Bt cry2Aa2 operon in chloroplasts leads to formation of insecticidal crystals. Nat Biotechnol 19 71–74
30 Li J, Yu H, Zhang F, Lin C, Gao J, et al. (2013) A Built-In Strategy to Mitigate Transgene Spreading from Genetically Modified Corn. PLoS ONE 8(12): e81645. doi:10.1371/journal.pone.0081645

Benefits to the environment

The next generation of biotechnology innovations in genetically modified crops and animals may be used to reduce the use of pesticides and eliminate some of the waste that is rampant in today's food supply line. Bacteria may be used to produce fuels by cleaner, more renewable methods, and perhaps salvage the energy trapped in our solid waste and liquid sewage. The research behind the capability of bacterial species is in its earliest stages, but it promises to bring a revolution of new energy, and new ways to view our interaction with the living world around us.

A new generation of drug production and delivery

Many pharmaceutical production lines are currently limited by the inconsistent availability and high cost of necessary starting materials. Products from synthetic biology, particularly those that utilize fast-growing yeast and bacteria, will revolutionize drug production in the coming decade. Biotechnology enables a new generation of drug discovery and scalability by dramatically decreasing the cost and increasing the efficiency of producing drugs.

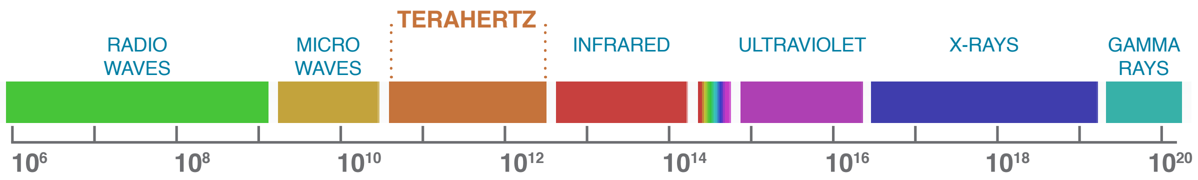
As the capabilities of biotechnology increase, so will the ethical dilemmas associated with them. The manipulation and patenting of genes, in particular, is a controversial procedure, and products derived using those techniques is banned in many countries. The power to reformulate the biological world presents enormous potential benefit for the environmental sustainability and the human race. Scientists are tirelessly working to address these concerns, and to generate safeguards to ensure that biotechnology may be effectively implemented without harmful effects. With these advances, the astounding potential of biotechnology will come to fruition, and will continue to transform society and health for the years to come.

TERAHERTZ

THz technology combines subsurface imaging and spectroscopy in a single device. Its market will grow from $127 million in 2016 to $570 million in 2021.

State of the Technology

Disruptive technologies, particularly in the analysis and imaging fields, have extended sensing beyond our biological capabilities, augmenting our ability to better understand the world around us. Our naked eye is limited by distinct thresholds of recognition: it is only capable of responding to electromagnetic radiation that falls between the wavelengths of 390-700 nanometers. However, the electromagnetic spectrum extends far beyond that range, on either side of the small span that our eyes can see. Technologies that utilize the properties of this "unseen" electromagnetic radiation have been a revolutionizing force in a countless number of applications, including those within manufacturing, biotechnology, medicine, communications, and computer science.



On the energetic side of the spectrum, the ability to harness X-rays has led to the development of non-destructive imaging, most widely used in medical and, security applications. Development of X-rays has also led to advances in crystallography and proteomics through X-ray diffraction and spectroscopy techniques.[1] Placed in perspective, the global X-ray market reached $10 billion in 2012, and is expected to increase by 18% to $12 billion by 2017.[2] On the less energetic side of the electromagnetic spectrum, radio waves are the basis for nearly all wireless data and communication globally, and are estimated to be at the core of a $2.1 trillion dollar industry by 2017.[3]

1 Discovery of X-rays and some of their uses
2 Global X-ray equipment market hits $10 billion, 2013
3 Global telecommunications industry revenue to reach $2.1 trillion in 2012, 2012

What are terahertz waves?

Between radio waves and the visible spectrum, lies a band of electromagnetic frequencies that has previously been understudied, but holds the capacity to be a disruptive force in sectors such as imaging, object recognition, chemical/biomedical analysis and communication. This spectrum band consists of frequencies ranging from 0.3 THz - 3 THz.[4] The utilization of this portion of the spectrum was previously limited by the technology used to generate and detect electromagnetic energy, but that is changing now.

Certain frequencies within the terahertz range are capable of penetrating through several millimeters of tissue, and unlike X-rays, are non-ionizing and do not damage tissues and DNA. Electromagnetic radiation in the terahertz range will also enable previously inaccessible advances in chemical and structural analyses. It will have a pervasive effect in sectors as varied as pharmaceutical production, homeland security, point-of-sale retail management and advanced computer-based object recognition. Therefore, terahertz-based technologies have the ability to capture existing markets, such as healthcare, defense, and wireless communication, while improving upon existing technologies and opening the possibility for new market opportunities.

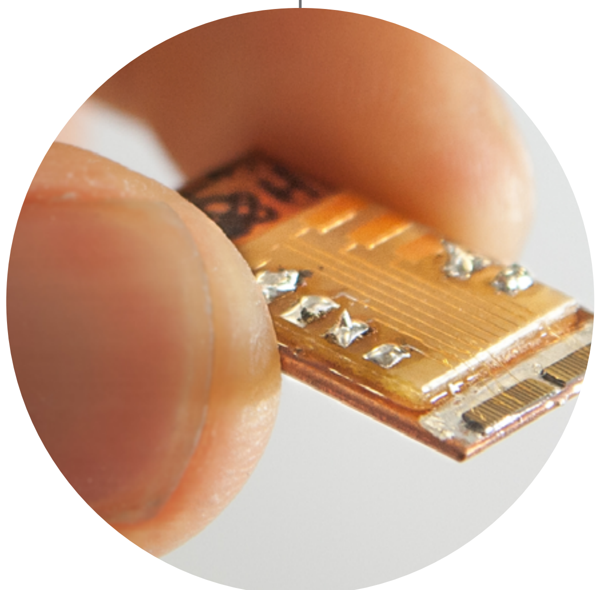
The market for THz products will reach $570 million by 2021.

4 Terahertz radiation

Shrinking Technology.

With the advent of increasingly smaller and cheaper wireless chips, terahertz technology is poised to revolutionize an even broader range of technologies for portable and personal use. In 2011, the semiconductor company, Rohm, introduced a silicon chip/antenna capable of transmitting terahertz waves at 1.5 Gbps. It measured only 3mm x 1.5mm, and cost less than $5 per unit. In 2012, researchers at the Imperial College of London and A*Star Institute of Singapore pushed the envelope even further, unveiling a terahertz antenna that measures a mere 100 nanometers. Terahertz wave technology, previously only available in large and bulky machines, is rapidly emerging into the field of handheld and portable devices.

RECORD OUTPUT POWER — 1 WATT



Source: TU Vienna

Growth & Demand.

Terahertz research is now at an all-time high, and will continue to grow dramatically in the approaching decades. There has been nearly exponential growth in the number of scientific publications regarding terahertz wave technology.[5] With each new breakthrough, terahertz technology becomes increasingly aligned to become a pervasive and disruptive force, with the market size rapidly expanding as the technology is refined and applications are diversified. Researchers estimate that the market size for terahertz radiation in 2011 totaled $83.7 million, during the relative infancy of terahertz research. They projected that the market size for terahertz applications will grow to $127 million by 2016, and reach $570 million by 2021, with a compounded annual growth rate (CAGR) of 35% during that time.[6]

5 "The growth of biomedical terahertz research." J. Phys. D: Appl. Phys. 47 (2014) 374009 (11pp)
6 "Terahertz Radiation Systems: Technologies and Global Markets." bcc Research, Report Code IAS029B, March 2012

Case Studies

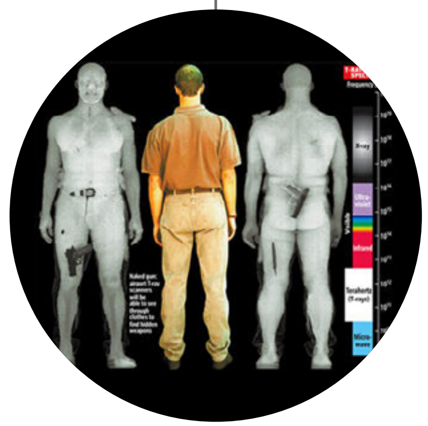
Security to Healthcare: Non-invasive imaging

Similar to X-rays, terahertz waves are being utilized for imaging purposes. The main advantage it has over X-ray-based devices is that the terahertz waves are non-ionizing, and therefore safer, and more widely applicable to repeated exposure and everyday use.

Move over millimeter scanners.

The physical security hardware market was valued at $36.48 billion in 2012, and is estimated to grow at a CAGR of 15.1% from now until 2019.[7] In May 2014, the world's first terahertz airport scanner developed by China Electronics Technology Group Corporation, a major defense company in China was debuted at the China International Defense Electronics Exhibition.[8] The new terahertz-based scanner touts significant improvements over the sub-millimeter scanners that are currently employed in the US today. For example, this new THz-based scanner would be able to scan continuously, screening over 500 people per hour. In addition, it has the ability to detect metal objects as well as non-metal materials such as ceramics, powders and liquids, all the while not revealing any specific body parts. Another British company, Digital Barriers,[9] has developed ThruVision, a terahertz-based scanner that claims to be able to distinguish a bag of flour versus cocaine from 80 feet away, while in motion.[10]

THE PHYSICAL SECURITY HARDWARE MARKET WAS VALUED AT $36.48 BILLION IN 2012, AND IS ESTIMATED TO GROW AT A CAGR OF 15.1% FROM NOW UNTIL 2019.



Source: Inteli-tech, Int'l. Product Review

7 Physical Security Market Analysis 2013 - 2019, 2014
8 China debuts first terahertz scanner for security checks, 2014
9 Digital Barriers, ThruVision
10 British company advances see-through camera tech, 2008

"He's dead Jim."

When tuned properly, terahertz waves of a slightly higher energy can safely penetrate a few millimeters of subcutaneous tissue. This allows for greater visibility and the potential for use in subcutaneous medical imaging and diagnostics. Qualcomm, a leader in communications technology is investing heavily in this potential. They have announced a $10 million prize, to be given in 2016, named the Qualcomm Tricorder XPrize competition[11], wherein contestants are to develop a "portable, wireless medical diagnostic device that fits in the palm of your hand", reminiscent of the fictional "Tricorder" featured in the futuristic series "Star Trek." The Scanadu Scout, which utilizes terahertz waves to decipher health metrics, is being heralded as a front-runner in this competition.

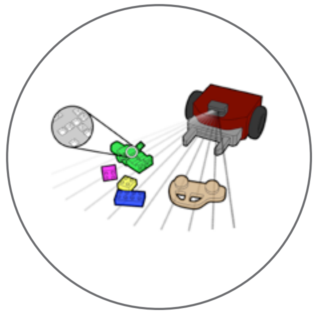
Scanadu Scout (size)

Source: Scanadu

In 2012, Scanadu presented details of the Scout, a hand-held sensory device, in order to acquire crowdsourced funding.[12] The proposed device is small and affordable (retailing at a price point under $200), and can determine heart rate, respiration, and temperature when held in the proximity of a person. It may be utilized in a home setting, and can be integrated with smart phones that record, interpret, and store health data. The Scanadu Scout rapidly became the most funded campaign in Indiegogo history[13], reaching its goal of $100,000 within 2 hours, and eventually acquiring over $1.6 million in funding. It is currently awaiting FDA approval, and shipment of the first prototype is on its way.

Decoding Hidden Messages.

Currently, Barcodes, RFID tags, QR codes, etc are being used to track products, but what if you could embed information directly in the product? Infrastructs, a joint venture of Microsoft and Carnegie Mellon University, in 2013 developed a method of incorporating identifiers and tags into the interior structure of 3D printed objects.[14] Once a message is embedded into a product, the terahertz rays are then used to image the structurally encoded message. Because the Infrastructs tag would be integrated into the structure of the object, it would cost only programming time. Additionally, it would eliminate the cost (currently around .5¢ for barcodes, 5-10¢ for RFID tags) and time necessary for tagging each item for retail sale. While this might not seem like much, barcodes are used en masse in the retail sector. A single Amazon.com warehouse can ship upwards of 450,000 items per day. This means the company could save $34 million annually in barcode costs across its 40 warehouses if Infrastructs was successfully implemented.



Source: Infrastructs

Concepts like Infrastructs pave the path for greater integration into every-day objects. Although embedded tracking may only apply to products currently, future applications may include advanced augmented reality, real-time gaming systems, and automated robotic systems for the purposes of object recognition and navigation at the industrial scale.

11 Qualcomm Tricorder
12 Scanadu Scout
13 Scanadu Scout breaks Indiegogo record with $1.37M for 'medical tricorder', 2013
14 InfraStructs

Cost Savings: From Chemical Analysis to Quality Control

Differentiating diamonds from graphite.

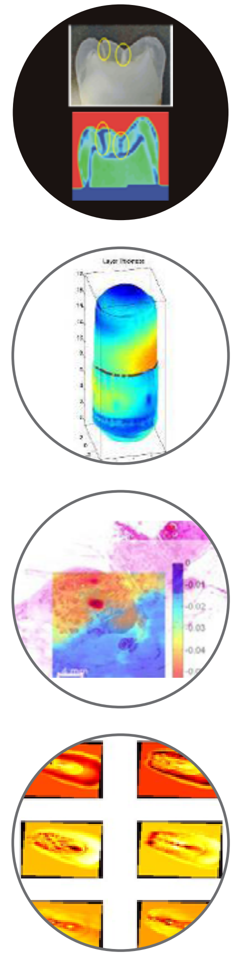
Existing technologies, like Raman spectroscopy, have enabled rapid chemical analysis, but current methods are not capable of detecting structural polymorphisms that are of crucial relevance in materials analysis.[15] Conversely, terahertz waves can identify a chemical's specific signature, including differentiating between elemental allotropes. This property allows applications that utilize terahertz waves to perform compositional analysis more precisely and efficiently. For example, terahertz waves would be able to differentiate between diamond, graphite, graphene and carbon nanotubes, all of which have the exact same chemical makeup, but vastly different chemical properties due to variations in the geometric arrangement of the atoms.

Teraview[16], a startup founded in 2001, entered the US market in 2006 with their proprietary TPI™ systems, which utilize terahertz rays for spectrometry in order to analyze chemical composition and structural integrity. Teraview believes the addressable US spectroscopic market to be approximately $850 million.[17] This concept forms the basis of Teraview's novel detection systems, which have been utilized in homeland security, basic research, and for quality control in production lines. Teraview has delivered the next generation of material composition analyzers to top universities around the world, and has also begun marketing their sensors for the purpose of pharmaceutical quality control.

Quality Control.

Currently, much of the pharmaceutical industry utilizes visual confirmation for pill integrity, a process that necessitates hours of personnel training, as well as the associated costs of worker wages, losses due to fatigue, and human error. Terahertz sensors have the ability to dramatically increase speed and accuracy while decreasing costs across all industries involved in quality control and product validation.

Several companies have risen to the challenge of addressing this large market segment. Zomega Terahertz Corporation,[18] TeraOptronics,[19] and Teraview are a few companies vying to enter the pharmaceutical space. Another company entering this space is Advanced Photonix, Inc., which announced this October, that it has signed a value-added reseller (VAR) agreement for its T-Gauge® industrial terahertz gauging system with Seltek Ltd, a leading manufacturer of measurement and process control systems.[20]



Applications of Terahertz imaging technology

top to bottom: tooth decay, pharmaceutical coatings, cancer biopsies, agricultural quality control.

Source: Teraview

15 SPECTROSCOPY: Terahertz Raman: Accessing molecular structure with Raman spectroscopy, 2013
16 Terahertz Technology: 3D Imaging and Spectroscopy
17 TeraView Reveals Plans for Push into US Market, 2005
18 Pharmaceutical Applications, 2011
19 Award Winning Technological Spin-Off Company
20 Advanced Photonix, Inc. Signs VAR Agreement with Seltek Ltd., 2014

Beyond Imaging

100 Gbps.

Terahertz rays, because of their specific wavelength, have, in addition to their imaging/detection capabilities the intriguing ability to function as a method of transferring information. Several companies are currently in the process of harnessing the power of terahertz rays to transfer wireless data at unprecedented rates. In 2012, the Tokyo Institute of Technology developed a terahertz chip capable of transmitting data at rates of up to 3Gbps, a dramatic improvement upon the capabilities of the most advanced WiFi standard, which currently has a maximum rate of 1.3 Gbps. Researchers theorize that terahertz waves may eventually be used to deliver data transfer rates of up to 100 Gbps. Amazingly, this Japanese chip is less than 2.5 cm in length, smaller than a 10-yen coin.[21]

THE SMALLEST TERAHERTZ CHIP WAS CREATED AT RICE UNIVERSITY IN JUNE 2014

Source: Rice University
Credit: Jeff Fitlow

250% More Battery Life.

The Japanese company KEEP has developed a new method, in which it has employed terahertz waves to increase the efficiency of solar panels by 40% and the battery life of lithium-ion (Li-ion) batteries by 250%.[22] This technology, named KEEP-TERAHERTZ is an advanced version of terahertz technology. KEEP uses terahertz waves, radiating at a low temperature to increase the performance of raw materi-als, a fairly unexplored concept. KEEP has passed the fundraising phase, and plans to go public within two years.

21 Terahertz frequencies bring Japanese researchers 3Gbps in a WiFi prototype, 2012
22 http://www.digitaljournal.com/pr/2261428

Future Directions

Like X-rays, microwaves and radio waves, terahertz radiation is poised to have a pervasive, disruptive effect on technologies spanning countless applications and sectors. The advent of smaller and more efficient terahertz producing chips allows for the incorporation of the technology into handheld devices, opening up the market to appliances that may be used by the average consumer in their home and daily activities.

Imaging.

The spectroscopy and imaging capabilities of terahertz waves are already revolutionizing chemical analysis in laboratories, clinics, and security checkpoints. The technology provides superior analytics over current methods, while still being safe and low-risk due to its non-ionizing characteristics. As THz imaging continues to evolve, diagnostic capabilities will only increase, perhaps allowing for non-invasive real-time status updates from within the human body, much like Star Trek's "tricorder".

Manufacturing & Quality.

The imaging capabilities of terahertz waves will also contribute to faster quality control in pharmaceutical production lines, a process that could easily be refined with the addition of automated programming. Compared to analysis by visual confirmation, terahertz imaging would provide a more rapid, streamlined and uniform process. The chemical analysis capabilities of terahertz imaging can also be integrated into the process of pharmaceutical analysis, allowing for the detection of incorrect formulations or intentional drug counterfeiting, techniques that could potentially revolutionize this $1 trillion industry.

Communication.

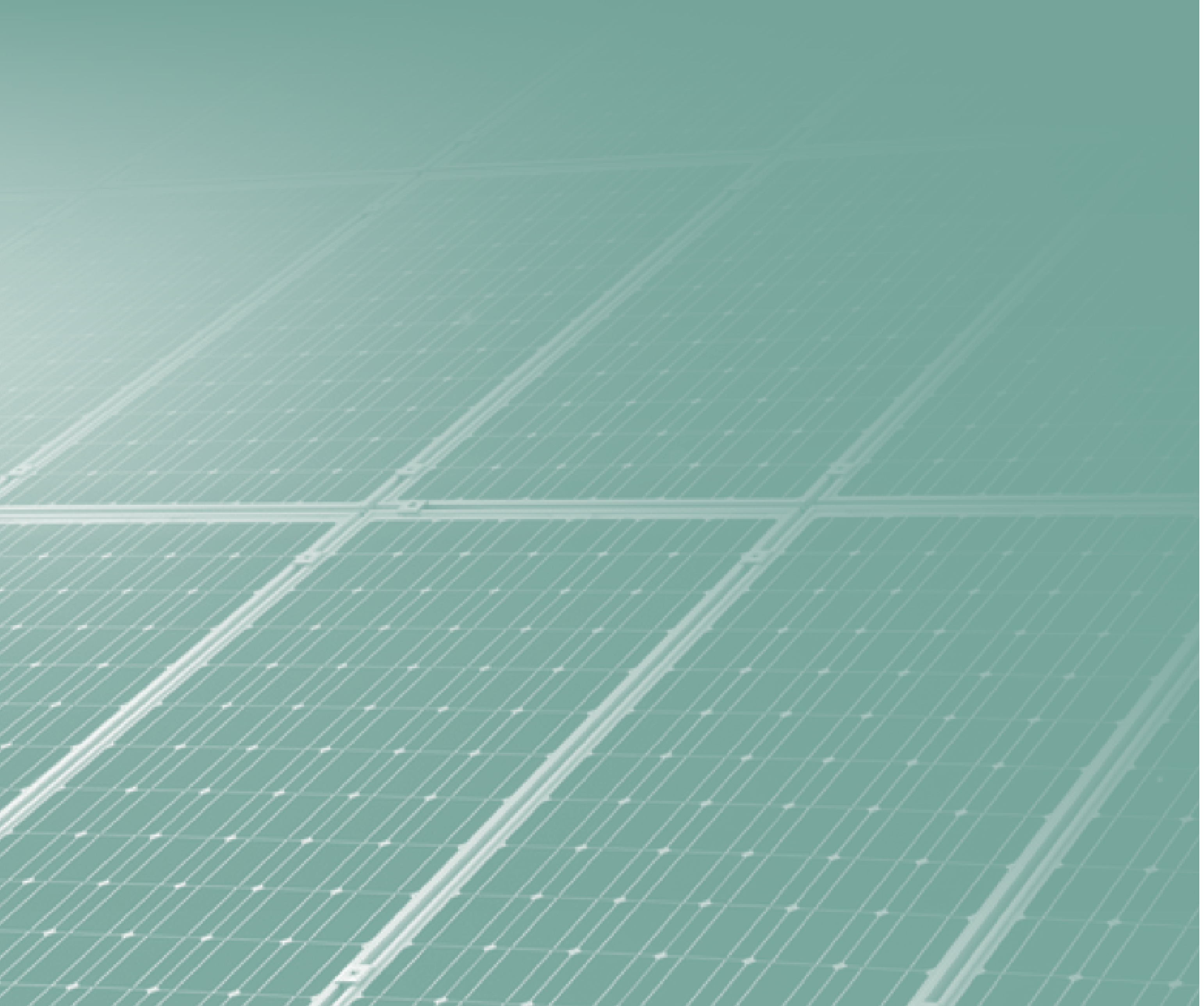
Terahertz waves also have begun to revolutionize wireless data transfer and are delivering data rates up to 20 times higher than currently employed WiFi systems. However, data transfer is currently limited to short ranges, and may be more applicable for device-to-device data transfer rather than long-range communications. Terahertz waves are also susceptible to atmospheric interference and therefore, further developments will be necessary for the technology to be utilized as a reliable form of sustained wireless communication.

Other Applications.

The advanced imaging capabilities of terahertz wave technology have far-reaching applications. It has been proposed to be of use in the non-invasive analysis of rare art and artifacts, as well as for the detection of structural flaws in the coatings of reusable spacecraft and building foundations. Similar to its potential uses in the pharmaceutical industry, terahertz imaging will bring fast and affordable quality control to agricultural produce supply chains, allowing for the detection of damaged or sub-par fruit in an automated manner.

ADVANCED ENERGY

The global renewable electricity capacity has doubled since 2000. In 2012, renewable energy accounted for 14% of total installed capacity in the United States, but over 56% of all the new electrical capacity installations.



State of the Technology

The global demand for energy is currently 156 billion megawatt hours (MWh) per year, or roughly 22 MWh per person (79 MWh per person in the US), and is expected to grow by more than 10% over the coming decade.[1] The development of new energy resources is essential for the activities that we consider prerequisites for modern society. Yet our ever-growing thirst for energy has not been quenched by significant growth in generation capacity or efficiency, placing increasing demand on fossil fuel reserves, which account for 80% of the world's primary energy supply.[2] We must find ways to sustainably meet our increasing demand for energy. Nobel Laureate Richard Smalley famously remarked to the Senate Committee on Energy and Natural Resources in 2004,

"Energy is the single most important challenge facing humanity today… For worldwide peace and prosperity it must be cheap. We simply cannot do this with current technology. We will need revolutionary breakthroughs to even get close."[3]

The challenge is enormous, but with an enormous challenge comes an enormous potential for rewards. These projected shortages are fueling massive public and private investments in the energy sector. Technologies currently under development will provide the revolutionary breakthroughs needed to sustainably and profitably transform global energy supply and demand, with the promise of generating increases in energy productivity on a scale not seen since the Industrial Revolution.[4] "There is tremendous opportunity for disruption in new energy services that we do not have today", says Arun Majumdar, former director of the US Department of Energy's Advanced Research Projects Agency-Energy, who likens the transformative potential of up-and-coming technologies to the electrical lighting that superseded whale oil.[5] New energy technologies could underpin advances that cannot be anticipated at present, and rapid developments in energy production, recapture, and storage are already showing promise for disrupting the traditional energy marketplace.

1 International Energy Agency, Key World Energy Statistics (2014)
2 Disruptive Technology: Renewable Energy
3 Our Energy Challenge
4 McKinsey, Report on Sustainability & Resource Productivity (Summer 2012)
5 Energy disruptors: Arun Majumdar on disruptive energy innovation

Alternative energy sources.

Research into new technologies for improved energy solutions continues to flourish. For example, though traditional photovoltaic (PV) cells have limited commercial viability, the technology underlying these cells has improved by orders of magnitude in recent years, and innovation continues to accelerate. As a result, many technologies are projected to outperform traditional gas and coal power plants much faster than expected. In addition, renewable sources of energy will be necessary to meet regulatory requirements for decreased emissions, such as California's goal to make all new residential construction zero net energy by 2020.[6] The global renewable electricity capacity has doubled since 2000. In 2012, renewable energy accounted for 14% of total installed capacity in the United States, but over 56% of all the new electrical capacity installations.[7]

Solar and wind. Solar power has the greatest potential for accelerated adoption in the coming decades. In 2013, grid parity was reached in various regions, including California, Australia and Germany. The cost of Solar PVs is expected to fall to as low as $40 per MWh in the coming decades. It could become the biggest single source of energy by 2050, with expected share of global electricity reaching 16%.[8] Onshore wind power technology has almost achieved parity with coal and gas, and it could supply as much as 10% of the global electricity by 2025.[9] Collectively, solar and wind power could generate an economic value of up to $275 billion annually by 2025, most of which would directly lead to an increase in power generating capacity.[11]

Biofuels. Another key energy source is biofuel, which has the potential to create near-term revolutionary change due to increases in production and efficiency. First-generation feedstocks for ethanol and biodiesel could provide for 10–15% of the global transportation fuel demand. Major oil companies appear to be invested in this area for the long term. For example, ExxonMobil recently invested $600 million in algae research in cooperation with Synthetic Genomics.[10] The US government has invested $100 million in the nation's first commercial-scale cellulosic ethanol plant to use corn waste as a feedstock, which recently started production. This plant will produce enough ethanol from corn cobs, leaves, husks, and corn stalks harvested by local farmers to power about 70,000 homes.[11] New innovations in this area may result in biofuel prices of $2 per gallon or less by 2020.[9]

Renewable energy is predicted to create $275 billion in annual economic impacts by 2025

6 California Zero Net Energy
7 US Department of Energy, "Renewable Energy Data Book" (2012)
8 International Energy Agency, Technology Roadmap: Solar Photovoltaic Energy (2014)
9 McKinsey Global Institute, "Disruptive technologies: Advances that will transform life, business, and the global economy" (May 2013)
10 Accenture, "Betting on science: disrupting technologies in transport fuels" (2010)
11 Project LIBERTY Biorefinery Starts Cellulosic Ethanol Production, 2014

Energy recovery.

Energy recovery represents a complementary approach to maximize the efficiency of energy produced by both conventional and alternative sources, by recycling input power for desired work instead of releasing it directly back to the environment. Studies have suggested that up to 20% of total power capacity could be made up from recycling industrial heat waste in the US (enough electricity to replace up to 400 coal-fired power plants).[12] Thermal recapture has been utilized for over a decade in industry. For example, in 1998 ArcelorMittal installed 16 boilers and a recovery turbine at its steel mill in East Chicago, IN to capture about 250 MW of waste energy, which is about half of the electricity it uses each day. Energy recycling saves ArcelorMittal tens of millions of dollars a year in energy costs, and has reduced carbon dioxide emissions by 1.3 million tons annually.[14] Recent innovations have also brought this technology into the transport space. Formula One cars in the 2014 season are being outfitted with a Kinetic Energy Recovery System that can reduce fuel consumption by up to 35% and result in a 10x boost in electric power as compared to the previous model.[13] Piezoelectric devices are small solid state devices that can be used to harvest vibrational energy. While these devices have traditionally generated microwatts of power, recent advances in material processing has increased their output to milliwatts, putting their output in the same order of magnitude as the input requirements for most microelectromechanical systems (MEMS).[14] This could lead to the use of completely wireless sensor networks that could remain powered for decades.

Improved storage.

The implementation of renewable sources of energy will be dependent upon advancements in other technologies, particularly in energy storage. Improved storage capacities will help integrate the periodic flows of wind and solar-based energy into the grid, make distributed generation more practical and provide new applications for battery-powered consumer devices and electric cars.[2] Lithium ion (Li-ion) batteries power current electric vehicles (EVs), and as their capacity improves and costs decline the EV could become as affordable as a vehicle powered by an internal combustion engine,[15] with a possible economic impact of $415 billion annually.[11] Superconductors represent a promising alternative approach to advanced energy storage. Nearly 10% of all electricity is lost as electrons travel from the power plant to the end users. Superconducting technologies currently being developed would help minimize these energy losses, increasing the overall efficiency of the power grid.[16] Overall, improved batteries would allow for better frequency regulation and peak load shifting, making intermittently available energy from renewable sources more feasible and deferring the need for further investments in infrastructure for energy distribution, with a potential economic impact of $35 billion annually by 2025.[11] Finally, improved energy storage will prove vital for the development of distributed energy (on-site generation). This would stabilize an unreliable power supply and provide a means of getting electricity to remote and undeveloped areas. The economic impact of distributed energy, including the potential for economic gains in developing countries, is estimated to reach $150 billion by 2025.[11]

12 'Recycling' Energy Seen Saving Companies Money, 2008
13 2014 Formula One exhaust energy recovery system explained, 2013
14 Energy Harvesting Comes of Age, 2012
15 Disruptive Technology: Energy Storage
16 Superconductors

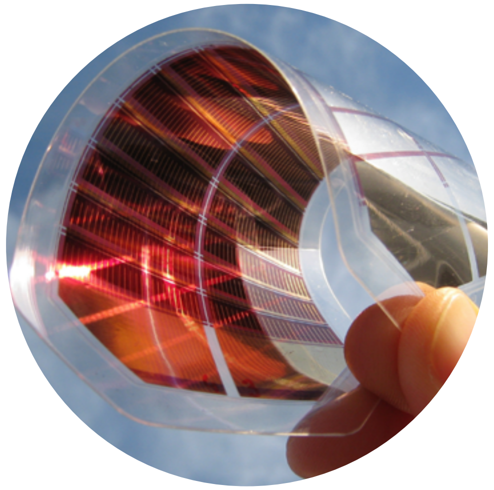
Case Studies

Energy production from a variety of renewable resources and enhanced storage promises to increase efficiency and reduce costs. While the future holds tremendous uncertainty regarding which specific technologies will thrive, it is clear that several key technologies hold great promise.[9] Here, we highlight a few examples of novel approaches that are delivering concrete results, and are likely to impact the energy industry by 2025.

Solar power.

Organic solar cells. Organic PV cells provide a unique method to make solar power both more efficient and easier to install. These solar cells are made of small organic molecules that act as semiconductors when struck with solar radiation.[17] Efforts to improve the efficiency of traditional solar cells have faltered because many common metal electrodes are typically unstable and susceptible to oxidation. This "electrode barrier" means that these materials obstruct the power conversion efficiency of organic solar cells. Recently, a team from the University of Massachusetts Amherst developed a novel organic solar cell that bypasses this problem, allowing virtually any metal to act as the electrode without facing the deleterious effects previously experienced.[18] And earlier this year, scientists at the National Physical Laboratory in the United Kingdom developed an organic PV cell that works best when cloudy, achieving 13% efficiency versus 10% in direct sunlight. These numbers seem less efficient than conventional solar cells, until you consider the most striking aspect of this technology: these cells can be cheaply printed into any shape, size or color using 3D printing technology. These customizable, easily installable PV panels are expected to have a sizable market share within five years.[19]

CHEAP, 3D PRINTED ORGANIC SOLAR CELLS THAT WORK BEST WHEN CLOUDY



Source: National Physical Laboratory, UK

17 Organic and Printed Electronics, OPV
18 Electrode Barrier' Broken for Organic Solar Cells, 2014
19 Scientists 3D Print New Solar Panels Which Work Best When Cloudy, 2014

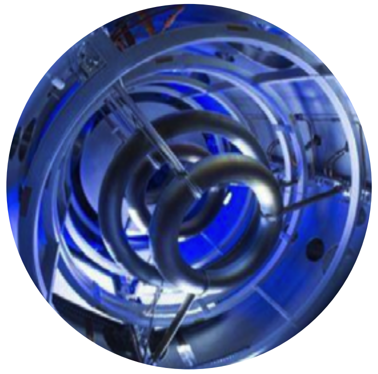
Transparent solar cells. Imagine if the windows in your house or office building could be replaced by invisible solar cells to generate electricity without appearing as anything other than ordinary glass windows. Luminescent solar concentrators (LSCs) transmit visible light but capture energy from ultraviolet and near-infrared wavelengths.[20] The startup company Ubiquitous Energy has developed a transparent coating (ClearView Power™) that enables any surface to act as an LSC without impacting the way it looks.[21] ClearView Power™ does not require changes to the existing infrastructure, and could be installed in a similar manner to existing infrared-rejecting films meant to reduce heating and cooling costs. The only difference is that it would generate power.[22] Researchers at Los Alamos National Laboratory and the University of Milano-Bicocca have recently demonstrated an alternative approach to producing transparent LSCs, wherein the superior light-emitting properties of quantum dots are used to efficiently harvest solar energy from windows.[23] These technologies are completely unobtrusive, unlike solar panels or colored LSCs. This means they have the potential to become ubiquitous, resulting in affordable scaling to commercial or industrial applications.

A transparent coating that could turn any glass surface into a solar panel.

Source: Michigan State University

High beta fusion power. Fusion power is often viewed as science fiction, with its promise of unlimited clean energy based on tapping into the power source of stars. But it may be much closer to reality than most people realize. Lockheed Martin plans to test a prototype for a high beta nuclear fusion reactor in 2017.[24] In this compact 100 MW reactor, deuterium gas is heated up with radio frequency energy to generate plasma and magnetic fields that can hold and confine the fusion process. Traditional fusion concepts have centered around a Tokamak ring, which must be built on a huge scale and will not be ready for use in a power plant until 2040.[25] In contrast, Lockheed Martin's high beta fusion reactor measures just 2 meters in diameter and 4 meters in length, and a fully operational machine should be grid-ready by 2022. By 2050, this technology could be able to meet global base-load energy demand.[26] The potential benefits of fusion energy are countless: zero emission, safe and plentiful input materials, and no threat of a meltdown.[27]

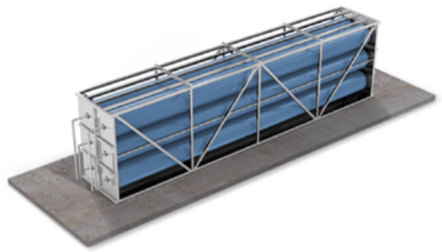
THE COMPACT FUSION REACTOR TEAM AT LOCKHEED MARTIN WITH THEIR PROTOTYPE, WHICH OFFERS A 90% SIZE REDUCTION OVER PREVIOUS CONCEPTS



Credit: Eric Schulzinger/Lockheed Martin
Source: Lockheed Martin

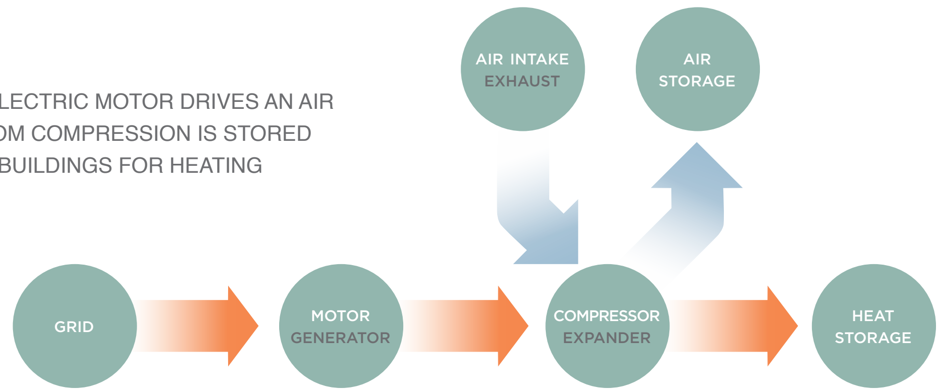
20 Scientists 3D Print New Solar Panels Which Work Best When Cloudy, MSU, 2014
21 Ubiquitous Energy
22 Totally Transparent Solar Cells Could Turn Our Windows Into Solar Panels
23 House windows that double as solar panels? Shiny quantum dots brighten future of solar cells, 2014
24 Charles Chase On Energy For Everyone
25 Can Fusion Energy Generate Unlimited Clean Energy by 2017?, 2013

Heat energy recapture. Energy recapture is an ideal solution to increasing energy consumption, as industrial processes discard tens of MW in thermal and vibrational energy as waste. LightSail Energy uses a method to capture heat energy from compressed air, which has previously been wasted, to re-generate useful energy. Experimental results have shown 90% round-trip thermal efficiency, without sacrificing performance.[26] The company has raised over $37 million in venture capital funds, from investors such as Bill Gates, Vinod Khosla, and Peter Thiel. This technology has the potential to "totally disrupt the electricity industry's assumptions with reliable grid-scale storage at a fraction of the cost of today's battery technology," [27] says Khosla. LightSail could provide grid scale storage as cost-effectively and efficiently as pumped-storage hydroelectricity, but without geological restrictions. LightSail Energy believes that its first-generation product will help renewable energy resources produce cheaper electricity than diesel generators, and that its second-generation product "will be the first energy storage system to outcompete gas peaker plants and will drive massive adoption of green energy worldwide."[28]

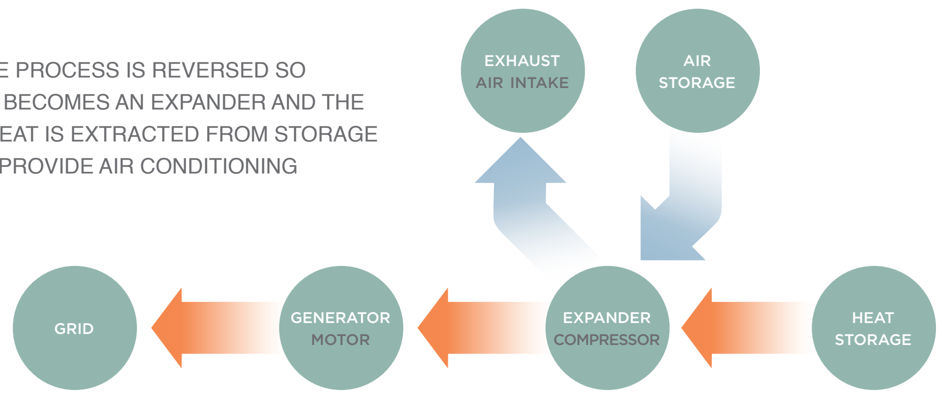


THE CONCEPT FOR A TECHNOLOGY THAN CAN CAPTURE HEAT ENERGY FROM COMPRESSED AIR TO PROVIDE DRAMATIC IMPROVEMENTS IN BUILDING ENERGY EFFICIENCY

TO STORE ENERGY, AN ELECTRIC MOTOR DRIVES AN AIR COMPRESSOR; HEAT FROM COMPRESSION IS STORED OR ROUTED TO NEARBY BUILDINGS FOR HEATING



TO DELIVER ENERGY, THE PROCESS IS REVERSED SO THAT THE COMPRESSOR BECOMES AN EXPANDER AND THE MOTOR A GENERATOR; HEAT IS EXTRACTED FROM STORAGE OR FROM BUILDINGS TO PROVIDE AIR CONDITIONING

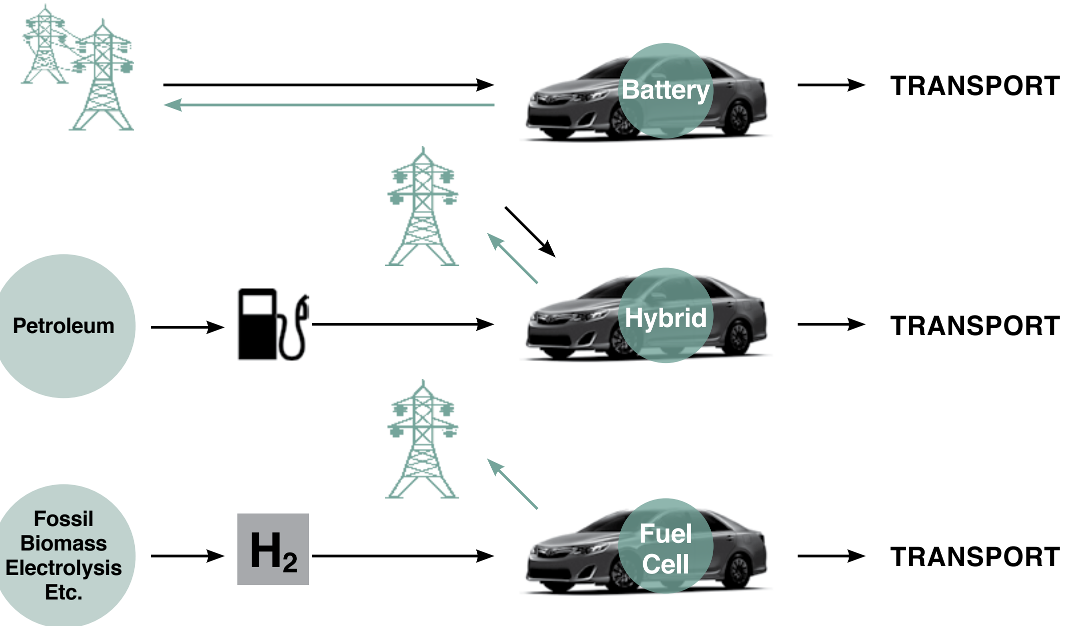


Source: LightSail Energy

26 We Store Energy in Compressed Air
27 LightSail Gets $37.5M From Thiel, Khosla, and Gates for Compressed Air Grid-Scale Storage, 2012
28 Compressed Air Energy Storage from LightSail Energy, Nanalyze, 2014

Supercapacitor storage. What if you could charge your smartphone in just a few seconds? Supercapacitors can achieve this feat, but existing devices do not store as much as batteries. Furthermore, state-of-the-art devices are too big and expensive for this task. But a new technology may break this impasse. BioSolar, Inc. recently filed a patent for a breakthrough supercapacitor technology (BioSuperCap™) that can be charged and discharged hundreds of times faster than conventional batteries and hold more energy than conventional supercapacitors. BioSuperCap™ uses a low cost polymer-based supercapacitor to bypass the limitations of conventional supercapacitors, making it up to 75% less expensive than conventional supercapacitors and efficient enough to work in a range of applications, from consumer electronics to the electricity grid.[29]

Distributed energy. Rather than remaining an unnecessary burden on an over-taxed electricity grid, EVs have the potential to become an integral part of power grid operation by acting as a distributed power system.[30] This "vehicle-to-grid" (V2G) or "cash back car" technology represents a cost-effective method of storing renewable energy and controlling its flow into the system to maintain a steady flow of power.[31] A single EV can output over 10 kilowatts, the average draw of 10 houses.[32] A pilot program between the University of Delaware and power-plant operator NRG Energy Inc. has already demonstrated the feasibility of this approach, using software to link a minimum of nine EVs, mostly Mini Coopers, together into a virtual power plant that can draw energy from the grid and discharge it as needed. When more electricity is produced than required, power is discharged to the car batteries for storage and then comes back out when demand rises. The utility agrees to pay for the reserved capacity whether or not it is used, and a controller in the EV ensures the battery is not drained. Although the cost of the necessary two-way chargers represents about $200 per car, this figure is easily compensated by the roughly $110 in monthly profit per car.[33]



Source: University of Delaware

29 A Breakthrough Supercapacitor for Storing the Energy of the Sun, BSC
30 Electric Drive Vehicles: A Huge New Distributed Energy Resource
31 Electric cars may hold solution for power storage, 2013
32 The Grid-Integrated Vehicle with Vehicle to Grid Technology
33 Electric Vehicles Sell Power Back to the Grid

Future Directions

Coexistence of conventional and novel technologies.

We have outlined several exciting technologies that could enable vast improvements in energy production from renewable resources. But traditional methods will not be pushed aside immediately. It is true that coal is on its way out in America: three quarters of all coal-fired power plants are at least 30 years old and, with an average lifetime of just 40 years,[34] many are on the verge of closing.[35] However, it is likely that most of these will be replaced with natural gas-fired power plants, which already produce most of the nation's electricity,[36] and which are also profiting from new technological breakthroughs such as hydraulic fracturing, also known as 'fracking'. Nonetheless, the dramatic growth of renewable sources means that these technologies should not be underestimated. Installed wind capacity is doubling every three years.[37] Solar PV grew at a combined annual growth rate (CAGR) of 57.3% from 2006 to 2011, and is expected to grow at a CAGR of 18.5% from 2011 to 2020.[36]

Regulations and subsidies.

The development of renewable resources has benefited greatly from subsidies, but these incentives will no longer prove necessary as these technologies become cost-effective due to technology improvements, scale in manufacturing, and reduced installation costs.[37] In addition, this change will give these newer technologies more political clout, and give rise to questions about subventions provided to traditional forms of power generation.[37] On the flipside, the trend in regulations favors the adoption of renewable energy sources. Although there are no renewable portfolio standards at the national level, in the US, 30 states had enforceable policies designed to increase generation from renewable resources as of 2012.[38] With regard to regulations, it pays to be ahead of the curve. Energy companies who invest and develop renewable streams of energy will not only be prepared for global, federal and state mandates, but they will also capture a positive public image in the process.

34 Most coal-fired power plants in the US are nearing retirement age, 2013
35 Sunny uplands, 2012
36 Significant Growth Predicted up to 2020, 2013
37 Solar Technology, PV (Solar Electric)
38 Most states have Renewable Portfolio Standards, 2012

The timeline of progress.

The technologies described tout massive gains in efficiency over traditional alternatives. How much longer can we expect these technologies to keep making gains? Let's consider the case of solar panels. The Shockley-Queisser limit first calculated in 1961 states that any type of single junction solar cell has a maximum efficiency of 33.7%. The best modern silicon cell efficiency is just 24%.[39] However, there are already multiple technologies under development that could beat this limit. Researchers at the Fraunhofer Institute for Solar Energy Systems in Germany have reported a solar cell that uses a lens to concentrate sunlight onto a stack of subcells in order to convert 44.7% of incoming light.[40] Meanwhile, researchers at the University of Cambridge Cavendish Laboratory boast that their hybrid solar cell, that layers an organic formulation on top of standard silicon solar cells, can achieve an efficiency of over 95%.[41] Finally, there are alternate strategies, such as the organic PVs and LSCs that we discussed earlier, which do not require such tremendous efficiencies because they have the potential to become so ubiquitous.

Combining technologies.

One important point to keep in mind is the uncertainty inherent in the realization of any of these technologies because advances in one field are dependent upon those in adjacent fields. Improvements in energy generation require advances in energy storage, which depend on other translational advances. Nevertheless, there are already numerous examples of ways in which this challenge is being overcome. For example, Pathfinder Renewable Wind Energy has recently proposed a massive project to deliver renewable energy to the Los Angeles area, in what is being touted as the 21st century's Hoover Dam, with the major difference being that it will be completely privately funded (with an estimated price tag of $8 billion). The company proposes to construct a 2.1 GW wind farm in Wyoming that will be coupled with a massive compressed air storage facility to be built 500 miles away in Utah. By linking the wind farm to the storage facility, a perpetual stream of low-carbon electricity will be supplied to the Los Angeles area.[42]

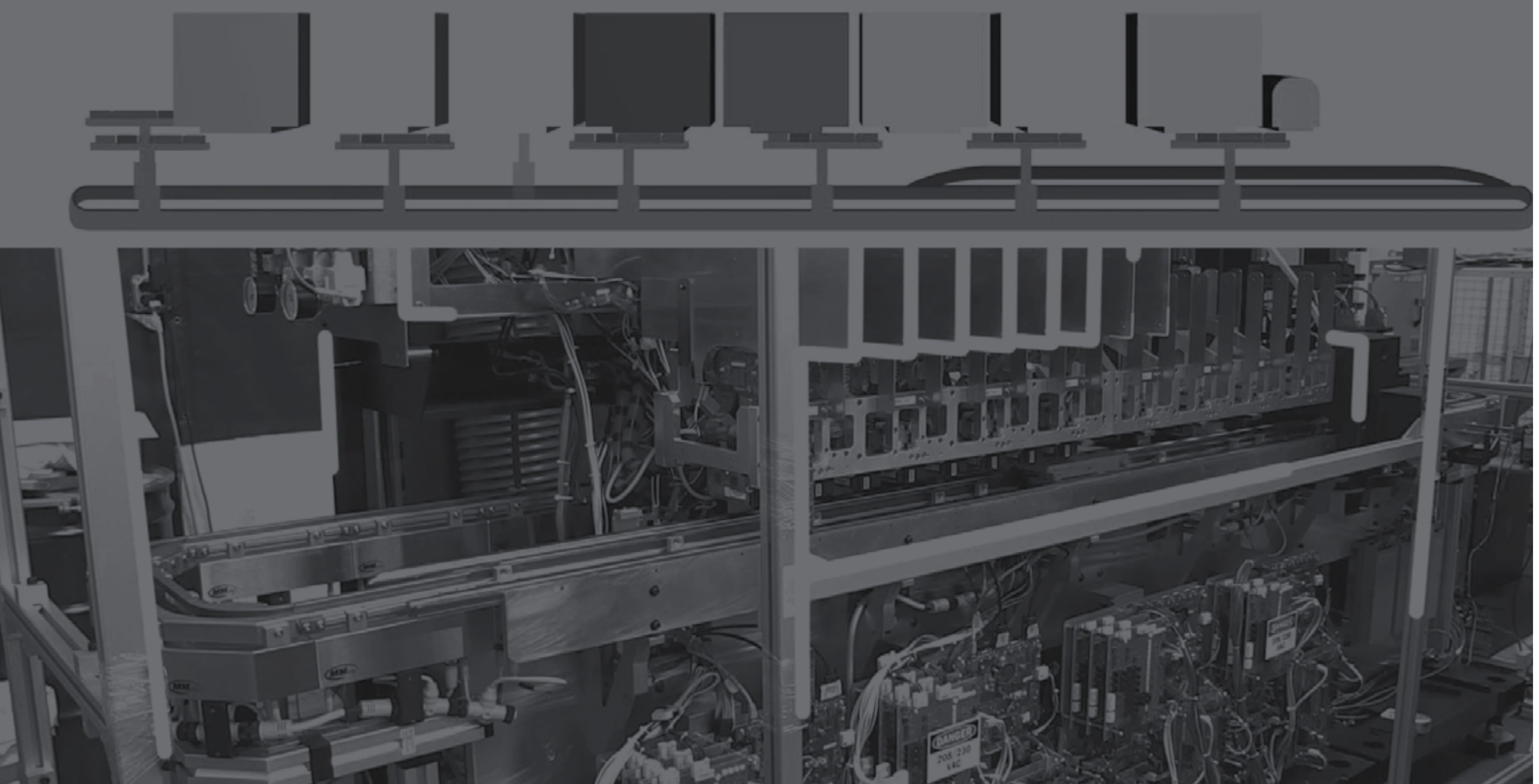
Decentralized, distributed production.

One exciting consequence of these technologies is the transformative potential they will have upon the way that energy is produced and distributed. We will start to see a shift from a centralized model, in which power plants form hubs of a large network, to a decentralized model, where individuals interact with the grid in a two-way exchange. Because solar panels can augment the power supply of individual buildings, widespread use of solar-based distributed electricity would decrease the need for expensive capital investments in grid infrastructure and greatly reduce the load on existing power plants.[2] Broad uptake of EVs presents another exciting opportunity for the distributed generation of electricity. As improvements in the Internet of Things enable the deployment of a smart grid, this approach will become increasingly feasible and profitable.

39 Solar Efficiency Limits
40 How It Works: The Highest-Efficiency Solar Cell, 2014
41 Hybrid Solar Cells Promise More Than 95% Efficiency, 2014
42 Going Private, 2014

3D PRINTING

Many of these companies are already in the process of adopting 3D printing as a part of their business model, with 98% of large companies and 85% of small companies either already in the process of adoption or planning to adopt it.



State of the Technology

The primary challenge in design has always been bridging the gap between what we can envision and what can be economically produced. The manufacturing methods available limit the practicality of production and influence the shape of our technology. For instance, the invention of machine tools in the early 19th century enabled the production of identical, high precision parts. This innovation enabled the development of interchangeable parts and lead to mass production. In the 1980s a new technology, 3D printing, was invented. It brings an entirely new set of capabilities to modern manufacturing.

3D Printing Technologies	
Stereo Lithography (SLA)	UV lasers are used to cure photopolymers. This was the earliest form of 3D printing and is the most common form of rapid prototyping.
Fused Deposition Modeling (FDM)	A heated extrusion nozzle melts a filament, commonly plastic. This is another form of rapid prototyping and the technique most commonly used in 3D printers for home and hobbyist use.
Selective Laser Sintering (SLS)	An infrared laser fuses a thermoplastic powder. This technique may be adapted to other materials.
Direct Metal Laser Sintering (DMLS)	A laser fuses a metal powder.
Electron Beam Melting (EBM)	An electron beam is used to melt a metal powder.
Bioprinting	A biosuspension containing live cells is extruded through a nozzle

What is 3D printing?

3D printing is the process of laying down successive layers of material, under computer control, to build a solid object. It encompasses a range of technologies based on the method or material used in deposition (see Table “3D Printing Technologies”). Because 3D printing does not require molds or specific tools to form the final product, it enables the rapid production of new products with minimal upfront investment, thereby making it an ideal platform for building prototypes to support rapid innovation.

Rapid Prototyping.

Computer Aided Design (CAD) drawings and the ability to digitally manipulate objects in three dimensions can help in the design of new products. They can help with subtle aspects such as:

i) How parts physically join together or interact,

ii) how they will function in a real-world environment, and

iii) the user experience of using the object.

Before the era of 3D printing, creating a prototype often meant creating molds and tooling equipment, which was an expensive and time-consuming process. As a result, development cycles were often slow and product engineers hesitated to try innovative designs.

Foundry tooling shops, such as Hoosier Pattern, have started using 3D printers in order to enable their customers to easily transform designs into reality. They use materials such as sand, which is versatile for printing out the mold of the foundry. In the past they often had to tell customers that their designs were too complicated to be practical. Now they can tell their customers to scale up their designs and even add complexity. If the first iteration doesn’t work, they can quickly and inexpensively make revisions and try again.[1]

1 Rapid Prototyping with Sand Sets a New 3D printed Paradigm for an Indiana Pattern-maker, 3D Printing Industry, 2014

Beyond Rapid Prototyping.

The potential of 3D printing extends beyond rapid prototyping. So far, the development of 3D printing has gone through four stages. After its initial use in rapid prototyping, it was used to test parts in systems. This was a use known as ‘functional prototyping.’ Subsequently, it was used to make complex tools, such as molds for injection molding, expanding the reach of traditional manufacturing technologies. 3D printing is now being used to produce functional parts.[2] It is possible to use 3D printing techniques with a wide range of materials (including polymers, ceramics, metals, and even living cells) to produce products in a wide range of sizes from the microscale (enabling the production of MEMS sensors, discussed elsewhere in this report)[3] up to the macroscale, including airplane wings[4] and houses.[5]

3D PRINTED OBJECTS SPAN A VARIETY OF SHAPES, SIZES AND USES

Source: Empire Cycles

2 3D Printing Promises to Revolutionize Defense, Aerospace Industries, 2014
3 Nanoscribe’s Technology
4 Cargo Forwarder Global, 3D Printing-Aircraft Production
5 The Printed World, Filton, 2011
6 Contour Crafting, RCS

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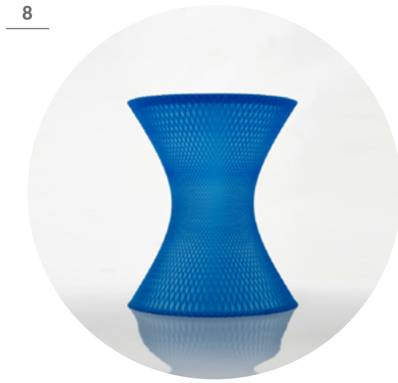

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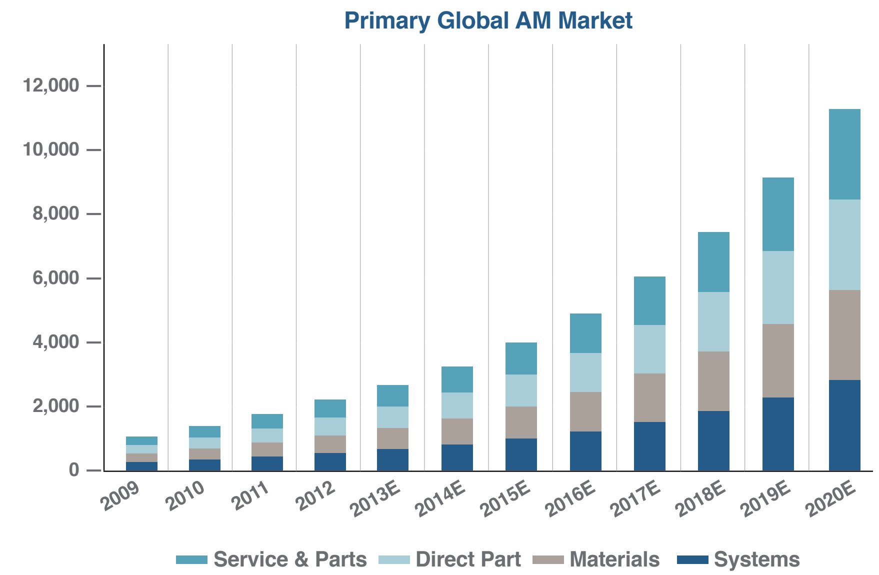
1 *Source: Shapeways*
2 *Source: MYKITA*
3 *Source: New Balance*
4 *Source: Shapeways*
5 *Source: Shapeways*
6 *Source: Shapeways*
7 *Source: Shapeways*
8 *Source: Thorsten Franck*
9 *Source: Solid Concepts*

While 3D printing is not yet a mature technology, it is rapidly becoming a viable part of the manufacturing toolbox. By using 3D printers, highly complex objects can be easily produced without a need for excess scaffolding or support materials. For example, material that is not structurally necessary can be omitted, reducing weight and cost. Assemblies that were previously machined as many small parts and later assembled together can now be printed as a single piece, reducing the need for extraneous production infrastructure. Moreover, 3D printing eliminates the need for expensive retooling for new designs (such as the production of molds), reducing costs for items produced in small quantities and facilitating incremental improvement and a shorter development cycle.[6]

Market Size.

The 3D printing market is significant and growing. A recent estimate indicates that the 3D printing market was worth $3.1 billion in 2013, up 34.9% from the previous year.[7] Continued strong growth is predicted, with several analysts projecting compound annualized growth rates between 20 and 45% over the next 15 years.[8] Sales volumes are also significant and growing. At the upper end of the market, 9800 industrial printers were sold in 2013 with 15,000 annual sales of industrial printers anticipated by 2015.[9] Consumer and enterprise printers (priced under $100,000) comprised an even bigger segment of net sales with over 56,000 units sold in 2013: an increase of 49% over sales from the previous year. Future sales are anticipated to increase by 75% and 100% in 2014 and 2015, respectively.[10] Because it has so much potential, many major organizations are making significant investments in 3D printing, including the United States Air Force (USAF), NASA, General Electric, Lockheed Martin, Boeing, Avio, SpaceX, and more. In fact, there are already 3D printed parts in satellites and aircraft, with more to come in the near future.



6 Additive Manufacturing: Pursuing the Promise
7 Roundup Of 3D Printing Market Forecasts And Estimates, Forbes, 2014
8 $100 Billion? $1 Trillion? Just How Big Is the Potential 3-D Printing Market?, 2014
9 The ‘Next Frontier’ for 3D Printing and Additive Manufacturing, Blue Sky Innovation, 2014
10 Gartner Says Worldwide Shipments of 3D Printers to Grow 49 Percent in 2013, Stamford, 2013

Case Studies

Aerospace.

Aerojet Rocketdyne is a leader in the development and manufacture of aerospace propulsion systems, precision tactical weapon systems, and armament systems, and they are making significant investments in 3D printing. In June 2014, they successfully test-fired a Bantam rocket engine which was produced entirely by 3D printing. Typically, such an engine is composed of dozens of parts. However, in this case, the prototype engine was printed in just three pieces; the injector & dome assembly, the combustion chamber, and the throat & nozzle section. By producing the engine using additive manufacturing, Aerojet reduced the total design and manufacturing time from over a year to several months, and brought down the cost of the engine by 65%. Intended as a proof of concept, this engine was based on the proven design of the Atlas Sustainer engine.[11] Even greater improvements in manufacturing efficiency are possible when products are designed using 3D printing rather than traditional manufacturing methods. This August, Aerojet was awarded an $11.75 million ($6.3 million from the USAF) contract for the development and demonstration of large-scale additive manufacturing.[12]

Source: NASA http://www.nasa.gov/content/nasa-industry-test-3d-printed-rocket-engine-injector/#.VFAFhvnF-So

11 Aerojet Rocketdyne Successfully Tests Engine Made Entirely with Additive Manufacturing
12 Aerojet Rocketdyne To 3-D Print Rocket Engine Parts under Air Force Demo, Space News, 2014

Medicine.

3D printing is playing an important role in medicine, as well. The ability to produce accurate anatomical models for complicated cases has made previously impossible surgeries a reality.[13] For less complicated cases 3D printing has led to faster surgeries, thereby reducing complications and saving money.[14] However, the possibilities extend far beyond anatomic models. In 2013 a US patient had 75% of his skull replaced with a 3D printed implant from Oxford Performance Materials (OPM). OPM produces FDA approved, patient-specific cranial and facial implants using 3D printing. The implants are comparable in material cost to traditional implants ($10,000-$25,000), but reduce operational costs because they are printed to be an exact fit based on imaging data, eliminating the need to trim the implant while the skull is open. The company plans to extend their method to other bony implants, and is preparing applications for FDA approval. Each incremental step into new bones represents a significant endeavor. The market size for bone replacements is estimated to be $100 million per unique bone. OPM also produces industrial parts and recently received a $750 million federal contract for high-tech aerospace components.[15]

Source: Oxford Performance Materials

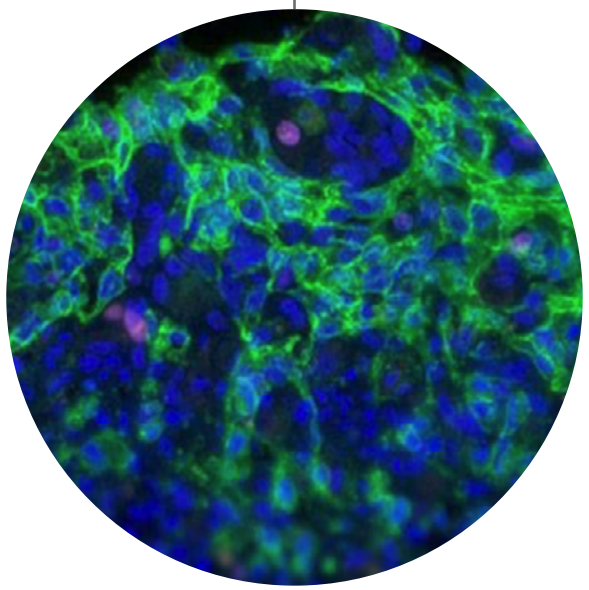
13 Materialise Helps Doctor Reset Improperly Healed Bones Using 3D Printed Implants, 3D Printing Industry
14 UK Hospitals Report Using 3D Printing to Reduce Surgery Times and Costs, 3D Printing Industry
15 Future in 3-D, TEDx Springfield

Biotechnology.

Even living cells can be printed. Organovo has developed a 3D printer which prints living cells using an ink jet type printer, thus allowing them to create thick tissues with multiple cell types placed in specific locations. These bioprinted tissues behave like tissues in vivo (with highly organized features such as intra-cellular tight junctions and microvascular networks) and are stable in culture for 40 days or more. In contrast, traditional, non-printed models start to break down after only 48 hours in culture, preventing their use as effective scaffolds in tissue replacement studies.

While unable to function as full-blown organs, bioprinted tissues show great promise for testing drug toxicity. Organovo has developed a bioprinted liver system which has been demonstrated to be able to distinguish between Acetaminophen (a liver-toxic drug) and a non-toxic analogue at physiologically relevant doses, a process not possible using existing models. Moreover, their 3D printed liver system was able to detect the toxicity of a drug that had previously been deemed safe in animal studies and preclinical trials, but found to cause liver damage when used clinically. Failed drugs account for 40% of all drug spending and 10% of drugs in Phase III clinical trials fail due to liver toxicity. Therefore, with annual drug R&D expenditure of $50 billion per year, an improved model for testing liver toxicity has the potential to save billions of dollars for the pharmaceutical industry every year.[16]

IMAGE OF ACTUAL BIOPRINTED TISSUE FROM A 3D PRINTER



Source: Organovo

16 3D Bioprinting Could Speed Up Drug Development, Life Science Leader

Consumer Goods.

3D Systems has been a leader in the 3D printing industry since the company's founding in 1986, by Charles Hull, the inventor of stereolithography. His company produced the first commercial 3D printer in 1989 and has continued to lead the industry by inventing selective laser sintering, color jet printing and multi-jet printing. Today, this innovation leader is developing a continuous, high-speed, fab-grade 3D printing production line for Google's Project Ara. Project Ara is expected to come to market in 2015 with modular smartphones. Project Ara allows every consumer to specify the look and functionality of their individual phone and upgrade individual components (e.g., the camera, microphone, etc) over time as improved technologies are released. Moreover, this production technology is not limited to smartphones. 3D Systems claims that they can now manufacture thousands of parts at speeds comparable to traditional injection molding operations.[17] This process improvement will not only enable mass customization, but may also allow 3D printing to enter the market of just-in-time, high volume manufacturing.

Source: Motorola

17 3D Sytems, Fab-Grade 3D Printing

Edible Materials

3D Systems also produces printers that are able to print edible materials. Two graduate student modified their 3D systems printer to print with sugar. The result was such a hit that the founded a company, Sugar Lab, to sell 3D printed candy.[18] In 2013, 3D Systems acquired Sugar Lab[19]. Through the acquisition, 3D Systems plans to produce a line of 3D printers that print spectacular 3D sculptures in sugar. This line of printers, named ChefJet, is intended for use in commercial kitchens and will retail for $5000 to $10,000. The machines are designed to be very user-friendly and can produce sculptures and candies in a range of flavors. While the present models are limited to sugar, the company plans to extend the range of printable substrates over time.





All of this innovation has positively impacted 3D Systems' financial outlook. In 2013 3D Systems' revenue was $513.4 million, up 45% from that in 2012 and its organic growth rate was 29%. In addition to rapid growth, 3D Systems has profit margins in excess of 50%. Furthermore, they are establishing a vertically-integrated business, selling 3D printers, as well as the raw materials used in printing, providing an end-to-end solution for consumers.

Source for all photos: 3D Systems

18 This Is The Best 3D Food Printer We've Seen Yet -- And It Makes Stunning Desserts, Business Insider Australia, 2014
19 3D Systems, The Sugar Lab

Future Directions

A recent survey of 100 manufacturing companies found that 25% are using 3D printing for prototyping only. 10% of the 100 companies are using it for both prototyping and the production of final parts, while 1% are using it only for the production of the final parts.[20] Many of these companies are already in the process of adopting 3D printing as a part of their business model, with 98% of large companies and 85% of small companies either already in the process of adoption or planning to adopt it.[21]

3D printing has moved beyond rapid prototyping to become a viable new tool for manufacturing, with capabilities that go above and beyond those of existing tools. Hence, expect it to be a driver of innovation as the 3D printing platform makes new ideas possible and economical.

Increased Personalization.

3D printing makes mass customization economical, thereby enabling every customer to have exactly what they want at an affordable price. Over time, 3D printed personalized products could change the shape of the consumer goods market.

98% of large companies and 85% of small companies plan to adopt 3D printing in the near future.

20 Key Investor Takeaways From a 3-D Printing Survey of 100 Industrial Companies, 2014
21 Roundup Of 3D Printing Market Forecasts And Estimates, Forbes, 2014

Biotechnology, pharmaceutical and medical industries.

3D printing in the medical fields is expected to grow by 19.3% annually between 2013 and 2020.[22] 3D printing is a natural fit for the medical fields since medical devices often need to be customized for an individual patient. Expect continued expansion in the use of 3D printing for planning surgeries, and increased production of implants, medical devices, orthotics and the like. Tissue engineering applications are very interesting, especially for use in drug testing and as medical models for research. However, the development of entire organ replacement applications is slow due to technological and regulatory constraints.

Source: Deniz Karasahin / Dk Design Studio (left photo)
Source: Materialise (right photo)

22 3D Printing Market Analysis By Application (Automotive, Aerospace, Aerospace, Medical), By Raw Material (Polymers, Metals, Ceramic) And Segment Forecasts To 2020, Grand View Research, 2013

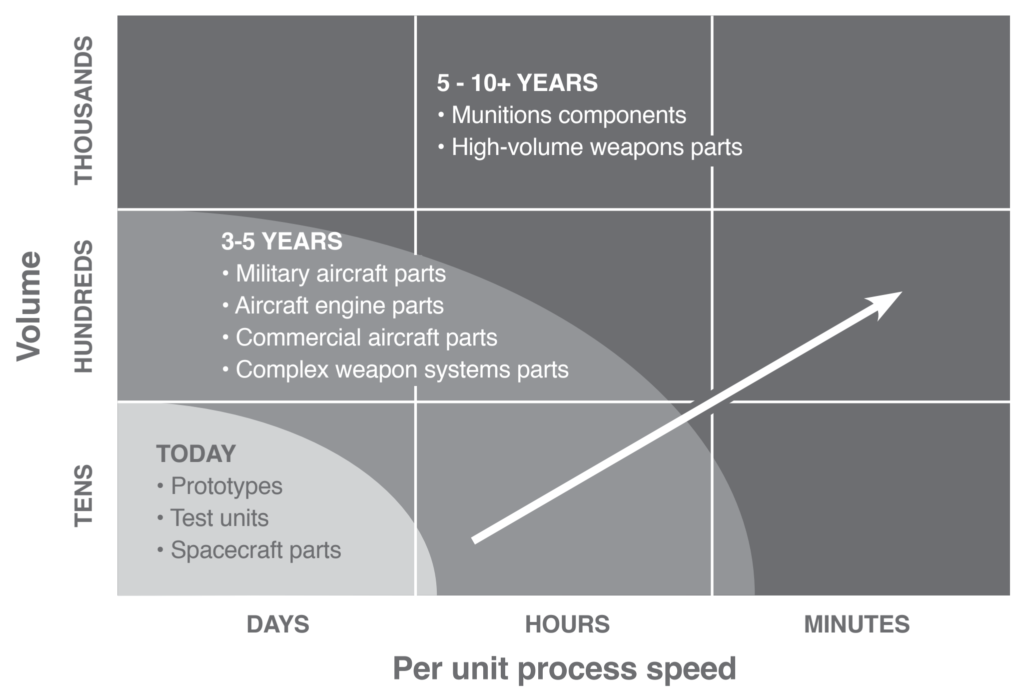
Possibilities for the food industry.

While the 3D printer is unlikely to become an all-purpose kitchen appliance in the near future, its use in creating sculptural foods (industrially or in commercial kitchens) is expected to increase. 3D printing will also enable the production of food that is nutritionally tailored for the needs of individuals, as well as the production of customized foods from a limited menu of shelf-stable ingredients. Both NASA[23] and the United States military[24] are investing in 3D printing food technology, which could lead to customized food in healthcare settings. 3D printers are currently being used in nursing homes in Germany to produce semi-solid foods (which resemble normal foods) from purees for people who are not able to chew and swallow solid food.[25]

The Aerospace Industry.

3D printing has already seen significant adoption in the aerospace industry, driven by the critical importance of weight reduction in aircraft. This trend is likely to continue in coming years, due to rising fuel prices. 3D printing will also see increasing use in the automotive industry, to reduce weight and meet tightening efficiency standards without compromising safety or performance.

3D printing - adoption map



Source: PwC Analysis, 2013

23 3D Printing: Food in Space, NASA
24 Chow from a 3-D printer? Natick researchers are working on it, 2014
25 3D Food For The Elderly: How This Company Is Making People's Lives Better, 2014

Energy conservation.

Dramatic weight reductions can be achieved when products are designed through 3D printing techniques. For example, 3D printing could reduce the weight of vehicles and aircrafts by up to 30%. The resultant lighter machinery requires less energy operationally over the life of the vehicles. 3D printing also makes it possible to extend the life of old equipment by regenerating malfunctioning parts. Regenerating new parts would requiring only 2-25% of the energy of building the entire product anew. [26]

Entry into the home market.

Last year, at least two 3D printers aimed at novice home users entered the market, and another is coming soon. While they are not without their shortcomings, they are at the vanguard of what will be a growing trend. The technology and software used by 3D printers will continue to improve, making 3D printers cheaper and more user-friendly. Over time, expect 3D printers to become a standard piece of office equipment.

Source: MakerBot

26 Additive Manufacturing: Pursuing the Promise

Distributed Manufacturing.

In the near future, it will become increasingly feasible to manufacture items in small quantities at the point of use. Initially, this will be most relevant as an alternative to expensive operations to ship spare parts to remote areas (Antarctic research labs, aircraft carriers, etc.), or as an alternative to carrying large numbers of spare parts on long-distance missions, such as flights into outer space. However, with continued improvements in 3D printers, and decreased costs, it may become more economical for certain items to be manufactured on demand at local distribution centers or even in the home, rather than manufacturing parts centrally and shipping them all over the world. The reduced cost to manufacture small numbers of items may also enable new companies to enter existing marketplaces at low cost and quickly become competitive with existing players.

Space Travel.

A manned space mission to Mars would span months or years of time. Many see 3D printing as a critical component for enabling these extended missions to take place. Not only will 3D printing allow for the production of needed spare parts, it could be used to produce needed supplies and even habitats on the moon or Mars prior to the arrival of astronauts.[27] In preparation for such extended missions, NASA sent a 3D printer to the International Space Station in September 2014.[28]

Don't expect a Star Trek replicator anytime soon.

High fidelity printing and high quality materials come at high prices and most machines can only work with one type of material. Expect to have dedicated machines for specific classes of items for the foreseeable future, with larger build sizes coming at high prices. Nevertheless, 3D printing is already revolutionizing manufacturing and its impact will only grow over time as capabilities grow and costs decrease.

27 NASA and 3D printing: the sci-fi love affair that keeps getting hotter, 3D Printing News, 2013
28 SpaceX Launches 3-D Printer, Other Station Gear, 2014

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Patricia Rubert-Nason's PhD research focused on using computational modeling to understand the mechanism of chemical reactions on catalytic surfaces. While 30-40% of global GDP is dependent on catalytic processes, exactly what happens on the surface of catalysts is poorly understood for most reactions. The development of effective computational models of catalytic processes not only furthers our understanding of the basic science behind the catalyzed reactions, but can also enable the rational design of improved catalysts. Patricia's other accomplishments include helping design and develop the OsteoSonic, a device for measuring bone density which won NASA Tech Brief's "Create the Future" Design Contest in 2003, and helping design a rain barrel and diverter system for Sustain Dane, a local non-profit. Sustain Dane sold thousands of rain barrels and the system is currently for sale nationwide from the company Enginuity which estimates that the systems have saved over 9 million gallons of water. Patricia received a BS in BioEngineering from Rice University in 2004 and a PhD in Chemical Engineering from UW Madison in 2013. She is currently a freelancer who researches and writes about science and technology.

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Aki Ueda's research focuses on the molecular mechanisms of immune cell biology and the progression of autoimmune diseases. By better understanding the way inflammatory cells develop, change, and interact with their surroundings, she hopes to contribute to improved treatments for ailments such as rheumatoid arthritis and Crohn's disease. Aki currently is a Post-Doctoral Fellow at Northwestern University in the Microbiology-Immunology department. Aki completed her PhD from Northwestern University, in Biomedical Sciences, from the Dermatology department in 2012. During this time, she was a recipient of the 2-year and 1-year Pre-Doctoral Fellowships from the American Heart Association. She completed her BA in Biology from Cornell in 2006.

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Charles Wright's research focuses on the stochastic behavior of individual organisms. He has used high-throughput microscopy and large-scale computational analysis to explore the connection between neuronal function and organismal behavior in worms, and is now studying the dynamics of growth and division of bacterial cells under various environmental conditions. He hopes to leverage advances in technology and computation to better understand the regulation of complex, dynamical and often noisy biological processes within the context of the organism as a whole. Charles is currently a PhD candidate at the University of Chicago in the Graduate Program in Biophysical Sciences. He received his BA in Physics, Molecular and Cellular Biology, and Spanish from Vanderbilt University in 2008.

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Justin Starr acts as a technical interface between PreScouter's clients and scholar network. He also works to implement new features and procedures to improve the service delivery process. Prior to joining PreScouter, Justin worked in the robotics industry as a reporting manager for RedZone Robotics and on the business development team for QinetiQ North America's Technology Solutions Group. While at QNA, Justin coauthored more than $7.9 million in funded proposals for DARPA and ONR. Justin obtained his M.S. & Ph.D. in Materials Science from the University of Florida, where he developed new types of functional nanomaterials and was awarded a Most Outstanding Instructor award for his teaching. He also obtained a B.S. from the University of Virginia in Engineering Science where he was a Jefferson Scholar & Rodman Scholar.

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Cloudera

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Organic solar cells that break the 'electrode barrier'

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doi: 10.1126/science.1255826

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Todd Emrick (top), Thomas Russell (bottom)

3D-printed solar panels that work best when cloudy

TYPE
Research Institute – National Physical Laboratory

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IMAGE
Fernando Castro

Ubiquitous Energy

TYPE
Startup (founded 2011)

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PUBLICATIONS
doi: 10.1002/adom.201400103
doi: 10.1002/adom.201470040

Quantum dot solar cells

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PUBLICATIONS
doi: 10.1038/nphoton.2014.54

IMAGE
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LightSail Energy

TYPE
Startup (founded 2009)

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The grid-integrated vehicle with vehicle to grid technology

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PUBLICATIONS
doi: 10.1016/j.jpowsour.2007.03.010

IMAGES
Jeremy Firestone (top), Willett Kempton (bottom)

World record solar cell with 44.7% efficiency

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IMAGE
Frank Dimroth

Hybrid solar cells promise more than 95% efficiency

TYPE
Academic – University of Cambridge

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PUBLICATIONS
doi: 10.1038/nmat4093

IMAGE
Richard Friend

Pathfinder Renewable Wind Energy

TYPE
Startup (founded 2008)

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