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The Internet of Things: the next growth engine for the semiconductor industry

A study of global semi-conductor trends and powerful drivers behind them – special focus on the impacts of Internet of Things.

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The Internet of Things: the next growth engine for the semiconductor industry

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Preface

The ever-expanding array of cutting-edge devices such as smartphones, tablets, ultramobile, electric cars, new aircraft, and wearable devices, is driving a constant expansion of the number of semiconductor components we use in our daily lives. In 2013, this growing demand saw the global semiconductor industry exceed US$300 billion in sales for the first time ever, and the momentum has been successfully maintained in 2014. So, will this golden age for the semiconductor industry continue? How will the semiconductor market develop over the next few years? What are the key success factors? And how should semiconductor companies prepare for emerging trends?

This study aims to identify the major factors and trends that will drive the global semiconductor market over the next few years, and recommend to semiconductor companies the products, components, and regions to which they'll need to pay most attention. In addition to this analysis we are taking a close look at the next technology mega-trend: the "Internet of Things (IoT)". We highlight its potential benefits and challenges, and suggest ways that semiconductor companies can benefit from the IoT's development.

We would like to extend our sincere thanks to Dr. Reinhard Ploss, CEO of Infineon Technologies, and Keith Jackson, President and CEO of ON Semiconductor, whose insights have tremendously enhanced our report.

Join us on our journey into this new and emerging world as we take a closer look at the possible future of the semiconductor industry.

If you would like further information or to discuss any of the findings in our report and how they might impact your business, please do not hesitate to contact either of us (raman.chitkara@us.pwc.com or werner.ballhaus@de.pwc.com) or any member of our global technology team listed at the end of this document.

Raman Chitkara
Global Technology Industry Leader

Werner Ballhaus
German Technology, Media and Telecommunications Leader

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List of abbreviations

ASIC	Application-specific integrated circuit
ASP	Average selling price
BRIC	Brazil, Russia, India, China
CAGR	Compound annual growth rate
CMOS	Complementary metal oxide semiconductor
CPU	Central processing unit
DRAM	Dynamic random access memory
GDP	Gross domestic product
IC	Integrated circuit
IDE	Integrated development environment
MCU	Microcontroller unit
MICA	My intelligent communication accessory
MPU	Microprocessor unit
ODM	Original design manufacturers
SRAM	Static random-access memory
SoC	System on Chip
SW API	Solidworks application programming interface
WSTS	World semiconductor trade statistics

A Report structure

We start our review of the semiconductor industry with an analysis of its global growth and prospects, broken down into component, regional, and application categories. Then, we focus on the Internet of Things (IoT) and one of its applications: "wearables". We classify the role of semiconductors in the IoT ecosystem and analyze the impacts of the IoT and wearables on the semiconductor industry. Finally, we bring out the challenges and market trends that semiconductor companies will face and provide three recommendations to semiconductor companies for capturing value from the IoT.

B Methodology

Calculation of sales forecasts
Sales forecasts are based on analyses of technological trends and the main value drivers. This is followed by analyses of macroeconomic factors, changes in consumer behavior and demographic developments. Mathematical forecast models are used as the basis for investigating the effects of individual value drivers and for forecasting the developments of the semiconductor market. The data obtained are then assessed by our industry experts, checked for consistency and adjusted where necessary.

Currency used for the sales forecast
The currency used for sales forecasts is the United States dollar, the "base currency" of the semiconductor industry, at least in the main commodity markets. Exchange-rate fluctuations have not been assumed. The figures are reported in nominal terms, and thus include inflation effects. The historical data is taken from WSTS and PwC analysis. Sales are shown as "billing revenues".

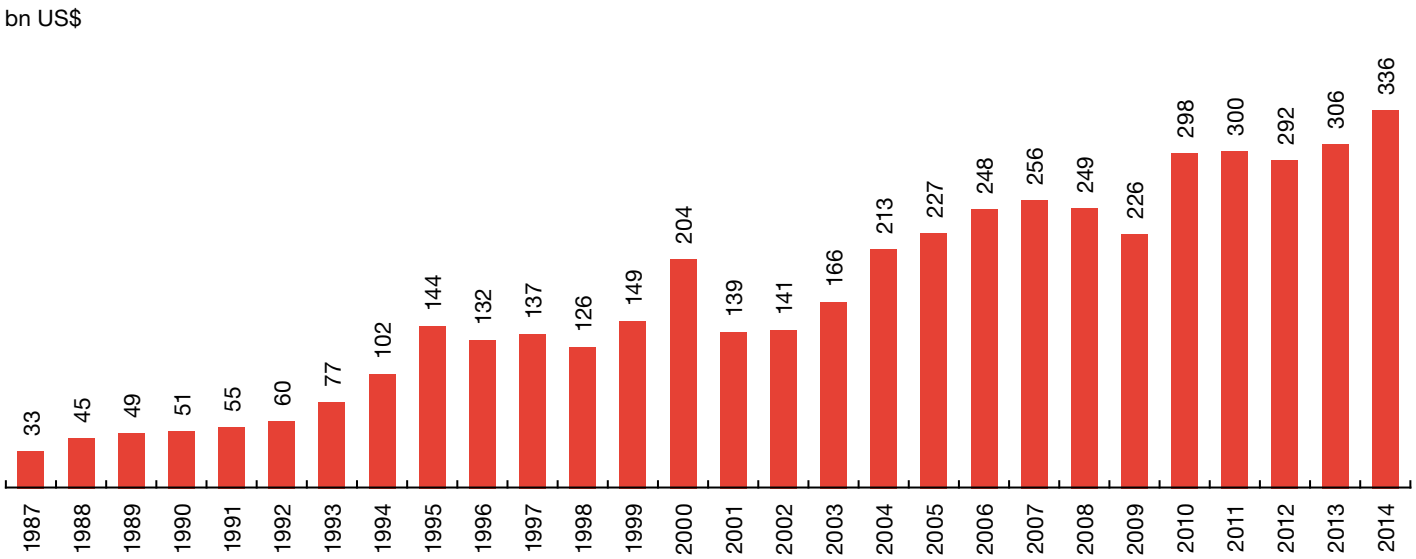
Interviews with experts
Interviews with Dr. Reinhard Ploss, CEO of Infineon Technologies, and Keith Jackson, President and CEO of ON Semiconductor, were conducted in January 2015.

C The Global semiconductor market

Total sales of US$336 billion in 2014 saw the global semiconductor industry once again achieve record sales, growing 9.9% over 2013's record US$306 billion. Several semiconductor application markets stood out in 2014. Data processing was the largest market by sales, reaching US$134 billion in 2014, a 12.8% increase from 2013. The communications and automotive markets have shown particular strengths, driving growth in 2014 which is expected to continue in coming years. Annual sales in almost all regions have shown sustained growth, with Asia-Pacific continuing to grow in importance. In terms of installed semiconductor components, logic integrated circuits (ICs) was the largest category, with sales reaching US$90 billion in 2014, a 6% year-on-year increase. Memory was the fastest growing category, seeing an 18.2% annual increase. Another remarkably fast-growing category was sensors, achieving sales of US$9 billion in 2014, an 8.2% annual increase. We expect sensors to see the highest growth rate, with a CAGR of 10.4% from 2014 to 2019.

Rapid technological innovation is driving growth in the semiconductor industry. As more and more cutting-edge devices (such as smartphones, tablets, ultramobiles, electric cars and wearable devices) emerge, they are constantly expanding the number of semiconductor components we use every day. The advance of digitization and the IoT will further increase demand for semiconductor products. Taken together, these factors will drive solid growth for the global semiconductor market over the next five years.

Fig. 1 Global semiconductor billings – history



Source: WSTS, PwC analysis.

"Internet of Things (IoT) as well as digitization will belong to the big drivers for the growth of semiconductor industry in the next years. Currently, IoT is still highly fragmented with a lot of single solutions. A key factor for success will be the competence to integrate and apply these single solutions. For example, it is crucial to combine the functionalities of sensors, actuators and computing power – such as security, connectivity and microprocessors."

Dr. Reinhard Ploss, CEO Infineon Technologies

"We observe three key trends in the semiconductor industry in the years ahead. The big one is the connectivity of information which is also called Internet of Things. It stimulates a huge demand of sensors for the semiconductor industry. Power consumption and automation are the other two important trends. Some of them may not be totally new but they are continuing to drive the semiconductor industry and offer us opportunities in multiple forms. When we look at the markets, in our perspective the automotive and communication markets will be the two largest drivers for the growth of the global semiconductor market for the next years."

Keith Jackson, President and CEO of ON Semiconductor

1 Overall market forecast

PwC's analysis of the global semiconductor market suggests that between 2014 and 2019 billings will increase by US$96 billion to US$432 billion, corresponding to a compound annual growth rate (CAGR) of 5.2%. Our analysis assumes that there won't be an economic downturn in the period to 2019 and we also believe that technological progress will maintain its high pace and that the scaling down of semiconductor feature sizes will continue.

We have gathered eight key findings for the global semiconductor market:

1. The industrial and automotive markets will both drive significant growth in demand for semiconductors.
2. The trend towards integrating more semiconductor features on a single chip will continue.
3. The sensor sector's remarkably high growth rate is being driven by numerous innovations in sensor technology and strong demand generated by the emerging concept of the Internet of Things (IoT).
4. Accelerating sales of tablets continue to drive the data processing application market. However, the significant growth of ultramobile devices strongly suggests that these will gradually displace tablets as the leader, and become the powerful driver for data processing application markets in the future.
5. The communications market today generates much of its revenue from the sales of premium smartphones. However, the advent of utility/basic smartphone will lead to rapid growth of semiconductor sales, especially in developing economies, presenting both opportunities and challenges to semiconductor players.
6. The consumer electronics market is driven by the growth in units sold, particularly in digital set-top boxes. With the development of sensor and network technologies, new product categories (i.e., wearables) are emerging and these will stimulate further growth of the semiconductor market.
7. In the automotive market, China's lead will continue, owing to the number of vehicles produced and an increase in the average semiconductor content per vehicle. India is expected to return to growth in the medium term while the growth rates of Brazil and Russia will slow. In their place, we expect high growth in Mexico, Poland, Indonesia, Turkey and Thailand.
8. The IoT is the next growth engine for the semiconductor industry, particularly for the sensor, communications, and industrial segments.

As the above shows, there are likely to be considerable variations in growth between components, regions, and applications. In the following section we examine the likely drivers of demand across each of them for the next five years.

2 Growth by component

Fig. 2 Global semiconductor billings – forecast by component

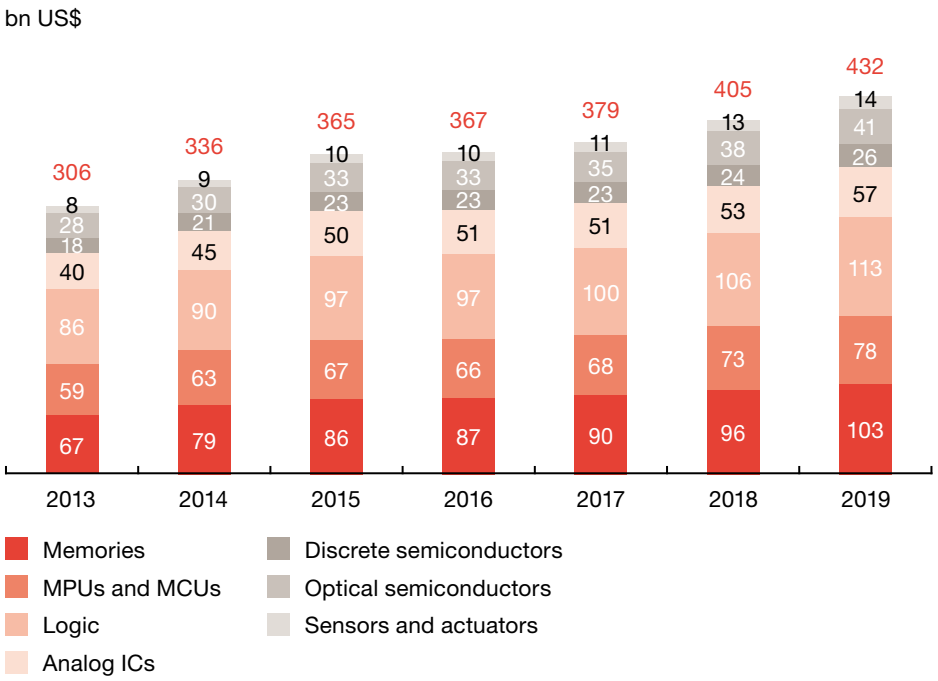
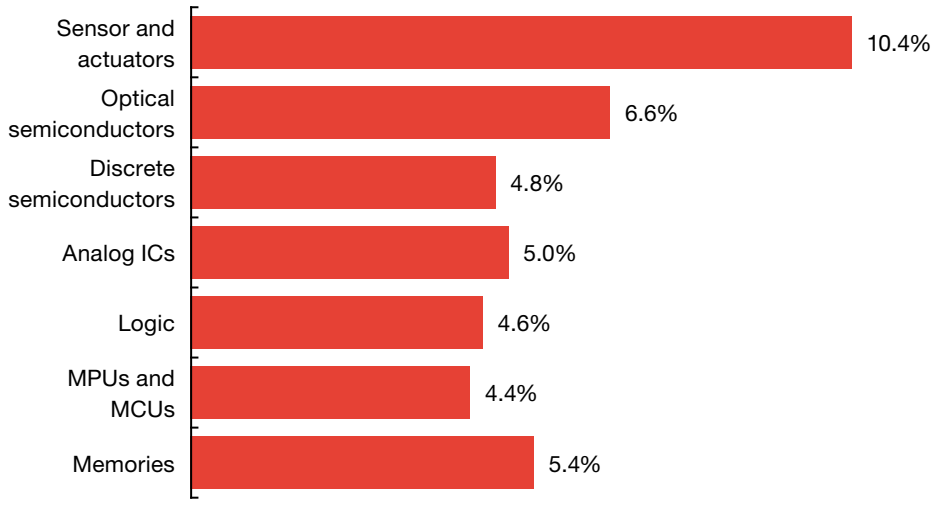


Fig. 3 CAGR 2014–2019 by component



Source: Gartner, PwC analysis.

"We expect solid growth for sensors over the next years. This is obvious if you look at the automotive segment, where Advanced Driver Assistance Systems (ADAS) and self-driving cars are about to create huge demand for sensors. The IoT is another key driver, where sensors will be essential to facilitate new applications."

Dr. Reinhard Ploss, CEO Infineon Technologies

Examining the worldwide semiconductor market in terms of installed components, logic integrated circuits (ICs) will remain the largest single segment in the period to 2019. We expect a total of US$113 billion revenues for Logic ICs in 2019, followed by memory at US$103 billion and microcontrollers (MCU) and microprocessors (MPU) at US$78 billion. However, the highest growth rate will be seen in the sensors and actuators segment with a CAGR of 10.4%.

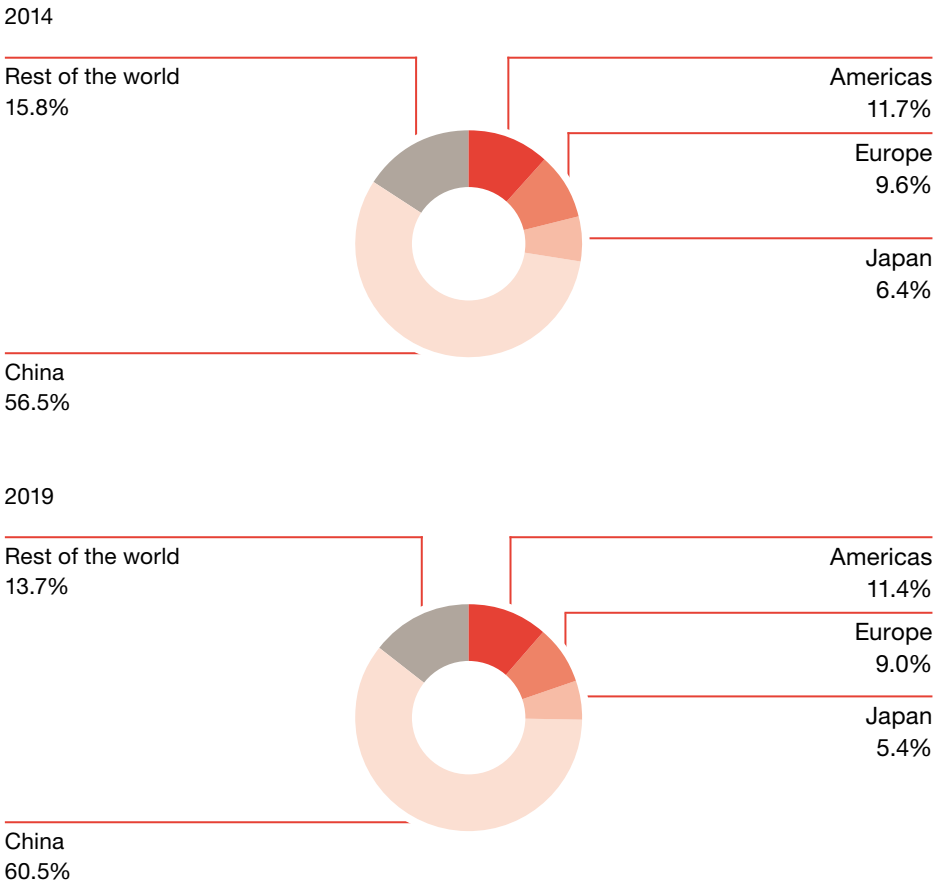
Key drivers for the growth in our forecast by component can be found in the application markets. Particular applications in smartphones, cars, and consumer electronics will contribute to most of the growth in the logic segment. Likewise, analog products with applications in telecommunications and automotive will lead to substantial growth for analog ICs, whereas the general purpose market will suffer from declining average selling prices (ASPs).

The emerging concept of the IoT creates a compelling investment case in the sensor segment. Without sensor endpoints, the progress of the IoT would not be possible, as sensors enable the collection of changes in a range of ambient conditions such as temperature, light, movement, etc. Furthermore, the development of new types of devices relies heavily on innovation in sensor techniques. For example, clothing integrated with wearable sensors can measure the energy output of a user's muscles as well as their breathing. Small unobtrusive and transdermal sensors enable devices to read and transmit information about biometrics and blood biomarkers.

In the memory sector, the NAND flash memory market became larger than the DRAM market in 2013, owing to increasing demand for smartphones and tablets as well as weaker demand for commodity DRAM used in personal computers. In 2014, high-volume production of 15 and 16 nm NAND chips has been increasing. In addition, volume production of 3D NAND chips has been announced by Samsung. We expect NAND flash to widen its lead over DRAM in the coming years.

3 Growth by region

Fig. 4 Global semiconductor consumption – forecast by region



Source: Gartner, PwC analysis.

> ***"The American semiconductor market will continue to grow over the next five years. This growth mainly benefits from tremendous technology innovations in America and full access to the emerging markets like China."***
>
> Keith Jackson, President and CEO of ON Semiconductor

"Regarding semiconductor consumption the strongest growth will remain in Asia, although the gap to the Americas will narrow. We expect Europe to recover, but we should watch the situation carefully. Today, the European industry plays a big role in segments such as aerospace, automotive, energy, industry and security. However, in the upcoming age of IoT, non-European competitors will try to advance on these traditionally European dominated segments. To maintain its position, the European industry has to accelerate its efforts in digitalization and should build up competencies in system solutions."

Dr. Reinhard Ploss, CEO Infineon Technologies

Our analysis of the global semiconductor market indicates an annual growth rate of 5.2% to 2019, with significant regional variations. In Asia, China will continue to expand its semiconductor market leadership and increase its market share, as a result of strong economic growth and the rapid growth of its IC design sector. In contrast, Japan will grow only by an annual rate of 1.5% in the projected period and its semiconductor market share is likely to continue shrinking. Europe and the Americas will see moderate annual growth rates of 3.9% and 4.5% to 2019, respectively. For the rest of the world, growth will be concentrated in Taiwan, South Korea and Singapore.

A note on the growth of China's semiconductor consumption – two key driving factors

China's semiconductor consumption market continues to grow and, with the exception of 2010, its market share has been increasing every year since 2003. Of particular note is that since 2013, more than half of worldwide semiconductor consumption revenues take place in China. This strong growth is driven by two key factors.

- **The continuing transfer of worldwide electronic equipment production**
  In 2013, electronic equipment production in China increased by US$45 billion, while decreasing in the rest of the world by US$15 billion. As a result, China's market share of electronic equipment production reached 35.1% in 2013. Most industry analysts believe that China's increasing share of electronic equipment production will continue to rise at a moderate rate over the next few years. Gartner forecasts that China's share of electronic equipment production will increase to more than 38% by 2017.
- **The above-average semiconductor content of electronic equipment**
  In 2013, the semiconductor content of China's electronic equipment production – at 34% – remained well above the 20% worldwide average. We predict that the semiconductor content of electronic equipment will gradually increase to over 35% by 2017, while the worldwide average content increases to 25%.

4 Growth by application

As shown in Figures 5 and 6, in the period to 2019 the largest overall application segments will remain data processing and communications. However, the industrial segment will exhibit the highest growth rates with 9.7% CAGR up to 2019.

Fig. 5 Global semiconductor billings – forecast by application

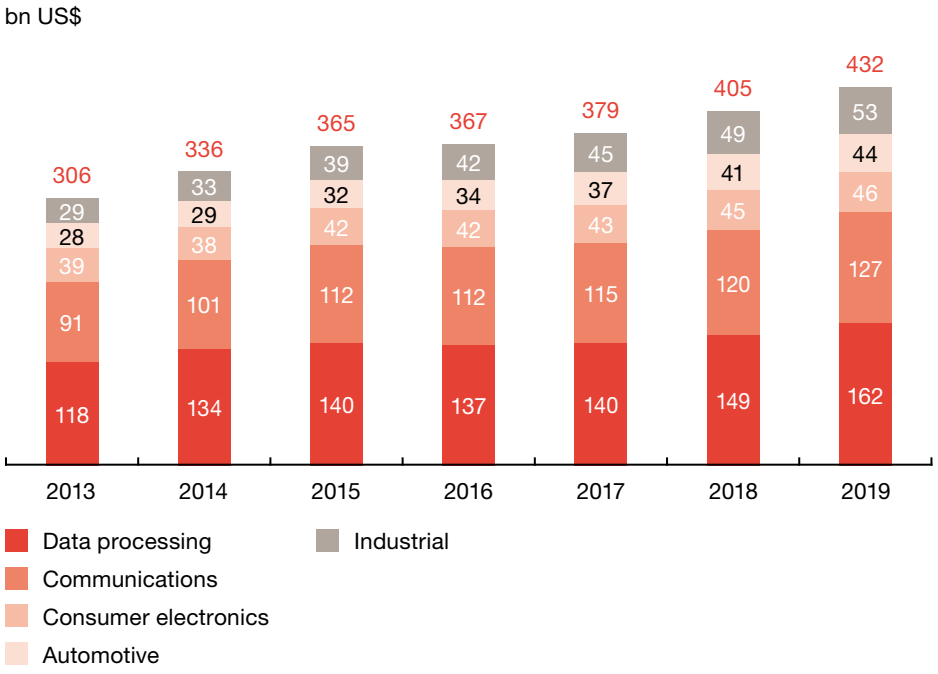
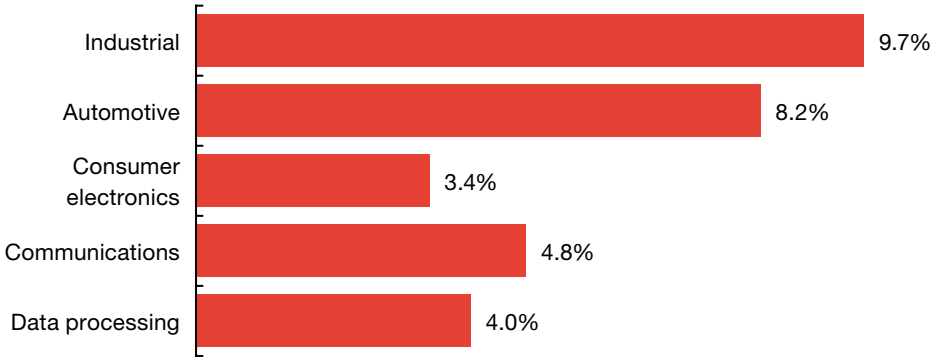


Fig. 6 CAGR 2014–2019 by application



Source: Gartner, PwC analysis, PwC Autofacts 2015 Q1 Forecast Release.

Data processing

Semiconductor sales in the data processing segment, which includes devices such as desktop PC, notebook, ultramobile, and tablet, will continue their gradual growth in the period to 2019. Notebook computers will no longer be the powerful driver they once were, and will experience a continuous decline. Desktop PC sales will keep shrinking in the long-term as we believe. In contrast, tablet sales will continue to see a high growth rate of 7.6% in the period to 2019. This will be largely driven by stronger unit sales of less-expensive tablets. Semiconductor billings for tablets are expected to exceed those for notebooks in 2018.

In 2014, semiconductor sales in ultramobile, an effective hybrid of PC and tablet, achieved a remarkable increase of 84.7%. In terms of their dimension and function, ultramobiles are designed to perform the same tasks as a notebook PC but have the dimensions of a tablet, a touchscreen, and some additional functional buttons at their edge. They are therefore a good choice for "mobile workers", especially in today's world in which mobile internet access has come of age. While still classified as a niche product, we believe ultramobile will see considerable growth in sales in the period to 2019 with a CAGR of 21.1%. What's more, we expect ultramobiles to gradually overtake tablets and become the most powerful driver of semiconductor sales in the data processing segment.

Communications

The communications segment of semiconductor sales is split into five categories: premium smartphone, utility/basic smartphone, traditional phone, wireline communication, and other wireless communications. Thanks to the introduction of next-generation mobile communication systems (i.e., Advanced LTE), smartphone sales will continue to take center stage and eclipse traditional, basic and feature phones. However, the advent of utility/basic smartphones will usher in a new battle. These low-end smartphones are designed to serve the needs of broader customer groups, particularly in developing economies such as the Asia region. We've already seen strong growth of 18.6% in semiconductor sales for low-end smartphones in 2013 and expect the market share of these devices to increase rapidly in the years to 2019.

Rapid growth of semiconductor sales in the low-end smartphone markets presents particular opportunities and challenges for semiconductor players. Two major challenges stand out:

- How to quickly capture this significant growth opportunity, particularly the huge potential in developing countries.
- How to develop powerful integrated application processors (AP) at a reasonable cost.

We believe that those players who react to these challenges fastest, will win the greater share of the market in this new battle.

Despite the remarkable increase of low-end smartphones, semiconductor sales in the communications segment will still be strongly driven by premium smartphones owing to their high semiconductor content value per phone.

Wireline communication will also remain an important application market for the semiconductor industry. Existing networks are already overloaded with current data traffic, so there is huge demand for higher capacity and transmission speed, especially with regards to the development of the IoT. Solutions in the form of ultra-high-speed chips and novel high speed and complex circuits can only be realized with the most advanced semiconductor technologies. Therefore we expect positive growth for semiconductor revenues related to wireline communication devices in the period to 2019 with a CAGR of 2.2%.

Consumer electronics

In consumer electronics the trend towards devices combining computing, internet and TV in one digital set-top box will remain the major driver of growth. Semiconductor sales related to digital set-top boxes will achieve a CAGR of 22.7% in the period to 2019. The majority of semiconductor revenue in the consumer electronics segment will be generated by TV devices. Additionally, the rising penetration of smart TVs will also have a positive impact on semiconductor billings and hence we're also likely to see an upturn in the TV market in 2017. Semiconductor sales in video games are highly influenced by the latest releases of games and gaming consoles. We expect sales recovery in the video games segment in 2015 thanks to the recent release of new video game consoles (e.g., Sony's PlayStation 4, Microsoft's Xbox One, and Nintendo's Wii U), as well as some highly anticipated new games for PlayStation 4 and Xbox One. In addition, Nvidia recently introduced its own Shield TV game console. This is a mix of gaming console and streaming-box, it's "whisper quiet" and while significantly cheaper than current gaming consoles, and it has enough processing power to leapfrog recent gaming consoles. Furthermore, as innovative and advanced features on smartphones and tablets, such as high-resolution graphics capabilities, these form factors will contribute to growing semiconductor sales. Sales of DVD players and recorders will, however, continue to decline as will semiconductor sales related to digital cameras and portable media players which are substituted by smartphones.

The development of sensor technologies and network techniques is enabling cloud-based services and driving the creation of new consumer electronic product categories, such as smart wearables (discussed in the following chapter). As new classes of consumer electronics devices emerge they will drive the growth of new cloud services in a virtuous circle that will have a positive impact on the semiconductor industry.

Automotive

Conventional cars are still the most important driver for semiconductor sales in the automotive segment. In 2013, conventional cars sales contributed 94% of total semiconductor revenues from automotive. While this proportion will decrease over time as a result of increasing competition from electric cars and hybrids, we still expect semiconductor revenue from conventional cars to rise to US$38 billion in 2019 (from US$25 billion in 2013).

The worldwide market for electric cars and hybrids is growing fast. It benefits from increasing demand among operators and consumers, rising vehicle availability, lower prices and energy shortages. The growth of this market will lead to additional demands on electronic equipment and create a positive impact on the semiconductor industry. Compared with conventional cars, semiconductor content per vehicle is 1.5 to 3 times higher in electric cars and hybrids. We expect that the CAGR of semiconductor content sales market will reach 20.5% for electric cars and hybrids in the period to 2019.

In BRIC nations (Brazil, Russia, India and China), China will keep its place as the global volume driver in the automotive segment, with a high growth rate of 11.2% for the years 2014–2019. Indian domestic light vehicle sales have experienced a decline of 2.0% from 2013 to 2014. However, sales made a slight recovery of 1.5% in the year to date 2015. We expect India to return to growth over the medium-term. Growth rates in Brazil and Russia will slow down, subdued by decelerating GDP growth alongside geopolitical and social uncertainty. Nevertheless, both markets are expected to return to sustainable growth in the longer-term. Beyond the BRICs, potential markets are emerging including Mexico, Poland, Indonesia, Turkey, and Thailand. If they wish to seize the opportunities afforded by these new markets, semiconductor companies will need to adapt their strategies for market entry accordingly.

Industrial

The growth of industrial semiconductor sales is generally accepted to show a high degree of correlation with GDP growth. As economic recovery proceeds in the period to 2019, we're therefore likely to see high growth in the industrial segment. We expect a growth rate of 9.7% CAGR in the years 2014–2019.

In the industrial segment, the LED lighting sector is seen as one of the most powerful drivers and is showing strong growth (CAGR of 30.2% in the period to 2019). The fast-growing market demand for energy-efficient LED lighting solutions and the rapid expansion of LED lighting applications will present a huge opportunity for the semiconductor industry, especially for power semiconductor manufacturers.

Other sectors likely to enjoy demand growth are security and energy management-related applications and medical devices. With the development of connected digital medical devices, health services are gradually shifting from a clinical setting to the home environment. These devices produce data that can be used by healthcare organizations to improve healthcare and by consumers to better manage their own health and wellness. From fitness bands that monitor activity to flexible patches that can detect heart rate, body temperature and more, these applications will fuel capital investment in healthcare and contribute to the growth in industrial applications of semiconductors. Furthermore, the emergence of the IoT and cloud computing supporting machine-to-machine and digital terminals connecting to the internet will drive sustainable growth in the industrial applications of semiconductors.

D The Internet of Things and wearables: the next growth engine for the semiconductor industry

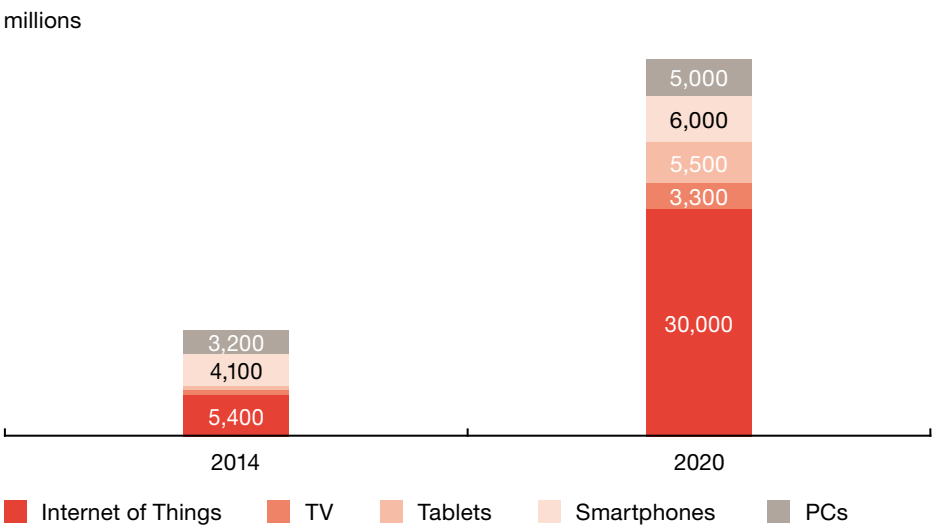
> ***"Internet of Things will drive the demand, not only for sensors, but also for microcontrollers, for actuators – with power semiconductors inside – and for security chips. You can find infinite possibilities and opportunities there. The success of IoT will also depend on, how the cyber security challenges will be solved – hardware based solutions are in our point of view the right approach to address existing concerns."***
>
> Dr. Reinhard Ploss, CEO Infineon Technologies

> ***"Internet of Things will have a profound impact on the number of units that we drive in the semiconductor industry. We think it is going to be a lot more units, which means also more unique types of devices that do not need a lot of expensive features and are going to be cheap."***
>
> Keith Jackson, President and CEO of ON Semiconductor

The IoT has indeed come a long way – from a futuristic concept just a few years ago, to real products, services, and applications that are capturing customers' imagination and driving their adoption of new services and devices. This is no longer hype – the reality is evident in cool new applications being announced every single day – smart watches, fitness bands and trackers, smart glasses to name just a few. The IoT is manifesting itself in technologies beyond consumer electronics in other markets and applications too. The rapid advances being demonstrated through self-driving cars and drones are just the beginning of the endless possibilities that a network of smart connected devices can bring to improving human productivity, safety, and overall quality of life. Today, we can confidently assert that the promise of the IoT is already being realized and its grand vision is just around the corner. The IoT is also becoming more than a buzz word in the minds of business leaders. A recent global study by the Economist Intelligence Unit revealed that an overwhelming majority of C-suite execs expect to be using the IoT in the next three to five years, and close to two-thirds of them believe that companies that are slow to participate in this market will fall behind. This indicates that companies intend to aggressively embrace and take advantage of IoT opportunities. As a result, we're likely to see them making big investments in defining, developing, and bringing to market their IoT products and services.

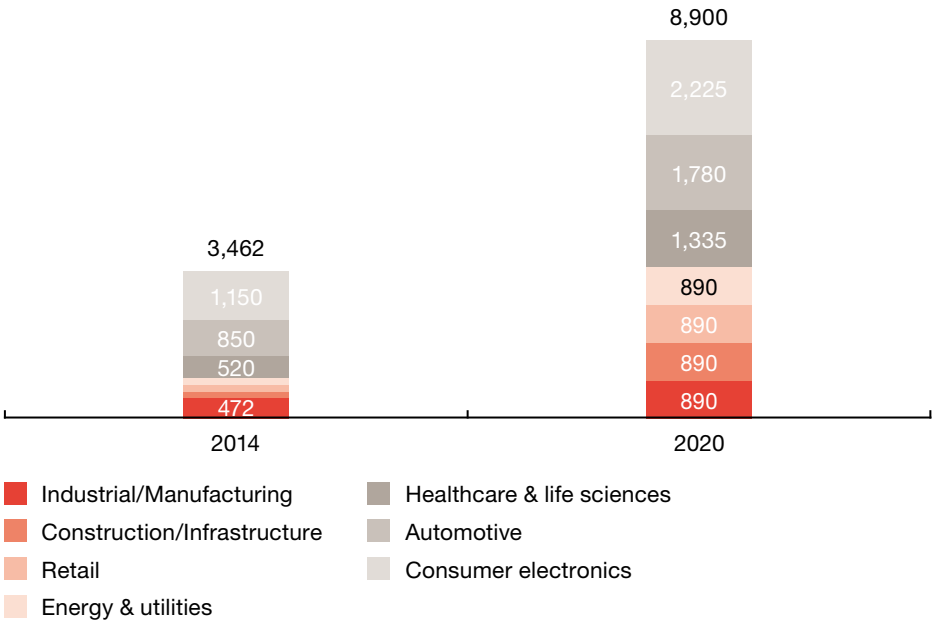
1 The IoT is expected to drive a massive increase in connected devices and revenue growth across multiple industries

Fig. 7 Connected devices by 2020



Source: Industry Forecasts Compilation, 2020 forecast from IDC, PwC analysis.

Fig. 8 IoT market by 2020



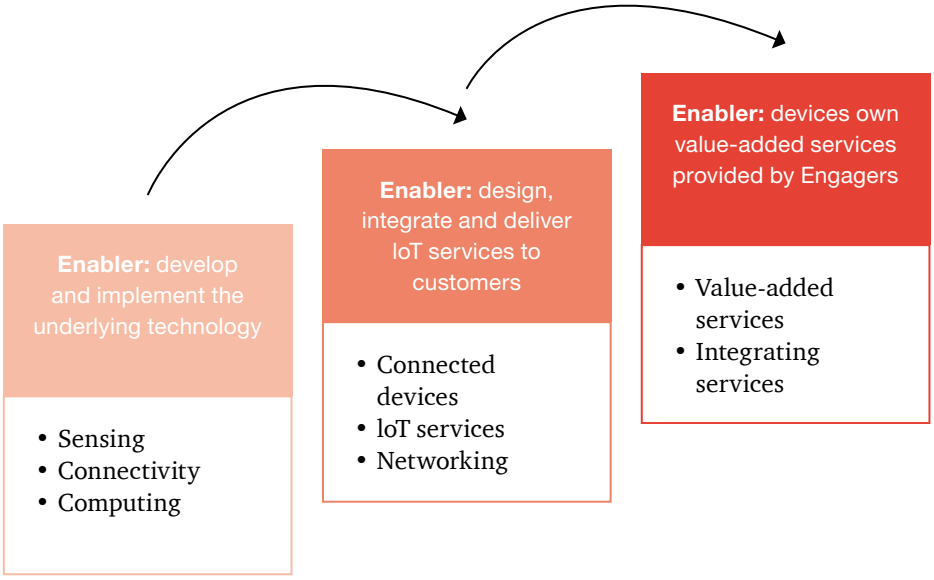
Source: Industry Forecasts Compilation, 2020 forecast from IDC, PwC analysis.

While there are varying estimates and forecasts for the number of smart connected devices, our study shows that we expect there to be anywhere between 30 to 50 billion connected devices by 2020. These 50B connected devices, according to industry analysts at IDC, will drive the total IoT market to US$8.9 trillion by 2020, with three segments – consumer electronics, automotive and healthcare – accounting for more than 50% of the total market in revenue terms. The breakdown of the projected US$8.9 trillion IoT market by 2020 shows consumer electronics at US$2.2 trillion to be the largest segment by size, followed by automotive (US$1.8 trillion) and healthcare (US$1.3 trillion). Other sectors like energy, industrials, and construction that haven't traditionally adopted many of the latest electronic systems and technologies are expected to grow at faster rates as a result of the development of the IoT.

These numbers reflect the total value from all components – hardware, software, products, and services – that will be delivered as part of the IoT solution. What portion of this could be the opportunity for semiconductor devices? Our analysis of a compilation of industry forecasts, suggests that around US$33 billion will come from "IoT related opportunities" by 2019, which includes new product categories as well as incremental revenue in existing categories that could be attributed to the IoT. This accounts for almost 34% of the total increase in semiconductor revenues forecasted across all applications – US$336 billion in 2014 to US$432 billion by 2019. The remainder of this article will focus on the market trends and outlook for different types of semiconductor devices powering these IoT applications, focusing specifically on the wearables market and the strategies that will be required to capture market share.

2 The IoT ecosystem and the role of semiconductors

A recent PwC study –"A Strategist's Guide to the Internet of Things", s+b publication, Winter 2014, PwC and Strategy& – offers an elegant method for viewing the IoT stack, consisting of Enablers, Engagers, and Enhancers.



Semiconductor companies would be classified in this scheme as Enablers, because they provide the technology building blocks for the "things" within the IoT. These infrastructure components help collect, process, and transmit real world signals and data for IoT products and applications.

THE ROLE OF SEMICONDUCTORS – ENABLERS

The underlying core capabilities – **Sensing, Connectivity,** and **Computing** – are essential for the IoT ecosystem and convenient categories for analyzing market trends. Of the three categories, the market for sensing in IoT applications is expected to grow the fastest, at a CAGR of 42%, followed by computing and connectivity at 27% CAGR, between 2014 and 2019. Computing is expected to approximately account for 60% of the total IoT semiconductor revenues, with the remainder of the revenues being split almost equally between sensing and communications device types.

Sensing: Sensors are becoming ubiquitous

The growing popularity of smartphones and tablets in recent years saw touch-screens, proximity sensors, accelerometers, and camera modules as some of the first sensors to hit consumer markets. The array of sensors is now rapidly expanding beyond motion and image sensing to include those that measure humidity, altitude, food calorie composition, and human health indicators as a result of the increase in the variety of consumer IoT applications such as wearables.

As the adoption of sensors increases, the IoT semiconductor revenue from sensing devices is expected to undergo rapid growth (42% CAGR from 2014 to 2019), generating more than US$7 billion in revenues by 2019. This could be attributed to two key trends: advances in sensor technologies and decreasing average selling prices (ASPs). Advanced manufacturing technologies such as MEMS and NEMS combine electronics and mechanical components at micro and nano scales by integrating the functionality of sensors, actuators, and integrated circuits into small form-factors, making them suitable for use in a variety of applications. In addition to these technological advances, intense competition in the fragmented sensor market, with many new entrants, has resulted in a steady decrease in ASPs, in turn leading to increased adoption of sensors. While smartphones, tablets, and wearable devices continue to be the primary drivers of growth in the MEMS sensors, other IoT applications such as healthcare and automotive are also witnessing increased adoption of miniaturized sensors. The overall number of sensing nodes or "end-points" is expected to increase to the hundreds of billions when IoT-type devices become all pervasive.

Connectivity: Connectivity capabilities are being integrated in an increasing number of devices and applications

Connectivity is a key capability required in IoT applications, both for consumer and enterprise infrastructure devices. The overall communications electronics market for semiconductors is expected to continue growing at 4.8% to reach US$127 billion by 2019. The smartphone devices sector is growing fastest, driven by the increased digitalization of consumers' lifestyles. The resulting explosion in mobile data traffic is driving the growth in mobile infrastructure equipment, which is fast migrating towards more 4G LTE deployments that promise increased network capacity and provide faster data transmission. This is evident from the shift in the mix from 3G to 4G in many markets. 4G LTE equipment as a percentage of all wireless infrastructure deployments is expected to double – from ~20% in 2013 to almost 40% in 2014.

Within the embedded device space, connectivity and network processing-related functions are increasingly being combined with embedded processors in applications beyond cell phones. For example, Qualcomm's Snapdragon 602A combines an application processor, GPU, DSP, GPS, 4G LTE, Wi-Fi, and Bluetooth targeted for the automotive infotainment segment. This trend is clearly a threat to pure-play compute-focused chip providers that do not have a robust connectivity solution as part of their portfolio. Further, "Combo wireless" connectivity chipsets with integrated NFC, Wi-Fi, and Bluetooth are expected to grow strongly in smartphones and consumer electronic devices that are expected to support multiple communication standards and protocols.

Computing: The IoT will drive higher growth in application-specific microcontroller units (MCUs) and flexible Systen on Chip (SoC) type designs

It's estimated that in the next five years, unit shipments of embedded processors attributed to the IoT will grow five times faster than the rest of the embedded processing market. Much of that growth will come from MCU-based devices, especially 32-bit MCUs which are becoming increasingly popular owing to the higher computing requirements of sophisticated real-time sensors for automotive, industrial, and medical applications. Yet another trend is observed in the growth of application specific MCUs that have integrated connectivity and/or sensors. These application-specific MCUs, which allow many home appliances and industrial devices to connect to the internet, are threatening the traditional, general purpose MCUs.

IoT applications ideally require a single chip at an acceptable form-factor and with very low power consumption suitable for battery operated devices. These requirements have driven growth in the number of SoC-type designs, comprising multiple embedded cores, embedded GPU, and integrated wireless connectivity in a single package. In the mobile compute markets, smartphones and tablets continue to disrupt traditional computing devices such as desktops and laptops, using their low-power ARM-based designs.

Spotlight: The wearable electronic devices market

Today, the average US home has around seven connected devices. This number is expected to almost triple by 2019. It's not therefore surprising that much early IoT activity is centered on the consumer segment, focusing on wearable devices, smart TVs, video game consoles, and digital set-top-boxes. One of these segments – wearables – has seen some of the coolest innovations of the last few years, and is now a booming consumer market. There's been a flood of wearable personal health tracking products that promise to improve overall health by monitoring activity, exercise, sleep, and heart rate. The sudden interest in wearables has resulted in intense competition, rapidly making this market crowded and fragmented, while waiting for a dominant design to take hold. Many wearable devices come with their own apps and by tethering to a smartphone link to a social network. But a growing number of standalone devices is also beginning to emerge.

Most popular categories of wearables based on application use cases:

- **Healthcare Monitoring:** Fitness tracking (sleep, exercise, heart rate), Training (sports, personal coaching), and Personal Medical Devices (pressure, glucose monitoring, etc.)
- **Human Computer Interfaces:** Smart Glasses, Smart Watch, Head Mounted Displays (VR headsets)

The semiconductor revenues from these two wearable categories is expected to grow from a combined US$15 million in 2013 to more than US$7 billion in 2019. When combined with software and services, the value according to some estimates could be around US$11 billion to US$15 billion a year in 2019. Both categories are expected to grow at 100%–115% CAGR for the next five years.

Challenges and market trends

Several aspects of wearable devices – from the underlying physics to the end-user experience – play a crucial role in driving increased consumer adoption and acceptance. Semiconductor companies will benefit from being cognizant of the challenges and market trends as they go about designing products to compete in these IoT segments.

Sensor technology:
Much of the magic surrounding wearables centers on the sensor technology. Advances in sensor technology and miniaturization using MEMS and NEMS are reducing prices and driving increased adoption. What began as health and fitness monitoring for the casual user is now expanding to personal medical devices that are able to more accurately measure health indicators, including oxygen saturation, UV exposure, calorie consumption, and skin temperature. Smart glasses, smart watches, and gaming headsets will continue to drive the need for cost effective image sensors that provide good enough image quality in a small form factor.

The wearable sensor market is set to explode, reaching more than half a billion shipments by 2019. While CMOS image sensors and inertial sensors are expected to account for more than a third of the IoT sensor market (Dollars) by 2019, the highest growth rate is expected for magnetic and pressure sensors.

Increased intelligence:
As the IoT evolves, wearable devices will transition from just performing monitoring and reporting functions into more sophisticated functions such as remotely controlling other things in the IoT, automatically triggering actions, and learning and adapting to situations, e.g. location-aware augmented reality. Increased processing capabilities will be needed to cope with the increasing levels of intelligence required to process complex stimuli in real-time, e.g., voice-control or gesture recognition. The percentage of semiconductor revenue represented by *compute* devices is expected to increase by 6–10% between 2015 and 2019 depending on the type of wearable product.

Design considerations:
Many wearable devices have stringent design constraints demanding ultra-low power consumption that can extend battery life and require only very infrequent recharging. To address these requirements specialized processors are being developed that are more configurable than the typical 32 bit embedded processor and consume far less power. Low-power design techniques such as multi-threshold CMOS are also being explored to optimize the design for power.

> ***"The biggest challenge for wearables comes from consumers. Wearables need to reflect fashion trend of users. However, consumers usually have different tastes which change all the time. It is an arduous task to figure out the right combination of things that get people excited and really take off."***
>
> Keith Jackson, President and CEO of ON Semiconductor

User-centric design:
Other design factors that might not be obvious are around aesthetics, usability, and style, driving a heavy emphasis on human-centered design, given that wearables are the human's direct, personal experience of the IoT. These design factors could translate into the need for innovation in semiconductor packaging technologies that allow for unobtrusive form-factors and increased durability to interact with bodily (e.g., sweat, saliva) and other fluids (e.g., water, soda, milk) with which the device might come into contact, without compromising device performance or reliability. The design of the wearable devices should also minimize the amount of 'training' that consumers need before they can begin using the device.

Connectivity:
Most wearables anchor on the smartphone platform, since that is viewed as a *defacto* wearable. This has led to the creation of a personal area network, centered on the user's smartphone, on which all wearable devices typically talk to each other using cheap, energy efficient protocols such as Bluetooth Smart or ZigBee. As the IoT evolves, wearables might begin communicating with other "things" in their environment, such as machines or equipment at workplaces, retail aisle displays, and digital signage in a shop window. These use cases and applications may require the support of additional communication standards in the future.

New materials:
Smart garments are yet another exciting application for wearables. Applications such as smart shirts track athletes' performance in real-time, using sensors integrated in the fabric, ideally in a non-obtrusive way to minimize any adverse impact on the wearer. Other applications for smart clothing include fabric that can moisturize, release medicines, and protect against environmental hazards. All these exciting new applications pose requirements for new materials. For example, smart fabrics based on phase change materials that can self-cool and thus regulate the wearer's temperature.

Security and privacy:
Privacy and security will be glaring concerns for people using wearable technology. According to a PwC survey ("The wearable future", Oct 2014), more than 80% of respondents indicated that they were worried that wearable technology would invade their privacy or make them more prone to security breaches. Typical concerns include ownership and usage of private data and restrictions on when and where certain wearable devices could be used. The former would be especially concerning for health-related data that is collected and analyzed at multiple "nodes" (the wearable devices themselves, hubs, or the cloud) by multiple entities (device makers, service providers, and third parties). An example of the latter could be prohibiting the use of certain devices while driving or operating machinery at work, to ensure personal and public safety. Overcoming these challenges will require a mix of regulation and innovation (e.g., advanced encryption technologies) as wearable devices become ubiquitous.

3 What should semiconductor companies do to capture value from the IoT?

The markets and applications potentially arising from the IoT arguably represent the greatest opportunity for semiconductor growth since the internet boom. However, the accompanying risks cannot be overlooked. Many of these nascent markets bring unique technical challenges and considerable uncertainty as a result of constantly changing customer requirements. Many technology standards are still in development, and use cases continue to evolve. Semiconductor companies should not only focus on these markets, but also be prepared to rapidly adapt to changing conditions. One way to achieve that is to develop a comprehensive approach to the IoT that spans strategy through execution, taking into account how to deal with new business and operating models as they emerge. Our top three recommendations are to:

- **Develop a clear IoT strategy spanning both applications and solutions**
  A fundamental first step for all semiconductor companies is to identify the target market segments they will compete in. They then need to prioritize their product and portfolio roadmap accordingly, and identify any capability gaps and how they'll close them, whether that involves organic growth, acquisitions, joint partnerships or a combination of all these.

  One option is to become a capability-focused player, offering select capabilities (e.g., sensors or connectivity solutions) across one or more applications. However, for wearable type applications, a more suitable option might be to adopt an application focus, offering a comprehensive set of capabilities (compute and connectivity, for example) for specific industry "verticals".

> ***"We realize two important implications for the semiconductor industry:***
> ***1. Collaboration to an increased degree will benefit both the IoT market for taking off and companies in order to participate.***
> ***2. The IoT market is governed by cheap sensors. Semiconductor companies have to find their way to play into this situation."***
>
> Keith Jackson, President and CEO of ON Semiconductor

More importantly, many of the opportunities from the IoT, especially in the consumer and wearables space, are expected to be high-volume, low ASP (and hence low profit margin) devices. To make their efforts worthwhile, semiconductor companies need to move up the stack to capture addition value – by starting to think beyond the device. Success in these markets depends on the ability not only to develop compelling products, but also to offer complete solution and service offerings, beyond the device – by having a strong software and applications strategy. This could involve creating a SolidWorks Application Programming Interface (SW API) on which developers can easily write apps for the product, or distributing high-quality developer tools, design tool-kits, and integrated development environments (IDEs) that will make the product development process smooth and seamless for partners. While not many chip makers have the expertise in system software, there is a growing trend amongst leading companies to provide not just silicon, but also middleware, e.g., protocol stacks and accelerators in firmware.

After finalizing their IoT product and portfolio strategy, leaders should pay special attention to closing gaps in their portfolio through either developing or acquiring key IP. For example, wearables, given the amount of personal health data they process, might require increased security features such as biometric identification and advanced encryption. Other examples might include acquiring specific connectivity IP that could be integrated into a System on Chip (SoC) to reduce footprint and power requirements, while lowering chip cost. In cases where complex technology is involved or is outside of the company's core capabilities, acquisition might be the best way forward. For example, Qualcomm's acquisition of Cambridge Silicon Radio (CSR), Microchip Technology's acquisition of ISSC Tech Corp., etc. are all examples of companies closing portfolio gaps to successfully compete in IoT markets.

- **Define a comprehensive ecosystem strategy**
  The IoT has many moving parts, and all players – Engagers and Enhancers – across the value chain are closely eyeing revenue opportunities. Developing a comprehensive ecosystem strategy is key to success in this diverse environment. This consists of both a technology and development ecosystem.

  Solving the technology ecosystem piece of the puzzle means first defining the company's role in setting standards and creating new platforms. Should it invest in creating a new platform and rally other players to adopt it? What will be the investment required to do that and is it justified? If the answer to that question is negative, businesses should strategically choose the most appropriate existing platforms and standards around which they can build the product or solution. An example would be a technology platform such as ARM's mbed OS, device server, and development tools that are specifically optimized for power efficient, secure connectivity for IoT device applications. Another is ARM's and Cadence's deal to use TSMC's new ultra-low power platform for IoT and wearables.

Addressing the second aspect, the development ecosystem, requires companies to investigate the appropriate partner(s) (e.g., original design manufacturers (ODMs) and distributors) they'll need to work with to build out IoT capabilities. Designing a chip for wearable products might require collaborating jointly with fashion houses and fabric designers or, in other cases, sports brands and sports equipment makers. For example, Intel has announced its collaboration with Opening Ceremony to design a fashion bracelet called MICA ("My Intelligent Communication Accessory"), that helps women stay connected through SMS messages and meeting alerts. In other cases, collaboration might be to address specific challenges such as navigating regulatory hurdles (for personal medical devices). Choosing the right design, manufacturing, and channel partners will ensure that the best overall solution is created for the end customer through effective collaboration across the value chain.

- **Develop an operational strategy to ensure flawless execution**
  Last but not the least, is plotting the path to operationalize the company's IoT strategy. This aspect is frequently overlooked, but failing to address it may result in unexpected outcomes that are directly attributable for failed execution. Many of the IoT applications might require new business and/or operating models that steer companies into uncharted territory. Collaborating across the value chain with a variety of participants from unfamiliar industries will require changes to go-to-market strategy, as well as sales and channel management practices. This is especially true of the wearables market, which has the most diverse set of potential value chain participants manufacturing items such as fashion garments and footwear, jewelry, sports equipment, and medical devices. Some wearable applications might involve both high volumes and a considerable variety of products. Managing these variables effectively means rethinking how best to organize the supply chain to meet customer requirements and then optimize it for competitive advantage.

E Summary and conclusion

PwC's forecast for the global semiconductor market suggests that between 2014 and 2019 billings will increase by US$96 billion, representing a compound annual growth rate (CAGR) of 5.2%. Data processing will be the largest single segment, with a total of US$162 billion in 2019, followed by the communications segment with a total of US$127 billion in 2019. The strongest growth will be in the smaller segments: industrial (forecasted CAGR of 9.7%) and automotive (forecasted CAGR of 8.2%).

Various applications that could be positively impacted by the IoT will drive rapid growth in the semiconductor industry over the next few years. While markets such as wearables, smart TVs, and autonomous vehicles offer huge opportunities to semiconductor companies, they are also fraught with many unresolved challenges such as privacy and security. Semiconductor companies, as Enablers of the IoT ecosystem, will play a critical role in providing the foundational capabilities required to develop innovative solutions. As they do so, they'll need to carefully consider how to capture value from the IoT and win in the IoT battleground. A necessary first step for semiconductor companies to emerge on top will be to formulate a comprehensive IoT strategy. But that alone will not be enough. Working out a solid execution plan – exploring paths to close portfolio gaps and subsequently engaging with partners across the entire value chain – will be essential if semiconductor companies are to emerge victorious.

F For more information – PwC can help

If your company is facing challenges doing business in the global semiconductor industry, or you just want to have a deeper discussion about what's happening in the sector and how we can help, please reach out to one of the technology industry leaders listed below.

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