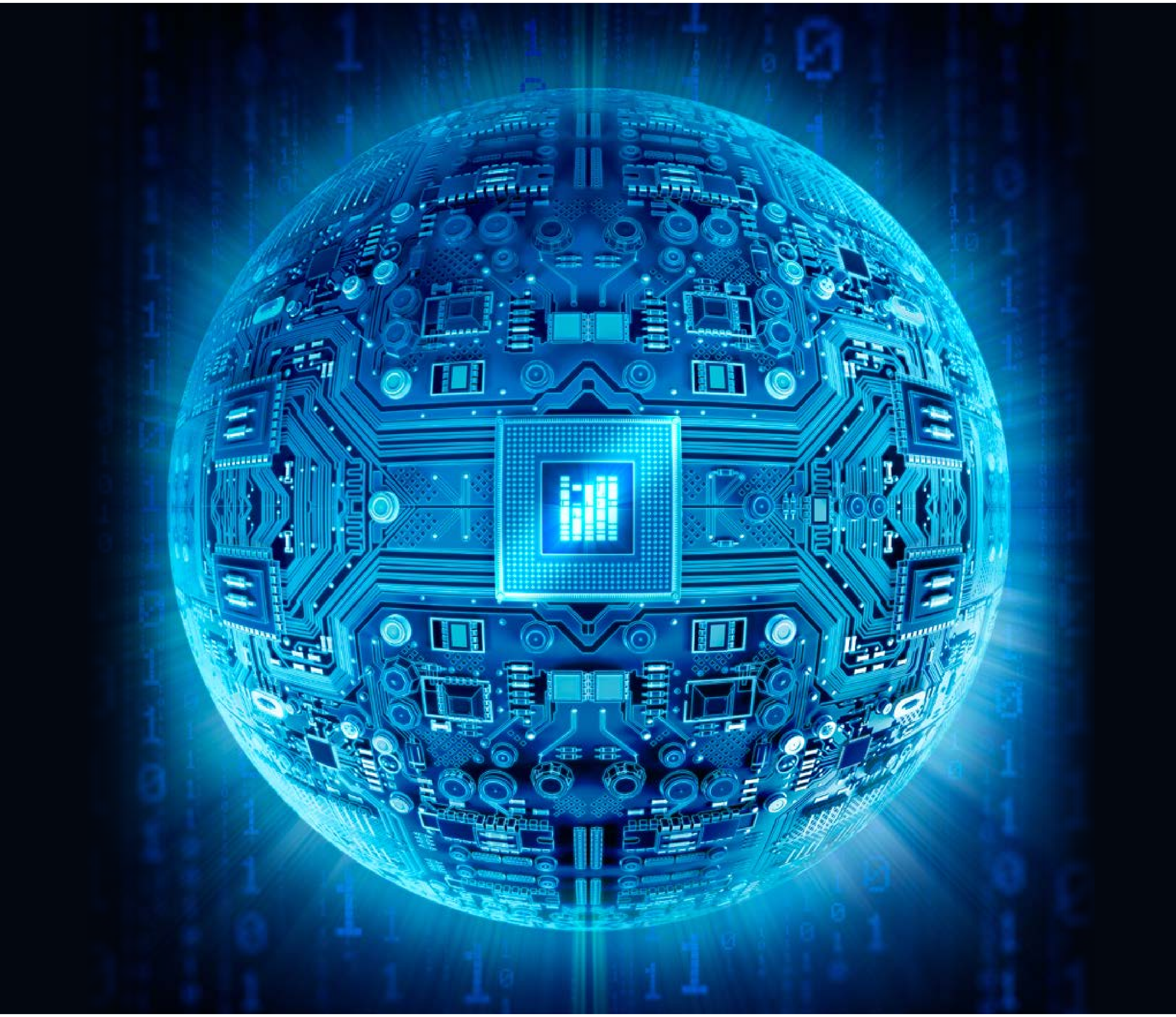
Enabling the Hyperconnected Age

The role of semiconductors



Global Semiconductor Alliance

OXFORD ECONOMICS

Foreword

At GSA, we talk a lot about the contribution and far reaching impact of the semiconductor industry. We see the effect of the industry on our economy, educational system, quality of life, and enablement of peoples. However, we also recognize that outside our field, many fail to see the semiconductor for what it is—the foundational core of the digital world—and that without the semiconductor, the internet ceases to exist, mobile phones are never created, and the race toward smart energy, smart cities, and autonomous driving never begins.

With that in mind, the Global Semiconductor Alliance, with the support of the 2013 GSA Board of Directors, commissioned Oxford Economics to take an independent look at the semiconductor industry to objectively measure both the societal and economic impact of what we feel is one of the greatest contributing industries in our modern world; one that enables unlimited possibilities and inspires innovators to dream.

Jodi Shelton
President, Global Semiconductor Alliance

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Global Semiconductor Alliance

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INTRODUCTION

Semiconductors fuel the Age of Hyperconnectivity

We are living in an unprecedented era of hyperconnectivity that is redefining our societies, cultures, and communications. And it has only just begun.

From data collection and search engines to e-commerce and social networking, the internet has become the ubiquitous cloud that is connecting every aspect of our daily lives. And powering this cloud is an intricate web of globally connected data centers, each filled with thousands of computer servers networked together and linking us to a seemingly unlimited breadth of information and content.

Today, our mobile devices support social media and web browsing, multimedia entertainment, and various forms of connectivity that allows instant access to thousands of applications and internet-based services. And tomorrow, mobile devices will support augmented reality, seamless voice control, 3D holographic screens, and powerful predictive analytics. The resulting explosion in data is staggering—according to IDC, the amount of data created globally will roughly double every two years, reaching 40 zettabytes by 2020[1]—that's almost equivalent to all human speech ever spoken since the beginning of time.[2]

Automobiles have offered keyless ignition, infotainment systems, and safety features such as rear-mounted radar and cameras for years. But today's cars leverage technology even further—with monitoring capabilities that determine if a driver is overly tired or impaired; parental controls to set maximum speed and provide location-based services; and night vision assistance to warn drivers of pedestrians, bicyclists and other potential hazards on the road. In the near future, cities will be serviced by fleets of autonomous taxis,[3] and vehicle-to-vehicle communication (V2V) will be commonplace.

Meanwhile, healthcare as our parents knew it is being transformed. New wearable devices can track heart rate, glucose levels, and food intake, helping doctors and caregivers monitor the biometrics of their chronically ill patients—regardless of their location—to identify patterns that may lead to more successful treatments. Even more leading-edge: Wi-Fi chips meant to be swallowed to deliver a raft of information instantly to doctors.[4]

And as humanity's global footprint widens and our energy needs grow more acute, a new generation of "smart" technology is being deployed to improve the efficiency of our power grids, enabling cities, towns, and homes to optimize energy consumption for a more sustainable future.

All of these advances offer unparalleled possibilities to enrich the lives of people around the world while generating growth and opportunity across the global economy. But none of this would be possible without the most fundamental building block of our modern age: the semiconductor, the material core of the digital world.

1 http://www.emc.com/leadership/digital-universe/20014iview/executive-summary.htm.
2 http://itre.cis.upenn.edu/~myl/languagelog/archives/000087.html.
3 http://venturebeat.com/2014/01/26/google-granted-patent-on-free-taxi-service-paid-for-with-ads/.
4 http://www.nylovesnano.com/semico_study/Semiconductor%20Economic%20Impact%20Full%20Report.pdf.

Semiconductors are at the heart of technological progress and innovation

The semiconductor is one of the most pervasive and powerful inventions in human history. When *The Atlantic* asked scientists, historians, and technologists to rank the top innovations since the wheel, the semiconductor came in fourth—just behind the printing press, electricity, and penicillin, but ahead of eyeglasses, paper, and the steam engine.[5]

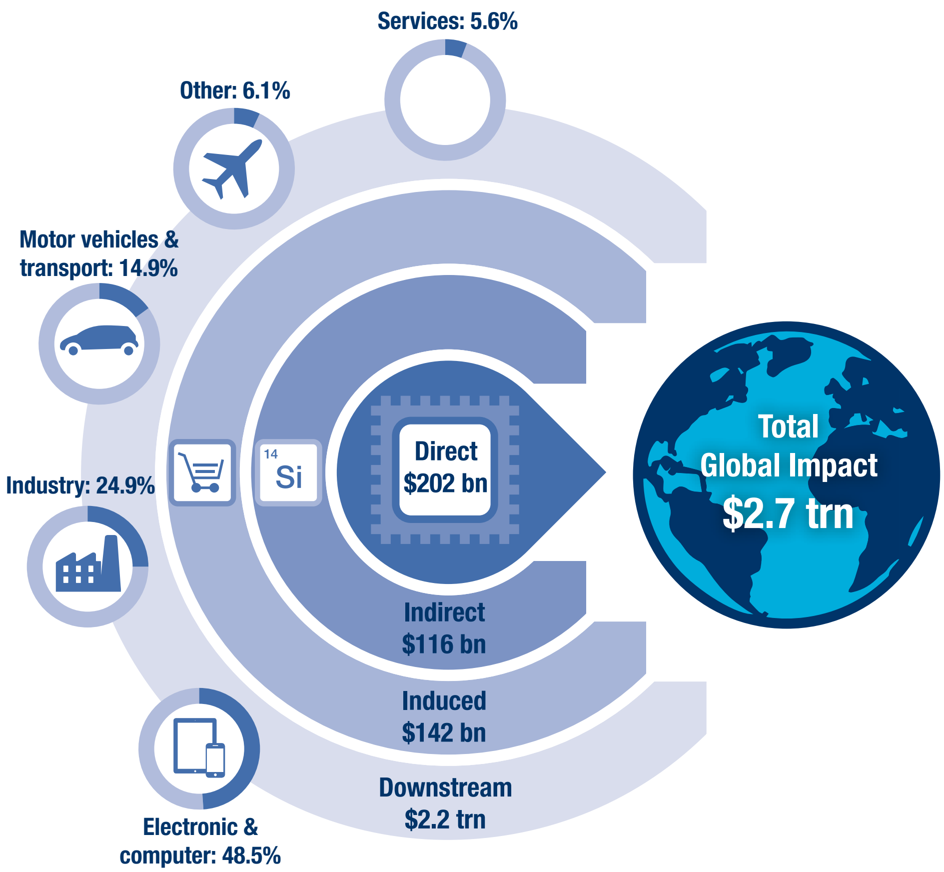
What is truly astonishing is the trajectory of the semiconductor's impact on technology and the subsequent effect it has had in our daily lives. Examples of this are everywhere:

- As of June 2014, Facebook had more than 1.32 billion monthly active users worldwide, creating a hyperconnected, global social network.[6]
- At more than 7 billion units, mobile devices now outnumber our global population. By 2017, some 10 billion devices will have downloaded 77 billion apps.[7]
- By 2020 there will be 50 billion networked devices, according to estimates from Cisco—though some industry leaders find this number conservative, since less than 1% of objects are today connected to the internet.[8]

Our analysis shows that semiconductors contributed to the creation of $2.7 trillion in global GDP in 2012.

Semiconductors touch almost every sphere of economic activity. In fact our analysis (see section 1 below) shows that semiconductors contributed $2.7 trillion to global GDP in 2012.

Figure 1: The economic impact of semiconductors



5 http://www.theatlantic.com/magazine/archive/2013/11/innovations-list/309536/.
6 http://investor.fb.com/releasedetail.cfm?ReleaseID=861599.
7 http://www.forbes.com/sites/connieguglielmo/2014/01/07/ces-live-cisco-ceo-chambers-to-deliver-keynote/.
8 http://newsroom.cisco.com/press-release-content?articleId=1334100&type=webcontent.

Yet for many—from policy-makers on Capitol Hill to investors on Wall Street; from college students to tech-hungry consumers—the semiconductor remains overlooked. Many do not realize that semiconductors are the critical building blocks for the transformative advancements of our time; mobility, computing, and smart devices; wearables, drivables, and flyables; advanced robotics, medicine, and green energy, just to name a few.

And as our planet grows ever more connected and our societies become more able to measure, analyze, and predict behaviors in the physical world, continued advances in the capabilities of the semiconductor will help whole new industries flourish, while allowing further dramatic increases in global productivity, economic growth, innovation, and sustainability. As a result, it will be crucial for policy-makers to support a healthy semiconductor ecosystem, and for educators to provide a steady stream of young minds to reach new frontiers.

Oxford Economics and the Global Semiconductor Alliance (GSA) have undertaken a groundbreaking study to examine how the semiconductor industry affects people, countries, and industries. Our report is divided into four sections:

1. **Semiconductors' global footprint: direct, indirect, and induced effects**
   Here we present the direct, indirect and induced effects of the semiconductor industry on the global economy.
2. **The innovation effect**
   Examples of how semiconductors support innovation (the "catalytic" impact) across five specific industries—computing, telecommunications, automotive, energy, and healthcare.
3. **At the frontier of knowledge**
   Where semiconductors will take us in the future, and why ongoing investment and research into the development of semiconductors is critical to global growth.
4. **Ensuring a thriving semiconductor ecosystem**
   Calls to action for policy-makers, students, and the business community.

Key definitions and methodology

To understand the full magnitude of the semiconductor industry's effect on the global economy, we looked at two main categories of economic impact: the sector-specific impact, and the downstream impact.

Assessing sector-specific impact
This refers to the narrower economic footprint the semiconductor industry produces—as an employer, a purchaser of supply-chain goods and services, and a source of consumption spending in the world economy. Blending published financial and labor-market data with a unique survey of the worldwide semiconductor industry allowed us to estimate the semiconductor industry's contribution to GDP and employment. Three elements comprise that economic footprint.

Direct impact: The GDP and immediate employment accounted for by semiconductor firms across the world. Our bespoke survey is the central building block for this core element of the study.

Indirect impact: Using Oxford Economics' global input-output model, we estimate the GDP and employment supported in the supply chain of the semiconductor industry as it acquires the materials and services necessary to produce its final products. For example, a proportion of the transportation industry's output can be attributed to spending by the semiconductor industry as it moves materials, equipment, and products around the world. Similarly, the semiconductor industry is a major purchaser from the electrical and optical equipment, business services, finance, and chemicals and chemical products sectors (to list a few).

Induced impact: Leveraging Oxford Economics' global macroeconomic model (which simulates and predicts economic activity across 201 countries) allowed us to quantify the economic impacts on other industries as employees of the semiconductor industry and its suppliers spend their earnings. Their consumption supports economic activity in a diverse range of industries, including retail outlets, companies producing consumer goods, and a range of service industries (banks, restaurants, etc.).

Determining downstream impact
The sector-specific impacts are impressive, but are in many ways less significant than the effects that semiconductors have once they are integrated into innovative products and devices that change our lives on a daily basis. This second step assesses the wider economic impacts semiconductors create not only in their application in other industries like technology, automotive, healthcare, and energy, but also by enabling new businesses—acting as a catalyst that powers further economic activity.

This ***downstream impact*** is determined by drawing on available evidence from academic sources and Oxford Economics' global industry databank. This enables us to quantify the contribution semiconductors make as crucial inputs to products and services across almost every area of the global economy. We used estimates of the share of 1960–2007 GDP growth in different US sectors that are estimated to be attributable to semiconductors.[9] These shares are then applied to the growth in GDP across comparable sectors worldwide.

9 http://www.semiconductors.org/clientuploads/directory/DocumentSIA/ecoimpactsemidraft_Samuels.pdf.

What is a semiconductor?

Modern-day semiconductors are billions of transistors joined together on a tiny piece of glass-like material called silicon. Each transistor, smaller than the cells in your body, works together by turning on and off over 100 billion times per second to allow electricity to flow in a certain way. It is this electricity flow that determines the behavior of the semiconductor and its application.

Semiconductors are essential for the operation of all modern electronic devices—and as their power, complexity, and sophistication have grown, so too have their uses. Semiconductors power our laptops, smartphones, and tablets. They are responsible for many of the modern advancements made in car electronics, avionics, and medical equipment; and semiconductors have enabled our white goods, appliances, and lighting to achieve unprecedented gains in efficiencies. Semiconductors are the essential building blocks that power modern technology.

1

Semiconductors' global footprint: direct, indirect, and induced effects[10]

The semiconductor industry's most vital contribution to the global economy is its ability to enable innovation and competitiveness across nearly every sector of commerce. In addition, the industry was responsible for generating $290 billion[11] in annual revenue in 2012 with expectations that this number will exceed $400 billion in 2017.[12] As a result, the semiconductor industry currently makes a direct contribution to global GDP—the industry's turnover less its costs, also known as its "value-added"—of $202 billion while sustaining 1.3 million high-value jobs,[13] and these numbers are expected to continue their rapid growth into the years ahead.

The semiconductor industry made a direct contribution to global GDP of $202 billion in 2012, and directly supported 1.3 million high-value jobs.

Like all industries, the semiconductor industry is supported by a supply chain providing goods and services that are essential to its production process. Indeed, Integrated Device Manufacturer (IDM) companies (see sidebar below), which make up the majority of the sector, spend 31% of their revenue on their supply chain. And although all sectors of the economy benefit from this supply chain spending, the biggest beneficiaries are the equipment and material providers, followed by business services and finance. Oxford Economics' global economic impact model shows that semiconductor firms' spending with suppliers—their indirect impact—contributed an additional $116 billion in GDP globally in 2012, supporting over 2 million jobs in the worldwide supply chain.

After calculating the direct and indirect impact, we must also consider how those employed by the semiconductor industry and its supply chain spend their earnings and support economic activity in other sectors. This induced impact of the semiconductor industry contributed another $142 billion to global GDP in 2012, with an additional 3.3 million jobs dependent on that consumer spending.

Aggregating these figures gives us the industry's immediate, up-stream economic impact—its total global economic footprint: a $460 billion contribution to world GDP in 2012, supporting over 6.6 million jobs worldwide.

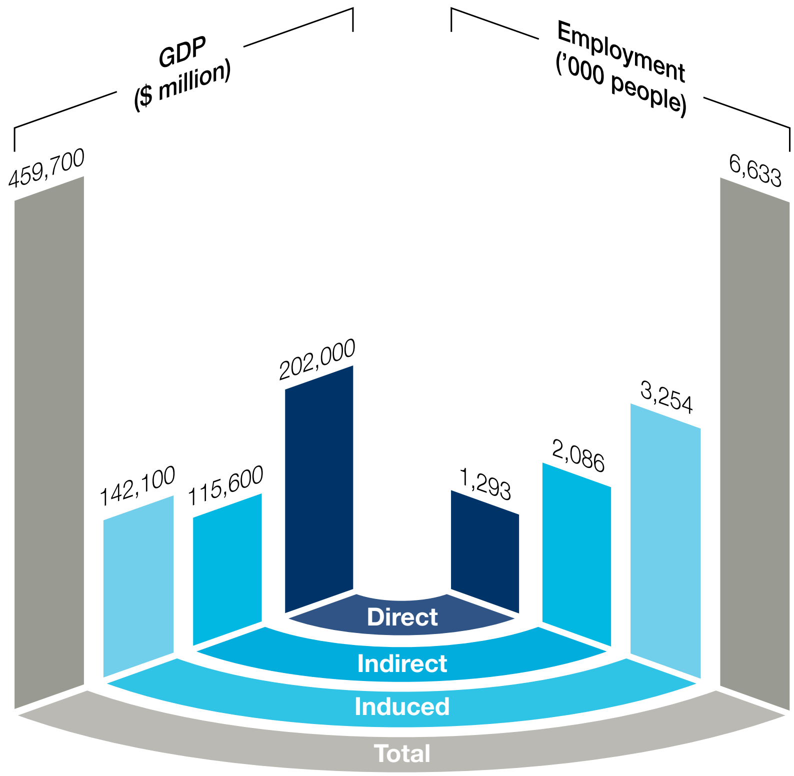
10 Results in this section are calculated using Oxford Economics' global economic impact model. Aggregate semiconductor revenue, R&D spending, and capital investment data are sourced from ICInsights. Data on employment, wages, taxes, and use of indirect inputs are sourced from the GSA's Financial Tracker database, SEMI, company financial reports, input-output tables from national statistical agencies, interviews with industry experts, and a survey of 31 semiconductor firms.

11 At a global level, industry turnover is equivalent to the direct and indirect GDP impacts of the sector. This does not account for the use of semiconductors by indirect suppliers to the semiconductor industry, but does exclude the use of semiconductors as an intermediate input by the semiconductor industry itself.

12 Global Semiconductor Industry 2012-2017: Trend, Profit, and Forecast Analysis, Lucintel, (2012).

13 All figures and results are given for 2012.

Figure 2: The economic footprint of the semiconductor industry



Source: Oxford Economics

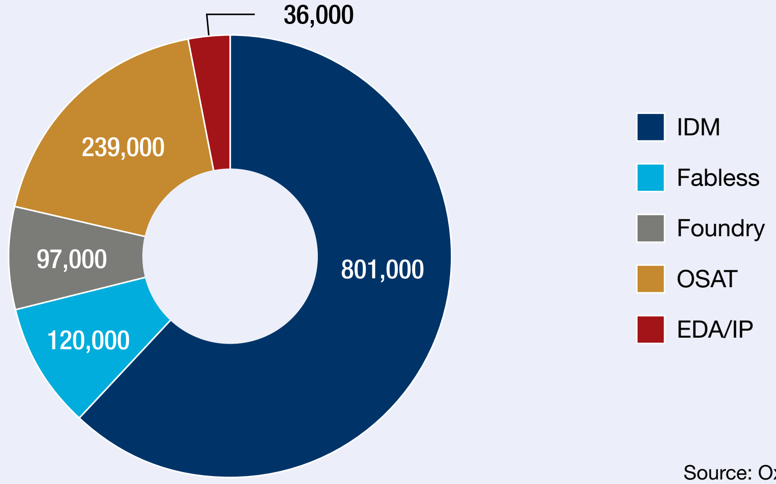
Impacts by type of semiconductor firm

Digging deeper into our analysis allows us to isolate the economic contribution of specific sectors of the semiconductor industry.

Integrated Device Manufacturers (IDMs) are companies that undertake most or all of the design, fabrication, assembly, testing, and sales of their semiconductor products in-house. Leading companies in this realm include household names such as Intel and Texas Instruments. The IDM sub-sector dominates the industry and thus accounts for the bulk of direct economic impact across the world, responsible for two-thirds of direct GDP contribution—or $135 billion—in 2012. In terms of employment, IDM firms supported 801,000 jobs, or 61.9% of direct employment benefits in 2012. Just over one-fifth of these jobs were based in the US, with nearly 13% in China, 11% in Japan, and 10% in Europe.

By contrast, **fabless manufacturers** design chips that they market and sell to customers, while outsourcing the fabrication, assembly, and test process to a third party. Leading members of this group include, for example, Broadcom, Nvidia, and Qualcomm. Despite accounting for 17.7% of direct GDP, fabless companies support only 9.3% of direct employment. This reflects the fact that fabless firms outsource chip manufacturing, assembly, and test, and thus achieve significantly higher levels of labor productivity. The fabless sector supports a greater concentration of employment in more developed economies such as the US (37% of total) and Europe (10.8%), reflecting its focus on chip design.

Figure 3: Direct employment by type of semiconductor business



Source: Oxford Economics

Foundries specialize in manufacturing the chips designed by fabless companies. Notable firms in this sector include GlobalFoundries, SMIC, TSMC, and UMC. Three-quarters of Foundry jobs are in three markets, with Taiwan accounting for 57% of direct foundry employment, followed by China (10%) and the US (9%).

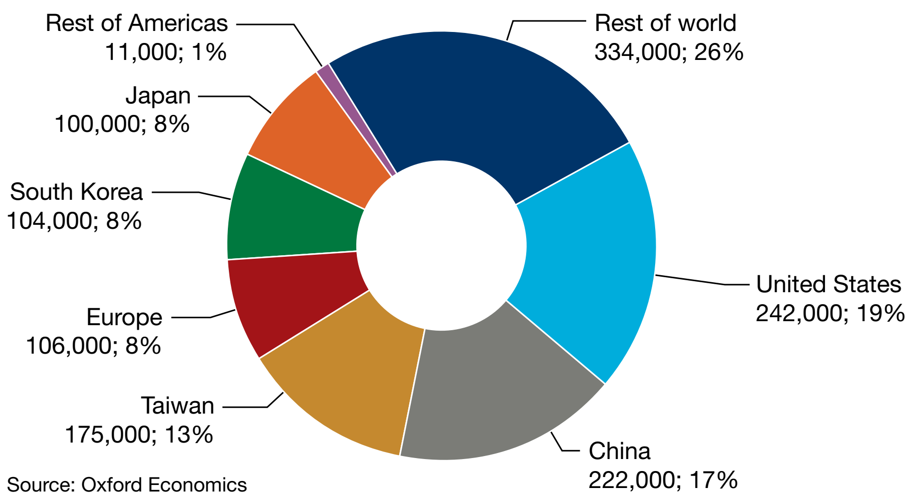
Outsourced Semiconductor Assembly and Test firms **(OSATs)** are contracted by fabless firms and some IDMs to package and test the chips that foundries produce. Companies in this realm include Advantest, Amkor, and ASE. OSAT companies are the industry's second-largest employers, accounting for 239,000 jobs supported, or 18.5% of the direct workforce, despite representing only 6.4% of the industry's GDP. Approximately 35% of OSAT employment is based in China, and a further 19.6% is based in "Rest of World"—beyond the US, Europe, Japan, China, Taiwan, and South Korea.

To help manufacturers and foundries rapidly produce innovative new semiconductors, **Electronic Design Automation** companies (EDAs) provide the critical software tools to design and produce chips, and communicate complex specifications between firms. Leading companies in this sector include Cadence, Mentor Graphics, and Synopsys. **IP** providers meanwhile develop core and ancillary intellectual property that is licensed by chip manufacturers in the design of their semiconductors. A leading example of this model is ARM Holdings, based in the UK. We estimate that one-quarter of jobs in EDA and IP companies are located in the US, with a further 21% in Europe. In addition China and Taiwan both account for 15% of EDA/IP jobs, meaning that four economies account for over three quarters of the sub-sector.

A globally distributed industry

As described above, the direct impact of the semiconductor industry was sufficient to support 1.3 million jobs around the world in 2012. Figure 4 (below) shows the truly global nature of the industry: we estimate more than 100,000 people were employed in each of Japan, South Korea, and Europe, and around 175,000 in Taiwan in 2012. The United States employed the greatest number of people, at 242,000. But the industry in China is estimated to have employed nearly as many people, reflecting a lower cost of labor and the growing importance of the semiconductor industry to China's economy.

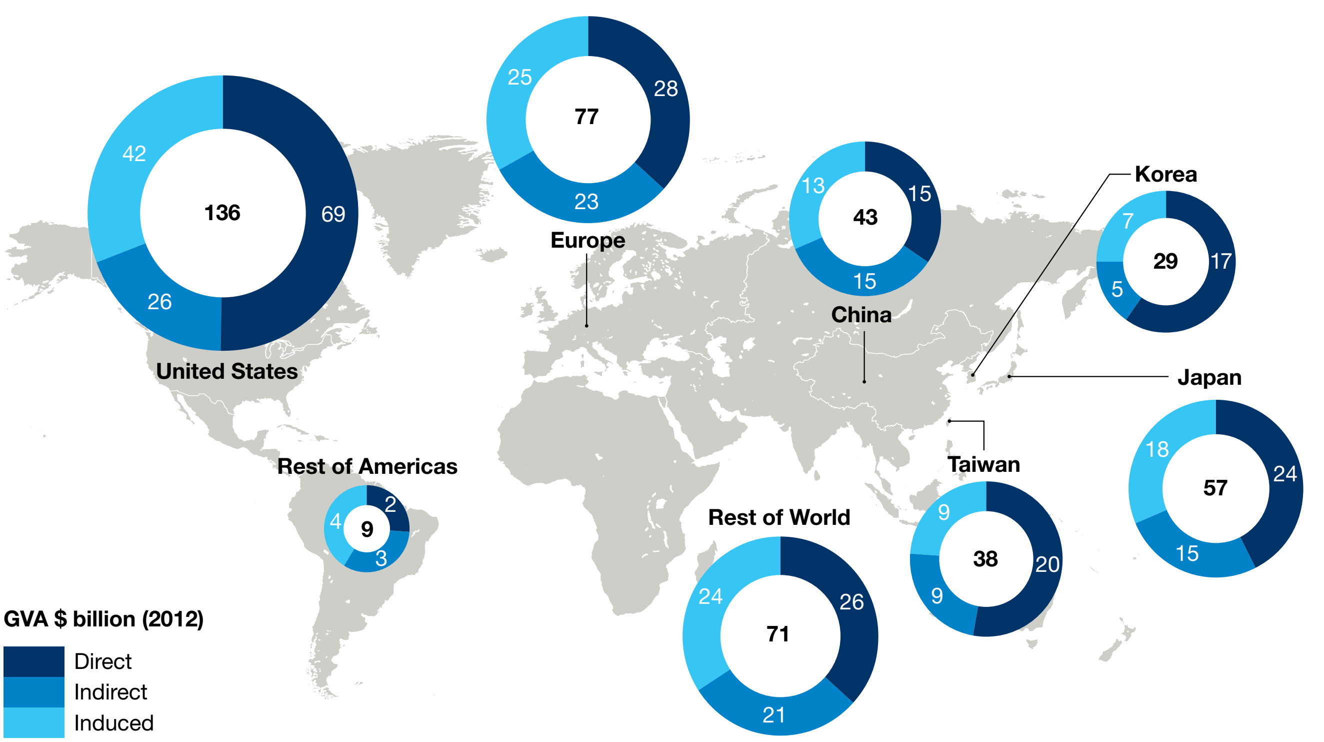
Figure 4: Geographic distribution of direct employment[14]



Source: Oxford Economics

As Figure 5 illustrates, in terms of direct GDP contribution, the advanced economies of the US, Europe, and Japan enjoyed the largest impacts from the semiconductor industry in 2012, at $68.7 bn, $28.4 bn, and $24.2 bn, respectively. But the impact is also sizable elsewhere: the direct GDP contribution in Taiwan, for example, stood at $20 bn in 2012 while China's was $14.9 bn.

Figure 5: Country GDP impacts of the semiconductor industry



Numbers may not sum due to rounding

14 SIA estimates direct US jobs at 244,800, slightly above our estimates. Differences are due to different sources for the underlying data.

Adding the indirect and induced GDP contributions to the direct figures provides an estimate of the industry's total economic footprint across the globe. As the map shows, the United States had the largest footprint at $136 bn by some distance in 2012, followed by Europe ($77 bn) and then Japan ($57 bn). However, relative to the size of the domestic semiconductor industry, China enjoys the largest upstream "multiplier effect" of any country, deriving a further 1.9 dollars of indirect and induced activity throughout its economy for every dollar in direct semiconductor impact.[15]

The economic benefits of the semiconductor industry are truly global, boosting wealth and prosperity in all corners of the globe.

Beyond the US, Europe, China and the other advanced economies of East Asia, the sector's activities in "rest of world" countries—led by activity in Southeast Asia—contributed around $71 bn to GDP in 2012. The supply chain impacts of the semiconductor industry span not just every sector of the economy but into most countries in the world, as international trade has flourished and the global economy has grown increasingly interconnected. Thus, despite the fact that the semiconductor industry is closely associated with advanced economies at the innovation frontier, many of its economic benefits boost wealth and raise prosperity in relatively poorer parts of the globe.

Why semiconductors matter to policy-makers

The semiconductor industry is extremely productive.[16] At $155,000 of GDP per full-time employee, the labor productivity of the worldwide semiconductor industry stands 37% higher than that of the US economy as a whole.[17] In fact, the semiconductor industry is one of the most productive industries in the world.

At a time when many countries are acutely focused on creating jobs that add sustainable value and improve their citizens' quality of life, it is increasingly important for policymakers to foster a healthy semiconductor ecosystem. It is widely recognized that boosting the workforce's skills in science, technology, engineering, and mathematics (STEM) can raise national competitiveness.

The semiconductor industry employs hundreds of thousands of people who have gained such advanced skills, and the quality of these jobs is reflected in the industry's pay levels. Taking the US as an example, the semiconductor and electronic component manufacturing sector employed over 62,000 engineers with an average salary of almost $97,000 in 2012. In addition, it supported some 27,000 jobs in computer and mathematical occupations, with an average salary of around $94,000.[18]

In the industry's geographic heartland the pay levels associated with the sector run at almost twice the national average. Average wages in Santa Clara County, California (Silicon Valley), for example, stand at $95,900 per year, compared with a national average of $49,300.[19]

15 As the world's largest of exporter of manufactured products like "electrical machinery apparatus," China benefits from supply chain spending by semiconductor companies across the globe, not just those in its own economy. Furthermore, as the world's foremost supplier of manufactured consumer products, the Chinese economy also benefits significantly from the consumer spending (induced) impacts. It therefore enjoys a high economic multiplier.

16 The IMF's December 2013 paper *"Anchoring Growth: The Importance of Productivity-Enhancing Reforms in Emerging Market and Developing Economies"* makes the point that productivity growth is a key driver of long-term growth prospects and improvements in living standards (https://www.imf.org/external/pubs/ft/sdn/2013/sdn1308.pdf).

17 Source: Oxford Economics.

18 Occupational Employment Statistics, Bureau of Labor Statistics, 2012.

19 Quarterly census of employment and wages (http://www.bls.gov/cew/).

2

The innovation effect

Beyond the impact produced by the semiconductor industry itself are the massive implications these chips have for end-users once they are integrated into the innovative products and devices that we use on a daily basis. This is what we call the catalytic, or downstream, effects of semiconductors—**and we estimate that it adds another $2.2 trillion to global GDP**.

Indeed, the speed with which semiconductors have developed—supporting exponential progress in all areas of technology—is astounding, and unmatched by any other industry. For example, an iPad tablet today contains more processing power than a 1990 Cray supercomputer—which was the size of a refrigerator.[20] And Intel Labs reported in late 2013 that PCs are nearly twice as fast as they were just four years prior, thanks to semiconductor innovation.[21]

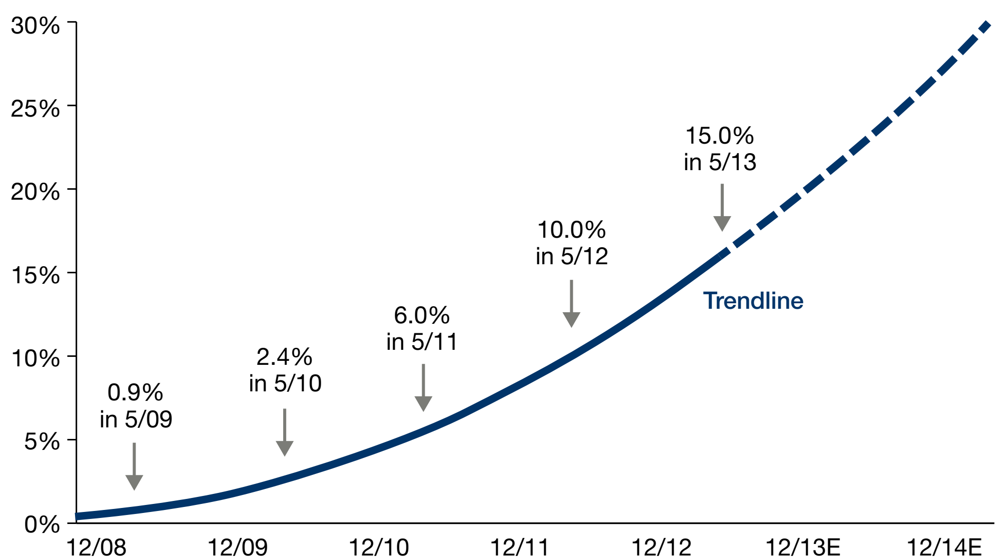
An iPad tablet today contains more processing power than a 1990 Cray supercomputer—which was the size of a refrigerator.

The effects of this rapid development, and the innovation it drives, can be seen across a range of industries, including computing, telecommunications, automotive, healthcare, and energy.

Connecting the world through telecommunications

Semiconductors not only enable traditional technologies to become smarter and more effective; they also have led directly to the creation of entirely new industries, such as mobile telecommunications, which is reinventing entertainment, media, commerce, and many other sectors of the global economy. The pace at which mobile phones have been adopted around the world is unmatched in the history of technology, according to the World Bank,[22] and its growth is in large part due to semiconductors.

Figure 6: Mobile internet traffic to double over 2013



Source: StatCounter Global Stats, May 2013

20 http://blogs.wsj.com/tech-europe/2011/05/11/ipad-2-more-powerful-than-1990s-supercomputer.

21 Intel's 2013 Year in Review Factsheet, newsroom.intel.com.

22 World Bank, *Maximizing Mobile*, 2012.

It is estimated that in the US alone from 1960 to 2007, more than 35% of the communication-equipment industry's growth was attributable to semiconductors.[23] And as semiconductors grow more powerful and energy efficient, so too do the mobile phones and networks they support—at an increasingly lower cost. This makes mobile telephony available to literally billions of people, many of whom live below the poverty line. In fact, more than 1 billion smartphones were shipped globally in 2013, according to research firm IDC.[24] In many parts of the world, a mobile phone number is often more stable than a home address.

It is estimated that in the US alone from 1960 to 2007, more than 35% of the communication-equipment industry's growth was attributable to semiconductors.

The rapid deployment of a mobile-phone infrastructure across the developing world has generated powerful secondary effects. For example, it has:

- allowed the development of robust networks that combat corruption, monitor democratic elections, bring healthcare and food to underserved areas, and create means for humanitarian groups to monitor "real time" activities in once-remote regions;[25]
- revolutionized agriculture by giving farmers ready access to market prices, weather data, and crop cultivation information;[26] and
- led to the success of a range of mobile payment systems (such as M-PESA in Kenya) that permit millions of "unbanked" citizens to conduct monetary transactions, and effectively develop savings accounts, further spurring economic growth.

The revolutionary impact of the smartphone across both emerging and advanced economies is clear. And it's only the tip of the iceberg: mobile devices—including not only smartphones, but tablets and new wearable devices like Google Glass and Pebble's smart watch—lie at the epicenter of the Hyperconnected Age and represent a new frontier in innovation, social, and economic development.[27]

23 Samuels, Jon D. (2012), "Semiconductors and U.S. Economic Growth."

24 http://www.idc.com/getdoc.jsp?containerId=prUS24645514.

25 http://cddrl.stanford.edu/research/combating_corruption_with_mobile_phones/.

26 http://www.cgiar.org/consortium-news/mobile-phones-helping-farmers-make-better-decisions/.

27 http://www.weforum.org/issues/hyperconnected-world.

How semiconductors make commerce mobile

Across the African continent, internet penetration is low and laptop computers are often too expensive to purchase. But the surge in mobile phone use—powered by semiconductors—has created a simple and pervasive means of sharing information and conducting business.

Safaricom, Kenya's largest mobile provider, launched M-PESA—a mobile payment system designed to make purchases, either by texting funds directly to a seller's account or by changing phone credits into cash on the spot—in 2007. Within a year, more than 66% of Kenyans had used the service.[28]

Today, M-PESA ("pesa" means money in Swahili) has evolved into a payment platform that is pioneering new innovations to make Kenya a nearly cash-free economy. With roughly 19 million subscribers,[29] nearly 80,000 agents and 37,000 merchants, about 43% of the country's GDP flows through the system.[30]

The success of M-PESA created demand across Africa, the Middle East, and into Asia—it now operates in South Africa, Mozambique, Tanzania, Egypt, Afghanistan, and India. And in March 2014, M-PESA debuted in Romania. This makes M-PESA the most successful mobile banking service in the world.

The benefits of services such as M-PESA are clear—millions of previously "unbanked" citizens can now be a part of the formal economy, substantially raising standards of living and quality of life.

Driving innovation in the automotive industry

Semiconductors have become critical components in virtually every aspect of automotive operations, and the transition from mechanical to electronic systems has created one of the fastest-growing market segments for the industry, at roughly 8% annual growth, according to a recent report from McKinsey.[31] This transition has made automobiles safer and more dependable than ever before: in its survey of vehicle dependability for 2013, JD Power & Associates found the lowest number of problems in new vehicles than at any time since their initial quality study was launched in 1989.[32]

The penetration of semiconductors into all facets of the car—from the engine and transmission systems to the airbags, cruise control, and braking componentry—has been dramatic. Ford Motor Co. estimated that in 2010, 30%–45% of a car's value came from the electronics embedded in the vehicle,[33] and the percentage is likely to grow as automobiles become more sophisticated: PwC expects the value of semiconductor content per car will grow from $315 in 2012 to $385 by 2017.[34] According to IC Insights, a market research firm, the automotive market for semiconductors will surpass $27 bn[35] by 2015.

28 http://www.strathmore.edu/pdf/innov-gsma-omwansa.pdf.

29 http://www.cisco.com/c/en/us/solutions/collateral/service-provider/vni-service-adoption-forecast/Cisco_Safaricom_CS.html.

30 http://www.bloombergview.com/articles/2014-03-31/forget-bitcoin-african-e-money-is-the-currency-killer?cmpid=yhoo.

31 McKinsey on Semiconductors, Autumn 2013.

32 http://www.consumeraffairs.com/news/lexus-porsche-toyota-lincoln-top-jd-power-dependability-rankings-021313.html.

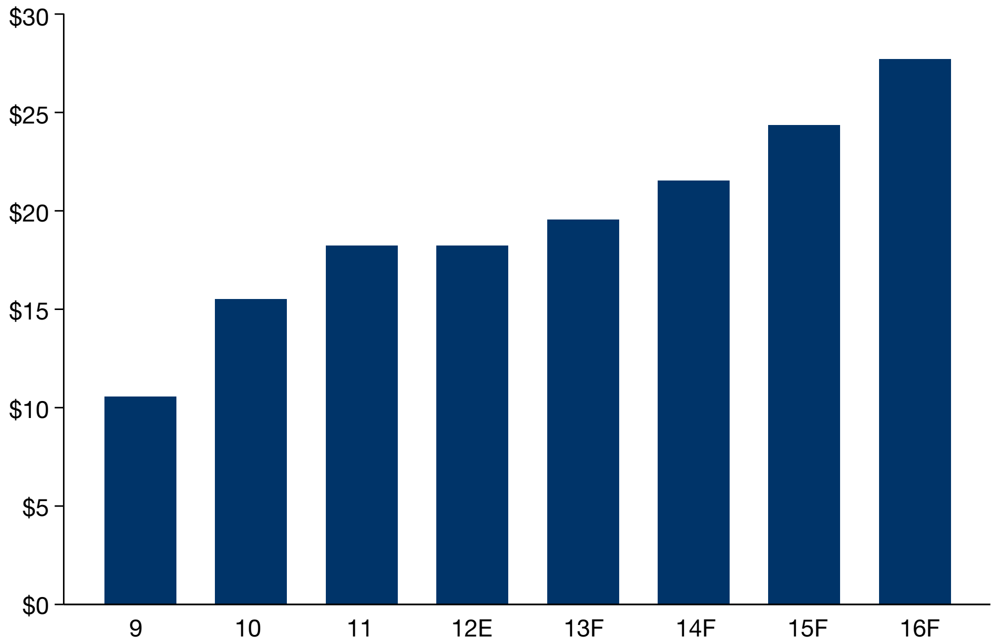
33 Presentation by Jim Buczkowski, June 2, 2011.

34 http://www.pwc.com/gx/en/technology/publications/semiconductor-report-spotlight-on-automotive.jhtml.

35 http://www.automotive-eetimes.com/en/fuel-efficiency-drives-semiconductor-content-in-cars.html?cmp_id=7&news_id=222902391.

Figure 7: Significant growth for the automotive integrated circuit market

US$ billions



Source: IC Insights

Semiconductors are also making automotive transit more sustainable. Achieving emissions reductions in conventional drive trains requires constant monitoring and correction of engine performance. Powertrain microcontrollers and power modules help make engines more efficient by reducing fuel-injection losses and optimizing gear ratios and shifting, which reduce energy waste from hydraulics and friction.

Some advanced technologies available in new cars vividly illustrate the growing capability of semiconductors to improve the driving experience. Some Infiniti models, for example, offer "steer by wire" systems that permit all-electronic handling of the car, but can be steered mechanically if any system fails. Other carmakers now offer advanced driver assistance systems (ADAS), which integrate adaptive cruise control, lane-drift warning systems, blind-spot detection, low-speed collision avoidance, and rear-facing cameras to help drivers avoid potentially dangerous conditions. Hybrid and all-electric vehicles have even higher semiconductor content: the Volt, for example—a plug-in hybrid car produced by GM—uses 10 million lines of software code and 100 electronic controllers,[36] and each Volt on the road has its own IP address.

36 http://www-01.ibm.com/software/rational/announce/volt/.

How semiconductors are reinventing the automobile

Imagine that while you sleep at night, your car is monitoring weather and highway conditions. Because of impending problems in the morning commute, it sends an alert to your mobile phone to wake you 20 minutes ahead of your normal schedule.

When you get into your car, it asks you for a destination. You instruct it to take you to your office. As you sit back and begin reading today's news on the dashboard display, the car starts automatically, pulls out of your driveway and begins the journey, crunching additional weather and traffic data to determine the proper route, adjusting the braking, suspension, steering, and fuel mix to give you the best possible performance—all without any assistance from you.

This is not science fiction. As automotive companies rapidly integrate cloud computing, sensor networks, wireless connectivity, and GPS navigation, the driverless car will soon be commonplace. In March 2014, Tesla founder and CEO Elon Musk said he aims to implement autonomous driving capability into the Model S within three years.[37] Meanwhile, Google's autonomous vehicles have now driven more than 700,000 miles.[38] At the heart of this tremendous transformation: semiconductors.

Many cars already have advanced capabilities that sense and respond to their environment. With adaptive cruise control, for example, your car automatically slows down if another car enters your lane too close ahead. Lane-departure warning systems use cameras to alert drivers if they drift off course. Blind-spot monitoring systems use sensors to alert drivers to cars that are not easily in view. And several automakers, including GM, Audi, Ford, and Lexus, offer cars that park themselves.

Widespread adoption of driverless vehicles could save an estimated $1.3 trillion a year, according to a 2013 report from Morgan Stanley.[39] This includes a $488 billion reduction in accident-related costs and another $507 billion in productivity increases, since drivers could work instead of focusing on the road. GSMA estimates that the worldwide connected car market will reach $54 billion in 2018, as software platforms and data networks become ever more closely connected.[40]

37 http://www.independent.co.uk/life-style/gadgets-and-tech/tesla-ceo-we-aim-to-have-selfdriving-cars-within-3-years-9226522.html.

38 http://www.informationweek.com/mobile/mobile-devices/google-self-driving-cars-get-smarter/d/d-id/1234906.

39 http://www.morganstanley.com/public/11152013.html.

40 Connected Car Forecast: Global Connected Car Market to Grow Threefold Within Five Years; GSMA, Feb. 2013.

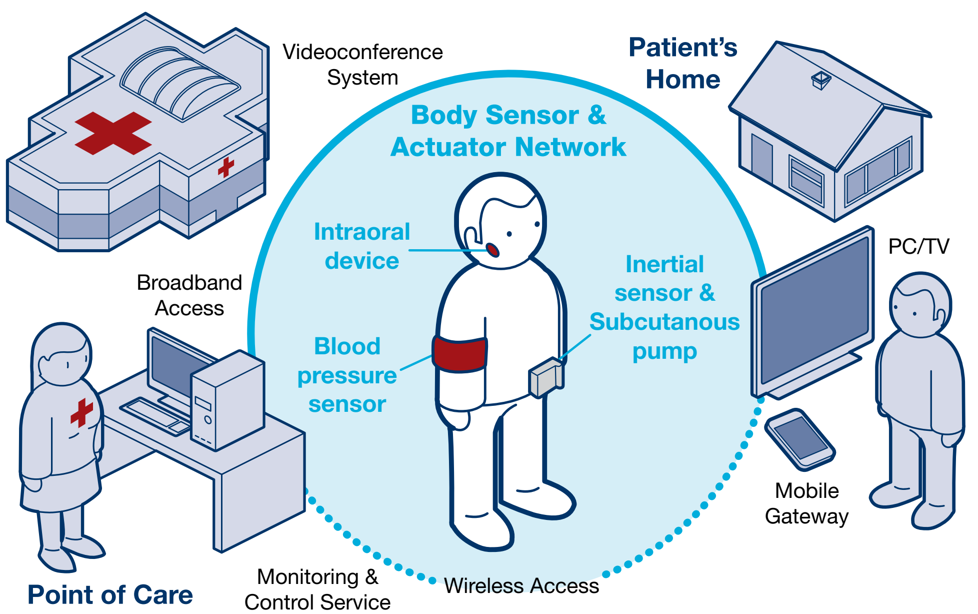
Transforming healthcare to improve the lives of billions

We often think of semiconductors simply as "commercial" products. Yet scientists and researchers have for years been searching for technological solutions to help improve medical diagnosis and the treatment of patients. Indeed, the rapidly growing processing power of semiconductors is both improving the patient experience today and changing the future of healthcare.

Thanks to the increasing power and sophistication of RFID devices and other tracking tools, semiconductors are already giving nurses and doctors far more powerful abilities to monitor patients, find medicines within the hospital, and track expensive diagnostic equipment.[41] As hospital systems merge their data into electronic record-keeping, they can easily check to ensure drugs don't cause adverse interactions; manage patient charges and reimbursements; and make sure that specialists treating a patient are aware of what other doctors and nurses are seeing during their interactions.

These initiatives will have significant positive effects on patient outcomes, but they are only the most visible current developments. As rapid improvements in semiconductor electronics merge with nanotechnology and wireless sensor networks, a new generation of micro-machines becomes feasible. These include new forms of pressure sensors for blood pressure, respiratory or kidney dialysis monitoring; micro-electrodes for cochlear implants; micropumps for infusion drug delivery; ultrasound sensors for medical imaging, and a whole range of micro-actuators, silicon microphones, and micro-electrodes to improve the performance of hearing aids.

Figure 8: Envisioning the future of remote healthcare



Source: Adapted from IEEE.org

At the same time, powerful large diagnostic equipment that used to reside only in a hospital or a doctor's office—such as ultrasound equipment and heart-rate monitors—will increasingly be available on mobile phones. Such devices put more control in the hands of patients and allow them to quantify their healthy behaviors more accurately.

41 http://www.healthcarefinancenews.com/news/rfid-yielding-savings-hospitals.

Of course, the ability to use wireless technologies to monitor patients remotely is a tremendous breakthrough for the healthcare industry. Telemedicine initiatives not only improve care for the chronically ill, but can make healthcare available to millions of patients in remote regions where access to doctors and nurses is scarce.[42]

The power of semiconductors also puts society on the verge of medical breakthroughs in which "designer" medicines will be created for individual patients based on their unique genetic profile. This is becoming feasible because powerful sequencing machines run by semiconductors can decode an individual's genetic profile in a single day, for as little as $3,000. Contrast this to when scientists first "cracked the code" of the genome 13 years ago; the identical task took 13 years and cost $3 billion.

How semiconductors are transforming healthcare

Technology has led to incredible breakthroughs in healthcare. Unlocking the complexities of the genomic code, rapid advancements in telemedicine and robotics, and breakthroughs in stem cell research are just a few examples.

But the ever-increasing power and sophistication of semiconductors are directly leading to even more promising capabilities in the Hyperconnected Age. In the nascent but rapidly developing field of bioelectronics,[43] devices are quickly expanding beyond what can be worn on the wrist, such as the Fitbit or Jawbone Up. Proteus Digital Health,[44] for example, has created an ingestible chip that communicates with a sensor placed on the patient's skin to monitor heart rate, sleep patterns, and levels of medication coursing through the bloodstream. This data gives doctors and nurses a more complete picture of a patient's treatment path.

In January 2014, Google announced it had developed a "smart" contact lens.[45] The lens has a tiny wireless chip and sensors that measure glucose levels—a potentially life-changing breakthrough for people with diabetes, who currently must monitor their glucose levels by constantly pricking their fingers. The contact lens would send alerts to wearers' smartphones or other devices to warn them when glucose levels cross certain thresholds. The company is currently seeking FDA approval for the device.

Meanwhile, Intel has also joined the fray, announcing in May a new "Make it Wearable" initiative,[46] challenging students, engineers, programmers, and other developers to push the boundaries of bioelectronics.

Though still in its early days, optimism for the potential power of bioelectronics is high: a recent study from Tufts University indicates that bioelectronics could be used to stop the growth of cancerous tumors.[47] According to a report from BCC Research,[48] the market for wearable devices will reach $30 bn by 2018.

42 http://www.informationweek.com/mobile/telemedicine-improves-patient-outcomes-study/d/d-id/1111285?.

43 http://www.gizmodo.com.au/2014/01/how-bioelectronics-will-cure-cancer/.

44 http://www.proteus.com/.

45 http://googleblog.blogspot.com/2014/01/introducing-our-smart-contact-lens.html.

46 https://makeit.intel.com/faq.

47 http://dmm.biologists.org/content/early/2013/01/31/dmm.010835.abstract.

48 http://www.bccresearch.com/market-research/information-technology/wearable-computing-ift107a.html.

Recharging energy and utilities

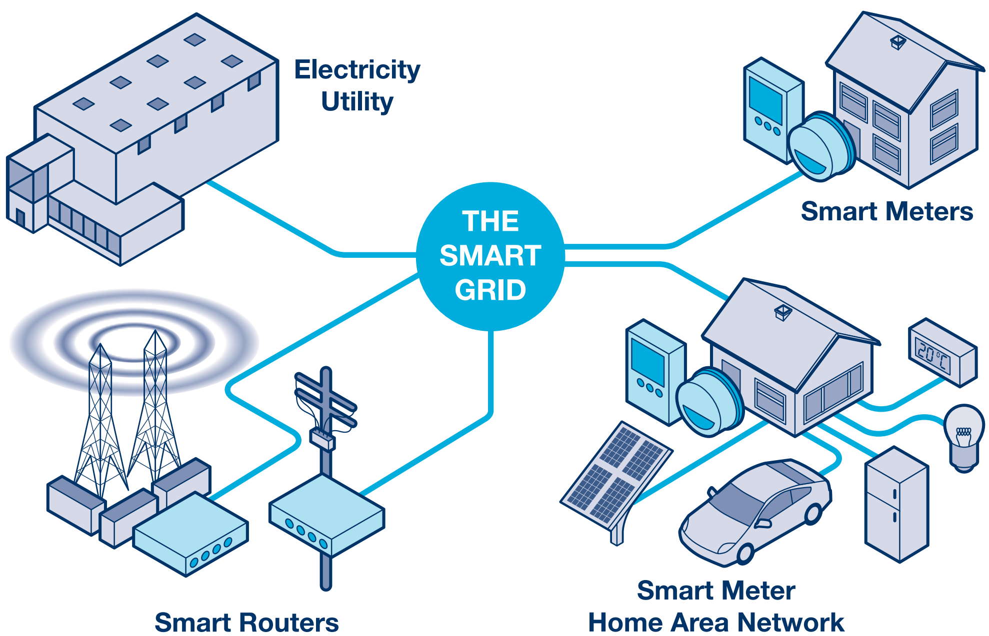
It's not only in high-tech industries that semiconductors are having a transformative effect. Their presence also critically improves products and processes in more traditional sectors of the economy.

In 2013, the Obama administration released a report estimating that power outages cost the US economy up to $33 bn each year.[49] The report also noted that the average US power plant is 30 years old, and the majority of the transformers and lines carrying electricity are more than 25 years old. This leaves many millions of businesses and consumers at risk when the next "superstorm" strikes; the White House estimates that power outages due to Hurricane Sandy cost the economy as much as $75 bn.

The global smart grid market is expected to surpass $400 bn by 2020.

Of course, the US is not the only nation running on an antiquated and overburdened electricity grid. Many countries are focusing on the development of "smart grids" that rely on semiconductors and software to monitor the flow of electricity and alert utility providers to specific issues or potential problems across the network—in real time, every minute of the day. GTM Research, which monitors the global clean energy industry, expects the global smart grid market to surpass $400 bn by 2020.[50]

Figure 9: **The smart grid**



Source: Adapted from Grid Net/Cisco

49 http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf.

50 http://www.greentechmedia.com/research/report/global-smart-grid-technologies-and-growth-markets-2013-2020.

At the same time, "smart meters" deployed across millions of households are helping to reduce energy inefficiency and make consumers more informed about reducing their energy footprint. Smart meters not only help consumers make better energy choices; they also help connect various types of alternative energy sources to the overall energy grid, creating more energy for more people. As consumers, businesses, and institutions increasingly deploy their own solar, wind, hydro, and geothermal energy solutions, smart meters—connected to smart grids—will automatically determine how best to source electricity based on overall demand and a variety of other conditions. By 2020, smart meters are expected to be installed in more than 85% of households across the EU, with North America and Asia-Pacific reaching 91% and 68% adoption by 2022.[51]

How semiconductors make cities sustainable

Cities are getting bigger: according to a recent study from Oxford Economics, by 2030 the world's largest 750 cities will see a population increase of 410 million, requiring 260 million new homes and more than 1,770 million square feet of extra office space.[52] City leaders know they must take action to reduce urban sprawl, upgrade infrastructure, maximize the use of natural resources, and—perhaps most important—get much smarter about energy use.

Perhaps they should look to Barcelona for guidance. The city aims to be the world's leading hyperconnected, zero-emissions metropolis. To do it, Barcelona is depending on a range of cutting-edge technologies, including solar power, sensor networks, smart grids and meters, LED lighting, and electric transportation—all with semiconductors at their core. As a result of these efforts, in March 2014 the European Commission named Barcelona Europe's Capital of Innovation, for its commitment to using new technologies to benefit its citizens.[53] Some examples of current projects include:

- **Solar water heating.** An ordinance passed in 2000 requires new buildings of a certain size to use solar energy to heat their water.[54]
- **Smart streets.** Barcelona's SIIR project (Integral Solution for Urban Infrastructures) aims to reduce the city's lighting costs by roughly 40%.[55] So far, 50 streets and more than 1,000 lampposts have been upgraded with LED lighting, and 50% of the city's lighting power can be controlled remotely.
- **Electric vehicles.** Barcelona is committed to promoting electric vehicles and has built a network of more than 260 charging stations across its metro region—the goal is for every citizen to have a charging station within 5 minutes of home. Barcelona also boasts more than 500 hybrid taxis, and fleets of electric cars and motorbikes are available to rent. The city's LIVE (Logistics for the Implementation of the Electric Vehicle) invites companies and innovators to collaborate on electric vehicle projects.[56]

Getting smart about energy isn't just good for the planet, it's imperative to sustain growth and prosperity for all people. And it can't happen without semiconductors.

51 https://m2m.telefonica.com/m2m-media/m2m-news/item/630-m2m-800-million-electric-smart-meters-to-be-installed-globally-by-2020.

52 "Global Cities 2030: Future trends and market opportunities in the world's largest 750 cities," Oxford Economics http://www.oxfordeconomics.com/cities/report.

53 http://europa.eu/rapid/press-release_IP-14-239_en.htm.

54 http://www.barcelonaenergia.cat/eng/operations/ost.htm.

55 http://www.slideshare.net/fullscreen/barcelonactiva/barcelona-smart-city-tour-15080538/3.

56 http://w41.bcn.cat/en/.

But smart meters and grids are not the only ways to be energy-conscious in the Hyperconnected Age. New wireless devices like the Nest Learning Thermostat[57] are fitted with "smart" sensors that monitor home heating systems and automatically adjust the temperature to reduce energy waste, promising to save homeowners hundreds of dollars annually. Meanwhile, a Seattle-based competitor, SNUPI Technologies, has created a home sensor network that alerts homeowners to leaky pipes or sudden changes in temperature.[58] Indeed, the hyperconnected home of the future will not only be energy efficient but will communicate in real time—thanks to semiconductor development.

Innovation in the US semiconductor industry grew at close to 9% from 1960 to 2007—25 times the innovation growth rate for the economy as a whole.

Assessing the downstream impact of semiconductors

These examples illustrate just some of the ways semiconductors improve our lives. Quantifying the full effect on the global economy is a complicated task, but the impact is striking. By some measures, such as Total Factor Productivity (TFP), innovation in the semiconductor industry grew at close to 9% over the period from 1960 to 2007 in the US. According to a recent analysis by Jon Samuels at Harvard, this is 25 times the innovation growth rate for the economy as a whole[59] and is estimated to have counted for nearly 30% of the US' aggregate economic innovation over this period.

Turning to individual industry sectors, Samuels estimates that between 1960 and 2007, semiconductors accounted for around 37% of the growth of the US communications equipment manufacturing industry, 14% of the expansion of the electrical equipment and appliances sector, and 24% of the growth in output among other electronic products. In other, less immediately related sectors of the US economy, the semiconductor contribution was also substantial, accounting for 4% of the growth in output of the furniture sector, for example.

These figures give a sense of the scale of the downstream contribution of semiconductors in the US. A more complete analysis would offer a global estimate of the full downstream impact of the industry by looking at its dollar contribution to the growth in output since the very early days of the semiconductor revolution.

This can be achieved by combining the Samuels estimates for the US with global data from the Oxford Economics' Global Industry Model, which gives a picture of the growth of different sectors of the world economy over a long time frame.

For example, the output of the global communications-equipment sector increased by around $570 billion between 1960 and 2012, of which around $210 billion annually is attributable to semiconductors. Annual global output of electrical equipment and appliances grew by approximately $1.7 trillion over the period, of which around $250 billion can be put down to semiconductors.

Aggregating these sector impacts, we can derive an estimate of the total annual downstream contribution of the semiconductor industry to global GDP today.[60]

57 https://nest.com/.

58 http://www.wallyhome.com/how/.

59 Samuels, Jon D. (2012), "Semiconductors and U.S. Economic Growth."

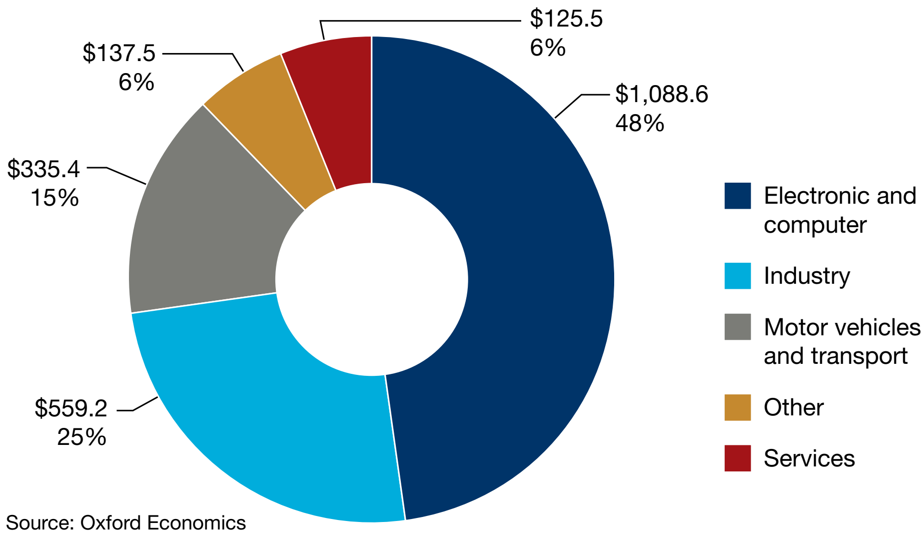
60 It is assumed that the semiconductor contribution to output growth from 2007 to 2012 remained at its 1960 to 2007 average. Further, we assume that the contribution of semiconductors to US output growth in each sector is the same for output growth in equivalent sectors across the rest of the world economy.

The results of that analysis reveal that the total downstream economic impact of semiconductors on global GDP was $2.2 trillion in 2012.

So while the worldwide economic footprint of the industry's activities, described in the last section, is large, the semiconductor's continual evolution is responsible for driving a downstream economic contribution many times greater—and growing rapidly.

Breaking down that $2.2 trillion contribution, it is clear that the most important contributions of semiconductor advancements are felt in sectors where semiconductors are vital inputs. Unsurprisingly, consumer electronic appliances, particularly computers, account for nearly half of the downstream contribution of semiconductors. Industry accounts for another 25%, while motor vehicles and transport make up 15% of the downstream impact.

Figure 10: The downstream economic impact (US $ bn)



Source: Oxford Economics

Drawing on existing academic research, we have identified sectors[61] of the economy that are most heavily dependent on semiconductors, where more than 5% of the sector's output growth since 1960 can be attributed to the semiconductor. We estimate that these sectors, in which semiconductors are integral to how they function, were responsible for over $7 trn of economic activity across the globe in 2012—around 10% of global output.

61 Including Computer and peripheral equipment manufacturing, Communications equipment manufacturing, Semiconductor and other electronic components, Other electronic products, Electrical equipment appliances and components, Machinery, Motor vehicles bodies and trailers and parts, Other transportation equipment, and Fabricated metal products.

3

At the frontier of knowledge

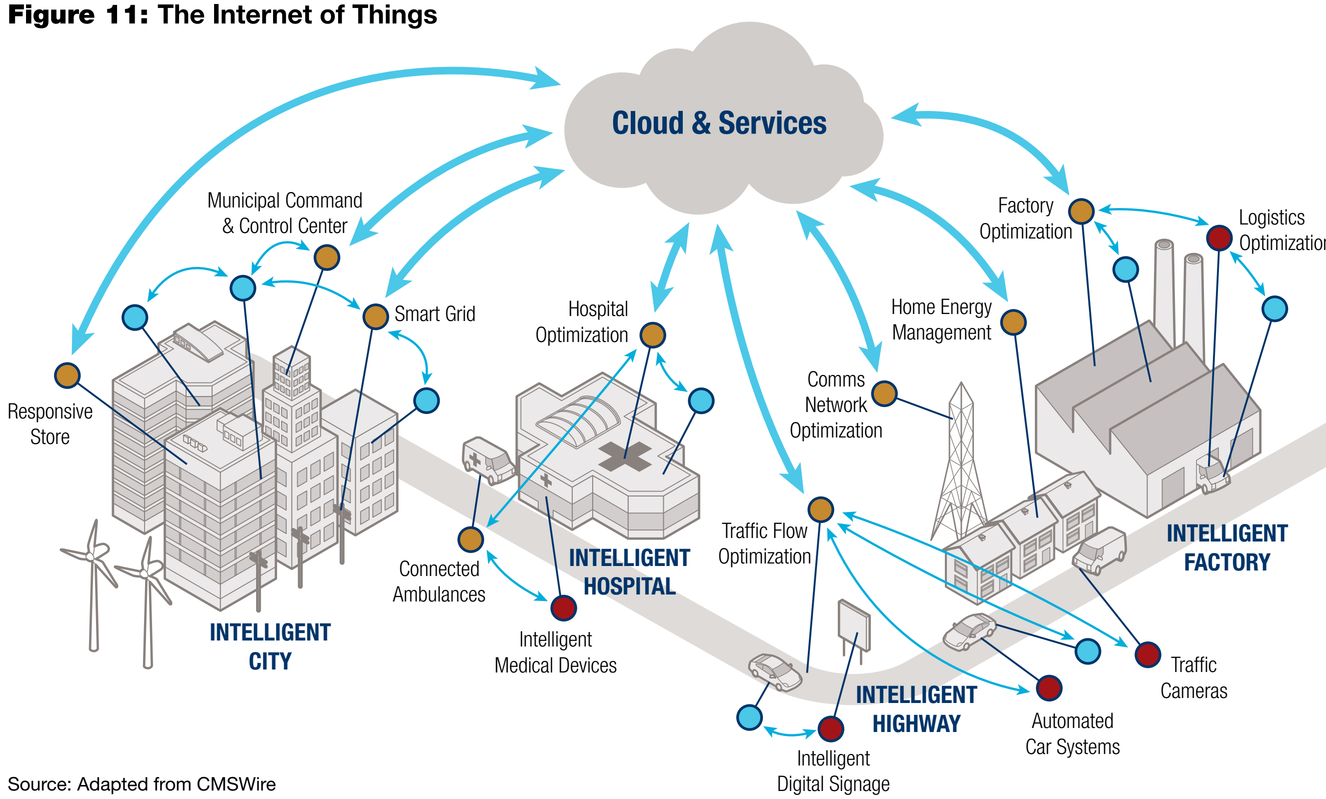
Where will semiconductors take us in the future? Their growing capabilities will continue to radically shape society and improve quality of life for people everywhere.

In the Hyperconnected Age, billions of machines, objects and people are quickly being connected through a vast network of sensors and clouds. Cisco Systems has put forth the widely cited industry vision that the Internet of Things will connect 50 billion objects by 2020.[62] The merger of computing, sensing, and communications will create a world in which the virtual and physical converge—where machines, people, video, sensors, news feeds, biofeedback, maps, and other data can be truly integrated.

The Internet of Things is expected to add as much as $15 trillion to the global economy over the next two decades.

This revolution in interconnectivity is radically altering how companies conduct business as well as the type of products and services they offer. But the Internet of Things will do much more than just improve logistics or perform preventive maintenance in their factories. The ability of once inanimate objects to "talk" to each other is revolutionizing everything from manufacturing to healthcare. One recent study conducted by General Electric indicates that the Internet of Things can be expected to add between $10 trillion and $15 trillion to the global economy over the next two decades.[63]

Figure 11: **The Internet of Things**



Source: Adapted from CMSWire

62 Evans, Dave (2011). "The Internet of Things: How the Next Evolution of the Internet is Changing Everything." Cisco whitepaper. http://www.cisco.com/web/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf.

63 Evans, Peter and Marco Annuziata (2012). "Industrial Internet: Pushing the Boundaries of Minds and Machines." GE. http://www.ge.com/docs/chapters/Industrial_Internet.pdf.

IDC estimates the amount of stored data will double every two years, reaching nearly 40 zettabytes by 2020.

The explosion in connected smart devices and objects will in turn drive greater demand for **Big Data analytics** and **cloud computing**. IDC estimates that the amount of stored data will double every two years, reaching nearly 40 zettabytes by 2020.[64] For perspective, a single zettabyte of data is enough to fill 75 billion 16-gigabit iPads.[65] As of 2013, all of the data contained across the World Wide Web was estimated to equal about four zettabytes. Clearly, as the amount of accessible information increases in the Hyperconnected Age, so too will the demand for faster, more powerful semiconductors.

Nanoscience will lead to biological breakthroughs that change the way we diagnose and treat challenging diseases. Already, researchers have made significant achievements in developing implantable microelectronics to treat visual and neurological disorders.[66] Some researchers are also positing the development of "neural dust," tiny sensors that can be sprinkled into an individual's brain tissue to create seamless brain-machine interfaces.[67]

Continuing advances in **virtual reality** will power demand for semiconductors that can produce even greater bandwidth, higher screen resolutions and reduced latency times. The ability to experience an immersive, three-dimensional world whether through headsets like the Oculus Rift, high-definition screens or other platforms is already transforming gaming, urban planning, and medical training, including brain surgery, by allowing doctors to gain visual, tactile and sound feedback that mimics a real hospital procedure. And just around the corner: 3-D holographic technology that will allow you to interact with a floating sales clerk or play a game with an image that fills the room.

Robotics is already undergoing rapid advances, as a result of the deployment of ever more powerful semiconductors. Far beyond replacing labor in factories, sentient robots will help care for elderly patients, provide critical assistance for people with disabilities, and perform a variety of domestic—and even hazardous—tasks. Researchers at universities such as MIT,[68] the University of Pennsylvania,[69] and Virginia Tech[70] are making rapid breakthroughs to develop devices that can walk, see—and even learn from their mistakes. Mobile robots are already taking on more responsibilities for caregiving in hospitals and long-term nursing facilities.[71]

64 http://www.emc.com/leadership/digital-universe/2012iview/executive-summary-a-universe-of.htm.

65 http://technografy.com/2013/04/so-how-much-is-a-zettabyte-infographic/.

66 http://www.nanomedjournal.com/content/centralNervousSystem.

67 http://www.extremetech.com/extreme/161525-smart-neural-dust-could-carry-sensors-deep-into-the-human-brain-send-data-back-out.

68 http://robots.mit.edu/index.htm.

69 https://www.grasp.upenn.edu/.

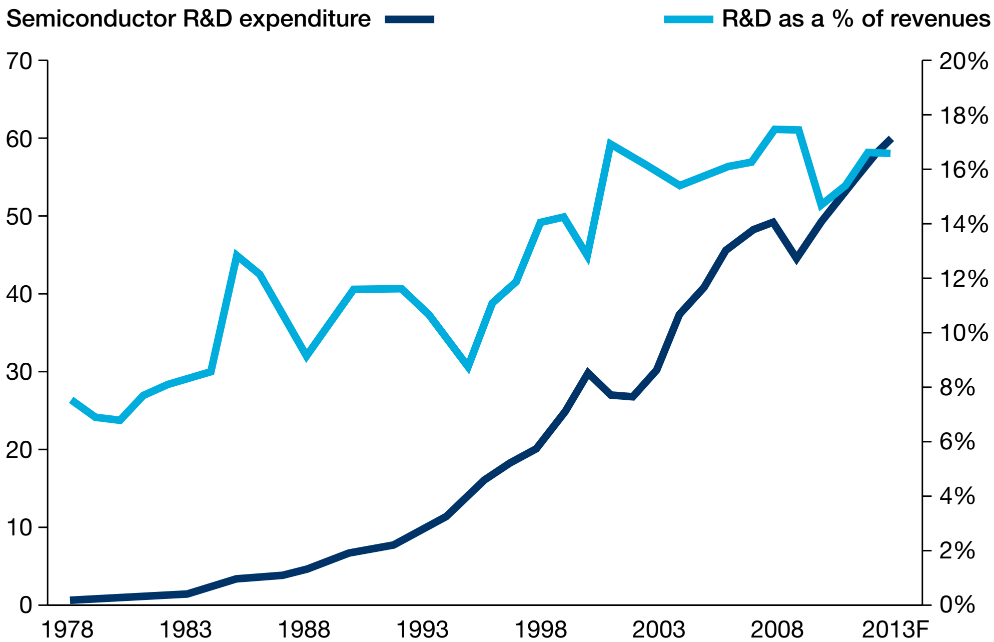
70 http://www.ise.vt.edu/ResearchFacilities/Labs/LabPages/RA_lab.html.

71 http://www.modernhealthcare.com/article/20130525/MAGAZINE/305259957.

The importance of semiconductor research

The pace of evolution and development in the semiconductor sector in recent decades has been impressive—and critical, considering the significant innovation semiconductors have supported across so many other industries. Such rapid innovation reflects the industry's tremendous commitment to research and development (R&D), which has grown dramatically over the past 35 years. As a percentage of revenue, semiconductor R&D spending has doubled from less than 8% in the early 1980s to an annual average of over 16% in the last decade. In 2012, overall semiconductor R&D spending was estimated at $56.9 bn, and is expected to remain around 16%–17% of revenue in the years ahead.[72]

Figure 12: **Semiconductor R&D from 1978 to 2013 (forecast)**



Source: IC Insights and Oxford Economics

At 16%, the R&D intensity of the semiconductor sector far outstrips most others.

To put this in context it is helpful to compare this degree of R&D intensity to that of other sectors of the economy. For example "The 2013 EU Industrial R&D Investment Scoreboard" analyzes the scale of R&D expenditure from the world's top 2000 companies ranked by their R&D expenditure.[73] It finds that average R&D spend as a share of revenue was 3.2% in 2012, even among these top-ranking R&D firms. The table below, from the same report, breaks down the level of R&D intensity in these companies by industrial sector. It is striking that in sectors like electronics and electrical equipment, and automobiles and parts, the share of revenue spent on R&D was below 5%. At 16%, the R&D intensity of the semiconductor sector far outstrips most others.

72 ICInsights McClean Report, 2013.

73 The report "provides an overview of changes in the main R&D and economic indicators of the world 2000 companies that invested more than €22.6 million in R&D in 2012."

Figure 13: R&D intensity in the largest 2000 R&D firms by sector, 2012

	R&D intensity (R&D as % of net sales)	Industrial Sectors by R&D intensity
High R&D intensity	Above 5%	Pharmaceuticals & biotechnology Healthcare equipment & services Technology hardware & equipment Software & computer services Aerospace & defense
Medium-high R&D intensity	Between 2% and 5%	Electronics & electrical equipment Automobiles & parts Industrial engineering & machinery Chemicals Personal goods Household goods General industrials Support services
Medium-low R&D intensity	Between 1% and 2%	Food producers Beverages Travel & leisure Media Oil equipment Electricity Fixed-line telecommunications
Low R&D intensity	Less than 1%	Oil & gas producers Industrial metals Construction & materials Food & drug retailers Transportation Mining Tobacco Multi-utilities

Source: European Commission "The 2013 EU Industrial R&D Investment Scoreboard"

In the US, the US National Science Foundation's "Business Research and Development and Innovation: 2008–10,"[74] provides R&D data for some key US sectors in 2010. It shows that R&D activity[75] in the "semiconductor and other electronic components" sector—somewhat broader than the semiconductor sector industry discussed above—was higher than all other sectors of the economy, with the exception of pharmaceuticals and medicines.

74 http://www.nsf.gov/statistics/nsf13332/.

75 Based on financials taken for all publicly traded fabless and IDM semiconductor companies that reported both revenue and R&D.

Figure 14: US R&D intensity by sector, 2010

Sector	R&D spend as share of sales
Pharmaceuticals and medicines	13.4%
Semiconductor and other electronic components	12.2%
Semiconductor machinery	10.6%
Communications equipment	10.1%
Data processing, hosting, and related services	6.6%
Chemicals	5.9%
Computer systems design and related services	4.6%
Navigational, measuring, electromedical, and control instruments	4.5%
Scientific R&D services	3.6%
Other computer and electronic products	3.0%
Military armored vehicle, tank, and tank components	2.7%
Automobiles, bodies, trailers, and parts	2.4%
Other transportation	1.3%
Architectural, engineering, and related services	1.0%
Resin, synthetic rubber, fibers, and filaments	0.6%

Source: The US National Science Foundation, "Business Research and Development and Innovation: 2008–10"

Sustaining this high level of R&D activity in the sector will be essential if the impressive economic contribution of semiconductors to the global economy is to continue to grow—and to support more breakthrough innovations. For example, physicist Joe Incandela used a global network of about 300,000 processors to discover the Higgs boson (known as the "the God Particle," which explains why matter has mass). At a recent conference he said: "We were able to do analyses that would have taken much, much longer—or perhaps not even have been possible 10 years ago. Imagine what happens when this kind of computing power is accessible to all scientists or to all people who are trying to understand things in general."[76] Again, such incredible scientific discovery would not be possible without increasingly powerful and sophisticated semiconductors.

76 http://www.cnn.com/2013/12/14/tech/innovation/lhc-higgs-boson-incandela/.

Whither Moore's Law?

In 1965, Intel co-founder Gordon Moore observed that the number of transistors (the basic building block of semiconductors) on the most advanced chips doubled roughly every 18 months. Remarkably, this exponential trend has continued for the past 50 years, with the number of transistors on a chip rising to several billion today.

The capabilities of semiconductors have roughly scaled with the number of transistors. In order to make this vast increase in transistor count possible, the size of transistors on a semiconductor chip has had to shrink drastically. In 1971, the node size, or the distance between two identical features on a chip, on the most advanced semiconductor chips was 10μm (10–5 meters, or about 1/10 the size of a human hair). In 2014, Intel is expected to commercially introduce the first chips with a node size of 14nm (1.4×10^{-8} meters)—almost 1,000 times thinner.

As the size of the electronic elements on a semiconductor shrink, the amount of power semiconductors consume shrinks, reducing the footprint of the device, boosting battery life for mobile devices, and reducing semiconductors' environmental footprint. At the same time, the speed of the devices increases—and the cost prices per computation fall—making ever more sophisticated devices more affordable to the average consumer.

This exponential increase in the computational power of semiconductor is what powers the modern, digital world. No other tool or machine in our modern life comes close. In fact, if the airline industry dutifully followed Moore's law, a flight from New York to Paris, which took seven hours and cost $900 in 1978, would by 2005 require one second and cost a penny.[77]

The challenge of keeping up with Moore's Law will continue to drive fundamental research and engineering opportunities well into the future. But will Moore's Law hold up? And what will happen to our modern society if the speed of semiconductor development slows?

Some believe new technologies and advances in material sciences can overcome some of the physical challenges involved in developing the next generation of semiconductor devices.[78] Others believe 3D design and innovative packaging and chip architecture will be the best route to drive continued semiconductor advances.[79]

Either way, continued development of powerful semiconductors is critical to fuel innovations across a range of industries—and the future will be determined by the bright minds who take up careers in semiconductor research and development.

77 http://www.intel.com/pressroom/kits/events/moores_law_40th/Images_Assets/Image_Usage_Guide_Readme.pdf.

78 http://www.techradar.com/us/news/computing/moore-s-law-how-long-will-it-last--1226772.

79 http://www.forbes.com/sites/michaelkanellos/2013/08/14/with-3d-chips-samsung-leaves-moores-law-behind/.

CONCLUSION

Ensuring a thriving semiconductor ecosystem

The semiconductor has fundamentally changed the way we live. Its impact cannot be disputed, nor can the enormity of its contributions be overestimated. Semiconductors have permeated nearly every aspect of our daily lives, and are responsible for either enabling or improving every 21st century device that is either directly or indirectly connected to a battery or plugged into a wall.

And because the semiconductor is so foundational and forever weaved into the fabric of our modern world, so too is the need to continue to cultivate and sustain a healthy and vibrant ecosystem. For, as this report illustrates, the semiconductor sector is unique. No other industry experiences the pace of innovation that Moore's law has brought to the development of microchips. No other industry helps so many other industries grow, innovate, become more productive, and ultimately prosper. And in a world of agile, fluid startups and virtual communities, perhaps no other industry requires so much raw scientific insight and capital to create the next generation of innovative technology.

The semiconductor sector is unique. No other industry experiences the pace of innovation, helps so many other industries grow—or requires so much raw scientific insight and new capital to generate the next generation of innovative technology.

The implications for stakeholders are critical:

For policy-makers. The semiconductor industry needs to constantly invest in R&D, and depends in turn on the education system to develop future scientists and engineers.

To help ensure the industry's future as a driver of competitiveness and prosperity, governments must ensure vigorous funding and scholarships for students in STEM fields (science, technology, math, and engineering), and programs to expand and diversify the talent pipeline.

In addition, governments must become cognizant of the contributions of the semiconductor industry, and the positive impact of the high-paying jobs they and other technology companies have on our local and national economies.

To that end, the GSA recommends that all governments consider the following initiatives:

- R&D tax credits and repatriation of offshore dollars;
- Patent reform to help protect those who are actually developing and implementing intellectual property versus those whose sole objective is to collect intellectual property in order to litigate;
- Immigration reform to help ensure that those who are educated and trained domestically, and who are ultimately creating jobs through their contributions, are not asked to leave;
- Increased collaborations with research units like DARPA to advance an important research agenda in material sciences or other issues on the frontiers of technology; and
- Aid in developing research consortia that foster and accelerate pre-commercial innovation in semiconductor materials, fabrication technologies, and architecture.

For students. The semiconductor industry offers compelling job opportunities for today's math, science and engineering students. No other industry is working simultaneously at the frontiers of material science, electrical engineering, software, and communications—and no other industry in the world holds as much promise to radically shape the future. Careers in the semiconductor industry can help lead to transformative breakthroughs that change society and bring new innovations to people around the globe.

For business executives and investors. While individual companies may rise and fall, the importance of the semiconductor industry requires constant inflows of venture capital and management insights. When companies invest in new systems powered by semiconductors, they fund critical work that helps the semiconductor industry to develop even more powerful solutions that can drive corporate innovation and unlock significant new value.

A deep understanding of the value of semiconductors for business innovation, productivity, and success will ensure that proper investment will be made in the future. Business leaders and investors must also understand how centrally semiconductor innovation resides at the core of innovation in our digital age.

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