The Industrial Internet: Robotics, Automation, and the Future of Manufacturing
China Materialia is an investment and advisory company that makes venture capital investments in companies with world-class technologies and promising market potential in China. The firm also offers innovation and strategy advisory to multinational companies, Chinese companies, and Chinese government.

Tekes

Tekes – the Finnish Funding Agency for Innovation

Tekes is the main public funding organisation for research, development and innovation in Finland. Tekes funds wide-ranging innovation activities in research communities, industry and service sectors and especially promotes cooperative and risk-intensive projects. Tekes’ current strategy puts strong emphasis on growth seeking SMEs.
# Future Watch Report

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Executive Summary

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”

-Mark Weiser, Chief Technologist at the Xerox Palo Alto Research Center (PARC), 1991

Xerox’s legendary PARC facilities have produced more than their fair share of era-defining innovations, as well as prescient research and development endeavors.

The opening quote is from 1991, but it was in 1988 “when Xerox PARC chief technologist Marc D. Weiser first conceived of ubiquitous computing. Weiser saw a future populated by smart objects, a web of sensors on everyday items better connecting us to our environment and our environment to the Internet. Today, Cisco says that more than 13 billion devices are net-connected and there will be 50 billion by 2020.”

As show in Appendix I, this works out to about 6.58 connected devices for every human being on earth in 2020. Although scientists at PARC foresaw the Internet of Things (IoT) concept in the late 1980s, they did not foresee the ramifications of this concept in the context of industry.

Furthermore, the Cisco projections do not account for a world in which entire companies, sectors, and industries are also connected via an Industrial Internet.

The term Industrial Internet (II), “coined inside GE’s R&D division, reflects the company’s hope that adding more sensors to machinery will result in a deluge of data that will in turn let companies squeeze more efficiency out of their operations.”

The following Future Watch Report explores the concept of the Industrial Internet – assessing its present state and projecting its future prospects. McKinsey views IoT and II as “under-hyped technologies with great economic potential – on the scale of $2.7 trillion–$6.2 trillion of estimated economic impact in 2025.”

By “embedding sensors and actuators in machines and other physical objects to bring them into the connected world,” IoT and II will allow “businesses and public-sector organizations to manage assets, optimize performance, and create new business models.”

The report first introduces the Industrial Internet, specifically delving into sensors, actuators, and software, which all represent enormous opportunities for companies in the US, Europe, and Asia.

The existing – and future – II platforms of major corporate players are explored, followed by a brief overview of automation. The roles of automation and robotics in the context of the Industrial Internet are then discussed.

The secondary sector, manufacturing, is then explored, building on the context of the preceding topics. Contemporary examples of the Industrial Internet follow, in energy, as well as industries like aviation and healthcare.

Lastly, we summarize our conclusions and predict opportunities for innovation-minded companies and organizations.
“Industrial machines have always issued early warnings, but in an inconsistent way and in a language that people could not understand. The advent of networked machines with embedded sensors and advanced analytics tools has changed that reality. For the first time in history, remotely distributed machines across the globe – from MRIs to wind turbines to aircraft engines – can be monitored in real time, unlocking the language of machines and opening tremendous benefits.”

-Jeff Immelt, CEO of General Electric, 2013

As a concept, the Internet of Things (IoT) has become a buzzword for technology executives and futurists alike. Along with related concepts and technologies, it can seem like a sea of acronyms as opposed to a coherent movement.

With the development of the Industrial Internet (II), we have yet another concept – and yet more acronyms – to contemplate. Fortunately, the Industrial Internet is merely an extension of IoT principles and technologies, not a radical reimagining of them.

“The crucial feature of the Industrial Internet is that it installs intelligence above the level of individual machines — enabling remote control, optimization at the level of the entire system, and sophisticated machine-learning algorithms that can work extremely accurately because they take into account vast quantities of data generated by large systems of machines as well as the external context of every individual machine. Additionally, it can link systems together end-to-end — for instance, integrating railroad routing systems with retailer inventory systems in order to anticipate deliveries accurately.”

In truth IoT and II are one and the same. The only distinction is that IoT is predominantly geared towards consumer applications and needs, whereas II is solely concerned with business and industry solutions, leading some to refer to the concepts as IoT (Internet of Things) and IIoT (Industrial Internet of Things).

“The primary difference between IoT and IIoT over the next few years is that the IIoT will incorporate over a century of existing, ‘brownfield’ infrastructure like commercial boilers and fleet tracking while IoT is an emerging set of ‘greenfield’ services and technologies that must build infrastructure as it grows.”

To expand our definition, “The Industrial Internet is the union of software and big machines — what you might think of as the enterprise Internet of Things, operating under the demanding requirements of systems that have lives and expensive equipment at stake. It promises to bring the key characteristics of the Web — modularity, abstraction, software above the level of a single device — to demanding physical settings, letting innovators break down big problems, solve them in small pieces, and then stitch together their solutions.”

The brainchild of General Electric (GE), II can thus also be viewed as a branded IoT. As such, it is no coincidence that the development of II has been most frequently applied in areas GE itself excels in, like aviation, healthcare, and energy.

But it would be a mistake to view II development to-date as a GE “product” per se. Undoubtedly, the company will profit from the development and expansion of the II ecosystem. However, it increasingly appears as if GE seeks to make II the dominant standard for Industrial Internet of Things applications, fully aware that its competitors will both accelerate II
adoption and – ultimately – siphon off profits.

On March 28, 2014, GE announced a partnership with AT&T, Cisco, IBM, and Intel to form the Industrial Internet Consortium (IIC). “The new, non-profit IIC group will focus on testing IoT applications, coming up with best practices and standards, influencing global IoT standards for Internet and industrial systems, creating a forum for sharing ideas and in general pushing the ecosystem forward.”

The companies realize that even as competitors, the companies – and indeed all stakeholders, including producers and consumers – benefit from recognized international standards for sensors, actuators, and software – the essential building blocks of every II system. Some speculate that progress on such standards will be the single biggest factor in mass adoption of IoT and II.

To say that GE is bullish on II would be an understatement. The company estimates that downtime for maintenance and services among a basket of industries costs roughly $20 billion annually. Furthermore, the company speculates that over $150 billion annually is wasted “across major industries that the Industrial Internet can eliminate.”

“The Industrial Internet can change all this through software and analytics, data visualization tools, mobile collaboration devices with intuitive user interfaces, and contextually relevant information [as shown in Figure 1]. It will enable preventive maintenance based on the actual conditions of industrial assets, bringing us toward a world of ‘no unplanned downtime.’”

But this lofty vision is predicated on the appropriate infrastructure, specifically including sensors, actuators, and software.

Sensors

On the surface, GE – and other proponents of II – may distill the concept into one where “technology merges big iron with big data to create brilliant machines.”
It sounds simple enough, but without important elements like sensors, these so-called brilliant machines would in truth be as dumb as those from the era of Carnegie and Rockefeller.

Appendix 2 illustrates the overall IoT ecosystem, including the myriad types of sensors. Distinct silos within sensors include:

- MEMS
- Reed
- Magnetic
- Seismic
- Acoustic
- Light
- Imaging
- Thermal
- Temperature
- Humidity
- Chemical
  - Gas [Molecular]
  - Luminescent
  - Electrochemical

And these are but a few. Organizations such as the IIC are grappling with establishing a “common set of standards, and developing energy sources for millions – even billions – of minute sensors” according to Cisco.¹⁵

Sensors are the eyes and ears of the Industrial Internet, feeding thousands of gigabytes of data into advanced analytics and big data processing systems. More and better sensors mean more and better data. And this becomes the self-reinforcing premise of II: big data processed by algorithms that learn and adapt to the information being processed, improving the overall efficiency and effectiveness of the II system.

Actuators

If sensors are the collectors of data, then actuators are the instruments that automate the Industrial Internet. Industrial actuators can perform many functions, leading to some ambiguity as to what they actually are and do.

“In general terms, however, the term may be applied to any actuator called upon to do any specific industries’ heaviest work. Variants generally associated with the industrial actuator term may either be linear or rotary output types powered by electric motors and compressed air or oil. Linear types include rack-and-pinion, ball screw, and piston varieties, while rotary types are generally driven by scotch yoke and gear train mechanisms.”¹⁶

So sensors collect data, and software processes that data and delivers instructions to machines. Actuators are the recipients of these instructions and perform the action(s) prompted by the software system.

There is a variety of classification for actuators, such as actuation method, small or large displacement, small or large force, displacement speed, etc. Common actuation methods are electric, magnetic, piezoelectric, gas pressure, air pressure, oil pressure, shape memory alloys, and martensitic transformation alloys.

Solenoid Valves

The solenoid valve for water or gas flow is one of the oldest and simplest actuators (Figure 2).
A small 20mV voltage generally drives it. When no voltage is applied, the valve is closed (known as a “normally-closed” valve). When a small 20mV voltage is applied, the valve is open and water or gas can flow through.

**Piezoelectric Actuators**

Historically, ceramic piezoelectric actuators have been important. These materials will generate an electric voltage when subjected to a force, and alternately they will create a force when subjected to an electric voltage. They can sustain large forces. They are very small displacements, of the order of percent of their original length. The most commonly used piezoelectric material is known as PZT (lead zirconia titanate) and its crystals are grown in large quantities (Figure 3).

**Figure 3: PZT Crystals**

The effect is commonly used to produce and detect sound waves, to produce high voltages, in advanced high-magnification microscopy, and a very large number of other applications.

**Electro Active Polymers (EAP) and artificial muscles**

Electro Active Polymers change their size or their shape when subjected to an electric field. The main characteristic of this type of actuator is that they undergo large displacements of several 100 percent.

One application of EAP is artificial muscles (Figure 4). Artificial Muscle, Inc. – part of the Bayer Group – is a leader in the space (http://www.artificialmuscle.com/).

**Figure 4: Artificial Muscles**

**Oil Pressure Actuation**

This is commonly used in heavy machinery and is a well-proven technology (Figure 5). Pressure on the oil cylinder can generate extremely high forces because oil is incompressible. However the acceleration and the speed are limited.

**Figure 5: Oil Pressure Actuator**

**Pneumatic Actuation**

Using compressed gas or compressed air is a very common actuation method. Many factories use large centralized compressed air systems and distribution networks to thousands of air-operated tools across the factory (Figure 6).

**Figure 6: Pneumatic Compressor**
Shape memory alloys (SMA) and martensitic transformation materials

Shape memory alloys are materials that undergo a martensitic transformation with temperature and change their shape as a result. A common SMA is 50% Nickel/50% Titanium composition, known as Nitinol (NiTi). It is used in medical stent applications where a stent can be introduced into a patient through the veins in the compressed state, and then deploys by itself in the body as the material heats up (Figure 7).

Figure 7: NiTi Stent

With both sensors and actuators, there will be enormous opportunities for companies and manufacturers to carve out a slice of the ever-expanding Industrial Internet pie.

However, at present a handful of component and solutions vendors “like DIGI, Echelon, and Freescale from the industrial control world who have extensive experience with a variety of legacy industrial connectivity solutions” reign supreme.17

“These vendors specialize in understanding specific industrial usage models, and then they create domain expertise to translate those usage models into sensors, actuators, control logic, data aggregation, local network connectivity, and services layers. They have built experience in working with legacy industrial equipment built over the last century and developed trust from decades of working with customers.”18

As time passes, these legacy concerns and affiliations will diminish though, as more and more machinery and factories are built from Day 1 for II connectivity. This phenomenon will correspond to more opportunities and lower entry barriers.

Software

Software is the II component that brings meaning to the work of sensors and actuators, performing granular and holistic functions to make the system function. Sensors collect the data, but it is software that makes sense of it for humans and machines to understand.

As noted by Industrial Internet expert Jon Bruner, “The barriers between software and the physical world are falling. It’s becoming easier to connect big machines to networks, to harvest data from them, and to control them remotely. The same changes in software and networks that brought about decades of Silicon Valley innovation are now reordering the machines around us.”19

The Silicon Valley comment is worth noting, because II proponents believe such will be the scale of societal impact when the Industrial Internet matures into universal adoption. Innovations on the scale of those produced by Silicon Valley over the last five decades will emerge within the ecosystem, say its most fervent advocates. And it will be software that provides the brains behind this giant hypothetical leap.

Figure 8 illustrates an II software platform overview. Layers of software address operational functions, but also must interact with web and mobile applications, as well as end-user display technologies. Application Programming Interfaces (APIs) play a significant role...
in the various silos of II software performance.

Essentially, II software uses a network connection and an open interface to turn any machine into a web service unto itself, “ready to be coupled to software intelligence that can ingest broad context and optimize entire systems of machines.”

While an II system is only as good as the data it collects, in truth it is the software that does the heavy lifting. Talented software companies and developers will be the new engineers of the Industrial Internet era, as II “makes the physical world accessible to anyone who can recast its problems in terms that software can handle: learning, analysis, system-wide optimization,” etc.

The ramifications of this are widespread, and indeed they will alter the way machines are fundamentally conceived. With software doing the “thinking,” machines will be able to operate in the most efficient ways possible. Indeed, “a machine that anticipates being controlled effectively can itself be designed more efficiently.”

“With machines connected in Internet-like ways, intelligence can live anywhere between an individual machine’s controller and the universal network level, where data from thousands of machines converges. In a wind turbine, for instance, a local microcontroller adjusts each blade on every revolution. Networked together, a hundred turbines can be controlled by software that understands the context of each machine, adjusting every turbine individually to minimize its impact on

Figure 8: Industrial Software Platform Overview

Source: GE Software COE, 2013
nearby turbines." Machines will operate similarly to the turbines in the example above, aware simultaneously of their own activities and the activities of every other machine on the network. Software is the nerve center of this awareness, and it will allow factories to operate at levels of efficiency heretofore unimaginable.

Moreover, there will be an aggregate effect as more and more machines and factories collect more and more data. “Software intelligence, which relies on collecting lots of data to build models, will become smarter and more granular as the scope of data collection increases.” So the overall II ecosystem will improve via collection and dissemination of such data models.

As software intelligence increases, companies will be able to capitalize on substitution effects in the context of assets and labor.

With assets, “The Industrial Internet will, as Astro Teller, Captain of Moonshots at Google[x], suggests, ‘trade away physical complexity for control-system problems.’ As machines deliver their work more efficiently, we’ll need fewer of them and the machines themselves will become simpler.”

With labor, software will enable factories to pare down staff related to operating and maintaining machinery. “Given a high-volume stream of accurate machine data, software can learn very fast. And, by transmitting what it learns back into a network, it can accumulate knowledge from a broad range of experiences. While a senior pilot might have 10,000 to 20,000 hours of flying experience, a pilotless aircraft operating system might log hundreds of thousands of hours in just a year, with each of many planes transmitting anomalies back to a universal learning algorithm.”

Just as automation adversely affected low-level factory workers, II will similarly displace employees. “If information is seamlessly captured from machines as well as people, we’ll need fewer low-level data shepherds,” for instance.
Since so many II principles have been articulated by GE, it is worth exploring the philosophies and contributions of other technology companies. With the formation of the IIC, the slow march towards universal standards and protocols has begun. In the meantime, competing platforms will coexist; competing, collaborating, or both, with one another.

**Cisco**

As a company built on the very premise of networking, Cisco was an early IoT proponent. Envisioning its network products as the backbone of IoT infrastructure, Cisco has devoted R&D resources to ensuring it is prepared to capitalize as IoT becomes more ubiquitous.

However, not content to focus on the consumer side of the phenomenon, the company has recently made forays into the Industrial Internet and manufacturing via its Cisco Industrial Smart Solution (CISS) initiative. Specifically, the initiative seeks to marry operational technology (OT) with Cisco’s core competency: IT.

“Cisco research states only 4 percent of the devices on the manufacturing floor are actually connected to a network. Many manufacturers have used proprietary networks in the past. A smart manufacturing environment requires a standardized IP-centric network that will enable all devices within a plant to communicate to both operational and enterprise business systems.” So the company sees myriad opportunities to sell its network devices within the II ecosystem.

As a charter member of the IIC, Cisco will be collaborating on national and international IoT and II standards with an eye towards advancing its CISS market penetration and revenues. While GE will be both a collaborator within the IIC and competitor outside of it, Cisco can be viewed as more of a player in the networking realm of II than the machinery side, which GE excels at.

To characterize it as “just” networking though would be an understatement of the company’s ambition.

Cisco ultimately hopes to provide “the breadth of plant infrastructure capabilities across networking, wireless, security, physical video, compute, and communications to flexibly support the current and future business needs of manufacturers, uniquely meeting the needs of both business IT and operational technology in a secure, reliable, and integrated platform.”

Cisco’s CISS and Connected Factory concepts are not just in the research and planning stages either: the company already has several big wins under its belt. The company has used its II platforms to help General Motors achieve a 166% ROI via standardized operations, helped Emirates Aluminum optimize plant production, and used its networking technologies to accelerate Anglo Platinum’s production.

Cisco has also shored up its collaboration and partnership with other industrial automation and robotics firms to offer turnkey II solutions. “Cisco has strategic relationships with leading suppliers of industrial automation equipment and control systems including Rockwell Automation, Honeywell, and Emerson as part of a strong factory and plant partner ecosystem to deliver best of integrated and tested OT and IT solutions.”

**IBM**

Although IBM has been more associated with IoT than II to-date, its membership in the IIC indicates the company is taking the impact of II seriously. Through its Smarter Planet program, the company has a toehold in the consumer market for IoT services,
but it also has overlapping interests with companies like GE in commercial areas like logistics and healthcare.\textsuperscript{32}

Some speculate that IBM's involvement with the IIC is more about advancing the company's MQ Telemetry Transport (MQTT) messaging protocol standard than expanding into physical II infrastructure.

IBM boasts that MQTT “is so lightweight that it can be supported by some of the smallest measuring and monitoring devices, and transmit data over far-flung, sometimes intermittent networks. It is also open source, which makes it easy to adapt to a variety of messaging and communication needs.”\textsuperscript{33}

Presumably, “some of the smallest measuring and monitoring devices” would include sensors used in IoT and II, so the company would benefit from having the IIC adopt this standard internationally for II.

This strategy would mesh with the company’s path since spinning off its PC division to Lenovo. By focusing on more “big picture” revenue streams like those generated by intellectual property rights, it is a safe bet that IBM will be a major player in facilitation of the Industrial Internet’s back end, rather than front end participation via hardware.

IBM's pre-IIC partnership with AT&T is another example of this strategy; a partnership based on the facts that “AT&T boasts a global network, while IBM has the software in place to analyze and visualize data from just about any sensor you could care to think of.”\textsuperscript{34} IBM is thus making a relatively pure Advanced Analytics play within the II ecosystem, geared specifically towards big data, as seen in Appendix 3.

The caveat “relatively” is important though, because IBM has such formidable R&D resources and human capital at its disposal. Increased hardware activity in the IoT and II space is a possibility via collaboration, as evidenced by partnerships with companies like Semtech Corp. In October 2013, the two companies “announced a significant advancement in wireless technology, combining IBM software and Semtech hardware to create a system capable of transmitting data up to a distance of 15 km (9 miles), depending on the environment.”\textsuperscript{35}

Nokia Ten years ago, Nokia released a

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**Figure 9: Nokia Imagining IoT and II Applications in its 2004 M2M White Paper**

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*) heating, ventilation, air conditioning

Source: http://www.m2mpremier.com/uploadFiles/m2m-white-paper-v4.pdf

Nokia’s research and advocacy within the burgeoning IoT sphere helped lay the foundation of the present-day ecosystem, including the Industrial Internet. The company even included “Industrial machines” in its 2004 M2M white paper (Figure 9), demonstrating it was ahead of its time (and would-be competitors like General Electric) in recognizing the potential of IoT.

Struggling to find its place in the technology landscape of the late-2000s, the company was battered by upstarts like Apple and Samsung in the handsets segment it once owned. Nokia had been instrumental in developing the still-used GSM standard. It had been making mobile handsets since 1982, when Apple was only known for its Apple II personal computer and the founders of Google were 9-years old.

2007 was the highpoint for Nokia handsets and their operating system (OS), Symbian. Market share for the OS peaked at 66% that year, when Apple’s iOS held 1% of market share and Google’s Android OS was still in development. Four years later it was a very different story. Symbian had plunged to a 17% share of the market, whereas iOS held 15% and Android had a dominant position at 53% (Figure 10).36

Seeking to reinvent itself yet again after specializing in wood pulp, rubber, electricity generation, tires, footwear, and communication cables – among other things – over the course of its 150 years in existence, Nokia agreed to sell its handsets division to Microsoft in a deal worth €5.4 billion.

Re-launching as Nokia Advanced Technologies, the company is “expected to take better advantage of Nokia’s vast patent portfolio and its richly financed R&D organization” moving forward, with a particular focus on the IoT ecosystem.37

Far from licking their wounds, Nokia’s CTO, Henry Tirri, is optimistic, noting how the company’s over 30,000 patents

Figure 10: The Peak and Plunge of Nokia’s Symbian OS
will help it transition into an IoT-focused organization. In February 2014, Tirri observed that “a lot of [Nokia’s] technological assets will help in the future evolution of this world: global connectivity, our expertise in radio connectivity, materials, imaging and sensing technologies.”

In the same interview, Tirri emphasized that “Advanced Technologies will itself be a business, which is quite a fundamental change from being a corporate function to becoming a business in its own right. Technology licensing and advanced R&D will be intertwined within the business, as opposed to being a separate corporate research team and IP business.”

Now that Nokia is out of the handset segment, its world-class R&D apparatus is free to pursue a broad range of future opportunities, with IoT and II being especially well-suited to the company’s competencies in nano-sensing, software, and connectivity.

Indeed the next chapter in Nokia’s storied history could be one with the IoT and II ecosystem as its backdrop. The company has everything it needs – technical acumen, talent, and resources – to be a major player in sensors and data transmission especially.

Google

Notably absent from the IIC, Google has been under the radar with its IoT efforts to-date, especially relative to its outsized stature within the technology industry.

In 2011, the company generated a lot of buzz when rolling out its Android@Home platform, which was envisioned as a proprietary ecosystem for IoT in the home automation segment. Deals were struck to manufacture an Android compatible LED light bulb, and Android@Home was viewed as a viable alternative to the Zigbee and Z-Wave home automation standards.

But ultimately, deliverable dates kept getting pushed back, and nothing coherent emerged. Google was still hiring engineers for Android@Home as recently as 2013, however, so the full story may not be written as of yet. In any case, the platform was strictly conceived as an IoT and home ecosystem.

Figure 11: Smart Grid Ecosystem

automation concept, and has nothing to do with II.

Google’s work with energy companies in California and the company’s own driverless car are a different story entirely though. These are both purely II plays for the company.

In energy, the company has been a vocal proponent of smart grid adoption and has been a facilitator to that end. GE statistics project that even a 1% increase in energy generation efficiency would equate to $66 billion in savings over the next 15 years (Appendix 4).

As a pet project for Google founders Larry Page and Sergey Brin – and either a prestige project for the company or a cynical PR ploy, depending on one’s general opinion of Google – the company’s smart grid forays have been substantial.

As seen in Figure 11, the smart grid ecosystem marries IoT and II, with – for example – home automation and smart appliances accounting for the former and sensors and generation stations accounting for the latter.

“Monitoring demand is the most fundamental job for a smart grid, a term which usually refers to power grids with sensors tracking energy usage, demand spikes, and backup power usage. Smart grids generally rely on home usage-measuring smart meters to pinpoint-shutdown energy-hogging appliances to avert grid failure. Another key feature: The ability to redirect energy around downed power lines or other broken links in the energy chain.”

Google is betting on the inevitability of smart grid expansion from both supply and demand standpoints. On the supply side, the company is working directly with utility companies and state and national legislatures to expedite smart grid adoption. On the demand side, Google launched its PowerMeter platform for homeowners with smart meters to demonstrate proof of concept. Furthermore, in January 2014 Google announced it was acquiring Nest, a maker of smart thermostats, run by a team of ex-Apple stars, for $3.2 billion.

Google has also “invested more than $300 million in distributed solar companies that allow homeowners to place photovoltaic panels on their home and cut their power bill; those installations depend on effective smart-metering to manage power use throughout the day. As the grid gets smarter—and starts including not just distributed power generation but also distributed power storage devices—technology like that developed by Nest will be increasingly important.”

It is Google’s driverless car, however, that has attracted more interest and press coverage, and deservedly so. The project is a feat of engineering, and a demonstration of the enormous potential of machine learning to automate complex tasks.

Not only does the hardware and software of the driverless car have to collect and interpret a mind-boggling amount of data in real-time, the software and algorithms need to operate in gray areas and internalize the lessons learned.

“For four-way stops were a good example. Most drivers don’t just sit and wait their turn. They nose into the intersection, nudging ahead while the previous car is still passing through. The Google car didn’t do that. Being a law-abiding robot, it waited until the crossing was completely clear—and promptly lost its place in line. ‘The nudging is a kind of communication… It tells people that it’s your turn. The same thing with lane changes: if you start to pull into a gap and the driver in that lane moves forward, he’s giving you a clear no. If he
pulls back, it's a yes. The car has to learn that language.\textsuperscript{43}

Google’s driverless car and the lessons its team extrapolates from its current testing phase could have an enormous impact on the overall II ecosystem, ultimately trickling down into manufacturing specifically.

Indeed, “the autonomous car is a full expression of the Industrial Internet: software connects a machine to a network, links its components together, ingests context, and uses learned intelligence to control a complicated machine in real-time.”\textsuperscript{44}

This is the prototypical dream of II enthusiasts in the manufacturing sector. It would be naïve to think that Google is not savvy enough to recognize and exploit that fact down the road.

In other words, Google's driverless car could be a stepping-stone to more widespread – and transformative – applications of its underlying technology.

After all, “the Google car has now driven more than half a million miles without causing an accident—about twice as far as the average American driver goes before crashing.”\textsuperscript{45} That sort of production and consistency is exactly the kind of performance that draws attention and (perhaps more importantly) the additional investment that the technology needs to achieve widespread adoption and success.
One of the old struggles of the capitalist world is that between Capital and Labor. The struggle between ownership of the land, ownership of the machines, and ownership of the labor force. At various times and in various places it was resolved in various ways. From the King owning the farms and the farmers in the European Middle Ages, to the Luddites revolution against textile mills in the English Industrial Revolution, to the carefully negotiated distribution of profits between team owners and football players in the modern US National Football League.

Two of the arrows in the owners quiver are machines and automation. Machines lead to mechanization, replacement of physical human labor (Figure 12). Automation adds sensors and software, to replace mental human labor.

Following the work of Charles Taylor on efficiency, manufacturing plants filled with measuring devices. Following increasing social costs, strikes, and general worker challenges in one country after another, they filled with automated robot machines. Robots can perform tasks 24 hours a day, every day, without ever getting bored or hungry. They can perform many tasks faster and with more precision than humans. They are perhaps the “ideal worker”. In fact the term “robot” is derived from the Czech word “robota”, meaning “drudgery” or “slave-like labor”.

**Automation and Robotics in China**

Today automation and robots are entering the Chinese manufacturing plants in large numbers and at large speeds. Historians and academics can debate whether China’s labor surplus impeded the country’s industrialization and accelerated its subsequent catching-up process, but there is compelling contemporary evidence that an epochal shift is underway. “The International Federation of Robotics tracked a 50 percent jump in purchases of advanced industrial robots by Chinese manufacturers in 2011, to 22,600 units, and now predicts that China will surpass Japan as the world’s largest market in two years.”

Companies like Foxconn have used cheap migrant labor to manually assemble electronics components. While Western nations and the Asian Tigers automated electronics and automobile assembly. But in late 2012,
Foxconn, “which employs nearly one million low-wage workers to hand-assemble electronic gadgets for Apple, Nintendo, Intel, Dell, Nokia, Microsoft, Samsung, and Sony,” predicted that it would add approximately one million industrial robots to its assembly operations over a three-year period.\(^{47}\)

There is certainly a vocal contingent of China watchers who scoff at the notion of widespread automation of Chinese manufacturing operations, citing the need of a truly Harmonious Society to employ its behemoth population. However, as growth slows – dipping below the 8% threshold required to absorb new graduates – Chinese companies may see automation as the lesser of two evils, and even receive government support (financial, tacit, or otherwise) for their efforts.

Consider the following anecdote from the pre-crisis era of GDP growth: “If all new [infrastructure] tunnels were built with the advanced equipment, that would trim the need for the employment of about six million migrant workers… In certain fields we don’t want to have fast development in China, in order to solve the national employment problem.”\(^ {48}\) As GDP growth dips to sub-7% levels, what will tip the scale towards increased productivity and output, even at the expense of widespread migrant labor?

ABC’s “Nightline” crunched numbers and speculated that, “Industrial robots, typically equipped with a movable arm, use lasers or pressure sensors to know when to start and finish a job. A robot can be operated 160 hours a week. Even assuming competition from nimble-fingered humans putting in 12-hour shifts, a single robot might replace two workers, and possibly as many as four.”\(^{49}\) iPhones are essentially

**Figure 13: The Market for Industrial Robots in China**

![Graph showing the market for industrial robots in China, comparing 2010 and 2011 sales data.](image-url)
handmade at this point. Financial analysts at Foxconn – and mainland manufacturing operations – cannot ignore the benefits of widespread automation of repetitive and boring tasks, especially when the companies’ bottom line stands to gain so hefty. Indeed, failing to introduce robotics en masse would buck the trend of China’s rise to the number one destination for industrial robots (Figure 13).

From an innovation standpoint, industrial robotics will be an extremely hot market segment over the next 5-15 years, and there are myriad opportunities for innovations in the technologies themselves, their integration into Chinese manufacturing operations as currently constructed, and educational and workforce training endeavors. Western nations made this labor shift, and China will inevitably experience many of the same – if not amplified – growing pains. But these pain points should be viewed objectively for what they truly are: opportunities for innovation.

**Machine to machine communication**

Manufacturing, with the factory at its center, has three overarching goals: quality, repeatability, and low cost. Process control is the favored method to achieve these goals. Process Control deals with architectures, mechanisms and algorithms for maintaining process

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Figure 14: Siemens Programmable Logic Controller (PLC)
output within a desired range. Industrial control systems include Supervisory Control And Data Acquisition (SCADA) systems, Distributed Control Systems (DCS), where the controls are not centralized but distributed within the sub-systems, Programmable Automation Controller (PAC), that digitally control assembly lines, amusement rides, or light fixtures, Programmable Logic Controllers (PLC), that digitally control in real-time a series of inputs and generate a series of output (Figure 14), and Manufacturing Execution System (MES), that manage resources, schedules, and orders.

Artificial intelligence allows machines to learn from experience and adapt their response. The field has been around for a long time and has created wonderful stories and movies. It is perhaps finally starting to impact industry. One hot topic today is Artificial Neural Network (ANN). In this discipline, biology is used as the template for mathematical and computational models.
The German government calls it Industry 4.0.

Certain analysts call it Smart Manufacturing and “the Next Industrial Revolution.”

General Electric – as we have seen – calls it the Industrial Internet.

Whatever the terminology, every major industry in every major economy has it on their radar: the Internet of Things, and the tantalizing revolution it seems poised to unleash upon the manufacturing sector.

But what does that mean, and how exactly will full-blown II manufacturing “look” in a more advanced and mature form?

According to McKinsey, “the potential for cyber-physical systems to improve productivity in the production process and the supply chain is vast. Consider processes that govern themselves, where smart products can take corrective action to avoid damages and where individual parts are automatically replenished.”

The gist of McKinsey’s prediction is that hyper-connectivity within factories “will decentralize production control and trigger a paradigm shift in manufacturing,” with logistics being the initial short-term benefactor.

This meshes with the overall GE vision for the evolution of II: intelligent devices and machinery networked into intelligent systems, which will lead to intelligent decision making and optimization of networks, fleets, facilities, and assets, as shown in Figure 15.

Naturally, this will be a sequential process, albeit with myriad opportunities at every stage.

First, we will project what each of these

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Figure 15: How the Digital World Meets the Industrial World

phases of evolution will encompass. Second, we will detail what the Industrial Internet will be capable of, and how II in the manufacturing context is unique versus II in other contexts.

Three Phases of Evolution

In Phase 1, the physical and pseudo-physical aspects of II (hardware and networks, respectively) will need to be adopted. Companies need to “buy in” at an operational level, outfitting their machinery with enough sensors and actuators to create truly “intelligent” devices.

Also in Phase 1, the “intelligent systems” aspect of II infrastructure will require further development and maturation. Large-scale operations will not risk their livelihoods on unproven technologies, nor will they sufficiently invest in retrofitting existing machinery with sensors and actuators if mature, complementary software does not exist to harness the data produced by sensors. “Factory managers are understandably conservative in managing [expensive existing] systems, and demand highly-robust, proven technologies in settings where the functioning of a big machine or assembly line is at stake.”

Opportunities in Phase 1 include design and production of physical II infrastructure, namely sensors and actuators. Companies with software and systems expertise will also be winners during this period. Laboratories and research facilities should also see more robust funding, as companies and industries engage in gamesmanship to see who will be first to cross the commercial version of Geoffrey Moore’s Chasm concept.

In Phase 2, the power of intelligent decision making will give manufacturers new and exciting tools to optimize their operations. This phase will be characterized by accelerating adoption of II, with early adopters benefitting from productivity gains that allow them to reinvest in improved II technologies. Laggards will subsequently scramble to “catch up,” so it should remain a relative bonanza in regard to hardware and software opportunities.

Notably, this stage can be viewed as Industrial Internet 2.0, because intelligent decision making will have been fed back into the system. Advanced analytics applied to Big Data will lead to rapid, substantive advances in II technologies and processes. Additionally, machine learning will exponentially improve the systems aspect, which will in turn positively affect overall efficiency and productivity.

In Phase 2, the Industrial Internet will still consist largely of retrofitted legacy machinery. II manufacturing operations will be highly advanced, sensors and actuators will be greatly improved and less expensive, but the Industrial Internet will remain intrinsically ad hoc relative to its ultimate composition in Phase 3.

In fact, there will be a unique opportunity that bridges Phases 2 and 3 in upgrading these ad hoc systems and machinery into the first generation of their “pure” II equivalents.

It will be in Phase 3 that those who are at present most bullish on the prospects of II manufacturing will be vindicated. Machinery will be conceived, designed, and produced with II-specific functionality at its core. Algorithms will have been exponentially improved via machine learning, experience, and experimentation. Even the IP protocol itself – currently at IPv6 – will have improved; specifically adapted to the unique exigencies borne of the Internet “running” factories in every industry in every country around the world.

Phase 3 will not be an end-state. Rather, it will be the end of the
beginning. The “vision” of II in a manufacturing context – with all its inherent benefits – will have been realized, but certainly not maxed out; quite the opposite in fact.

It is the end of the beginning because it is as far forward as we can logically predict with relative certainty. If things progress how they have to-date, Phase 3 represents the realization of a world in which all machinery is “smart” machinery; all factories are “smart” factories.

It will be at this stage that II blossoms into everything we presently know it is capable of being, and almost certainly even more beyond that.

We will now discuss what that looks like, and the specifics of how II will leave an indelible mark on the manufacturing sector.

II in the Context of Manufacturing

“Manufacturing is becoming broadly accessible to innovators operating at small scale. Sophisticated prototyping facilities are available at minimal cost in maker spaces across the country, where anyone with a modestly technical mindset can make use of newly simple tools — not only microcontrollers like the Arduino, but also 3D printers, laser cutters, and CNC machine tools. Powerful computer hardware — controllers, radios, and so forth — has become so inexpensive that, at least at the outset, nearly any problem can be reduced to a control challenge that can be solved with software.”

Jon Bruner, Data Journalist for O'Reilly Media, 2014

When contemplating the future of II, it is important to note just how rapidly the ecosystem is advancing. As noted in the above quote, even now manufacturing innovations and solutions can be largely software-based, which is a radical change from just 5 or 10 years ago. Soon, when a machine breaks down or needs to be reconfigured, it will not be a technician who gets the call: it will be a programmer.

In accordance with Moore’s Law, the power of processors continually increases, while their size and cost continually decrease. Even now “processors that are powerful enough to handle real-time streams of sensor data and apply machine-learning algorithms are now cheap enough to be deployed widely on factory floors to support such functions as machine-wear detection and nuanced quality-control observation.”

Ultimately, all factory functions will be brought under this umbrella, forging an environment where “software running on an inexpensive processor, reading data from inexpensive sensors, can substitute for more expensive capital equipment and labor.”

The world’s largest manufacturers have invested billions of dollars in SCADA systems to manage automation, but II is about more than just automation. It is about high-level intelligence and analysis built into the machines and the networks they connect to. This is an important distinction, and factories themselves will need to prepare for the introduction of such high-level technology.

“Factory settings can be extremely difficult environments for computing. J.P. Vasseur, at Cisco, says that it’s not uncommon to see 40% packet-loss rates in factory networks due to humidity and electromagnetic interference. Current systems often depend on simplified software — derived from ladder logic and implemented on programmable logic controllers — that is easy for workers to learn and use.”
The transition to IP-based architectures will need to evolve in order for plants and personnel to adapt. In the words of McKinsey, the critical need for large-scale manufacturers will be “finding people who are able to design robust algorithms: those who make the system user-friendly so that the people who use it day-to-day can immediately recognize problems and know how to react without getting tangled up in a web of interdependencies.”

And this is just one of the many ways that companies will need to adapt their mindsets to the new realities of II-driven operations. Instead of physical flows, companies will need to recognize that “there will no longer be a difference between information and materials, because products will be inextricably linked to ‘their’ information.”

McKinsey provides an example of this phenomenon, where “a piece of metal or raw material will say, ‘I am the block that will be made into product X for customer Y.’ In an extreme vision, this unfinished material already knows for which customer it is intended and carries with it all the information about where and when it will be processed. Once the material is in the machine, the material itself records any deviations from the standard process, determines when it’s ‘done,’ and knows how to get to its customer.”

“What happens is a complete consolidation of devices and process management. “Process and device” will be inseparable; physical things become part of the process. What this means for the plant is that machines and workflows merge to become a single entity. The work flow ceases to exist as an independent logistical layer; it is integrated into the hardware.”

This does not make human operators and workflow managers obsolete. II may demand different skill sets from these types of personnel, but it will not “replace” them. Rather, it will make them more productive, as the speed of information increases and decision making tools become more robust.

“A new kind of hardware alpha-geek will approach those areas of the industrial internet where the challenges are principally software challenges. Cheap, easy-to-program microcontrollers; powerful open-source software; and the support of hardware collectives and innovation labs make it possible for enthusiasts and minimally-funded entrepreneurs to create sophisticated projects of the sort that would have been available only to well-funded electrical engineers just a few years ago — anything from autonomous cars to small-scale industrial robots.”

Thus II will benefit large and storied companies like GE and IBM, but it will also benefit startups and small entrepreneurs. Indeed, in the context of manufacturing, all stakeholders — those associated with both supply and demand — should benefit equally from the quantum leap forward II represents.
The Industrial Internet holds great promise for the factories of tomorrow, and indeed companies like GE and Cisco are actively applying II to the manufacturing sector of today. However, in several industries, II is presently being leveraged with great success to a degree manufacturers only aspire to. We will now look at three such industries: aviation, healthcare, and energy.

**Aviation**

As a joint venture with Accenture, GE launched Taleris in 2012, leveraging the Industrial Internet to provide "airlines and cargo carriers with tools to predict, prevent and recover from operational disruptions like those caused by severe weather." Using predictive analytics technologies to contextualize aircraft data from a holistic point of view, Taleris is able to preempt issues before they occur. However, this is far from the scale of ambition when it comes to aviation innovation and II.

Eventually, the industrial internet will support broad use of automation to replace human operators with software that is safer, more reliable, and more efficient, completing the tie between global networks and machines. A single software stack will extend from the network planning and demand management level all the way down to throttles and brakes.

While that may be a vision ahead of its time, there are short-term inevitabilities when it comes to II in the sky, such as "high-bandwidth connections within airplanes, between airplanes, and from airplanes to ground controllers. These connections aren't being built as a unified system; rather, they're independently-developed networks that might eventually fit together as modules."

**Healthcare**

Healthcare is the one industry where II is not just an exciting prospect; it could literally mean the difference between life and death. In other words, more than productivity and profits are at stake. GE has a proud history of innovations in medical technology, and it is using II to carry on that tradition. Partnering with Adventura Hospital and Medical Center in Florida, the company set out to reduce emergency room crowding.

"Aventura invested in AgileTrac, a GE software system pooling and crunching gigabytes of patient and equipment data zipping across a hospital-sized Industrial Internet. Each patient now receives an electronic wristband during admission. The wristband automatically checks in as patients arrive in their beds, travel around the hospital, and check out. Similar tags track IV pumps, heart monitors and other equipment. Aventura estimates that AgileTrac has cut more than 3,000 hours in discharge time at the 400-bed hospital over nine years."

II will ultimately enable more efficient flight plans and maintenance regimes, as well as improved overall usage of airplanes and labor. To make an enduring, direct impact on airlines' bottom lines, however, II will need to address fuel economy.

"Fuel is the biggest cost for every airline, and, spread across a large fleet, tiny refinements in flight paths, climbs, and descents can have an enormous impact on fuel consumption. Labor and capital are also big costs to anyone that operates an airplane; high capital utilization and effective maintenance management are crucial."

Efficiency gains as small as 1% over the next 15 years would translate into savings of $30 billion in fuel costs according to projections by GE, as shown in Appendix 4.
months and freed up the emergency room.\textsuperscript{67}

Other investments will be directed towards improving clinical operations via specialized medical imaging software that can run in the cloud.\textsuperscript{68} Cost savings in this regard – and other silos related to overall infrastructure – could begin to chip away at the estimated $732 billion that global healthcare systems waste annually.\textsuperscript{69}

“The industrial internet will make the health care sector more efficient by providing intelligence on top of machine data. Software will ingest sensor readings and perform real-time analysis, freeing doctors and nurses to do work that requires more sophisticated and nuanced patient interaction. Progress is already well underway in home monitoring, which lets patients who just a few years ago would have needed constant monitoring in a hospital bed recover at home instead.”\textsuperscript{70}

As with aviation, healthcare efficiency gains of just 1\% over the next 15 years would translate into major savings: an estimated $63 billion according to projections by GE.\textsuperscript{71}

\section*{Energy}

The role of II in energy generation was discussed in the Industrial Internet Platforms section above, specifically in the sub-section on Google and its participation in smart grid development.

GE is applying II to energy generation as well by focusing on its expertise in turbine design and production. In May 2013 the company unveiled the world’s first “smart” wind turbine.

“It has the option to come with a battery that allows producers and the wind turbines themselves to make decisions based on data coming in and supply predictable power in the short-term. “We are using advanced forecasting algorithms and a small amount of battery storage to meet a forecast of how much power we will be able to deliver for the next 15 minutes to one hour,” says Keith Longtin, general manager for wind products at the GE business. The sensors and software alone can make the GE2.5-120 wind turbine 25\% more efficient and 15\% more productive than comparable GE models.\textsuperscript{72}

The company was also tapped to overhaul New York City’s largest power plant, using proprietary II software and hardware in a collaboration with TransCanada Corp. The plant’s largest gas turbine was connected to sensors and software to analyze performance data.

Real-time, interactive monitoring of the system allows the turbine to run at its optimal level at all times. As a result, the power plant “is now using less fuel to produce the same amount of power, making electricity cheaper and, relatively speaking, cleaner. TransCanada says that the upgrade has increased output by 5\%. That’s enough electricity to power 10,000 NYC households.”\textsuperscript{73}

In Appendix 5, global energy production and consumption is diagrammed in an Industrial Internet context. Assuming full buy-in, GE claims it can impact 100\% of energy production and 44\% of energy consumption. Additionally, conserving just 1\% of fuel costs over the next 15 years would amount to $66 billion in savings, made possible by the Industrial Internet.\textsuperscript{74}
When GE Chief Marketing Officer, Beth Comstock, was asked in June 2013 why the company was pushing forward so aggressively with its Industrial Internet investments ($3 billion initially), she replied, “Basically to bring all the great innovation you’ve seen in Silicon Valley now to industry. We probably haven’t seen anything yet when it comes to data when machines start talking to machines and machines start talking to people. We have to make sense of it.”

General Electric expects the Industrial Internet “to generate an additional $15 trillion in global GDP by 2030 by helping to trim costs and wastages.”

In the advanced economies of the US, Europe, and the Asian Tigers, II endeavors help level the playing field against lower-cost upstarts like the BRICS nations. “Emerging markets have an advantage in ‘20th century things’ like labor costs. But big data lets the West claim an advantage in the ‘21st century way’ — one can become more efficient and productive by harnessing the data.”

But there are advantages for these same upstarts as well. In China, for instance, the Industrial Internet will amplify the country’s leapfrogging strategy. It will also give Chinese manufacturers opportunities to generate revenue from II infrastructure elements like sensors and actuators.

On a societal level, the Industrial Internet will impact countries like China, the UK, and Italy in a more fundamental manner, as all are experiencing rapidly aging populations and a decline in the number of skilled manufacturing personnel of working-age (Figure 16). II will help close the knowledge gap left by waves of retirees, and increase the productivity of working-age citizens. In other words, the Industrial Internet can offset – or even reverse – the adverse effects on nations with increasingly top-heavy senior populations.

Figure 16: Short-term Conditions for II Adoption

In the next five years...

40% of skilled manufacturing workers will retire¹

50b machines will connect to the Internet²

#1 Priority of CIOs is to drive more business insight³

A new generation of workers expects answers at their fingertips.

Another interesting headwind in China relates to its annual graduation rate of engineers. With all this talent, the country needs to find ways to employ them all, and II could be the answer. Working in 21st century factories will mean more than just being good with one’s hands. It will require the kind of hard skills and mechanical acumen that engineers possess. As such, China’s labor pool is already prepared for mass adoption of II, which is more than most countries can claim.

The New York Times vetted GE’s claim that the Industrial Internet could add $10-15 trillion to global GDP over the next 20 years, and itself proclaimed that, “Internet-era technology is ready to sweep through the industrial economy much as the consumer Internet has transformed media, communications and advertising over the last decade.” 78

The original GE report found “that in the U.S. alone the Industrial Internet could boost average incomes by 25 to 40 percent over the next 20 years and lift growth back to levels not seen since the late 1990s. If the rest of the world achieved half of the U.S. productivity gains, the Industrial Internet could add from $10 to $15 trillion to global GDP – the size of today’s U.S. economy – over the same period.” 79 Appendix 6 breaks down this projection by sector.

In closing, the Industrial Internet is another stage in a process of evolution, where manual labor gave way to mechanization, which subsequently facilitated automation. Mechanization replaced physical labor, automation replaced simple decisions, and II will replace – or at least supplement – advanced intellectual labor.

II is the forefront of mankind’s relationship with machines. In the Industrial Internet machines perform communication, sensing and actuating, decision making, learning, and prediction. It sounds like the future, but the future is now.
APPENDIX 1

The Internet of Things Was “Born” Between 2008 and 2009

<table>
<thead>
<tr>
<th>World Population</th>
<th>6.3 Billion</th>
<th>6.8 Billion</th>
<th>7.2 Billion</th>
<th>7.6 Billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connected Devices</td>
<td>500 Million</td>
<td>12.5 Billion</td>
<td>25 Billion</td>
<td>50 Billion</td>
</tr>
<tr>
<td>Connected Devices Per Person</td>
<td>0.08</td>
<td>1.84</td>
<td>3.47</td>
<td>6.58</td>
</tr>
</tbody>
</table>

Source: http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf
APPENDIX 2

APPENDIX 3

Source: http://articles.economictimes.indiatimes.com/2012-12-16/news/35837159_1_consumer-internet-hospitals-data/2
APPENDIX 4

INDUSTRIAL INTERNET: THE POWER OF 1%

Efficiency gains as small as 1% could have sizable benefits over 15 years when scaled up across the economic system.

**Oil & Gas**
- $90B in savings from reduced CapEx

**Power**
- $66B in fuel cost savings

**Healthcare**
- $63B from efficiency gains

**Aviation**
- $30B in fuel cost savings

**Rail**
- $27B in rail operations savings

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**INDUSTRIAL INTERNET BENEFITS**

- **Oil & Gas**: Reduces operating costs and fuel consumption while boosting availability of key equipment sets and enhancing production rates.
- **Power**: Optimizes power plant fleet with advanced monitoring, enabling deeper integration of gas and power networks.
- **Healthcare**: Improves resource use and outcomes by locating and identifying the status of mobile equipment.
- **Aviation**: Improves flight path planning and enables aircraft to tell crew which parts need replacement and when.
- **Rail**: Optimizes operator response through real-time overview of network operations.

Source: GE estimates

Source: http://www.gesoftware.com/sites/default/files/page-row-media/Power_Of_1_Percent_Big.jpg
Future Watch Report

APPENDIX 5

Energy Production
13 BTOE

- Oil 31%
- Coal 28%
- Gas 22%
- Renewables 11%
- Nuclear 5%
- Hydro 3%

Energy Consumption
9.5 BTOE

- Light-Duty Transport 14%
- Buildings 32%
- Other 10%

Industrial Internet can impact 100% of energy production

Industrial Internet can impact 44% of global energy consumption


Industrial Internet opportunity (~$32.3 Trillion) 46% share of global economy today

Endnotes

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