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Upstate New York
ams Project:
Assessing the Economic Impact

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Prepared by Semico Research Corp.

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Executive Overview

Economic development activities to attract new manufacturing jobs to a community are viewed as important and beneficial because of the jobs that the new business adds to the work force. However, it is not just the new manufacturing jobs that contribute to the economic activity of the area. One new manufacturing job can translate into several additional jobs due to the increased need for support jobs, housing, food, retail operations and both private and government services. In addition, the materials and services that are part of the product being produced results in the growth of existing supplier businesses or new support businesses moving into the area. This report provides an analysis of the impact that the construction and operation of a semiconductor facility would bring to Oneida County.

The construction phase of the project includes, site preparation for electric and gas utilities with building construction scheduled to start first quarter 2016. The construction time frame is nine calendar quarters with initial wafer production and ramp starting in first quarter 2018. The wafer fabrication facility will initially be equipped in half of the production area and five years later install and ramp will occur in the second half of the facility.

The markets and the product categories anticipated to be manufactured in this facility are growing faster than the overall semiconductor market and are targeted at rapidly growing applications such as mobile products, automotive, health and fitness, industrial and many of the electronic devices being referred to as the Internet of Things.

By 2020 fab workers are estimated to be 273 with a multiplier job impact resulting in an additional 1,479 employment opportunities for the local economy. Direct jobs are projected to peak at 1000 in 2027, which will result in a combined total job creation (direct and multiplier jobs) of 6,452.

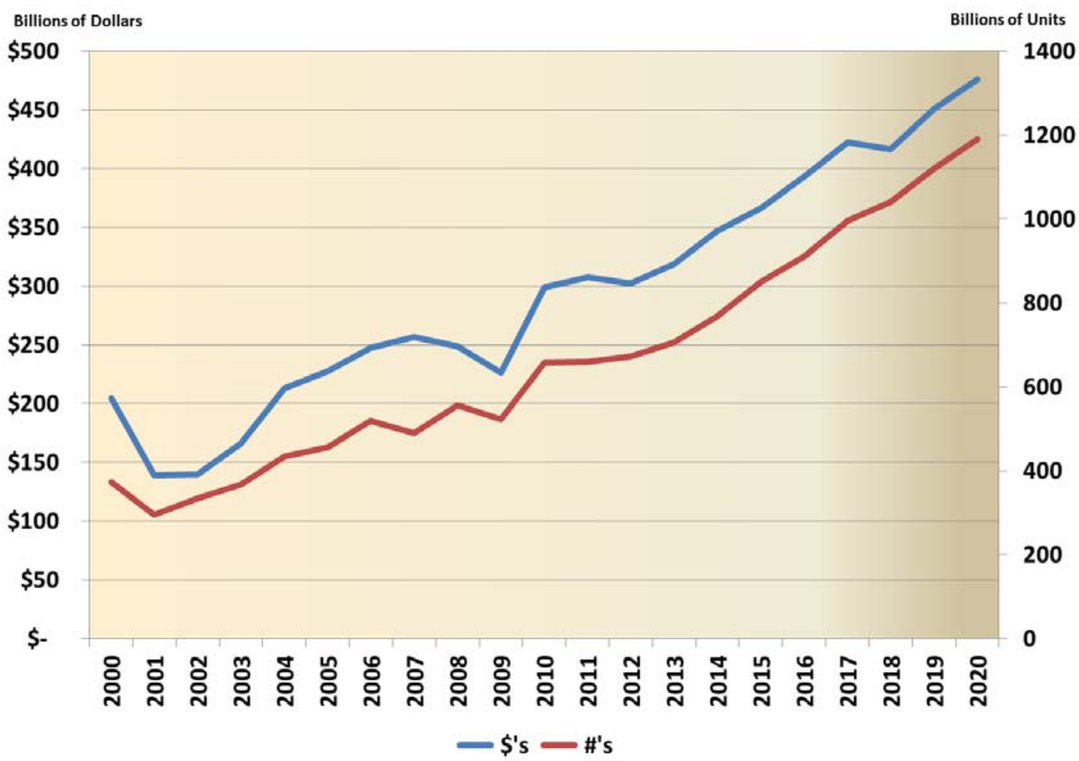
The ams project is one of those projects that provide both jobs as well as increased educational funding and product output to New York State. The total project cost is $700 million over a 10 year period. The economic return on investment (ROI) is 191% in 5 years and 474% in 10 years.

Semiconductor Market Overview

As the semiconductor industry matures, market growth rates have slowed from historic double-digit rates to single digit compound annual growth rates. The overall semiconductor market will grow at a CAGR of 5.4 percent over the next 5 years. This trend is anticipated to continue through the next ten year period.

The worldwide semiconductor industry produced $337.5 billion in revenues in 2014. Complementing this revenue the industry sold 768 billion units. The unit volume is forecast to increase at a CAGR of 7.6 percent over the next five years. The revenue compound annual growth rate for the industry in the past 5 years was 8.9 percent, and is forecast to achieve 5.4 percent in the next five years.

Figure 1: Semiconductor Revenue and Unit Shipments

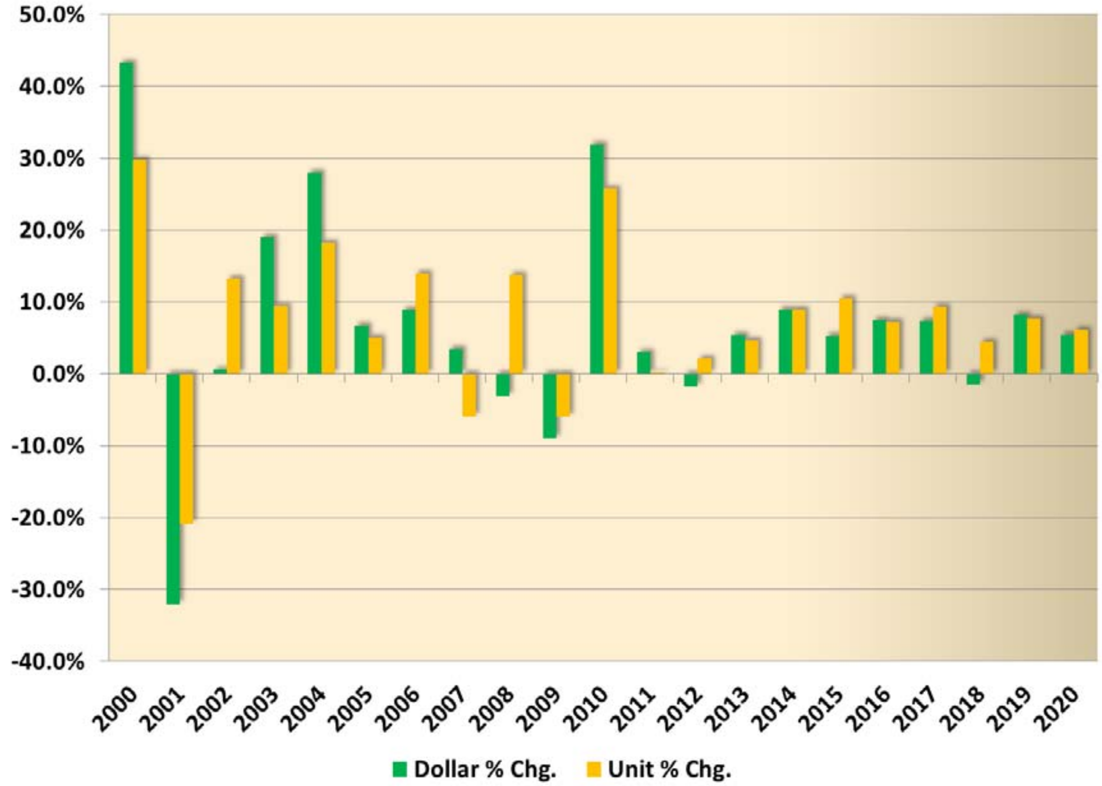


Source: Semico Research Corp.

Manufacturing capacity and unit demand is driven by end application growth which is significantly impacted by consumer acceptance of new technology and electronic product demand. In the next five to ten years the growth of the Internet of Things will be a prime driver effecting unit changes. In addition, technology advancement, integration, new markets and new manufacturing strategies also influence the need for new manufacturing capacity.

The semiconductor industry's growth rates have moderated since the crash of 2008. While recent history has shown slow stable growth, Semico has incorporated a correction year in the forecast occurring in 2018 followed by a recovery year in terms of growth rates for 2019. The correction year is assumed to be driven by weak memory markets and oversupply of memory capacity as well as a weak year in the world economy. Semico does not foresee two consecutive down years for the semiconductor industry in the next five years.

Figure 2: Revenue and Unit Growth Rate

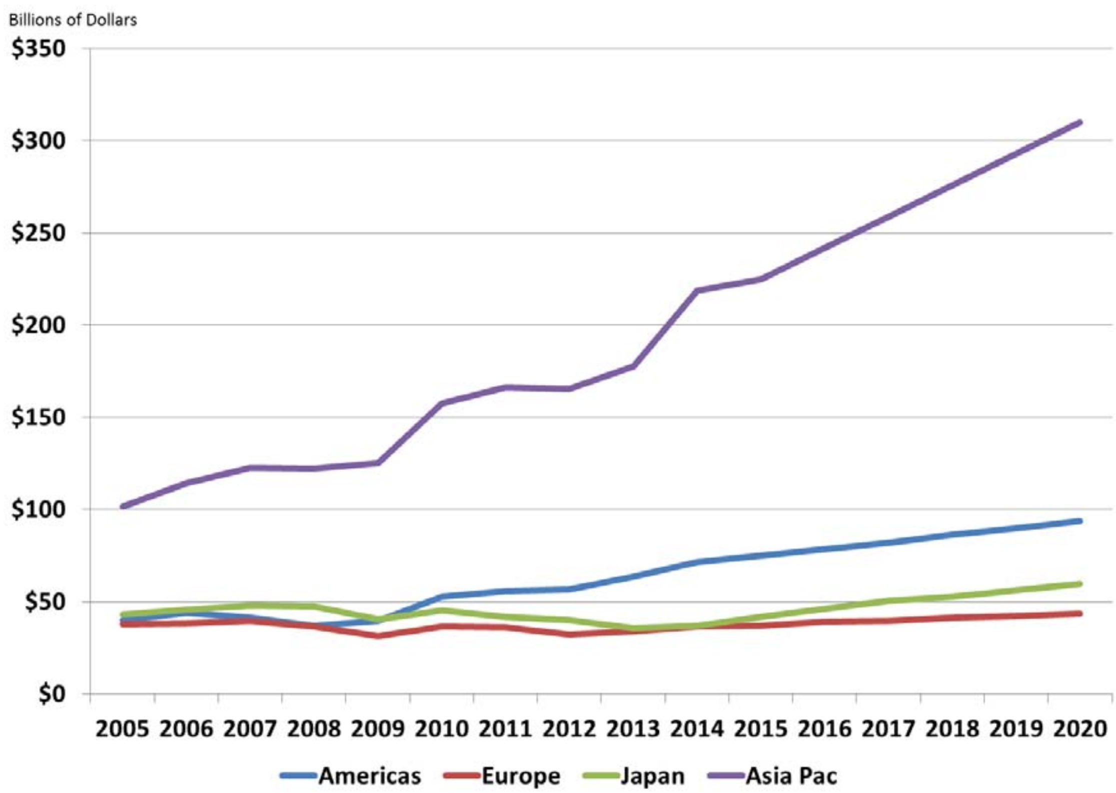


Source: Semico Research Corp.

Geographic Semiconductor Market

The chart below shows dollar shipments by major geographic region: North America, Europe, Japan and Asia. This presents the impact of changes in where semiconductors are consumed by OEMs and ODMs. What is interesting to note is while Asia has and continues to grow, recently the Americas is back on a growth trend which is unlike Japan and Europe. Industrial, automotive and enterprise as well as a move to have more domestic production by OEMs appear to be the main contributors to this trend.

Figure 3: Geographic Revenue Shipments



Source: Semico Research Corp.

General Trends - Macro Economic Issues

The health of the world and U.S. economy contributes to the health of the semiconductor industry and vice versa. As of 2015, the US economy continues its slow but steady expansion. While China is still the most vibrant large economy in the world, the economic growth rate is slowing and the country is now dealing with inflation and escalating costs. The semiconductor industry reacts to inflection points of the world economy and consumer demands. Overcapacity, excess inventories and weak end markets can drive average selling prices down resulting in lower industry revenues. The lower revenue can lead to shutting down facilities and or worker layoffs.

However, it is now typical for occurrences at the U.S. and world macro-economic level to impact semiconductor vendors, electronic original equipment manufacturers and semiconductor equipment makers. Here is a list of items at the macro-economic level that can now affect semiconductor demand and revenues.

- Oil prices - price stability

  If the Iran treaty passes expect to see world oil supplies rise. This could help to increase consumer spending because oil prices will remain low, keeping discretionary income for electronic purchases higher.

- Housing prices - Rising in the US, possible real estate bubble in China

  Good for U.S. consumer confidence; bad for China

- Interest rate changes likely

  Higher rates in the U.S. indicates the economy is good in the region however, higher rates will be a drag on consumer confidence

  China is dropping rates as economy slows

- Deficit has improved in U.S.
- Inflation in the U.S. in check
- Employment news in the U.S. is good as unemployment now stands at around 5%
- Consumer spending varies depending on the country or region, a mixed bag

Global Concerns

The semiconductor industry is truly a global business; the health of all the geographic regions impacts the market. In addition to looking at regions, there are some global concerns that each region watches. Global competition impacts where, when and why manufacturing facilities, design centers and expansion are done.

- Falling component pricing as a result of competitive world market manufacturers competing with a lower cost base than U.S. or Europe.
- Middle East conflict fuels uncertainty

    Iran – Nuclear deal adds uncertainty, i.e. when will Iran be able to sell oil

- North Korea – recently quite but a point on uncertainty
- Russia's military moves resulting in sanctions hurting their economy
- India pushing to build a 300mm analog fab
- China economy slowing, can they maintain a 7% GDP growth target

Drivers for Growth

The following list looks at new possibilities for 2016 and beyond relying on Analog and sensors.

- End markets improve in 2015 and 2016
- Innovation continues in the end product segment

    New Applications in Automotive

    - Driver assistance
    - Connected car
    - EV/Hybrid

- New Applications in Medical
    - Mobile Health
    - Chronic care
    - Remote care
    - Implantable

    New Applications in Consumer

    - Health and fitness
    - Augmented reality

    New Applications in Telecom

    - Mobile payments
    - Electronic wallets

- 5G
- Cloud storage
- Server farms

New Applications in Security

- Two way home security
- Public monitoring
- Smart grid
- Smart lighting

- iPhone continues to stimulate new designs & spurs upgrades
- Streaming digital in 4K emerging

Netflix and Amazon drive creative content

- Consumer adoption of technology continues to increase
- PC market will experience enterprise upgrades
    - Important base market but stagnant
    - Tablets cannibalizing notebook sales
    - Tablet market becomes more competitive, cheaper and more powerful

Capital Investment

Both the Indian and Brazilian governments have a positive view of semiconductors and actively support the development of this industry in their country. China has established a $20 billion dollar fund for the purpose of partnering with local businesses to expand, acquire or develop the semiconductor ecosystem in China.

As manufacturing production facilities have gotten more expensive to build, the industries appetite to over build capacity has great diminished. The foundry business is now very reactive to market conditions. At the first sign of weakening demand the foundries quickly push out equipment delivery schedule or slow their ramp rate. This is also true for the memory market which now has consolidated down to four major suppliers. As a result, the probability of seeing significant over capacity in the industry has been greatly reduced

Key drivers of investment by semiconductor manufacturing companies

Semiconductor Investment Choice

The cost of building and facilitizing a semiconductor facility ranges from over $500 million to several billion for a Giga fab. This fact alone makes it critical for semiconductor companies to develop a partnership with the government where they locate. New York State is the only state to have shown the ability and willingness to compete for semiconductor manufacturing in the world stage. Attraction of new business to a region is very important to the revenue base and therefore is very competitive. Financial incentives are key for a semiconductor facility to build in a different location than where it is already established. Moving to a new location typically is a result of several factors. Some of these factors are:

- Local manufacturing required
- Synergies with
  - R&D
  - Design
  - Packaging and Test
  - Patent protection
- Incentives
- Access to skilled labor
- Reliable power and water
- Technology transfer from universities
- Access to research capacity
- Subsidized higher education
- Special industry support
- Workforce assistance

There are some basic criteria that must be met before a region is considered for semiconductor manufacturing. Land desirability, adequate and reliable utilities and a robust infrastructure are key components to site selection. The establishment of one manufacturing facility will make the area more attractive to other manufacturers.

Availability of skilled workers and access to a continual stream of educated employees is necessary. It is too expensive for a company to relocate all of the engineers and specialized staff for a fab.

The network of universities can enable the development of interest in a locality. Universities are not only a source for future management and skilled workers, but also a source of consultation, R&D capabilities, graduate students and mentoring programs.

Secondary, but still important, is the standard of living for employees. Access to diverse cultural programs, schools, recreational areas, medical, environmental conditions and arts and sciences are key to families employed by a semiconductor fab.

Following is a checklist of items that are impacted by the location of a new facility in an area.

- Telecommunications
- Infrastructure
  - Roads

    - Hospitals
    - Business environment
    - Taxes
    - Tariffs/barriers
    - Labor regulations
    - Legislative climate
    - Bureaucracies
- Land
    - Adequate for future expansion
    - Natural disaster threats
- Reliable Utilities
    - Water
    - Electric
    - Heating/Cooling Cost
- Fire Departments with HazMat capabilities
- Raw Materials Access
- Airports
    - International
    - Local
- Universities
    - Availability of scientists
- R&D centers
- Other similar businesses
- Investment appeal of area
- Cost of living
- Cultural amenities
- Recreational amenities
- Environmental restrictions or benefits
- Advantages over other locations

Reasons for Investment Choices

Overriding influences on site selection are the financial incentives and existing location of other semiconductor facilities. The availability of work force, materials and infrastructure is considered to be resolved if another company is in the area. An organization within the state must be dedicated to keeping the program progressing even after an agreement is reached.

Areas attracting new high tech industry investment must work to establish a positive business climate and embrace policies that reduce taxes, streamline procedures and clarify regulations, and provide high quality public services.

Direct assistance must be provided to businesses looking to relocate includes information on:

- Highways
- Education
- Public safety
- International trade
- Community development
- Technology transfer from universities
- Access to research capacity
- Subsidized higher education
- Special industry support
- Workforce assistance

Active participation by the universities in a given state is critical to assure an atmosphere of scientific development. Future workers come from science-based programs.

Enabling Environment

A company moving to a new region does not expect all of the requirements to do business to be in place at the beginning of the agreement; however, the presence of strategic planning, policy development and milestone accountability are required. The partnership with organizations in the state will reduce roadblocks or enable barriers to progress to be resolved quickly and efficiently. Having a positive track record is very advantageous.

IP Protection

Most companies have been increasingly aware of the value of their IP. As a result, companies see the risk to their products, market position and profitability if IP is stolen or comprised. Locating manufacturing facilities in places that offer strong IP protection like the U.S. is appealing especially when compared to countries like China. China has improved on its IP protection efforts but it still has a long way to go to reach the standard seen in the U.S or Europe.

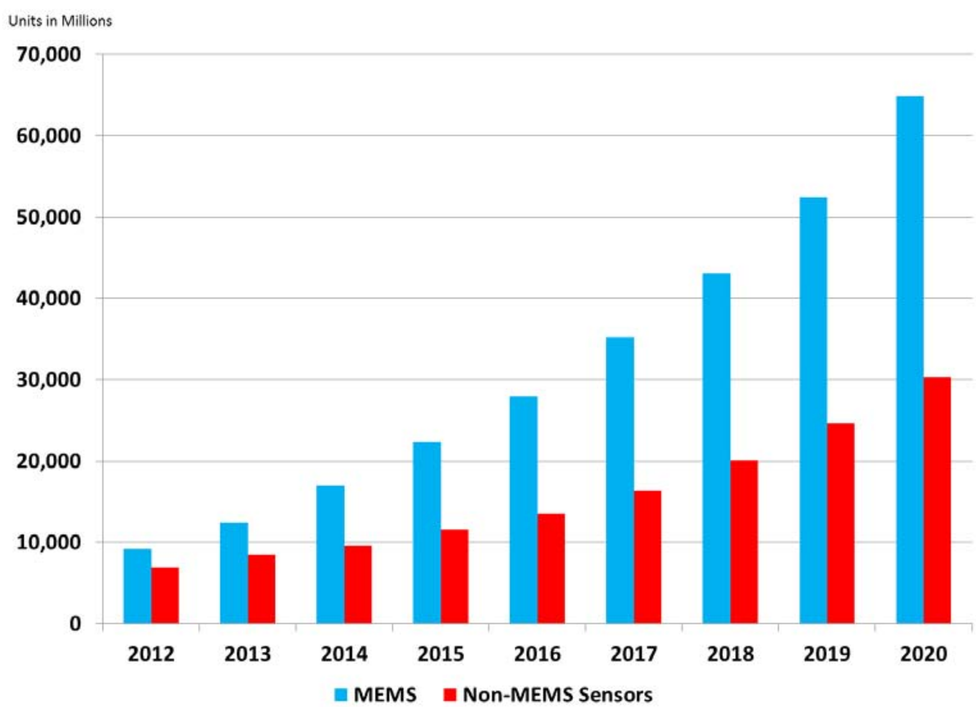
ams' Participation in Semiconductor Categories

The semiconductor industry is divided into six major semiconductor functions or product categories. The definitions of the categories are according to the WSTS/SIA (World Semiconductor Trade Statistics/Semiconductor Industry Association).

- Memory
- Micro Logic
- MOS Logic
- Analog (Linear)
- Discretes
- Sensors

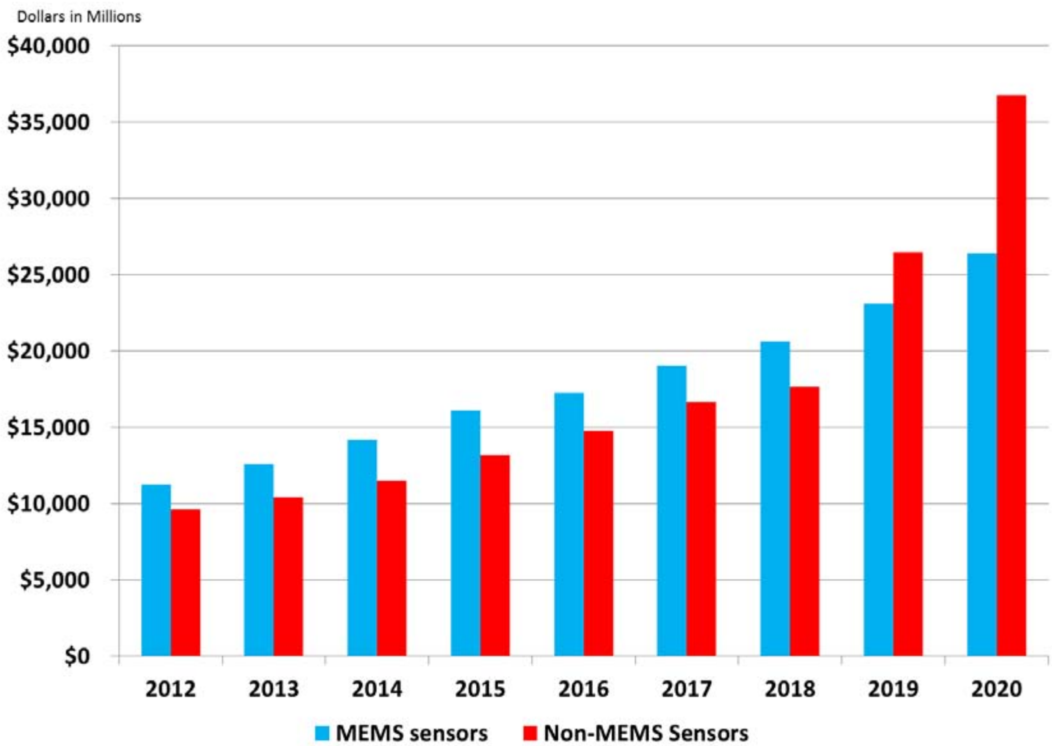
While the total semiconductor industry is growing at mid-single digit growth rates, there are segments of the industry experiencing much higher growth rates. The semiconductor products that ams will focus on are in two of the high growth segments. The sensor market has been an enabling technology for the mobile market and is experiencing very strong demand as sensors are designed into a broad range of products from smartphones, vehicles, tablets, PCs, wearables, health and fitness and industrial applications. In addition to new applications, the segment is growing because of the new technologies that are being implemented in the form of MEMS sensors and other MEMS products. The following graphs show the size and growth of the sensor market—both MEMS and Non-MEMS—in units and dollars.

Figure 4: Sensor Market Units



Source: Semico Research Corp.

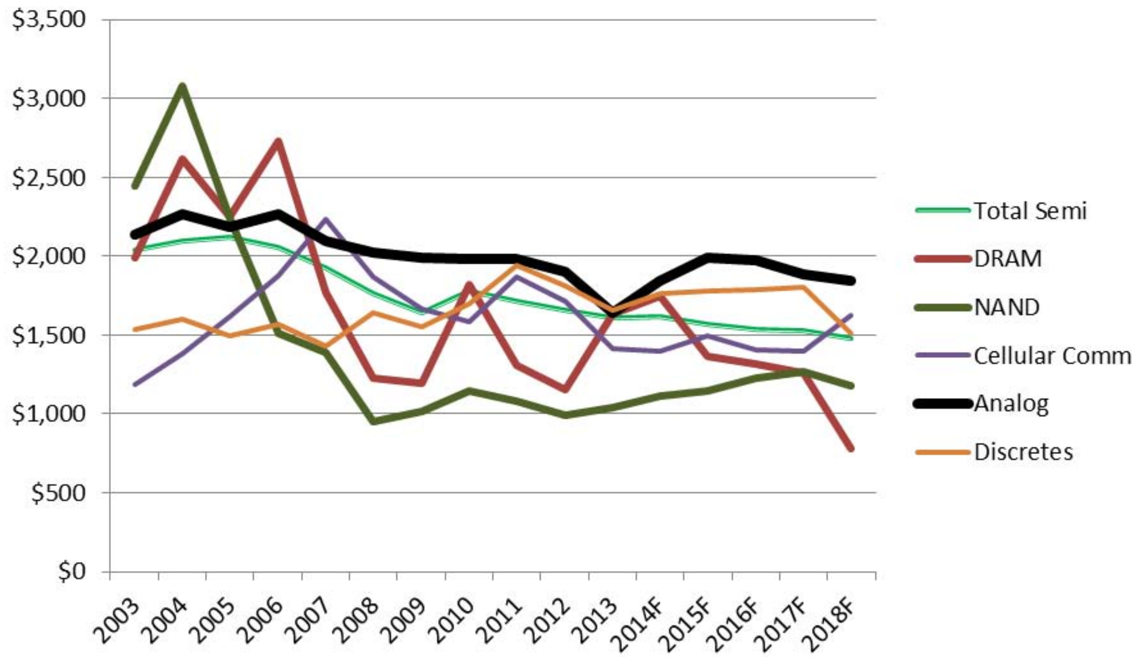
Figure 5: Sensor Market Dollars



Source: Semico Research Corp.

Another segment of the semiconductor market that is seeing above average growth is the Analog market, especially for power management and RF. Revenue per wafer is a good way to compare various semiconductor categories. The chart below shows the revenue per wafer over time for four product categories and the total semiconductor industry. Except for a few early years when Memory was hot, analog ICs have maintained higher revenue per wafer than the total industry and specifically DRAM, NAND and Cellular Communication ICs.

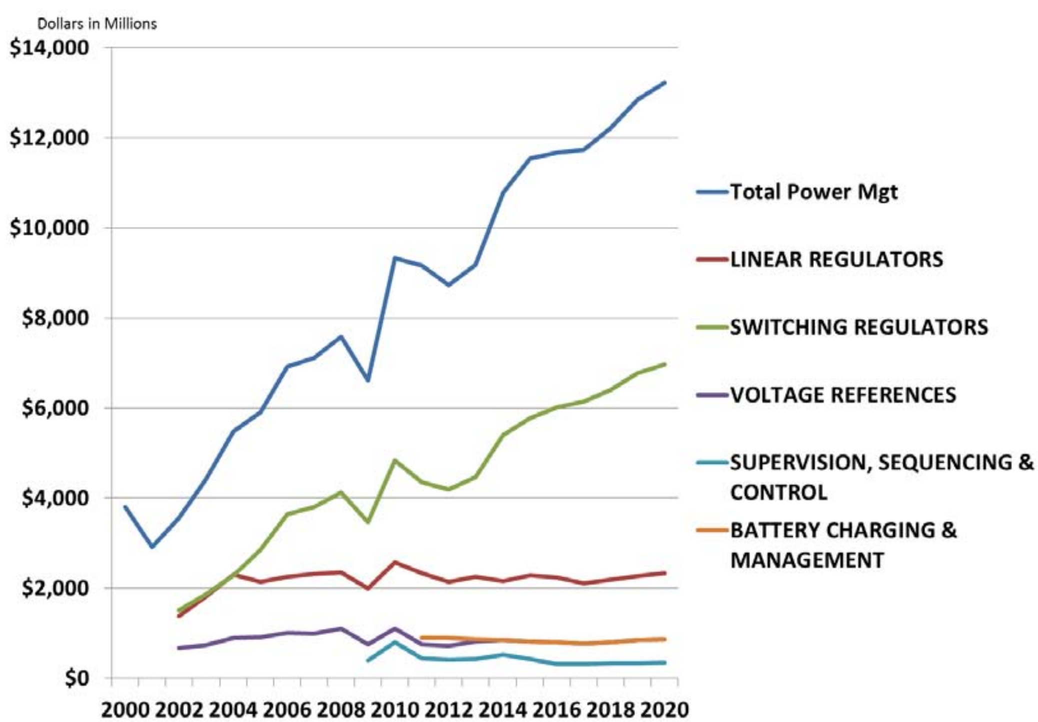
Figure 6: Analog Revenue per Wafer



Source: Semico Research Corp.

The chart below depicts the growth for the analog power management segment of the semiconductor industry.

Figure 7: Power Management Growth Rates



Source: Semico Research Corp.

Following is a more in-depth review of the analog market and the MEMS/sensor market.

Analog Market Overview

As electronic systems evolved to mobile devices the importance of analog products has grown. Interfacing with the real world via cameras, touch, gesture controls, audio and video applications all require RF (radio frequency) analog functionality. In addition, power management ICs are critical to the success of these devices to reduce the power drain on the battery. These growing applications have added significant volumes to the analog unit sales.

While manufacturers of mobile devices place power reduction and extended battery life at the top of their priority list, OEM's are also focusing on increasing the efficiency of products to get the highest energy star rating. This move to produce greener products is helping to put analog circuits at the forefront of system designs. Even the companies themselves are taking pride in being green. In 2012, Newsweek magazine ranked the top 100 greenest companies in the United States. Analog Devices was 19th, an achievement they are very proud to have.

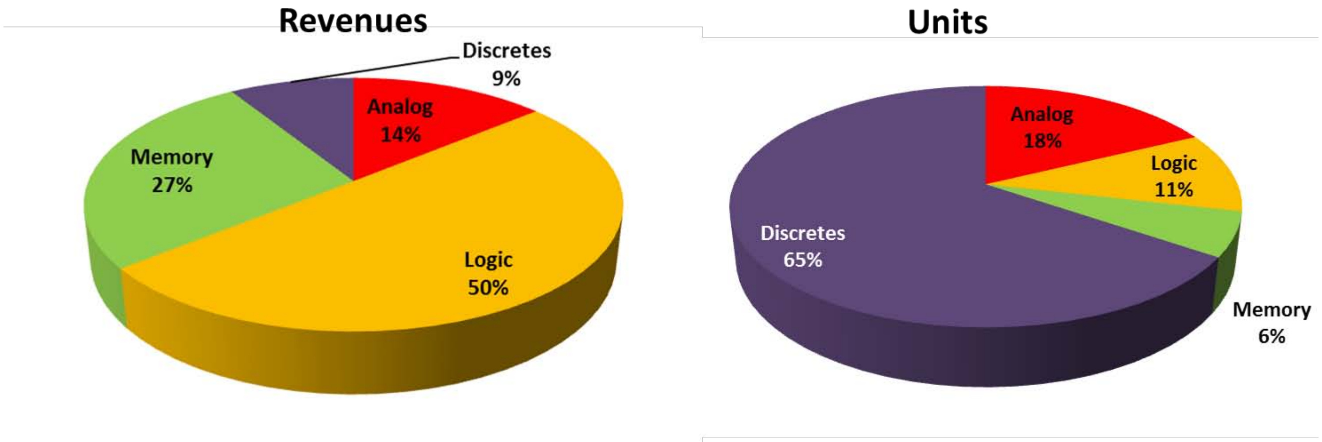
There continues to be demand for analog circuits across all application categories. We find analog products in garage door openers to white goods, to portable electronics, to automotive and communication products. Analog circuits are truly pervasive and ubiquitous throughout the marketplace. While smaller, faster and lighter are attributes most commonly touted by semiconductor companies, when it comes to analog circuits, that is not always the case. For the most advanced logic chips, manufacturers continue to drive down process technologies to sub-20nm nodes. On the other hand, for many of the general purpose analog products, the oldest process technologies are still used. Analog products will continue to utilize a broad spectrum of manufacturing process technologies in the foreseeable future. Analog circuits have obtained the unique position of being able to offer products utilizing 1μm or larger technology down to state-of-the-art 40nm and smaller designs.

This section breaks down the analog market into major sub-markets with forecasts out to 2020. It also covers the unique manufacturing requirements across the broad spectrum of products in the analog product segments.

Total Analog Market

The total analog market registered over $44 billion in sales revenue in 2014, a growth of 10.6% over 2013. Units grew a corresponding 10.9% to over 115.6 billion units. Unlike the other major semiconductor categories such as memory and logic, the analog market maintains a relatively stable impact on both total semiconductor revenues and units. Analog products contribute 14% of total semiconductor revenues and 18% of total units. On the other hand, Logic products, i.e. microprocessors, application processors, microcontrollers, contribute 50% to the total semiconductor revenue and only 11% of the total units. Discrete products are the exact opposite. The discrete product market only contributes 9% of the total revenue but accounts for 65% of the total units.

Figure 8: Analog Share of Total Semiconductors 2014

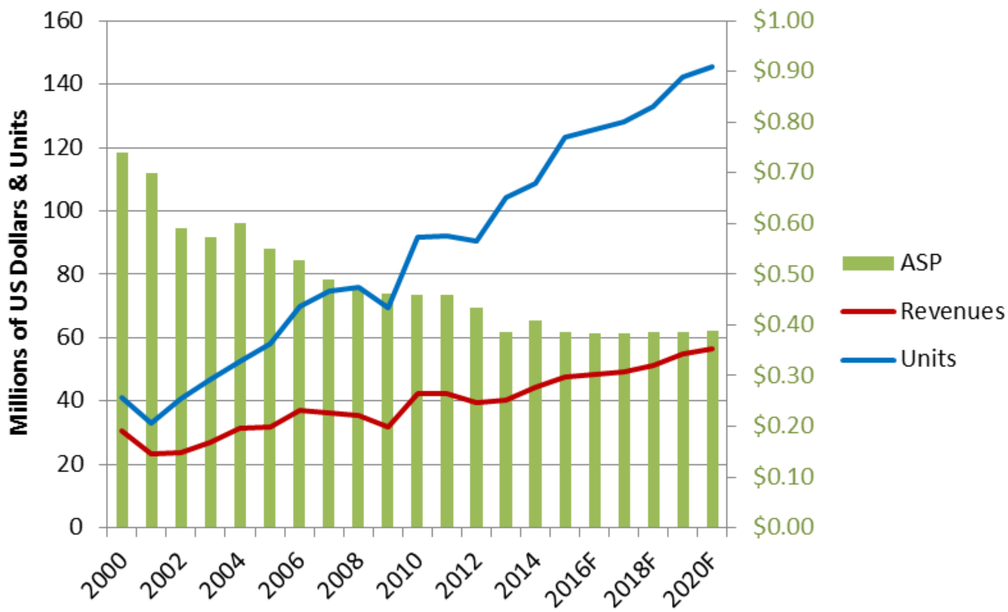


Source: Semico Research Corp and SIA/WSTS

In 2015 the analog market is expected to grow 7% to reach over $47 billion for the year. As for units, 2015 is seeing unit volumes increase by 6.4% to over 123 billion units. Historically, over the past 5 years, analog revenues have grown at a CAGR (compound annual growth rate) of 6.8% while units have grown over double that rate at 10.8% CAGR. By 2020 the total analog market will reach $56.5 billion and 145.6 billion units.

Analog products have experienced a general decline in ASP (average selling price). In 2000 analog ASPs were over $.70. Today, analog ASPs have dropped to $0.38-$0.39. Although average selling prices have declined for analog products as a whole, technology changes, tight capacity for certain types of products and market demand are some of the reasons for more stable pricing in certain categories. Increased manufacturing efficiencies such as moving production into 300mm wafers and the move to more advanced process technologies have also had an impact. Manufacturing efficiencies helped to reduce manufacturing costs which in turn allows prices to fall while still maintaining an adequate return on investment.

Figure 9: Analog Revenues, Units and ASPs, 2000-2020

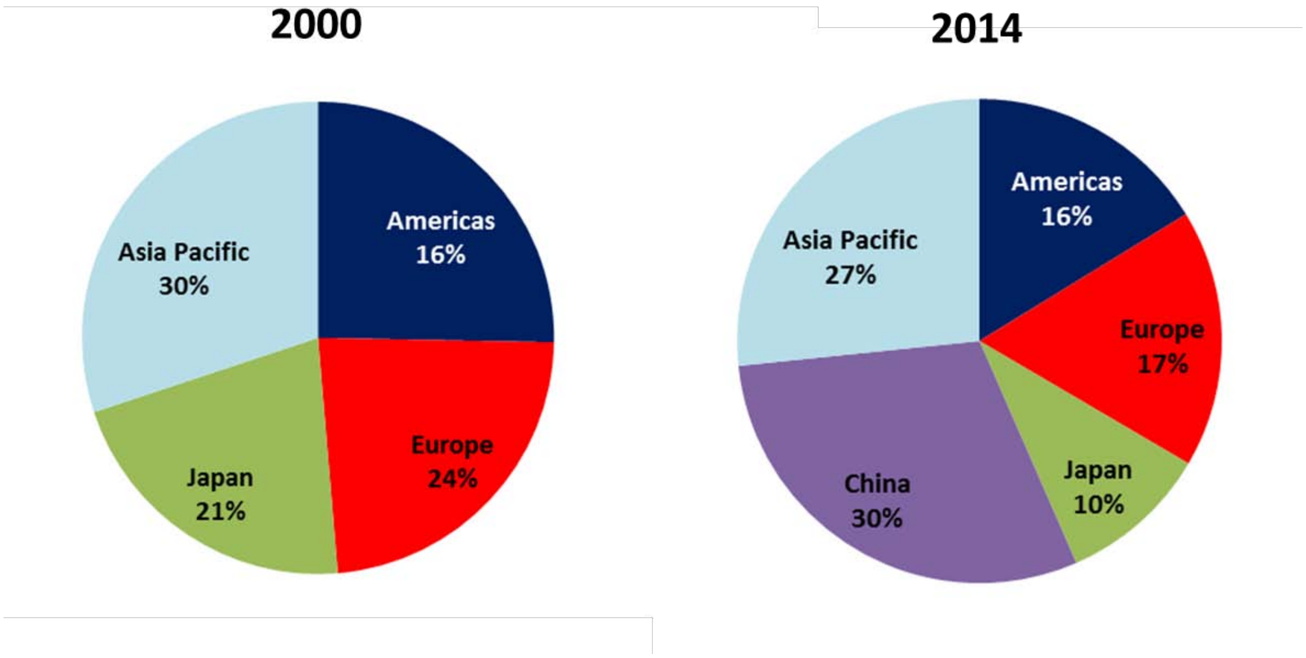


Source: Semico Research Corp and SIA/WSTS

Analog Market by Region

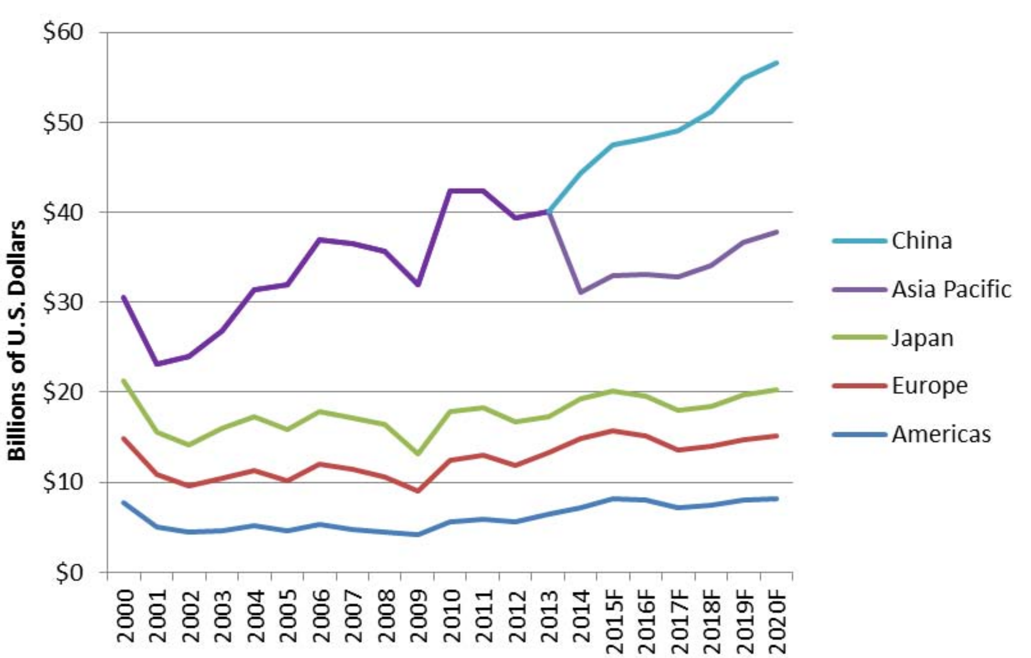
The Analog market has experienced significant shifts in terms of revenues by region. In 2000, Asia Pacific (including China) accounted for 30% of total Analog sales. In 2014, China was such a significant market, SIA began reporting China as a regional category of its own. Asia Pacific, including China now represents 57% of total Analog sales. The growth in China and Asia Pacific has come at the expense of Japan and Europe. The Americas has held steady to a 16% regional share; however, that percentage has fluctuated over the years.

Figure 10: Analog Revenues by Region



Source: Semico Research Corp and SIA/WSTS

Figure 11: Analog Revenues by Region



Source: Semico Research Corp and SIA/WSTS

Analog Market by Major Product Category

Analog market data is broken out into two major categories, General Purpose Analog ICs and Application Specific Analog Circuits. General Purpose Analog ICs are segmented by the product functionality while the Application Specific Analog Circuits are categorized by the specific end application for which the device is designed for. If the end application for the device cannot be specifically determined or if the device is used in many applications without one end-application dominating, the device is classified into the General Purpose Analog category. The following table provides a breakout of the subcategories that are tracked by the SIA (Semiconductor Industry Association) for General Purpose Analog and Application Specific Analog.

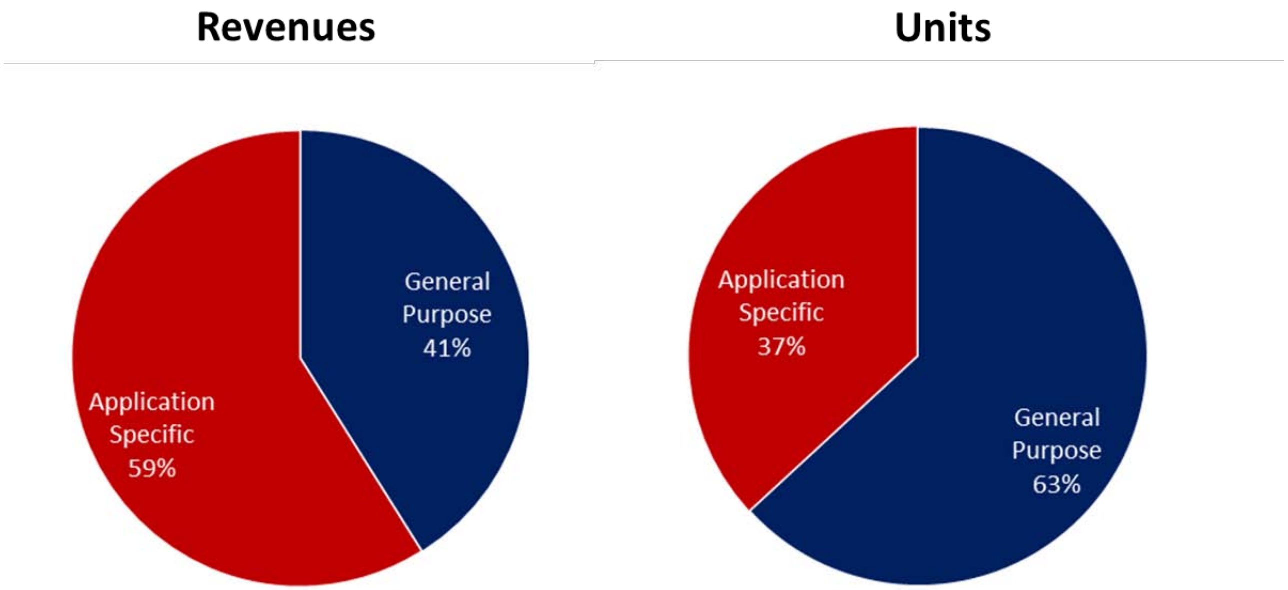
Table 1: Analog Product Categories

General Purpose Analog	Application Specific Analog Circuits
Amplifiers/Comparators (Signal Conditioning)	Consumer
Signal Conversion	Audio/Video
Interface	DSC/Camcorder
Interface Logic and Amplification	Other Consumer
Interface Conditioning and Protection	Computer
Power Management	Computer Systems and Displays
Linear Regulators	Storage Devices
Switching Regulators	Computer Peripherals
Voltage References	Other Computing
Supervision, Sequencing and Control	Communications
Battery Charging and Management	Cellular Phones
Other Power Management	Wireless Infrastructure
	Wireless Communication - Short Range
	Other Wireless Communication
	Wired Communication
	Automotive
	Infotainment
	Other Automotive
	Industrial & Others
	RFID Transponders
	Medical/Healthcare
	All Other Industrial

Source: Semico Research Corp and SIA/WSTS

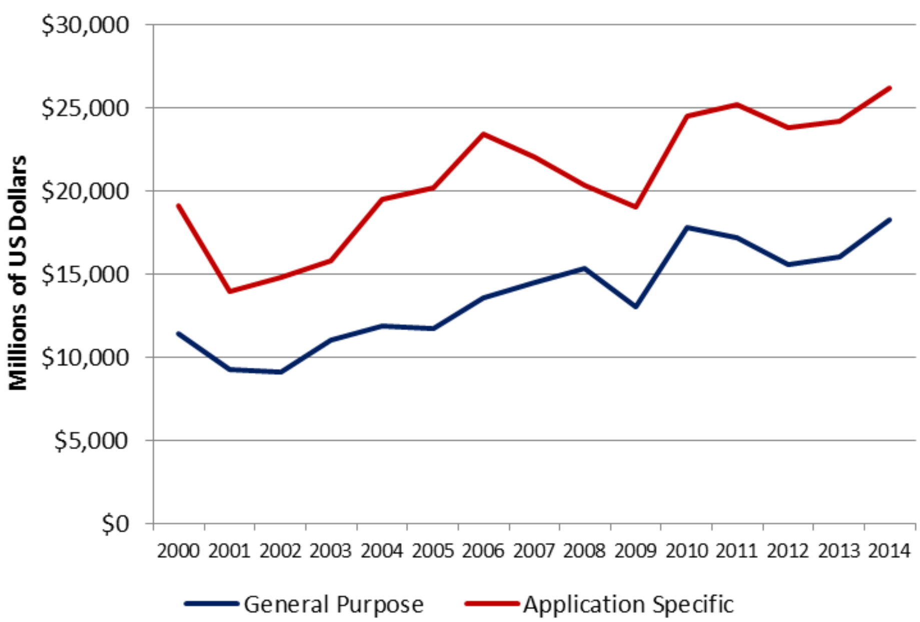
Application Specific Analog products maintain a bigger share of the revenue pie; however, General Purpose Analog commands a larger portion of the units.

Figure 12: General Purpose & Application Specific Analog Market Share 2014



Source: Semico Research Corp and SIA/WSTS

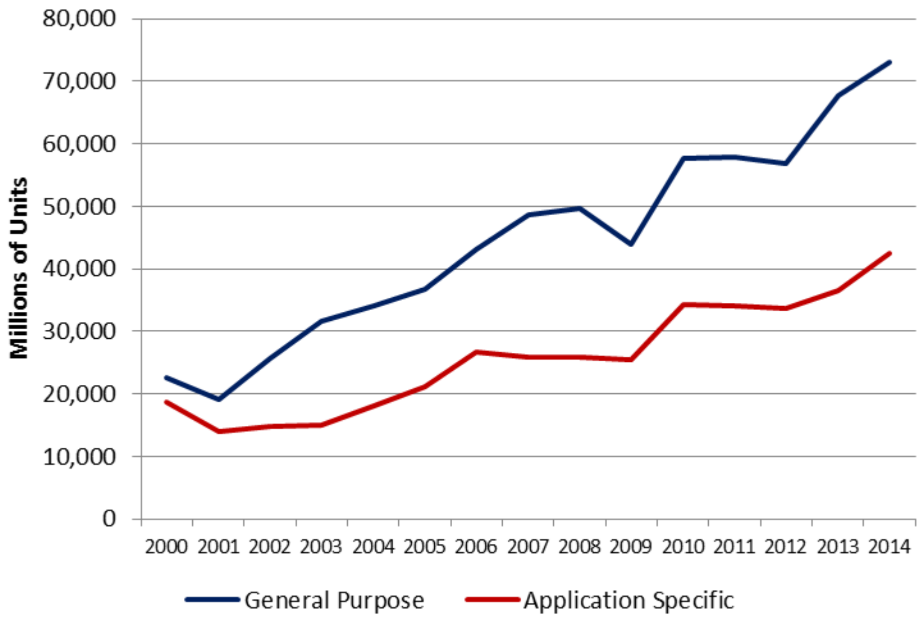
Figure 13: General Purpose & Application Specific Analog Revenue Growth 2000-2014



Source: Semico Research Corp and SIA/WSTS

General Purpose Analog revenues have grown at a CAGR of 4.4% while Application Specific Analog revenues have grown at a slower rate of only 3.0%. On the other hand, over the past 10 years, Application Specific units have grown at a CAGR of 8.9% while General Purpose Analog has grown at 7.9%.

Figure 14: General Purpose & Application Specific Analog Unit Growth 2000-2014



Source: Semico Research Corp and SIA/WSTS

The impact of a faster growing unit base is a declining average selling price. The average selling price of an Application Specific Analog was $0.61 in 2014 while the average selling price for a General Purpose Analog was less than half that, $0.25.

The next section will provide information on the trends and key drivers for continued growth for key analog markets.

General Purpose Analog ICs

General Purpose Analog is a major analog product category which includes the following subcategories: Amplifiers/Comparators (Signal Conditioning), Interface, Power Management ICs, and Signal Conversion (Data Conversion). These categories are defined in terms of functionality instead of a specific circuit type. A device is classified into one of these subcategories based on its primary function, regardless of the mix of circuitry used in the device. Semico views many of these products as jellybean-type products.

The general purpose analog integrated circuit market is significant in size. First quarter 2015 unit shipments were 17.3 billion, registering a 3.7% decline compared to the first quarter 2014 and a 2.8% decline compared to the 4th quarter 2014. But shipments are expected to return to the 18 billion range in Q2 2015 and increase to 20 billion in Q3 and in Q4 2015. The corresponding quarterly revenue was $4.3 in Q1 2014 going up to $4.5 billion Q1 2015.

Many of these products utilize old semiconductor process technology. We see many products being produced on 5- and 6-inch wafers with a trend to transition more of these products to 8-inch wafers. There is one exception.

Power Management products have seen exceptional growth over the past X years and is already beginning to look toward 300mm wafer production. AMS has products in the Power Management category. Additional detail on the Power Management category follows.

Over the last several years worldwide aggregate ASP's have been declining in the General Purpose Analog category and we expect this trend to continue throughout the forecast. An increasing number of these products are being produced in China where they have low cost labor and access to older production lines.

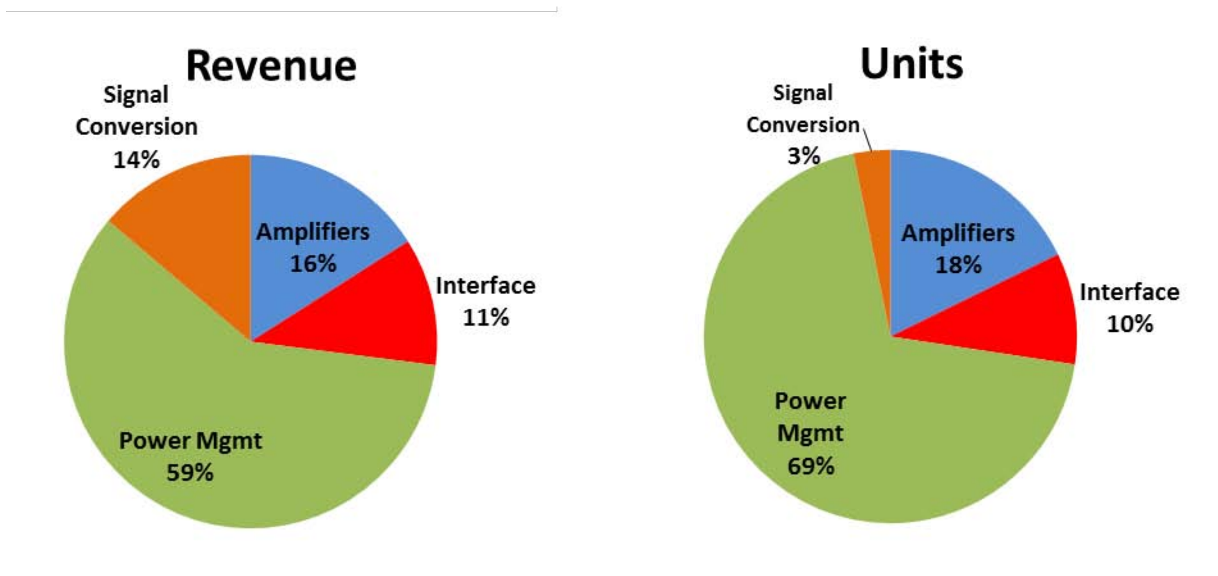
General Purpose Analog ICs are ubiquitous throughout the electronics market and Semico forecasts a general upward trend for unit shipments through 2020.

Power Management

Power Management is by far the biggest category in the General Purpose Analog group. In 2014, Power Management devices represented 59% of the total General Purpose Analog revenue and 69% of the units.

Power Management devices convert, control or distribute DC power. This category includes devices which convert a source voltage into another voltage which can be used for powering other integrated circuits and include a management capability to control the output voltage. AC to DC power conversion is included in this category. Only products that are integrated circuits are classified in the category.

Figure 15: General Purpose Analog Product Breakout, Revenue & Units 2014



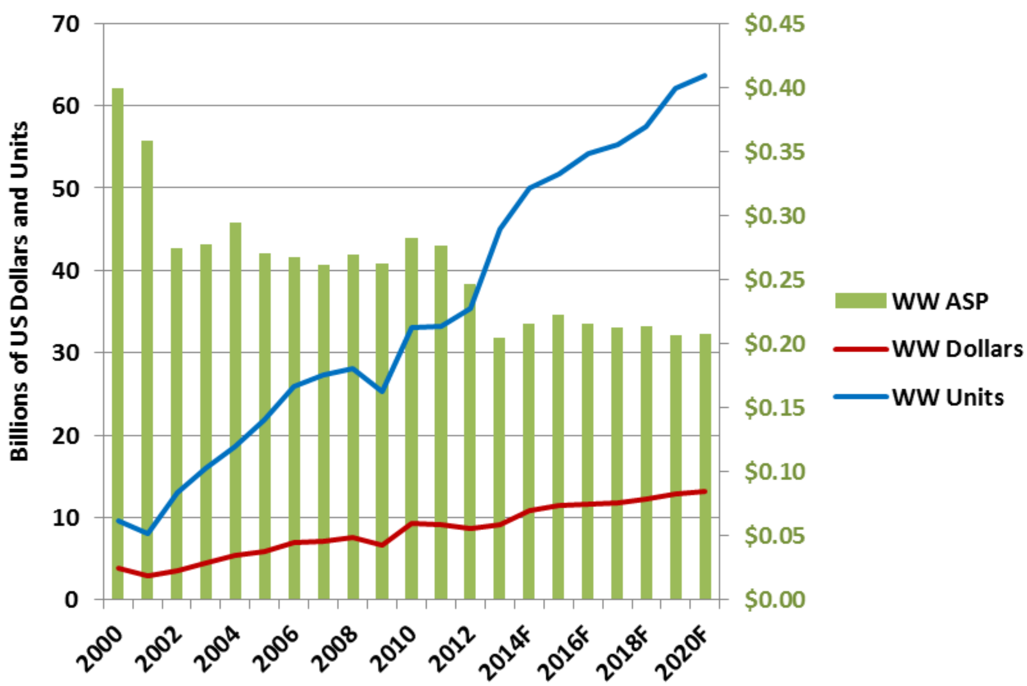
Source: Semico Research Corp and SIA/WSTS

Power management is in the forefront of system designs today. In addition to the consumer’s demand for high-quality end-to-end speech with louder, better-quality speakerphone performance, high-quality microphones, and high-definition audio playback, mobile devices such as smartphones and tables are offering near-field communications (NFC), RF connectivity, GSM, Bluetooth, Wi-Fi, and GPS. All these functions translate into the need for better power management and more sophisticated solutions. Furthermore, popular applications like social networking and mobile Web access means increased power consumption as users crave ever-more data bandwidth through 3G connections and 4G LTE. In the next five to ten years, this category is set to experience continued growth due to the additional applications and functionality needed to implement the Internet of Things.

Over the past 10 years, Power Management revenues have grown at a CAGR of rate of 12.2% while units have grown 15.1%. That compares to the overall General Purpose Analog growth rate of only 6.4% CAGR for revenues and 11.7% for units.

In 2014 this category topped $10.8 billion while units reached 50 billion. By 2020 revenues are expected to grow another 2.2% CAGR reaching $13.2 billion with units reaching 63.6 billion.

Figure 16: Power Management, Revenue, Units, ASP 2000-2020



Source: Semico Research Corp and SIA/WSTS

Top Analog Manufacturers

Analog manufactures offer a broad-based of products that range from standard products to Application Specific including mixed signal. The semiconductor required for these products cover the entire spectrum of semiconductor process technology. There are many products still using very old technology that have a place in the market by using newer packaging techniques to more leading edge technology for the performance or power sensitive applications.

The table below lists the key Analog vendors.

Table 2: Analog Key Vendor List

Analog Devices	Maxim
ams AG	Microchip
Atmel	Microsemi
Avago	NXP
Bosch	ON Semiconductor
Broadcom	Panasonic
Fairchild	Plessy
Freescale	PMC-Sierra
Fujitsu	Rohm
Hitachi, Ltd.	Renesas
IBM	RFMD
Infineon Technologies	ST
Intersil	Texas Instruments
Linear Tech	Toshiba
LSI	Wolfson
Marvell	Zilog

Source: Semico Research Corp

Top Analog Foundries

The table below lists the key Analog foundries.

Table 3: Key Analog Foundries

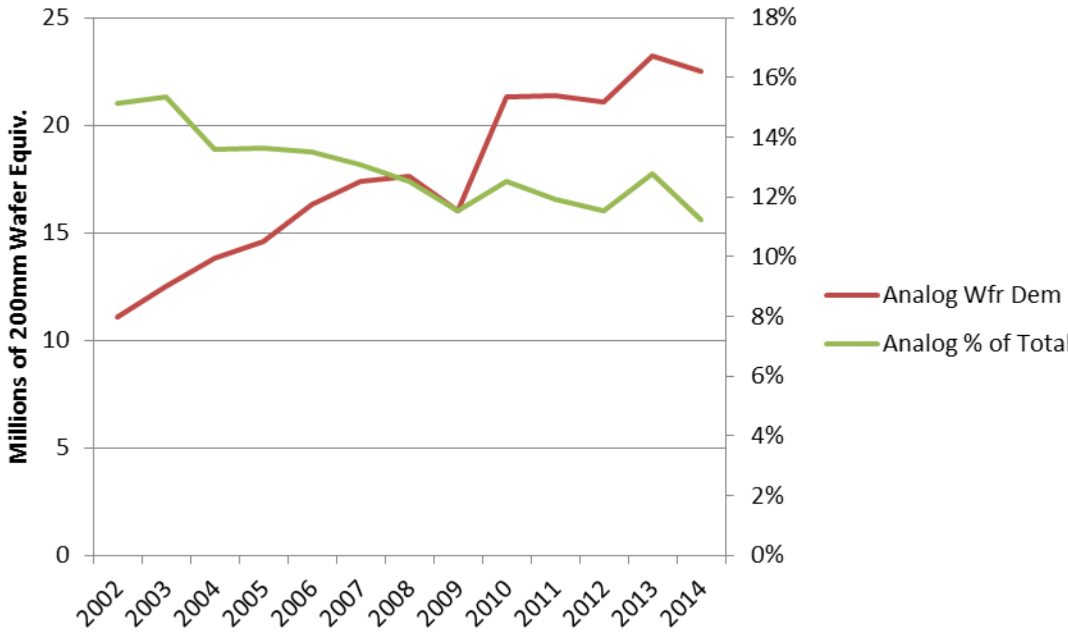
Dongbu HiTek
Dalsa Semiconductor
GLOBALFOUNDRIES
Huahong Grace Semiconductor Manufacturing Corp.
Magnachip
SMIC
Tower Jazz
TSMC
UMC
X-FAB
Vanguard

Source: Semico Research Corp

Analog Wafer Demand and Capacity

Total Analog wafer demand has grown at a 7% CAGR over the past 5 years and is expected to increase to over 14% CAGR over the next five years. Increased analog unit demand for power management, RFID, and RF transceivers will be driven by the rollout of consumer, industrial and automotive Internet of Things.

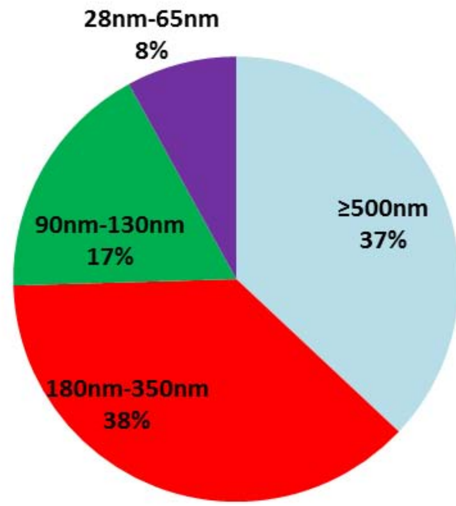
Figure 17: Analog Wafer Demand as a Percent of Total Wafer Demand



Source: Semico Research Corp and SIA/WSTS

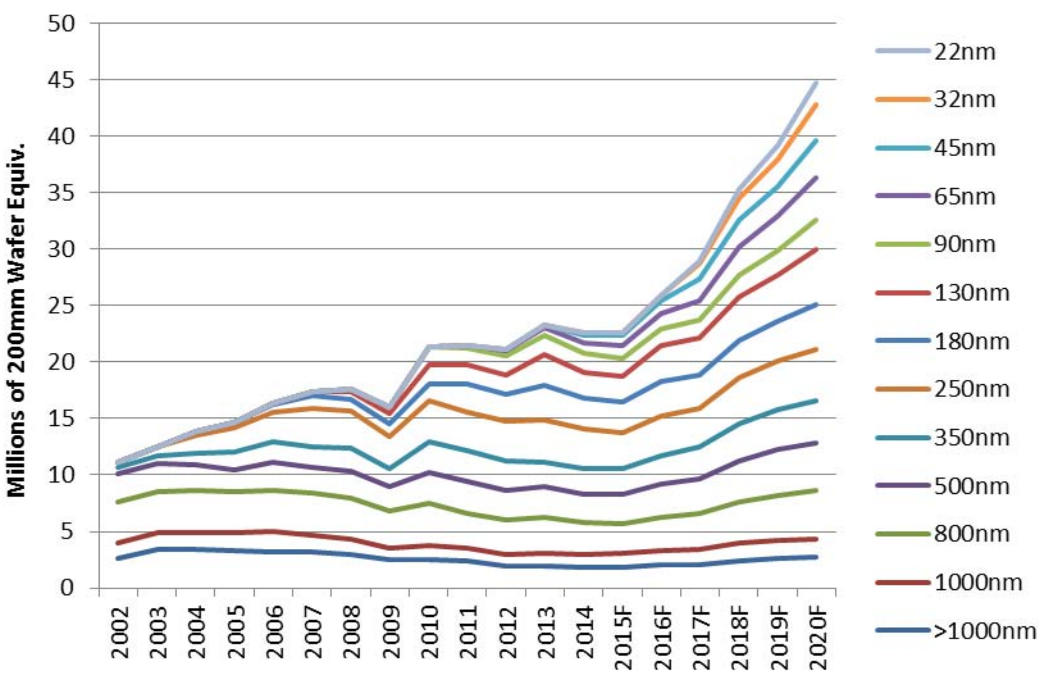
In general, analog products utilize mature fabs and process technologies. Approximately 75% of the total wafers used to produce Analog products utilize 180nm process technology or larger. However, as Figure 11 and 12 show, today, analog products utilize a full spectrum of manufacturing technologies as well as wafer sizes. The diversity in the manufacturing technology, wafer size and processes is indicative of the broad spectrum of products that are required for applications requiring analog circuits. The conversion of signals from analog to digital, digital to analog, the management of power flow, the transmitting and receiving of all mobile devices by RF circuitry continues to grow and is expected to increase over the next 10 years as all IoT connected devices require more connectivity and low power.

Figure 18: Analog Wafer Demand by Technology 2014



Source: Semico Research Corp and SIA/WSTS

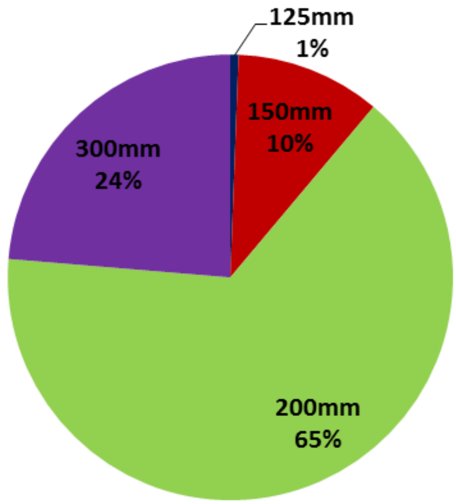
Figure 19: Analog Wafer Demand by Technology



Source: Semico Research Corp.

As previously mentioned, 75% of all Analog wafer demand continues to utilize mature technology. That translates into continued use of 200mm wafer fabs, although 300m is becoming more attractive. In terms of silicon square inches, just over 65% of all silicon used to manufacture analog products are in the form of 200mm wafers.

Figure 20: Analog Wafer Demand by Wafer Size 2014 (Silicon Square Inches)



Source: Semico Research Corp.

The industry introduced 300mm wafers into volume production in 2001; however, the new wafer size did not show up in analog production until 2004 in very small volumes. In 2009, Texas Instruments purchased the 300mm manufacturing equipment from a bankrupt DRAM manufacturer, Qimonda, in Virginia. By the end of 2010, Texas Instruments started ramping production of analog products on 300mm wafers. In order to keep up with the industry shifts, Maxim followed suit with a foundry partner Powerchip Technology Corp. in Taiwan.

There are several reasons why the use of 300mm wafers for Analog production will continue to grow.

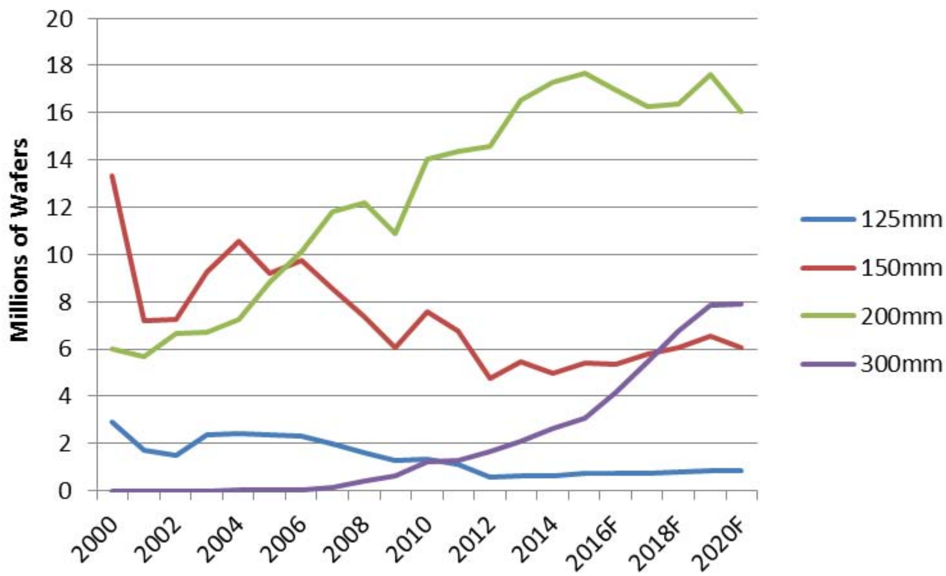
- First generation 300mm fabs are now fully depreciated and therefore, will become more attractive as production facilities for mature process technologies as the cost to run a 300mm fab continues to decline. In addition, there are increasing challenges with aging 200mm equipment both in terms of availability of parts and technical expertise to service the equipment.

- During the past two years, 200mm wafer capacity for RF front end devices for smart phones has been in tight supply. This has forced analog manufacturers to evaluate manufacturing options.

- Although most used equipment suppliers can still find an ample supply of 200mm tools, some 200mm fab operators have begun to notice an increase in price and/or a tighter supply of 200mm tools. A shortage of actual 200mm equipment and 200mm parts, will add to the incentive to move to 300mm wafer production.

- Analog chips continue to transition to more advanced process technologies in order to deliver market requirements for mobile devices, IoT, autonomous driving and high performance connectivity. Process technologies such as 65nm, 40nm and beyond, are primarily available on 300mm wafers.

Figure 21: Analog Wafer Demand by Wafer Size



Source: Semico Research Corp.

Semico's Fab Database lists over 200 fabs capable of manufacturing analog products. These fabs offer a broad range of capabilities including, but not limited to, the following.

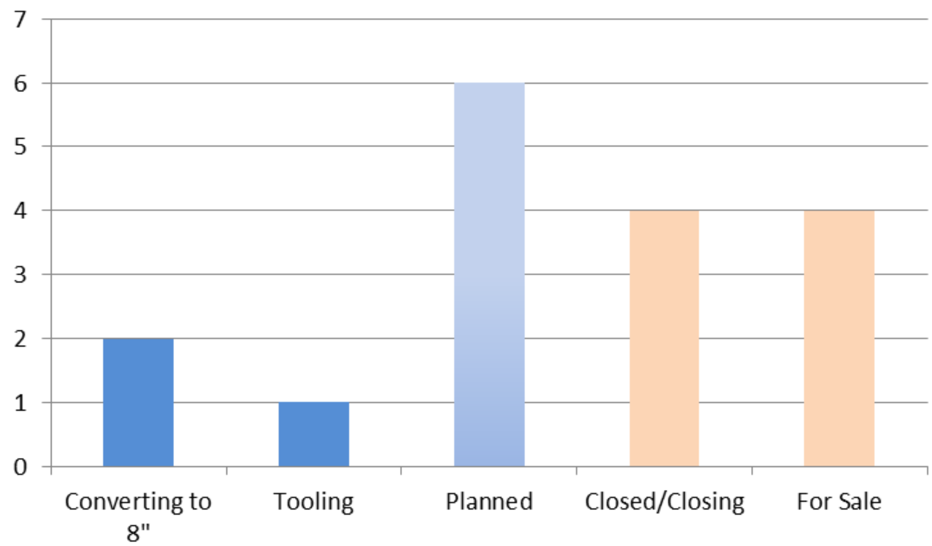
Table 4: Analog Fab Capabilities

	Analog Offerings
Wafer Size	100mm, 150mm, 200mm and 300mm
Process Technology Node	>1um, 1um, 0.8um, 0.5um, 0.35um, 0.25um, 0.18um, 0.13um, 90nm, 65nm, 40nm, 28nm
Processes	CMOS, Mixed Signal, BiCMOS, BCD, RFCMOS, HV, SHV, PMIC,
Materials	Bulk wafers, SOI, GaAs, SiGe

Source: Semico Research Corp. and Company Sources

Of the 217 fabs listed in the Semico Fab Database 198 fabs are operating, productions fabs. The other 19 are either for sale, converting from 150mm wafers to 200mm wafers, tooling up, planned, closing or are primarily R&D.

Figure 22: Analog Fab Status



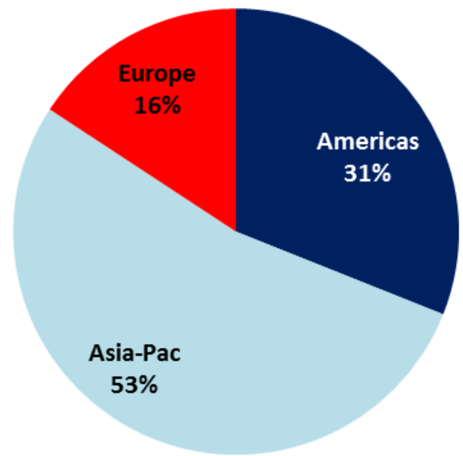
Source: Semico Research Corp. and Company Sources

Of the six planned fabs, only two are highly likely to be built: the ams facility and a facility in India currently named Cricket Semiconductor.

The 198 fabs that are currently in production have a total capacity of 27 million 200mm equivalent wafers per year. In 2014, the total semiconductor industry required 22 million 200mm wafer equivalents. Although that results in a capacity utilization of less than 82%, the number is a bit misleading. As previously mentioned, there are a number of processes, wafer sizes, technology nodes and materials that are used to produce analog ICs. It is not always easy to switch fabs or transfer materials, in order to use available capacity.

Fabs may not be located in the right region; it may not offer the right technology node or the right wafer size. Currently the largest number of fabs are located in Asia-Pac. Of the 108 fabs in Asia, 31 are in Japan and 14 are in China.

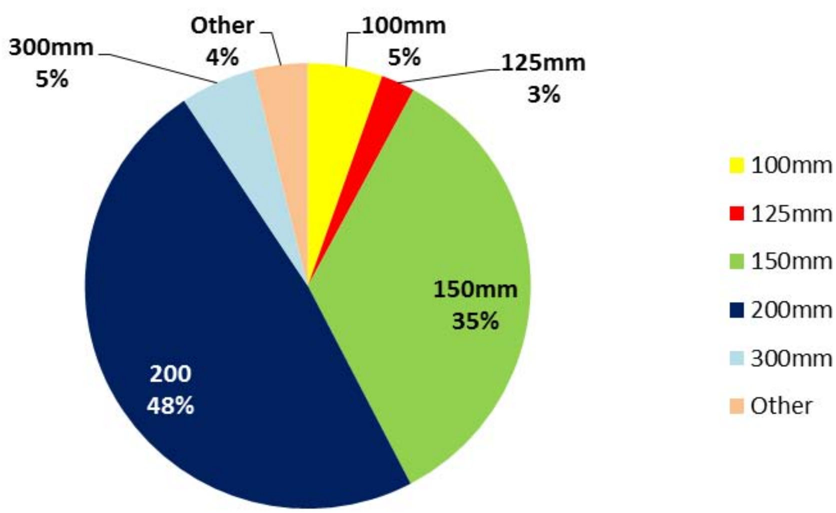
Figure 23: Analog Fabs by Region



Source: Semico Research Corp. and Company Sources

Most of the operating Analog fabs utilize 200mm wafers however; there are eleven 300mm fabs that offer Mixed Signal processes and other Analog manufacturing services.

Figure 24: Analog Fabs by Wafer Size



Source: Semico Research Corp. and Company Sources

All this variety sheds more light as to why the capacity utilization may not be higher than 82%. At any point in time, there may be a shortage of RF analog capacity but an over capacity of Interface devices.

UHF, NFC/HF RFID Market Overview

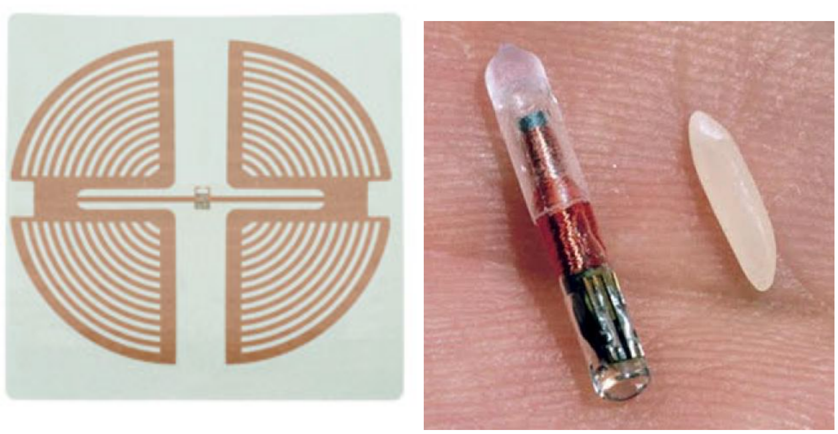
RFID stands for "radio-frequency identification". At the most basic level, an RFID system is made up of a tag, a reader, and a host. A tag—also referred to as a transponder—consists of an IC and an antenna, and a reader includes an IC that can detect, via radio waves, the information stored on the tag. The reader then transmits the tag's information to the host computer system, which can store the data or act on it as needed. RFID tags can be either passive or active; passive tags receive power from the reader, while active tags have their own power source. Another way to segment the market is by frequency: Low (LF), High (HF) and Ultra High (UHF).

Table 5: RFID Market by Frequency Range

	LF RFID	HF RFID	UHF RFID
Frequency range	30-300kHz	3-30MHz	300MHz-3GHz
Read range	4 inches	4-40 inches	40 feet
Applications	Livestock tracking, access control	Ticketing and payments	Anti-counterfeiting, retail inventory management

Source: Semico Research

Figure 25: RFID in Label and Animal Implant Form



Source: Wikipedia

RFID's origins go back as far as WWII, when pilots tracked other planes to determine if they were friend or foe. Today, RFID is used in retail, government, and industrial applications to track inventory, assets, or personnel and to prevent counterfeiting. Both Wal-Mart and the US Department of Defense require their suppliers to be able to track inventory with RFID. RFID can take the place of, or work in conjunction with, barcodes, but have the advantages of not needing to be "line of sight" to be read and being able to store more data.

RFID tags are tiny, require very little or no power, and are very inexpensive, making broad implementation possible.

NFC Segment

Near Field Communication (NFC) is in the HF segment of the RFID market. NFC's operation is limited to within 10 centimeters. With UHF RFID, data can be transmitted over longer distances; the E-ZPass toll tag used in many states operates with UHF active RFID. RFID is useful for tracking items like baggage, livestock, or shipping pallets. However, NFC is used for secure applications like passports and payment cards where it is not desirable to broadcast such information, thereby decreasing the likelihood that it could be intercepted and stolen by a thief. Both RFID and NFC chips are very small and easy to include in any type of application imaginable.

A global standard, NFC operates at 13.56MHz and has a data transfer rate up to 424 Kbps. It uses magnetic induction coupling when two devices are within 4 inches of each other.

NFC chips work in three modes:

- Read-Write: Information can be read from the chip or written onto it.

- Card Emulation: The chip enables a smartphone to act as a digital wallet or contactless smart card, making payments, maintaining loyalty card information and storing electronic coupons. The phone could also act as a physical access card such as a badge or bus pass.

- Peer-to-Peer (P2P): Information can be shared or the device can be paired with another device.

NFC communication occurs when two components, a Reader/Writer and a Tag come into close physical proximity or are tapped together.   A Tag holds information or commands, while a Reader/Writer reads the information on the Tag and acts on it. An NFC-enabled smartphone can perform as both a Reader/Writer and a Tag.

Secure NFC is made up of two chips. An NFC radio, which can interact with Tags, Reader/Writers or other NFC devices, connects to a host controller, such as the application processor in a phone. The second chip is called the Secure Element (SE). The Secure Element contains a secure processor as well as executable and storage memory. The sole purpose of the SE is to enable secure transactions via unique keys stored on the SE in a tamper-proof memory not readable in software.

A newer development, host card emulation (HCE) enables an NFC device to perform a contactless transaction when in card emulation mode, without the need for an SE. The credentials and application are then stored in the cloud, or in software on the mobile device. Google Wallet, when introduced in 2011, required an SE to be included in an Android phone, but the company has moved to HCE with cloud storage of payment credentials. HCE acts as a secure gate, allowing Google Wallet to send payment information to the payment terminal to conduct a transaction.

A unique feature of NFC is that an NFC transaction can take place even when one of the devices is not powered. If the battery is dead on a mobile phone, a payment can still be made.

The following table lists the major differences and similarities between RFID and NFC.

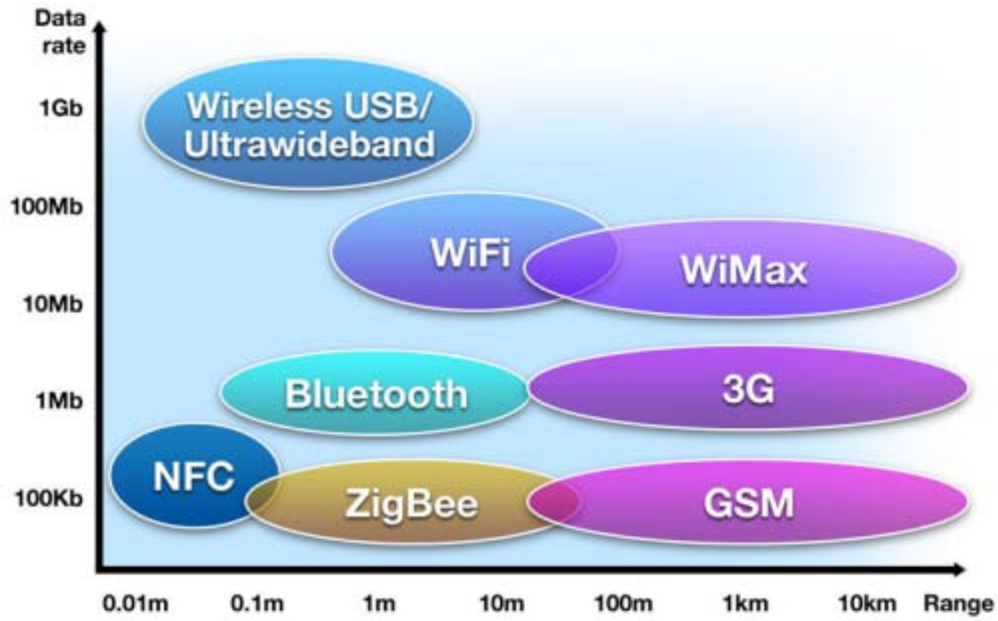
Table 6: Differences Between RFID and NFC

	RFID	**NFC**
Range	Long – measured in meters to kilometers	Short – up to 10 cm
Secure	No	Yes
One-Way Communication	Yes	Yes
Two-Way Communication	No	Yes
Read-Write Mode	No	Yes
Card Emulation Mode	No	Yes
Peer-to-Peer (P2P) Mode	No	Yes

Source: Semico Research Corp.

The following chart illustrates how NFC is positioned in the wireless chip space compared to other technologies like Bluetooth, Wi-Fi, and 3G. NFC's range is very limited, as well as its data rate. However, NFC is not meant to send large volumes of data; rather, it facilitates the connection between two devices so that data can be transferred via another technology.

Figure 26: Comparison of Various Wireless Technologies



Source: nfc-forum.org

RFID Market

UHF and NFC/HF RFID Reader ICs and booster chips are part of the short-range wireless communications segment of the analog market. This market includes many other wireless devices like Bluetooth, WLAN, UWB, and ZigBee. It also includes chips for cordless phones and other wireless equipment.

Figure 27: Revenue, Units and ASP for the Short-Range Wireless Communications Market

Source: SIA/WSTS and Semico Research

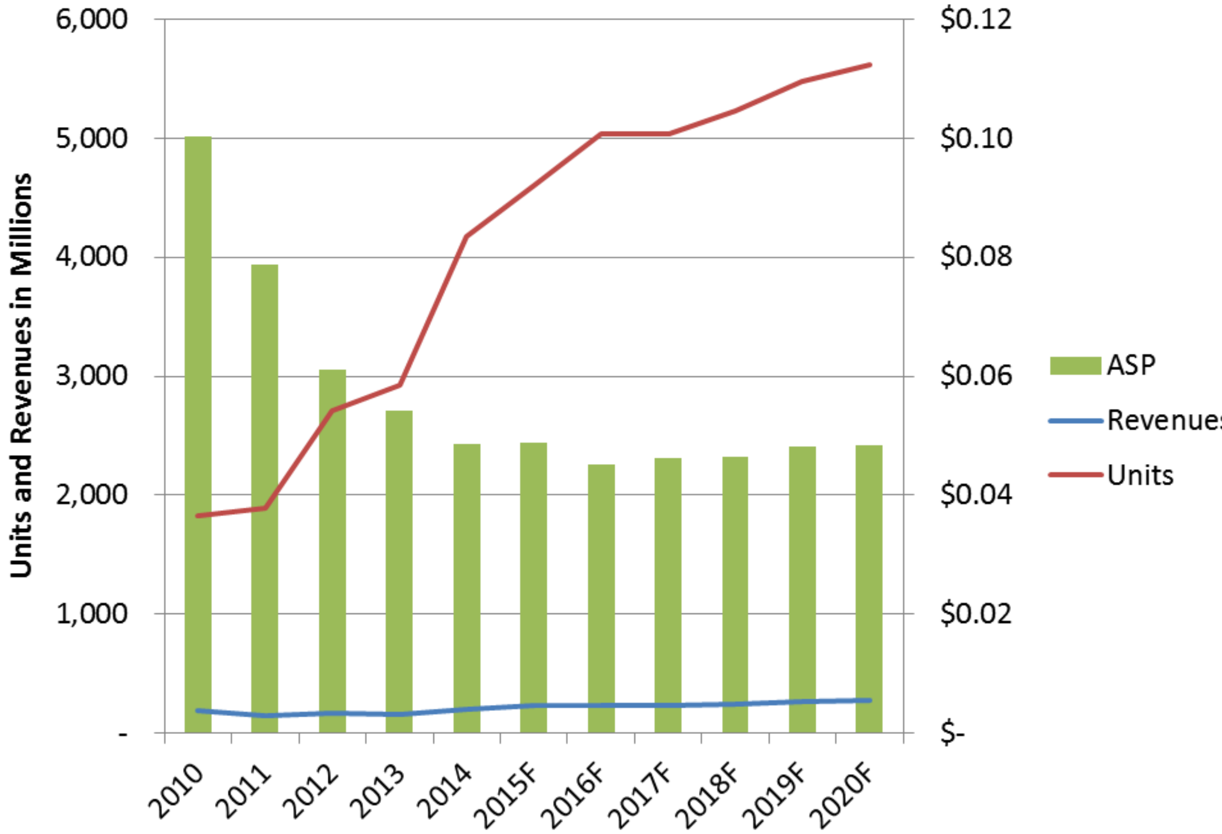
Table 7: Revenue, Units and ASP for the Short-Range Wireless Communications Market (Millions of Dollars & Units)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Revenue (M$)	$437	$643	$496	$737	$1,745	$1,262	$1,157	$1,168	$1,217	$1,306	$1,344
% chg		47%	-23%	49%	137%	-28%	-8%	1%	4%	7%	3%
M Units	482	771	517	776	1838	1336	1149	1048	1089	1204	1312
% chg		60%	-33%	50%	137%	-27%	-14%	-9%	4%	11%	9%
ASP	$0.91	$0.83	$0.96	$0.95	$0.95	$0.94	$1.01	$1.11	$1.12	$1.08	$1.02
% chg		-8%	15%	-1%	0%	-1%	7%	11%	0%	-3%	-6%

Source: SIA/WSTS and Semico Research

UHF and NFC/HF Interface and Sensor Tags are represented in the following graph and table. These are the very inexpensive portion of the RFID solution, so the ASP and revenues are very low.

Figure 28: Revenue, Units and ASP for the Transponder Market



Source: SIA/WSTS and Semico Research

Table 8: Revenue, Units and ASP for the Transponder Market (Millions of Dollars & Units)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Revenue ($M)	$183	$149	$166	$159	$203	$225	$228	$233	$243	$264	$272
% chg		-18%	11%	-4%	28%	11%	1%	2%	4%	9%	3%
M Units	1825	1893	2710	2925	4171	4611	5043	5036	5233	5479	5614
% chg		4%	43%	8%	43%	11%	9%	0%	4%	5%	2%
ASP	$0.10	$0.08	$0.06	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05
% chg		-21%	-22%	-11%	-11%	1%	-7%	2%	0%	4%	0%

Source: SIA/WSTS and Semico Research

Growth

The Internet of Things has been touted as the next big growth driver in the semiconductor and electronics industries. RFID is an enabling technology for the IoT, as it enables the collection of data from smart devices embedded with sensors.

However, privacy concerns abound with RFID. RFID-blocking wallets, passport cases and other devices are sold to prevent personal data from being stolen. One aspect hampering the growth of NFC is the perception that criminals can steal payment data by "eavesdropping" on an NFC transaction.

General trends

Currently NFC is provided as a two chip solution, the NFC radio chip and an SE or Secure Element Chip. Semiconductor manufacturers produce one or both of the chips. Companies such as Murata produce their own system in package solution but purchase the SE from companies like Infineon.

The NFC radio chip interacts with tags, readers or peers. The radio is connected to a host controller, such as an applications processor in a mobile phone. For secure applications such as payments or access control, the NFC radio must be joined by a Secure Element (SE) chip. The SE is a secure, tamperproof processor, containing executable and storage memory. The SE requires apps that want to access it to know unique keys that are stored on the SE in a tamper proof memory.

Trends in NFC chip development include:

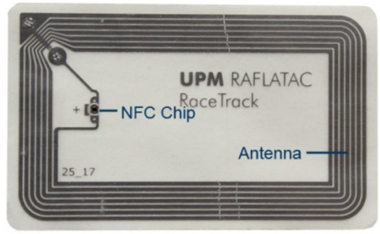
- Standalone Integration: NFC chip and secure element combined in one SiP package (Inside Secure, NXP, Renesas, Samsung, STM)

- Wireless Combo Device: combining NFC with other wireless communication protocols into a combo product (such as Wi-Fi/Bluetooth/NFC/FM) (Broadcom, CSR, Marvell, Qualcomm, ST-Ericsson, TI)

Packaging

An NFC inlay is shown in the figure below. It is composed of an NFC chip (the little black dot) and an antenna coil. An inlay is the basis for an NFC tag; it can be attached to a printed item like a poster, business card, or sticker. NFC tag chips have varying amounts of memory and so can hold varying amounts of text or URL lengths. They also vary in terms of performance or whether they can be made read-only. An NFC reader is used to encode the tags with data and made read-only if needed.

Figure 29: NFC Chip and Antenna in an Inlay



Source: buynfctags.com

Tags are then encoded with the data to be read. For high volume projects, this process is automated and can be performed for $.05/tag from companies like GoToTags. For low volumes, an app can be used to encode and format the tags. Tags can be encoded with the same data (like a URL or Twitter page) or unique data like a unique identification number (UID).

Key RFID Players

IDM

There are several IDMs in the semiconductor segment of the NFC market. Following are several of the larger players in this market.

Alien Technology manufactures UHF RFID chips and Squiggle tags, as well as readers and antennas.

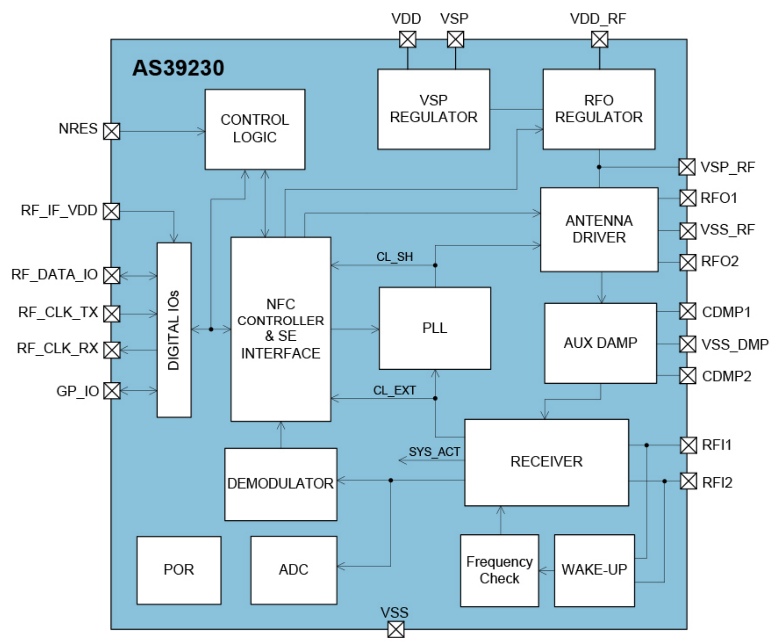
ams offers UHF and HF RFID reader and tag chips. The company has broadened its NFC product range. It now offers BoostedNFC analog front ends for embedded and mobile payment and ticketing, NFC/HF interface and sensor tags, and reader ICs.

The SL900A UHF EPC sensor tag includes an integrated temperature sensor and operates in either battery-assisted passive or in fully passive mode. Targeted to supply chain tracking, tire pressure monitoring systems, and contactless metering, this device won the Best of Sensors Expo 2014 award. The AS39XX series of UHF RFID reader ICs are optimized for use in a wide range of applications, including: product authentication, mobile/hand-held readers, fixed readers, point of sales, toll systems, mobile phones, car access, and embeddable consumer/industrial applications such as beverage dispensing.

On the NFC/HF side, ams also offers a chip with an integrated temperature sensor, the SL13A, which can be used in smart labels in environmental monitoring, supply chain applications, tracking medication, process control and contactless metering. This chip can also operate in either fully passive or semi passive modes, and supports data logging of up to 762 events with a time stamp.

For payment, ticketing, access control and peer-to-peer communications, ams' BoostedNFC analog front end improves NFC performance with Active Load Modulation for mobile and wearable devices that require tiny antennas. For example, the AS3923 booster IC shipped in Apple's iPhone 6, the first Apple device to include NFC. The booster supports NXP's NFC module, also in the iPhone 6. In February 2015, ams announced that it has teamed up with STMicroelectronics to offer a reference design that combines ams' BoostedNFC front end with an NFC controller and SE from ST. The device's metal case can actually be used as the antenna, freeing up space for other features.

Figure 30: ams' BoostedNFC Analog Front End Block Diagram



Source: ams

Broadcom acquired the UK-based NFC chip company Innovision for $47.5 million in June 2010. Introduced in September 2011, Broadcom's BCM2079x NFC controller chips were the industry's first to be manufactured on a 40nm CMOS process. This family of chips was designed for consumer electronics devices. The chips offer a lower polling power consumption mode and enables transactions via field power harvesting even if the phone battery is dead. It integrates transaction-based Application ID (AID) routing for simultaneous support of multiple secure elements within a device. This enables users to have, for example, one mobile wallet with their mobile network operator and another with their bank or their handset or OS manufacturer. Multiple single wire protocol interfaces enables this family to be used in SIM cards or Micro SD cards, or it can be embedded in NFC-enabled phones.

The company has a combo chip, the BCM43341, which is a single-chip dual-band (2.4GHz and 5GHz), 802.11g/n, Bluetooth 4.0, NFC, and FM receiver. The controller in the chip is based on the BCM2079x solution.

Broadcom offers a new automotive NFC chip, the BCM89095, which enables tap-to-connect functionality, keyless entry and automatic recognition of preferred vehicle settings. The company also recently introduced an expanded StrataGX secure MCU family with integrated NFC. The BCM58100 is targeted at mPOS terminals, PCs, and the IoT. Broadcom's BroadSAFE architecture adds security in the form of tamper protection, encryption, and secure storage and processing of card information and biometric user data.

The company cites its NFC and wireless charging products as key growth drivers for 2015.

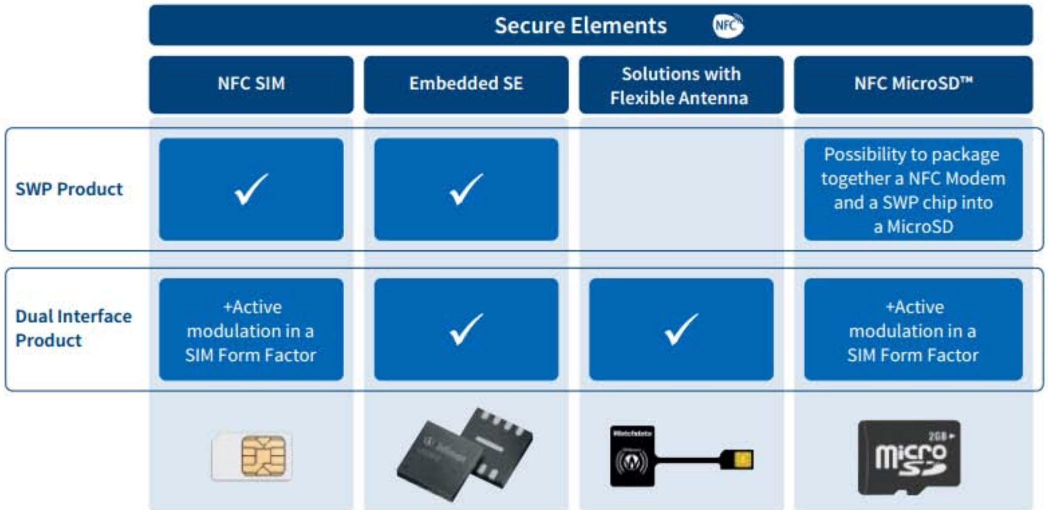
EM Microelectronic offers a wide range of RFID and NFC products: LF animal and access ICs, NFC/HF, smartcard chips, EPC and UHF ICs, RF reader ICs. The company operates a 200mm fab in Switzerland.

Impinj makes UHF reader ICs as well as tags. The Indy reader line includes the RS500 Reader SiP which is an integrated solder-ready solution. Impinj's Monza tag chip family has a range of memory sizes to suit different applications. Coca-Cola uses the Indy and Monza chips to authenticate, monitor, and maintain syrup cartridges that go into its Freestyle machines, which can mix flavors to enable over 100 drink options for customers.

Infineon offers tags, smart card MCU chips and secure elements. Form factors offered include SIM cards, MicroSD cards and embedded chips for mobile phones. The company is a founding member of the OSPT (Open Standard for Public Transportation) Alliance, which has developed the CIPURSE standard. CIPURSE is an open security standard targeted at public transit fare collection systems, using smart cards and other form factors. Infineon invented the open Digital ContactLess Bridge (DCLB) interface, which is the fastest interface between an embedded secure element and an NFC modem.

Infineon's security technology is named Integrity Guard. It includes two cores that cross-check each other to detect errors or attack on the device, in which case it triggers an alarm and shuts down the operation immediately. Data remains encrypted even during processing, unlike other devices that require the data to be decrypted for processing, which means the data is vulnerable at that point.

Figure 31: Infineon's NFC Products



Source: Infineon

INSIDE Secure is a fabless company that owns over 500 key NFC-related patents. In 2010, INSIDE Secure purchased the Secure Microcontroller Solutions division of Atmel. In 2011, INSIDE forged an agreement with Intel where Intel would incorporate INSIDE Secure's technology into future mobile processors and chipsets for PCs and Ultrabooks. In 2014, that agreement was expanded to extend Intel's license to a broad, royalty-free and fully paid-up license. The agreement also transferred to Intel INSIDE's MicroRead-v5 NFC hardware and software modem technology.

INSIDE's VaultIC Security Module is used in luxury goods or industrial products to deter counterfeiting and cloning. The device not only allows manufacturers to track their products through the distribution and retail channels, but also allows consumers to confirm the authenticity of the product with their NFC-enabled smartphone before purchase. The Vault IC is targeted to designer purses, watches, and expensive wines, among other products. The IC can prevent tampering or illegal code execution, and has a range of several centimeters, so it can be deeply embedded in a product.

INSIDE Secure offers its MicroPass line of NFC tags that can be read by any device. It is compliant with the NFC Forum Type 4 tag requirements, and contains 2KB of memory.

A new product from INSIDE is vaultSEcure, a secure element for mobile phones, tablets, PCs, and M2M applications.

Intel’s NFC product is the Wireless NFC 4000 targeted to mobile POS, payment cards, transit, tag reading and writing, and device pairing. It supports tri-modal designs.

Marvell introduced in 2012 its Avastar 88W8897 chip that combines Wi-Fi (802.11ac), NFC, Bluetooth and mobile MIMO. The solution includes a SE, which supports mobile payments in addition to facilitating pairing with other devices. The chip also supports Miracast audio and video streaming technology. Miracast allows users to stream between their ultraportable or tablet and their TV at 5GHz, while surfing the Internet at 2.4GHz. Marvell’s chip is significant as it was the first of its kind to be announced.

Maxim offers its DeepCover NFC and RFID tags and readers for access control, asset tracking, IP protection, medical sensor authentication and calibration, printer cartridge configuration and monitoring, and eCash.

MediaTek and **MStar** merged in February 2014. The company offers MT6605, which can connect to three secure elements at once, ideal for dual-SIM phones with a microSD slot.

NXP is one of the co-developers of NFC technology and the current market leader. In 2004, NXP co-founded the NFC Forum to help develop and promote standards and collaboration in the NFC industry. NXP’s NFC radio controller chips are compliant with the FeliCa (NFC-F) standard used in the reader infrastructure in Japan.

NXP developed MIFARE4Mobile, a technology used to manage MIFARE-based services including transit ticketing, access management, and loyalty programs in NFC-enabled devices. NXP’s solution includes the NFC radio, the OS software stack, and the SmartMX-based secure element. NXP also offers NFC tags (NTAG2 family), including MIFARE smart cards.

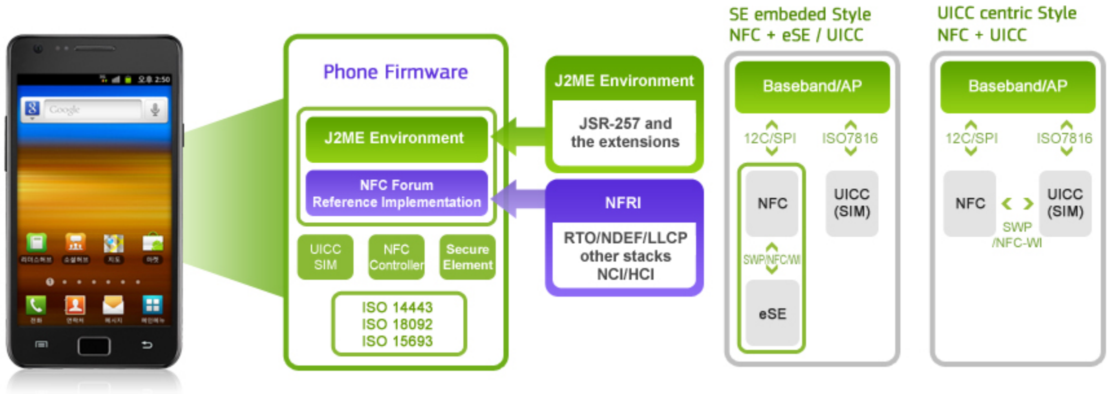
The company’s NFC controllers, frontends, tags, and reader ICs are used for access control, POS terminals, PCs, eGovernment, public transport, Pay TV, eMetering, gaming, industrial, and white goods applications. In 4Q 2014, NXP jumped into the automotive NFC market with both feet. Part of the announcement was related to a new flagship, automotive-qualified, high-end NFC controller, the NCF3340.

NXP also offers a full line of RFID and NFC chips: LF (HiTAG) transponder and reader ICs; HF smart labels (ICODE); UHF transponders (UCODE); HF/UHF combo tags; and NFC tag (NTAG), controller, and frontend ICs.

Qualcomm wants to enable secure transactions in mobile, automotive, wearables and IoT devices. On May 5, 2015, NXP and Qualcomm announced that Qualcomm will include NXP’s NFC and eSE (as the NQ220 module, a stacked system in package) in the Snapdragon processor platform. The NQ220 will help reduce time to market and design costs for products including mobile wallets, transit and access control.

Samsung’s NFC portfolio includes an NFC controller and an embedded SE.

Figure 32: Samsung NFC Architecture



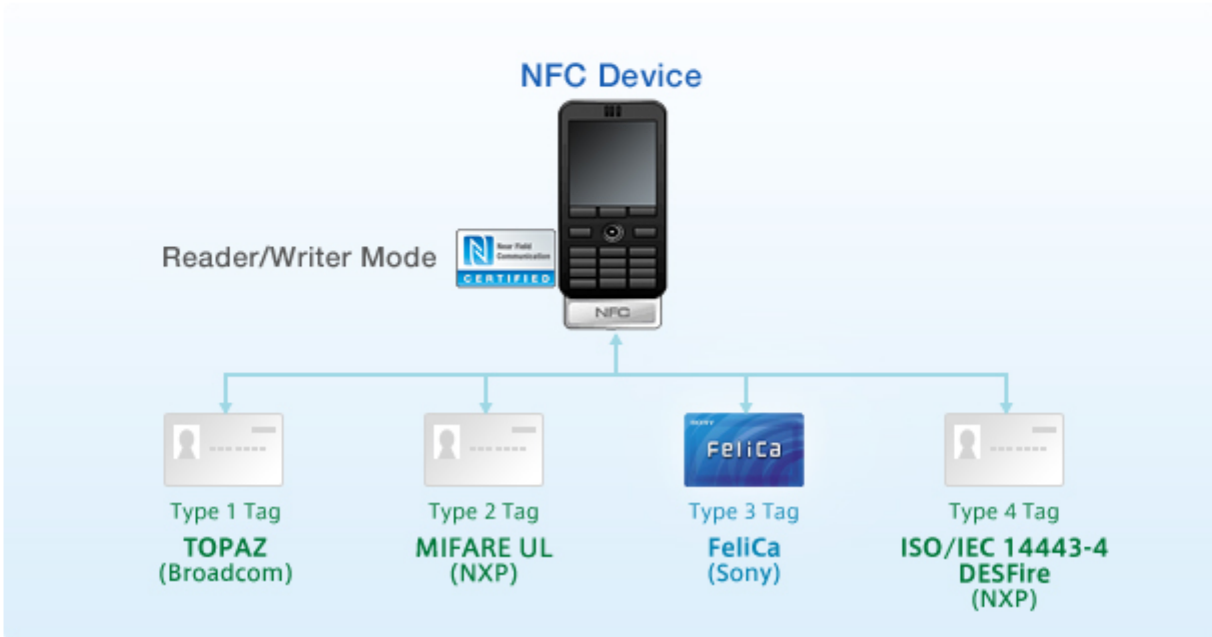
Source: Samsung

Samsung offers digital cameras, home audio speakers, printers, wireless adapters, tablets and phones with NFC in them.

Sony co-developed NFC with NXP in 2002. FeliCa, or NFC-F, is Sony's "brand" of NFC and it is included in the NFC spec developed by the NFC Forum, so all NFC devices support NFC-F communication. Sony supports the FeliCa smart card standard in use in Japan and Hong Kong in the public transportation systems. It is also used in ID cards on campuses, tickets at sports arenas, boarding systems for airlines, and for residential access control. FeliCa is powered by the reader it comes in contact with, so it requires no batteries. Mobile FeliCa is a modification of the FeliCa standard for use in mobile phones.

Sony's NFC product line includes several chips, contactless IC tokens, modules, tags, and readers. The company has rolled out NFC to its some of its cameras, smartphones, home audio systems, headphones, and televisions. This enables consumers to quickly share content between the devices.

Figure 33: NFC Forum Supported Tags



Source: Sony

STMicroelectronics offers a range of NFC products, including controllers, transceivers, eSE, and a range of secure 32-bit flash-based microcontrollers. ST's products are targeted at smartphones, PCs, contactless readers, points of sale, USB tokens, and more.

TI offers NFC transponders, RFID chips, and combo NFC/RFID transceivers. TI's NFC transponders are used to simplify Bluetooth and Wi-Fi pairing and connection processes in products like printers, speakers, headsets, remote controls, and wireless keyboards, mice, switches and sensors.

Foundry

ams offers 200mm foundry service with mixed analog/digital, high-voltage and RF processes.

CEITEC in Brazil operates a 150mm fab that produces RFID chips to track cattle, one of the country's largest industries.

GLOBALFOUNDRIES offers a low-cost embedded Flash platform for mixed-signal and NFC/RF products. In March 2015, the company announced a 40nm embedded non-volatile (eNVM) technology developed with NXP targeting NFC, identification, security, healthcare, and MCUs.

SMIC has a range of eNVM technologies, developed with eMemory, to support smart card and MCU products. The processes include OTP and

MTP eNVM ranging from 0.35um to 40nm and support RFID, among other products.

TSMC cites NFC as one of its mobile computing-related products that altogether made up almost half of the company's wafer revenue in 2014.

UMC offers eE2PROM and eFlash processes for smart card and SIM card chips. The company has an eNVM process, co-developed with eMemory, suitable for NFC, power and battery management, touch panel and sensor controllers, and more.

Sensor Market Overview

Sensors are devices that detect some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing. Sensors can be manufactured using semiconductor materials and manufacturing processes or non-semiconductor materials. This report will not cover the non-semiconductor sensors.

The sensor market encompasses both MEMS and non-MEMS sensors. MEMS are a Micro Electrical Mechanical System. These are very small mechanical devices fabricated with semiconductor technology and are on the scale of about 20 micrometers to a millimeter. MEMS are considered electronic components. MEMS technology is used to make sensors and other components known as actuators. The actuators include micro-machine actuators, micro mirrors, micro speakers, RF modules, and oscillators. Sensors can be either MEMS or implemented with conventional silicon technology. The MEMS devices are much smaller, lower cost and lower power consumption than the conventional sensors.

MEMS and sensors are used across a broad range of end use markets. The automotive market was the largest application for MEMS until a few years ago. The cell phone market has surpassed automotive applications due to the inertial MEMS sensors (accelerometers, gyroscopes, and magnetometers) used for motion sensing, navigation and other functions. The use of MEMS devices continue to grow as additional features are adopted or converted to MEMS. For example, cell phone microphones were quickly replaced by MEMS microphones as the quality of MEMS microphones increase and the cost decreases.

The Industrial and Automotive markets are the largest markets for non-MEMS sensors. These require more rugged design and manufacturing thus carry a higher Average Selling Price (ASP). Most of the non-MEMS sensors are semiconductor based, although, there are sensors which do not use semiconductor technology. There are semiconductor based and non-semiconductor based versions of such sensors as pressure, accelerometer, chemical/gas, strain gauge, bolometer and air flow (or mass flow). In this section, Semico is only including semiconductor based sensors.

The next two tables present the total sensor market by sensor type including MEMS sensors. Within these tables the MEMS based and non-MEMS based sensors are separated. The following figures present the unit shipments by type for each. This illustrates the wide variety of sensors in use and the high growth rates for almost all types.

In the MEMS sensor market, accelerometers are widely used in many applications for sensing vibration and motion. Microphones are growing at a high rate as cell phones grow and designs incorporate multiple microphones per handset. Microphones are also being adopted into many applications driven by the Internet of Things (IoT). The IoT market will also drive growth for MEMS sensors for environmental sensing such as temperature, humidity, chemical/gas and biological factors.

Table 9: Total Sensor Market by Sensor Type (Millions of Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
MEMS	**9,166.3**	**12,438.5**	**17,018.5**	**22,365.5**	**27,905.5**	**35,223.0**	**43,087.1**	**52,469.3**	**64,927.0**	**25.0%**
Temperature	50.4	89.8	121.5	206.9	329.0	581.5	1,065.2	1,747.8	2,798.3	68.7%
Humidity	0.0	21.5	41.8	101.4	164.3	292.8	544.4	930.2	1,584.9	83.3%
Pressure	1,058.7	1,394.2	1,884.6	2,590.7	3,363.7	4,423.0	5,374.8	6,261.5	7,843.3	26.8%
Accelerometer	3,654.9	4,389.7	5,422.4	6,502.1	7,497.6	8,805.7	10,124.7	11,687.4	13,614.1	16.6%
Magnetometer	304.2	660.9	1,088.3	1,632.2	2,086.0	2,655.7	3,328.1	4,040.8	4,934.3	28.7%
Gyroscope	702.2	1,049.4	1,484.3	2,081.7	2,832.8	3,547.3	4,463.2	5,374.9	6,422.0	27.7%
Microphone	2,117.8	2,874.1	3,954.6	4,897.4	5,861.1	7,237.5	8,558.0	10,200.2	12,005.9	20.3%
Position	0.0	0.0	16.9	40.3	109.9	167.6	262.6	364.0	512.7	76.6%
Proximity	0.0	0.0	0.0	0.0	47.9	107.7	219.5	411.1	687.1	NA
IR	5.3	10.8	31.8	59.1	96.1	147.7	212.2	324.6	516.0	59.1%
Chemical/gas	3.5	21.9	40.3	86.2	132.2	207.4	330.2	544.0	889.4	67.5%
Biological	0.0	0.1	1.8	24.8	59.5	120.0	192.5	295.7	481.9	153.8%
Air flow	0.0	19.5	33.8	63.6	83.8	117.1	157.6	245.7	357.7	48.2%
Ultrasonic	0.0	0.0	7.4	66.0	172.7	304.4	553.1	847.6	1,222.8	134.1%
Micro mirror	12.0	22.5	36.3	52.4	67.7	92.7	105.0	133.0	167.5	29.0%
Micro speaker	6.1	11.0	21.7	43.1	60.8	92.3	112.6	138.6	165.5	40.3%
Actuator	1,128.1	1,689.2	2,548.0	3,381.3	4,053.5	4,989.6	5,575.9	6,252.3	7,006.5	18.4%
RF	15.9	28.1	57.9	144.5	291.0	470.2	692.6	1,045.5	1,499.5	72.0%
Oscillator	107.3	155.8	225.2	392.0	595.8	863.0	1,215.0	1,624.4	2,217.5	46.4%
Non-MEMS Sensors	**6,911.1**	**8,473.3**	**9,612.8**	**11,557.5**	**13,578.8**	**16,407.4**	**20,134.7**	**24,641.8**	**30,354.8**	**21.1%**
Ambient light	876.3	1,294.3	1,597.9	2,001.4	2,565.5	3,265.5	4,261.7	5,431.7	7,010.4	27.9%
ECG	0.6	1.2	2.6	4.5	8.4	32.9	66.8	115.1	178.6	102.8%
EEG	0.3	0.5	1.3	2.8	5.0	10.0	21.6	36.0	56.4	87.8%
EMG	0.0	0.2	1.2	3.1	7.0	16.6	43.1	82.5	153.8	124.4%
Fingerprint	54.5	96.7	173.8	326.5	496.0	839.8	1,327.6	1,905.9	2,603.0	57.0%
Humidity	176.1	211.3	229.9	297.4	372.4	481.0	622.5	849.1	1,141.1	30.6%
Proximity	1,372.3	1,718.9	1,938.3	2,355.6	2,895.6	3,551.5	4,410.3	5,334.8	6,522.7	22.4%
Touch	1,836.7	2,059.4	2,281.2	2,537.5	2,789.9	3,082.1	3,540.4	4,035.2	4,654.0	12.6%
Ultrasonic	0.0	0.0	2.3	9.9	33.9	68.8	114.2	165.2	249.2	118.5%
UV	0.0	0.2	1.0	11.8	34.0	78.7	142.3	222.2	323.1	163.6%
Position	1,733.3	2,041.3	2,243.0	2,536.0	2,672.7	2,943.4	3,277.5	3,706.8	4,275.7	11.4%
Temperature	580.2	699.8	716.5	925.5	1,054.8	1,288.4	1,447.1	1,699.3	1,910.2	17.8%
Pressure	81.6	120.7	138.7	192.1	213.2	226.8	239.1	272.1	289.9	13.1%
Strain gauge, tension	117.9	130.7	157.1	174.5	201.2	233.9	280.5	346.7	453.5	19.3%
Bolometer	15.7	17.6	30.4	58.5	79.6	100.4	107.7	131.6	156.8	31.5%
Air flow	65.6	80.4	97.7	120.4	149.6	187.5	232.3	307.6	376.4	25.2%
Total Sensors	**16,077.5**	**20,911.8**	**26,631.4**	**33,923.0**	**41,484.3**	**51,630.4**	**63,221.8**	**77,111.1**	**95,281.7**	**23.7%**

Source: Semico Research Corp.

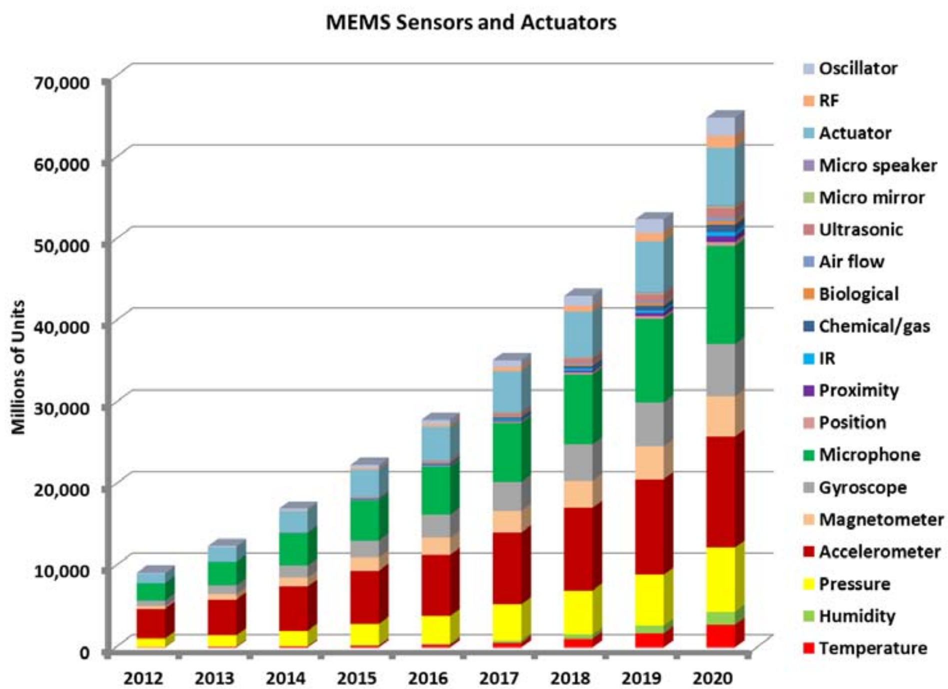
Table 10: Total Sensor Market by Sensor Type (Millions of Dollars)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
MEMS sensors	**$11,265.9**	**$12,623.5**	**$14,187.4**	**$16,143.1**	**$17,275.0**	**$19,073.0**	**$20,627.6**	**$23,125.4**	**$26,448.8**	**10.9%**
Temperature	$54.3	$77.3	$80.8	$86.4	$102.1	$149.8	$242.2	$340.6	$425.1	31.9%
Humidity	$0.0	$20.3	$33.0	$49.7	$59.9	$83.4	$125.2	$171.3	$217.1	36.9%
Pressure	$1,925.9	$2,093.8	$2,166.1	$2,557.7	$2,560.5	$2,904.8	$2,860.0	$3,064.9	$3,587.2	8.8%
Accelerometer	$4,982.1	$4,847.0	$5,015.1	$5,160.5	$4,801.1	$4,880.3	$4,892.7	$5,016.7	$5,444.7	1.4%
Magnetometer	$312.5	$506.6	$700.2	$847.5	$888.0	$1,022.2	$1,127.1	$1,292.7	$1,392.3	12.1%
Gyroscope	$1,472.5	$1,921.2	$2,373.1	$3,013.8	$3,693.2	$4,189.6	$4,866.0	$5,670.9	$6,375.0	17.9%
Microphone	$680.5	$720.9	$753.3	$785.6	$821.8	$725.4	$727.4	$714.0	$756.4	0.1%
Position	$0.0	$0.0	$10.9	$21.4	$42.0	$51.9	$68.9	$81.9	$105.8	46.0%
Proximity	$0.0	$0.0	$0.0	$0.0	$17.2	$31.5	$57.6	$92.5	$141.7	NA
IR	$3.5	$5.6	$18.6	$30.6	$41.8	$59.2	$71.7	$101.0	$133.7	39.0%
Chemical/gas	$17.0	$105.8	$182.2	$335.2	$442.2	$596.3	$799.4	$1,182.2	$1,662.3	44.6%
Biological	$0.0	$0.2	$2.6	$48.3	$103.1	$188.9	$265.2	$372.4	$523.8	142.8%
Air flow	$0.0	$108.0	$174.4	$307.0	$380.8	$503.7	$625.4	$906.0	$1,251.9	38.9%
Ultrasonic	$0.0	$0.0	$4.2	$31.7	$72.5	$91.3	$141.1	$178.0	$231.1	94.8%
Micro mirror	$888.0	$1,122.9	$1,254.2	$1,219.6	$1,316.3	$1,510.0	$1,513.6	$1,692.9	$1,893.2	7.1%
Micro speaker	$10.7	$16.8	$32.2	$61.5	$84.0	$117.2	$132.9	$145.6	$165.5	31.4%
Actuator	$842.3	$977.0	$1,255.0	$1,373.6	$1,532.1	$1,545.6	$1,577.1	$1,463.8	$1,366.0	1.4%
RF	$18.3	$28.1	$43.4	$90.3	$151.3	$202.2	$256.3	$334.7	$420.0	46.0%
Oscillator	$58.5	$72.1	$88.3	$122.8	$165.1	$219.8	$277.6	$303.4	$356.1	26.2%
Non-MEMS Sensors	**$9,629.0**	**$10,446.3**	**$11,508.1**	**$13,217.5**	**$14,788.8**	**$16,670.0**	**$17,638.6**	**$26,498.2**	**$36,754.4**	**21.4%**
Ambient light	$636.2	$735.7	$777.8	$792.6	$825.4	$942.9	$1,054.8	$1,232.3	$1,359.1	9.7%
ECG	$7.4	$13.9	$28.2	$42.8	$69.0	$230.3	$367.2	$633.3	$982.5	80.7%
EEG	$2.9	$6.0	$14.1	$26.2	$41.1	$69.9	$118.6	$198.0	$310.1	67.4%
EMG	$0.0	$2.5	$13.2	$29.8	$57.5	$116.5	$237.2	$453.8	$845.6	99.9%
Fingerprint	$449.3	$676.8	$1,043.0	$1,550.9	$1,984.0	$2,855.4	$3,451.7	$4,955.3	$6,767.7	36.6%
Humidity	$271.0	$302.6	$304.6	$348.3	$340.5	$375.5	$449.1	$488.1	$491.2	8.3%
Proximity	$1,002.6	$983.2	$950.2	$946.6	$952.4	$1,055.2	$1,127.5	$1,257.7	$1,327.8	5.7%
Touch	$1,949.9	$1,772.1	$1,735.2	$1,686.9	$1,525.6	$1,288.9	$1,042.7	$5,467.1	$11,349.5	36.8%
Ultrasonic	$0.0	$0.0	$2.0	$7.2	$19.9	$27.9	$37.9	$45.1	$61.2	77.5%
UV	$0.0	$0.2	$0.8	$8.9	$21.4	$39.4	$56.9	$88.9	$129.3	132.5%
Position	$730.8	$851.7	$885.2	$998.1	$1,014.9	$1,103.3	$1,211.0	$1,391.4	$1,623.8	10.6%
Temperature	$942.7	$986.3	$980.6	$1,041.7	$1,031.1	$1,106.8	$1,161.2	$1,219.7	$1,140.7	2.6%
Pressure	$399.4	$523.8	$533.6	$649.8	$752.9	$844.2	$775.2	$841.8	$833.7	7.7%
Strain gauge, tension	$392.2	$399.5	$398.7	$436.2	$492.5	$536.7	$571.3	$699.6	$894.4	14.4%
Bolometer	$501.7	$532.2	$850.5	$1,272.3	$1,417.2	$1,443.3	$1,238.9	$1,380.7	$1,480.0	9.7%
Air flow	$2,342.8	$2,659.8	$2,990.3	$3,379.2	$4,243.4	$4,633.9	$4,737.4	$6,145.3	$7,157.9	15.7%
Total Sensors	**$20,894.9**	**$23,069.8**	**$25,695.6**	**$29,360.6**	**$32,063.8**	**$35,743.1**	**$38,266.2**	**$49,623.5**	**$63,203.2**	**16.2%**

Source: Semico Research Corp.

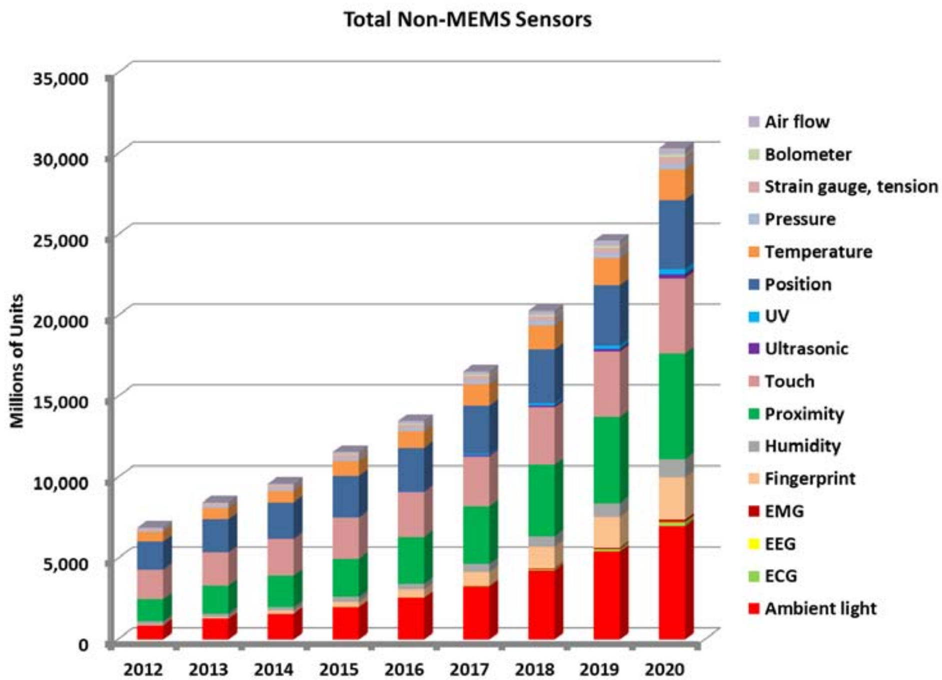
Other large volume sensors by 2020 are ambient light, proximity, and touch sensors. These are used for a variety of functions in wearables, cell phones, home automation and other IoT applications. Position sensors are implemented with a variety of technologies such as magnetic, Hall effect, capacitive, ultrasonic, inductive, piezo-electric, optical proximity, resistive and more. These are found predominantly in automotive and industrial applications.

Figure 34: Total MEMS Sensor Market by Sensor Type (Millions of Units)



Source: Semico Research Corp.

Figure 35: Total Non-MEMS Sensor Market by Sensor Type (Millions of Units)



Source: Semico Research Corp.

ams Sensors

ams offers sensors in specific areas. These are:

Chemical and gas sensors

Light sensors

Position sensors

On July 27, 2015 it was announced that ams had acquired the sensor business of NXP. The product line that ams acquired did not fit in with the future plans of NXP and their acquisition of Freescale. With the acquisition of NXP's sensor business, ams intends to expand its environmental sensor portfolio with advanced monolithic and integrated CMOS sensors that measure several environmental variables such as relative humidity, pressure and temperature in one sensor device. The target markets for the ams environmental sensor portfolio are smart phones, wearables, and other mobile devices as well as smart buildings, industrial, medical and automotive applications. Temperature and relative humidity sensor solutions will be in mass production early in 2016.

The barometric pressure sensor acquired from NXP has not yet been released to market. In 4Q 2015 ams will launch this pressure sensor. The pressure sensor measures altitude and is used for indoor navigation and location. The goal is to eventually combine temperature, humidity and pressure with ams' current chemical and gas sensing technology.

Semico examines in more detail the markets for the current ams sensor portfolio.

Chemical Gas Sensors

ams has a line of chemical gas sensors for appliance, automotive, building technology, consumer and industrial applications. The air quality sensors and the gas sensors are based on a MEMS technology. These are used to detect a broad range of volatile organic compounds (VOCs). The devices are discrete semiconductor components.

The company also offers a line of hydrogen leak sensors. These are large modules for automotive applications. They are used for hydrogen gas measurement in fuel cell systems and other in-process applications. This product does not appear to be based on a MEMS technology.

The total market for chemical and gas sensors is projected to exceed $4.0 billion on shipments of 1.1 billion units in 2015. Semico forecasts that this will reach $7.2 billion and over 2.6 billion units by 2020.

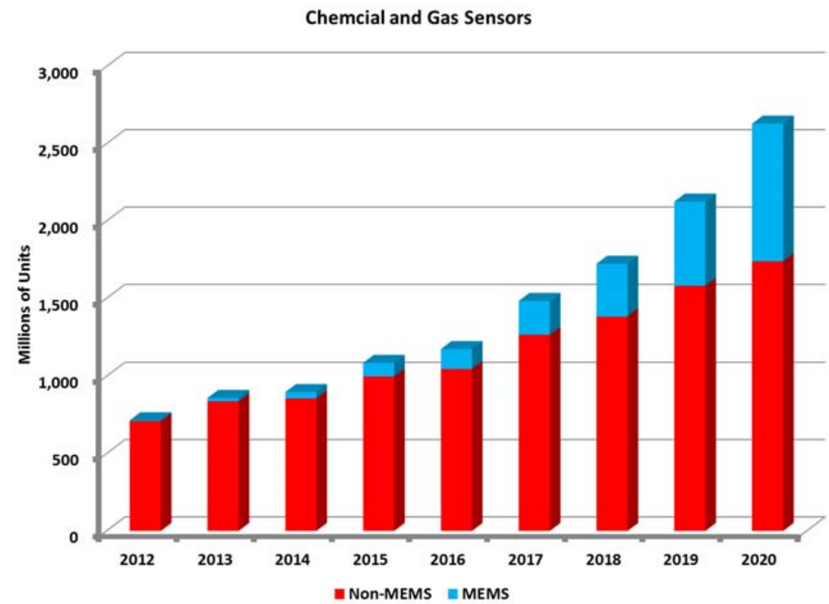
The following table and figure show that the market for chemical and gas sensors is dominated by the established conventional sensor technology. However, the MEMS solutions are growing at a faster rate.

Table 11: Chemical and Gas Sensor Market (Millions of Dollars & Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR '14 to '20
MEMS	$17.0	$105.8	$182.2	$339.8	$428.1	$621.2	$827.9	$1,182.2	$1,662.3	**44.6%**
M units	3.5	21.9	40.3	87.3	128.8	213.7	337.9	544.0	889.4	**67.5%**
Non-MEMS	$3,277.1	$3,331.4	$3,350.6	$3,712.0	$3,768.4	$4,422.8	$4,740.1	$5,220.7	$5,569.6	**8.8%**
M units	712.1	838.2	858.0	1,000.0	1,047.9	1,269.5	1,386.0	1,582.0	1,740.5	**12.5%**
Total Revenue ($M)	**$3,294.1**	**$3,437.2**	**$3,532.8**	**$4,051.9**	**$4,196.5**	**$5,044.0**	**$5,568.0**	**$6,402.9**	**$7,232.0**	**12.7%**
M units	**715.6**	**860.1**	**898.3**	**1,087.3**	**1,176.7**	**1,483.2**	**1,723.9**	**2,126.1**	**2,629.9**	**19.6%**

Source: Semico Research Corp.

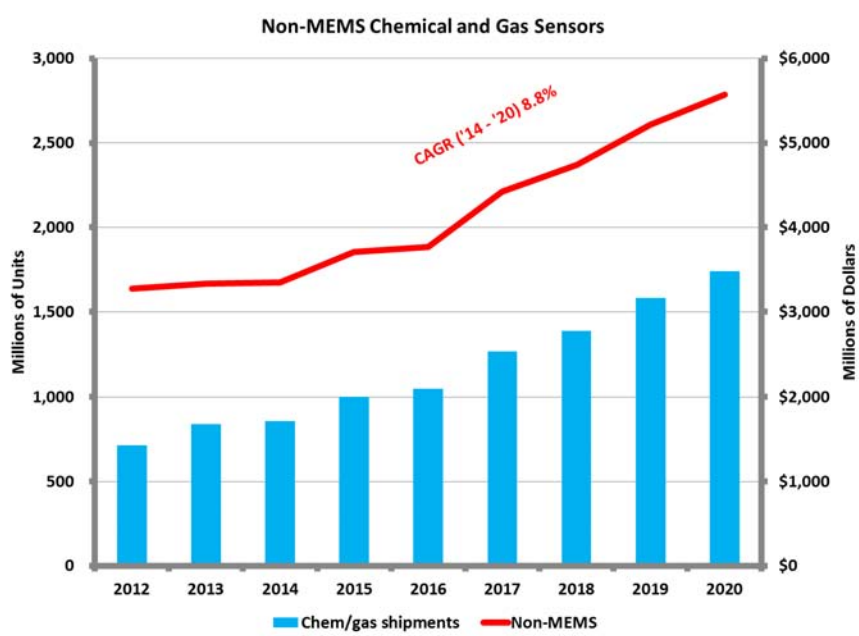
Figure 36: Chemical and Gas Sensor Market, MEMS versus Non-MEMS (Millions of Units)



Source: Semico Research Corp.

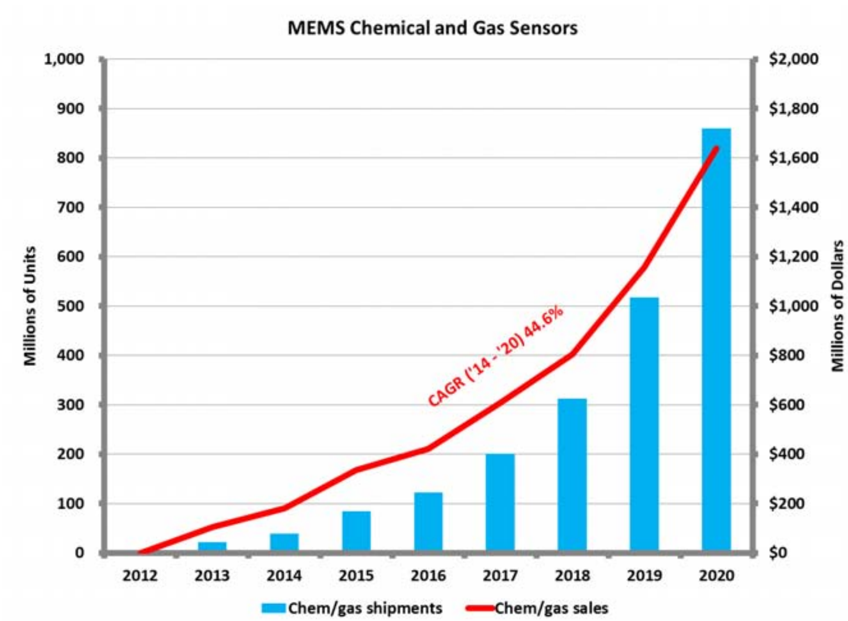
The next three figures present the sales and shipment data for chemical and gas sensors.

Figure 37: Non-MEMS Chemical and Gas Sensors, Sales and Shipments (Millions of Units & Dollars)



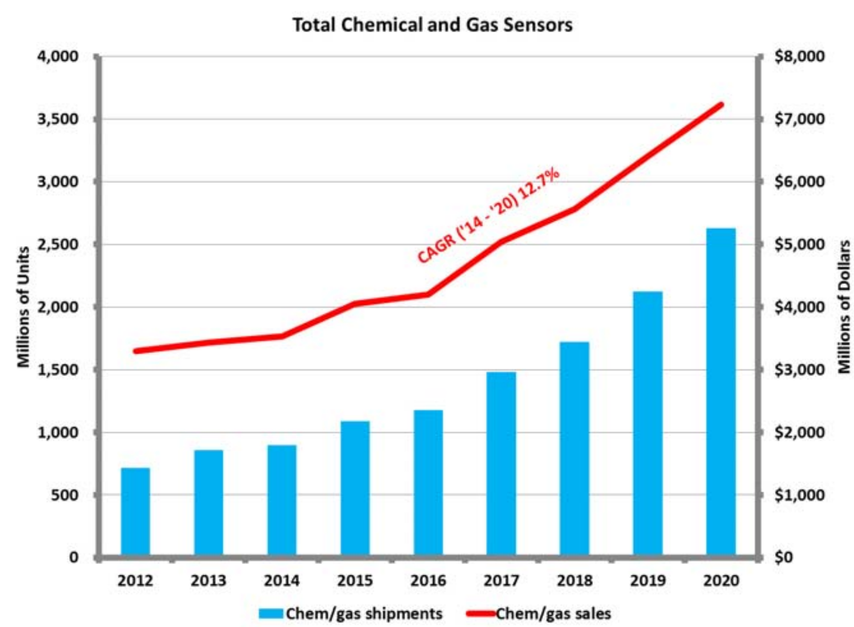
Source: Semico Research Corp.

Figure 38: MEMS Chemical and Gas Sensors, Sales and Shipments (Millions of Units & Dollars)



Source: Semico Research Corp.

Figure 39: Total Chemical and Gas Sensors, Sales and Shipments (Millions of Units & Dollars)



Source: Semico Research Corp.

Chemical and Gas Sensors by End Use Markets

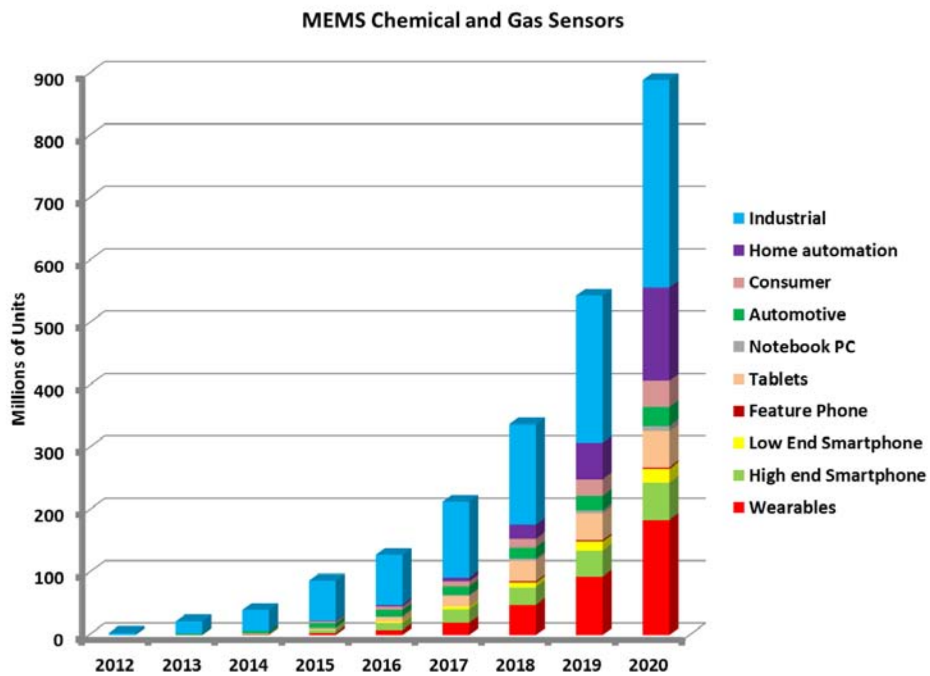
The next set of tables and figures present the chemical and gas sensor market by end use applications. The MEMS market is smaller but has a higher growth rate since these devices are most suitable for a wide variety of applications, in particular portable and consumer electronics. These sensors are expected to be adopted for home automation and industrial applications related to the IoT. The non-MEMS sensors ship predominantly into automotive and industrial applications. Building and factory automation are included in the industrial category.

Table 12: MEMS Based Chemical & Gas Sensors by Application (Millions of Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
Wearables	0.0	0.2	0.8	3.1	8.0	20.0	48.5	93.8	184.5	**147.5%**
High end Smartphone	0.0	0.0	0.0	4.7	11.3	21.2	27.9	41.8	59.9	**na**
Low End Smartphone	0.0	0.0	0.0	0.0	2.7	5.0	7.9	14.3	22.0	**na**
Feature Phone	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.4	2.3	**na**
Tablets	0.0	0.0	1.4	3.4	7.6	16.6	33.3	42.8	58.5	**86.3%**
Notebook PC	0.0	0.0	0.0	0.0	0.0	1.2	2.5	4.7	8.1	**na**
Automotive	0.0	2.1	4.3	7.7	10.9	13.9	18.2	23.4	30.1	**38.2%**
Consumer	0.0	0.0	0.0	2.9	5.4	8.2	14.0	26.5	42.0	**na**
Home automation	0.0	0.0	0.0	0.8	2.5	6.0	22.7	58.3	149.2	**na**
Industrial	3.5	19.5	33.8	64.6	80.4	121.7	160.7	236.0	332.8	**46.4%**
Total	**3.5**	**21.9**	**40.3**	**87.3**	**128.8**	**213.7**	**337.9**	**544.0**	**889.4**	**67.5%**

Source: Semico Research Corp.

Figure 40: MEMS Based Chemical & Gas Sensors by Application (Millions of Units)



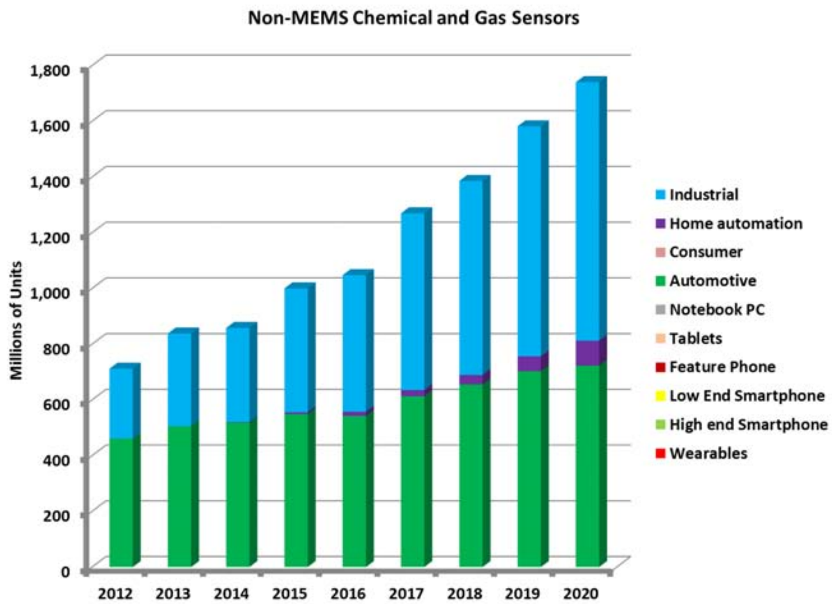
Source: Semico Research Corp.

Table 13: Non-MEMS Based Chemical & Gas Sensors by Application (Millions of Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
Wearables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
High end Smartphone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
Low End Smartphone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
Feature Phone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
Tablets	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
Notebook PC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
Automotive	461.3	505.9	518.4	549.0	542.5	613.3	655.5	702.6	723.0	**5.7%**
Consumer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**na**
Home automation	0.0	0.0	2.1	6.5	15.0	22.2	34.0	53.4	89.5	**86.7%**
Industrial	250.9	332.3	337.5	444.5	490.4	634.0	696.5	826.0	928.0	**18.4%**
	712.1	**838.2**	**858.0**	**1,000.0**	**1,047.9**	**1,269.5**	**1,386.0**	**1,582.0**	**1,740.5**	**12.5%**

Source: Semico Research Corp.

Figure 41: Non-MEMS Based Chemical & Gas Sensors by Application (Millions of Units)

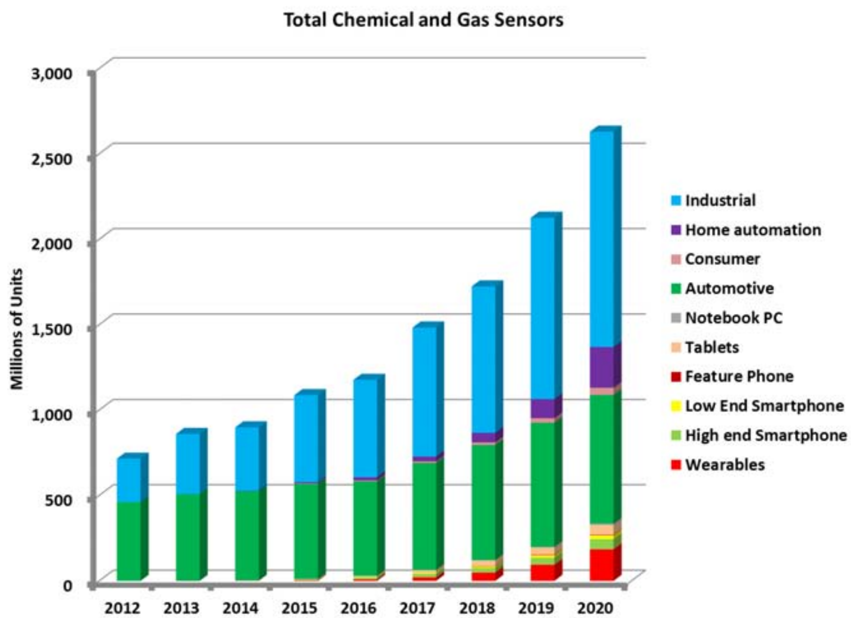


Source: Semico Research Corp.

The next figure presents the total market by application. It is the summation of the previous two tables.

The industrial and automotive markets dominate the chemical and gas sensor market. By 2020 Semico expects to see greater adoption in home automation and wearables as environmental monitoring becomes a growing feature for IoT applications.

Figure 42: Total Chemical & Gas Sensors by Application (Millions of Units)



Source: Semico Research Corp.

Key Players in Chemical and Gas Sensors

The market for MEMS based chemical and gas sensors is small but growing. There are a small number of vendors shipping products in addition to ams. These companies include:

- BST (Germany)
- Cambridge CMOS Sensors
- Denso
- miniFAB
- SIMSTsensor
- Synkera
- UniMEMS

There are more players in the market for conventional non-MEMS based chemical and gas sensors. These companies are focused primarily on automotive and industrial applications. Among these companies are:

- CIC microGUN
- Delphi

- FIS
- Honeywell
- Linear Dimensions
- Micronas GmBH
- Parallax
- Samyoung S&C
- Sensata
- Shenzhen Contin Medical Device Co., Ltd.

Light Sensors

There are a wide variety of light sensors. These are also known as photosensors or photodetectors. These sensors detect ambient light and/or IR. The product portfolio for ams includes ambient light sensors, ambient light sensor and proximity detection, and color sensor. Light sensors are not MEMS based technology. The company cites applications such as:

- Display backlight control
- Keyboard illumination control
- Solid-state and general lighting control
- Printer paper detection

In addition, ams has noted that some mobile vendors and wearable device makers have used its ambient light sensors for detecting heart rate. The light sensor is combined with an IR emitter.

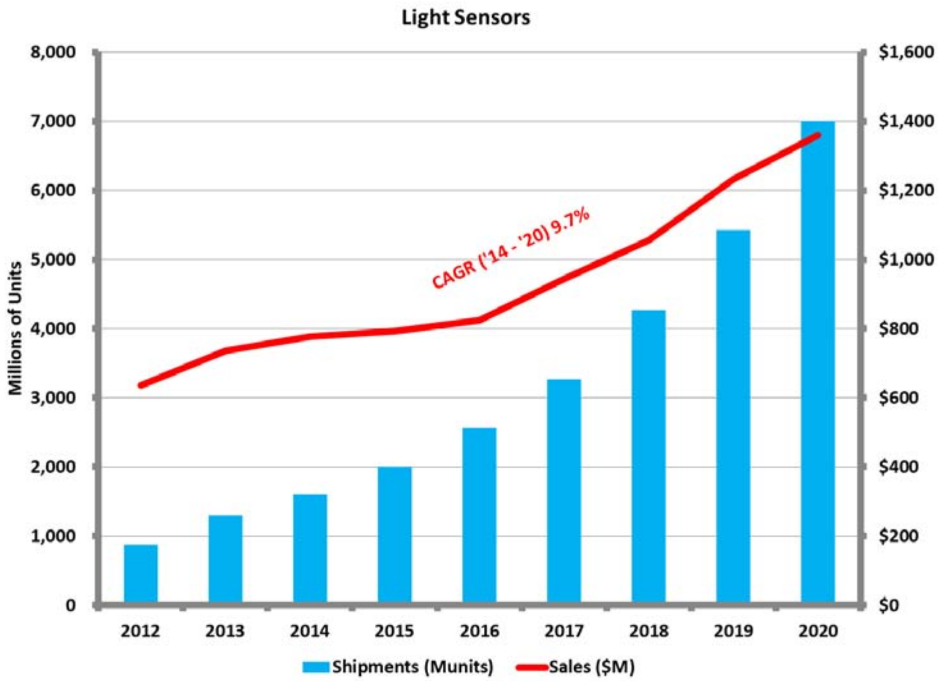
The following table and figure present the light sensor market.

Table 14: Light Sensors, Sales and Shipments (Millions of Dollars & Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
Sales ($M)	$636.2	$735.7	$777.8	$792.7	$825.2	$943.7	$1,056.7	$1,232.3	$1,359.1	**9.7%**
Shipments (M units)	876.3	1,294.3	1,597.9	2,001.7	2,564.6	3,268.2	4,269.4	5,431.7	7,010.4	**27.9%**

Source: Semico Research Corp.

Figure 43: Light Sensors, Sales and Shipments (Millions of Units & Dollars)



Source: Semico Research Corp.

Light Sensors by End Use Markets

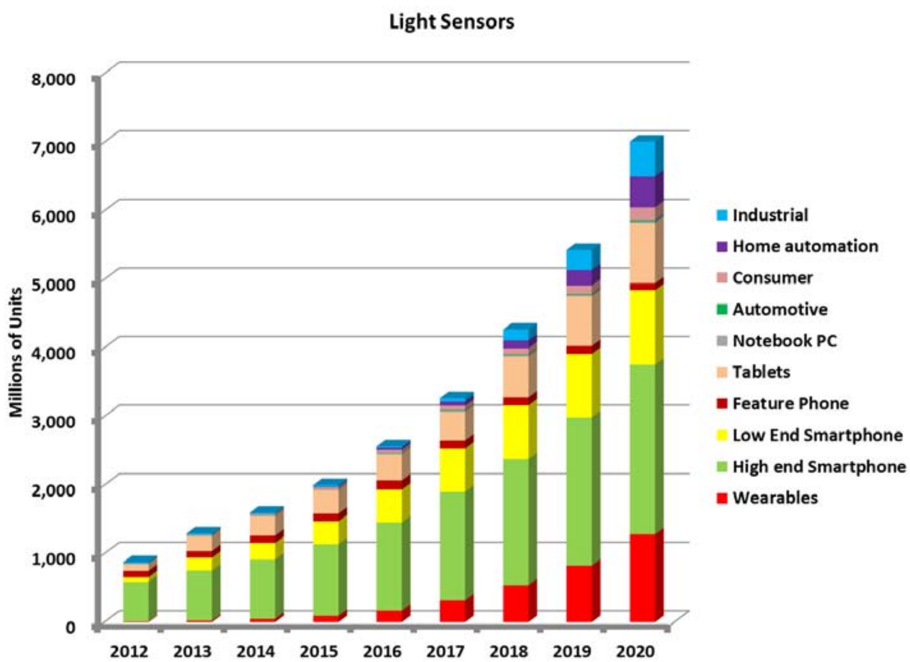
The next table and figure present the light sensor market broken out by applications.

Table 15: Light Sensors by Application (Millions of Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
Wearables	8.5	19.8	48.1	94.0	169.2	316.1	539.1	825.0	1,281.3	**72.8%**
High end Smartphone	579.6	732.6	866.3	1,044.9	1,286.6	1,586.3	1,842.1	2,161.3	2,472.9	**19.1%**
Low End Smartphone	67.4	187.5	242.6	333.9	479.1	629.9	782.0	926.3	1,087.3	**28.4%**
Feature Phone	93.0	98.1	106.8	112.4	134.1	119.8	118.2	115.8	102.3	**-0.7%**
Tablets	99.8	215.0	280.0	340.0	380.0	415.0	593.8	722.3	877.5	**21.0%**
Notebook PC	10.7	10.2	13.4	13.9	16.8	17.3	17.7	18.3	21.6	**8.3%**
Automotive	0.0	0.9	2.6	4.4	6.3	9.1	12.1	15.2	19.2	**39.7%**
Consumer	0.0	10.6	18.1	28.2	41.1	64.3	90.3	125.8	188.8	**47.8%**
Home automation	0.1	0.2	3.2	9.8	31.3	59.7	113.4	226.7	447.6	**128.2%**
Industrial	17.4	19.5	16.9	20.2	20.1	50.7	160.7	295.0	512.0	**76.6%**
Total	**876.3**	**1,294.3**	**1,597.9**	**2,001.7**	**2,564.6**	**3,268.2**	**4,269.4**	**5,431.7**	**7,010.4**	**27.9%**

Source: Semico Research Corp.

Figure 44: Light Sensors by Application (Millions of Units)



Source: Semico Research Corp.

The major market for light sensors is smart phones. Future growth markets are wearables, home automation and industrial applications.

Key Players in Light Sensors

There are a large number of chip vendors supplying a variety light sensors such as ambient light, IR detection, photoelectric, and phototransistors. These cover a wide range of applications as shown in the previous table. Among the key players—including ams—are:

- AKM
- Avago Technologies
- Baumer
- Exgen Global
- Fairchild Semiconductor
- First Sensor
- General Electric
- Honeywell
- IARD
- InfraTec GmBH
- Intersil
- Maxim Integrated Electronics
- Melexis

- Murata
- OMRON
- ON Semiconductor
- Optek-Damulet
- Panasonic
- Pixart
- Raytek
- Riko
- Rockwell Automation
- Rohm Semiconductor
- Shanghai Lanbao Sensing Technology Co., Ltd.
- Shenzhen Contin Medical Device Co., Ltd.
- SICK
- Texas Instruments
- Vishay

Position Sensors

A position sensor is any device that permits position measurement. It can either be an absolute position sensor or a relative one (displacement sensor). Position sensors can be linear, angular, or multi-axis. These are implemented with a variety of technologies such as magnetic, Hall effect, capacitive, ultrasonic, inductive, piezo-electric, optical proximity, resistive and more.

ams offers a broad range of high performance position sensors suitable for industrial, medical, robotics, automotive and consumer applications. ams utilizes Hall effect technology. The company's product lines include magnetic rotary position sensors, linear incremental magnetic position sensors, and the EasyPoint™ Joystick position sensor.

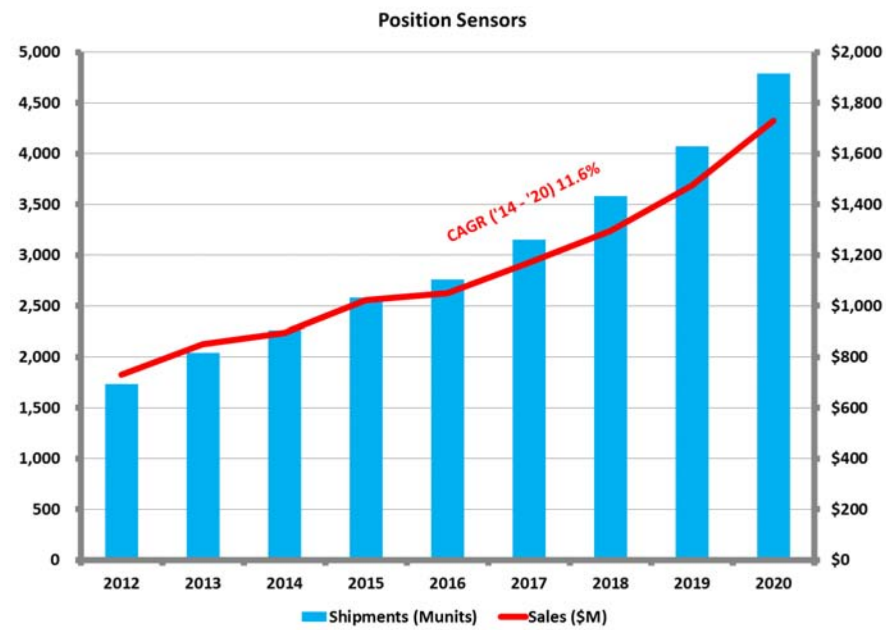
The EasyPoint™ Joystick position sensor is used in remote controls and gaming devices. The ams magnetic based position sensors are used for various industrial and automotive applications.

Table 16: Position Sensors, Sales and Shipments (Millions of Dollars & Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
MEMS	$0.0	$0.0	$10.9	$21.7	$41.0	$53.6	$70.6	$81.9	$105.8	**46.0%**
M units	0.0	0.0	16.9	41.0	107.2	172.9	268.8	364.0	512.7	**76.6%**
Non-MEMS	$730.8	$851.7	$885.2	$1,000.5	$1,008.0	$1,115.2	$1,223.9	$1,391.4	$1,623.8	**10.6%**
M units	1,733.3	2,041.3	2,243.0	2,543.5	2,651.3	2,979.3	3,315.5	3,706.8	4,275.7	**11.4%**
Total Sales	**$730.8**	**$851.7**	**$896.1**	**$1,022.2**	**$1,048.9**	**$1,168.8**	**$1,294.4**	**$1,473.3**	**$1,729.6**	11.6%
Total Shipments	**1,733.3**	**2,041.3**	**2,259.9**	**2,584.4**	**2,758.5**	**3,152.3**	**3,584.3**	**4,070.8**	**4,788.4**	13.3%

Source: Semico Research Corp.

Figure 45: Position Sensors, Sales and Shipments (Millions of Units & Dollars)



Source: Semico Research Corp.

Position Sensors by End Use Markets

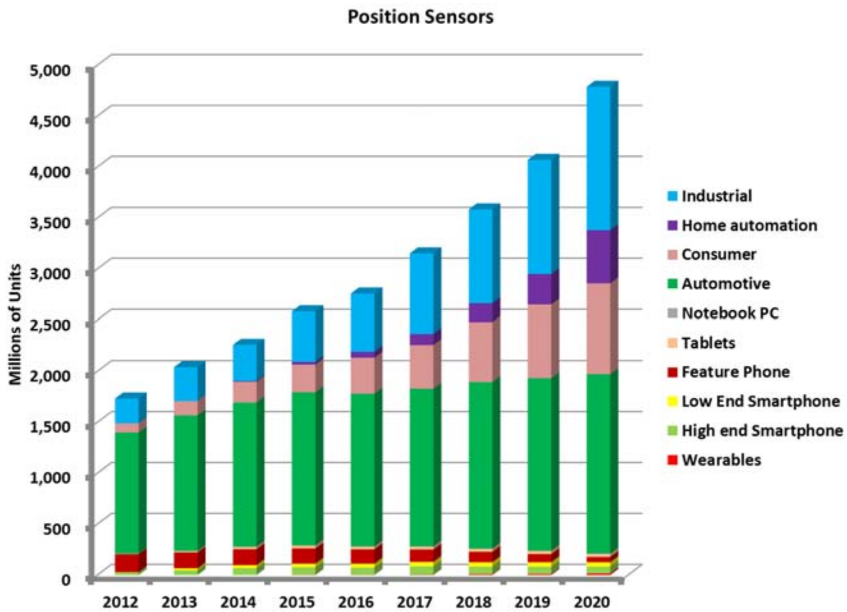
The next table and figure present the position sensors market broken out by applications.

Table 17: Position Sensors by Applications (Millions of Units)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	CAGR: '14 to '20
Wearables	0.0	0.0	0.0	0.6	1.0	2.7	6.5	9.0	14.4	**na**
High end Smartphone	24.4	47.6	69.3	76.0	72.1	82.3	76.2	72.5	67.4	**-0.5%**
Low End Smartphone	4.1	17.4	27.7	34.7	38.3	43.5	43.1	43.8	43.9	**8.0%**
Feature Phone	176.1	156.9	156.7	149.9	141.0	121.7	101.9	80.7	51.7	**-16.9%**
Tablets	4.2	14.0	22.4	27.2	26.6	29.1	28.5	29.4	29.3	**4.5%**
Notebook PC	0.0	0.0	1.1	1.2	1.2	2.0	3.0	3.1	3.8	**22.6%**
Automotive	1,189.9	1,331.3	1,414.8	1,504.2	1,500.2	1,547.2	1,634.9	1,694.3	1,760.6	**3.7%**
Consumer	90.6	141.4	205.5	273.1	353.7	428.5	587.3	718.9	887.2	**27.6%**
Home automation	0.1	0.3	7.9	24.6	57.6	109.2	181.4	297.9	522.2	**101.0%**
Industrial	243.9	332.3	354.4	492.9	566.8	786.2	921.5	1,121.0	1,408.0	**25.9%**
Total	**1,733.3**	**2,041.3**	**2,259.9**	**2,584.4**	**2,758.5**	**3,152.3**	**3,584.3**	**4,070.8**	**4,788.4**	**13.3%**

Source: Semico Research Corp.

Figure 46: Position Sensors by Applications (Millions of Units)



Source: Semico Research Corp.

The largest market for position sensors is automotive. The sensors are used in steering wheels, gear boxes, doors, and other applications. Industrial is the next largest market where they are used to monitor motors, gears, switches and other functions.

Key Players in Position Sensors

Most position sensors are non-MEMS based. Denso supplies a MEMS based position sensor for automotive applications. Semico foresees more MEMS based position sensors emerging during the forecast period. However, the vast majority of position sensors are conventional technology. In addition to ams, position sensor vendors include the following:

- AKM
- ALPS
- Baumer
- Delphi
- Diodes, Inc.
- GEMAC GmBH
- Honeywell
- Infineon
- MultiDimension Technology Co., Ltd
- Murata
- Netzer
- NXP

- Sensata
- Shanghai Lanbao Sensing Technology Co., Ltd.

Packaging and Technology Trends

To reduce cost, sensor vendors, especially MEMS vendors, are implementing multichip packaging. More than one sensor is inside one package. This requires wafer thinning for stacked chips. In addition to eliminating the cost of additional packages, this reduces the footprint of the board area enabling smaller end products.

Inertial sensors (accelerometers, gyros, magnetometers) are the first MEMS sensors designed into one package. Environmental sensor modules are starting to ship which include temperature, humidity and pressure.

Some MEMS and sensors require hermetically sealed packages. This is especially the case for inertial motion MEMS such as accelerometers, gyros and magnetometers. Temperature, humidity and changes in air pressure can adversely impact their operation. Conversely, other sensors need to have an opening in the package to sense the ambient conditions. These sensors include temperature, humidity, barometric pressure, chemical and gas, and biosensors.

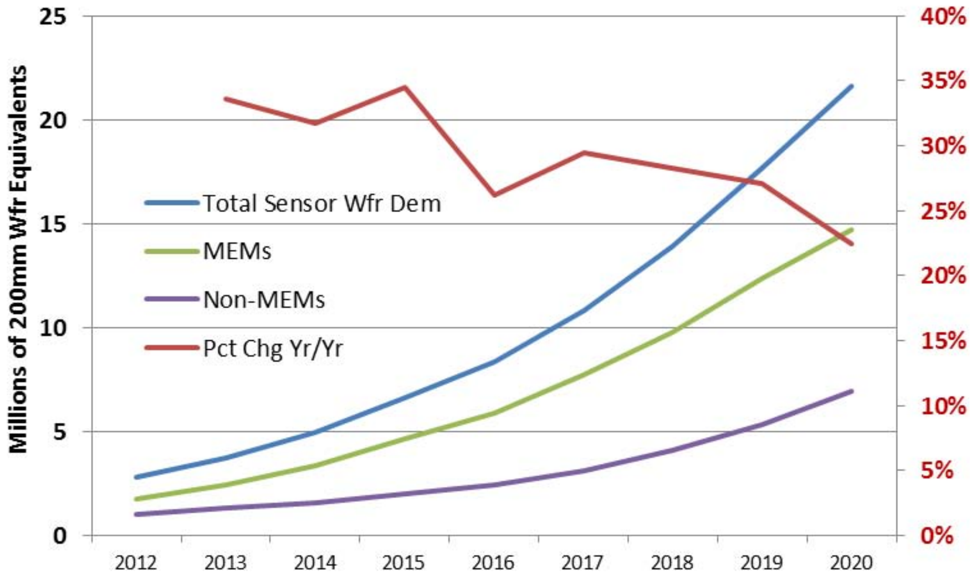
MEMS vendors must be careful in the layout and positioning of inertial sensors within a multi-chip package. The magnetic fields and cross talk can cause interference among the sensors.

MEMS and sensor vendors have made advances in more efficient manufacturing to reduce costs. Multi-chip packaging is also contributing to cost reduction. However, as the packaging becomes more complex, the cost of testing the final product is increasing. Currently, depending on the number of chips in a multi-chip package, testing can account for as much as 50% of the total production cost. Testing is becoming the next technical challenge for MEMS and sensor vendors.

MEMS and Sensor Wafer Demand and Capacity

Compared to the overall semiconductor industry MEMS and sensor units are expected to continue to experience a higher than average growth rate over the next five years. This will also place increased demand on the need for more manufacturing capacity.

Figure 47: Total MEMS & Sensor Wafer Demand



Source: Semico Research Corp.

Total MEMS and sensor wafer demand reached almost 5 million 200mm wafer equivalents in 2014. In 2015, wafer demand is expected to grow 34.5% to 6.6 million 200mm wafer equivalents. By 2020, wafer demand will reach over 20 million 200mm wafer equivalents, a CAGR of 26.7% over the next five years.

Today, MEMS and sensors are set apart by several unique manufacturing requirements and technology dynamics.

- Sensors are manufactured on 100mm, 125mm, 150mm and 200mm wafers. Typically, sensors are characterized by very small die sizes allowing for thousands of die per wafer. To-date, sensors have no required advanced technologies.

- Most MEMS devices are manufactured in mature fabs. Unlike traditional semiconductors, MEMS are not usually identified by or associated with a specific technology node. Due to the unique processes that are developed for each type of device along with differentiating process steps, most MEMS manufacturers do not associate MEMS devices with a particular process technology such as 1 micron or 0.35 micron when describing the manufacturing capacity required.

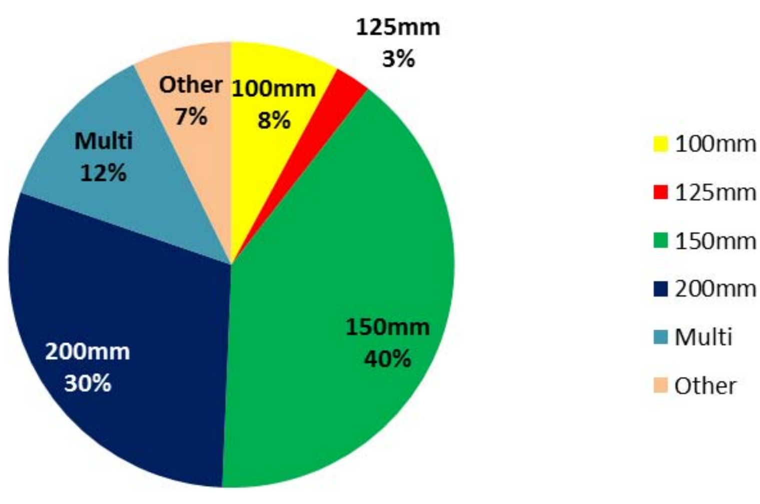
- As previously mentioned, the first high volume MEMS devices were utilized in automotive applications such as airbag deployment, fuel injection systems, and suspension systems. During the past few years as smartphones incorporated MEMS devices into the central semiconductor bill of materials, the need for higher volume MEMS capacity led to the development of CMOS MEMS processes.

- Foundries recognized an opportunity to fill older fabs with high volume MEMS devices. Developing a standard foundry process for MEMS manufacturing took several years. Initially volumes were low. Most MEMS manufacturers continued to develop specialized processes believing that provided a differentiating factor. However, as MEMS and sensors become more widespread and falling ASPs influence adoption in consumer applications, low cost manufacturing options are critical. MEMS manufacturers are now beginning to see the benefit of utilizing non-custom processes.

- Due to its high quality and lower cost, MEMS devices are expected to continue growing at a faster rate than traditional sensors.

Semico's Fab Database lists over 150 facilities that can manufacture MEMS and sensor products. Many of these fabs are also capable of running mature analog processes, discretes and other mature technology products. Currently there are over 60 fabs that process 150mm wafers and only 45 fabs that process 200mm wafers. However, there are over 19 facilities that are capable of running multiple wafer sizes from 100mm up to 200mm. In addition, there are over 11 facilities that operate R&D lines which can also process low volume test chips as well as sample products. Today's MEMS manufacturing continues to offer niche technologies, customized product development and small volumes. This results in a higher number of players with only a few capable of supplying high volumes for smartphone and other consumer applications. There are, however, still a number of specialized facilities that offer customized processing for prototyping and low volume applications such as medical and defense applications.

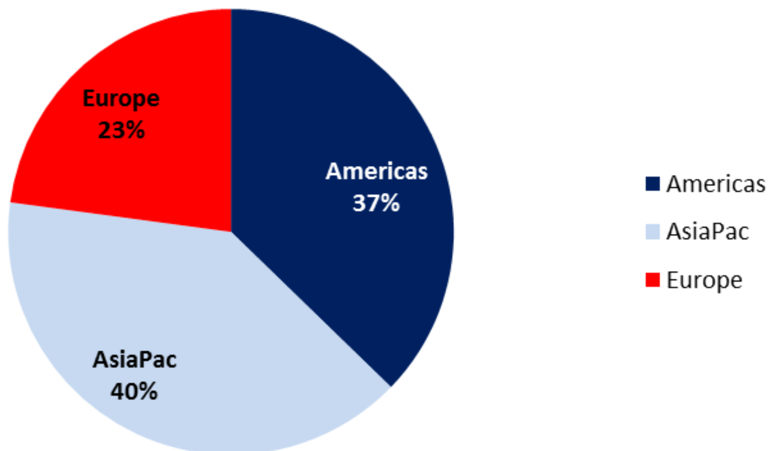
Figure 48: Total MEMS & Sensor Fabs by Wafer Size



Source: Semico Research Corp. and Company Information

Fabs are distributed around the world with a significant portion located in the Americas and AsiaPac. The fabs in AsiaPac can be further segmented by those located in China, Japan and other. Twenty fabs are located in China, 17 fabs are located in Japan and the remaining 24 facilities are located in Malaysia, Singapore, South Korea, and Taiwan.

Figure 49: Total MEMS & Sensor Fabs by Region



Source: Semico Research Corp. and Company Information

MEMS and sensor capacity utilization was only 73% in 2014. The low number reflects the mismatch in capacity and products required. The foundries have developed MEMS processes and continue to look for customers to fill their mature fabs. In addition, an over capacity situation exists in Japan as products continue to move to China and other AsiaPac locations.

The mismatch in products and capacity is also a result of all the new players and products being developed. Due to the high growth opportunity of sensors and MEMS, there are new companies entering the market with unique technologies. In the past development of the product technology as well as the manufacturing processes have taken up to four years. Many new products are still trying to differentiate features and performance through customized manufacturing processes. Due to the competitive time-to-market dynamics of the consumer and IoT markets, those development timeframes have shortened however, there are still a number of players trying to develop the next big thing in sensors.

MEMS and sensor unit demand is expected to grow at a rate of over 20% CAGR over the five years. That translates into over 26% increase in wafer demand. If no other fabs are converted or built to provide sensor and MEMS production, all the existing capacity would be fully utilized by 2017. The need for additional capacity will occur much sooner than that because a portion of the current capacity is designated as R&D, some MEMS capacity requires specialized processes that are not available in every fab.

Economic Impact and Analysis of New York and the ROI

The Upstate New York area has become a worldwide center for technology innovation especially for electronics and semiconductors. GLOBALFOUNDRIES has located one of the most advanced wafer fab in the world in New York. GLOBALFOUNDRIES 'acquisition of IBM's fabs, patents and semiconductor research assets is a plus for New York to retain these assets and business activities within the borders of New York. New York has proven its ability to work with businesses and assist companies in building a productive environment with its incentives and inherit advances that are offered and available. New York has had the vision of establishing a strong future direction for attracting and growing tech business to New York. Marcy Nanocenter is evolving into a premier center that rivals any center around the world.

Strengths

- Strong Labor force within a 90-mile radius
  - Labor force of 1.5 million
    - 6,911 target engineers
    - 2,613 target technicians
- Strong educational institution
  - Example merger of SUNY CNSE and SUNYIT created SUNY Polytechnic Institute
  - 1st in nation in Nanotechnology degrees
  - 2nd in nation in number of first tier universities
  - 2nd in nation for engineering degrees
  - 64 state universities and 86 private colleges/universities
  - 26 universities/colleges within 90 miles of Marcy, NY:
    - 20,000 STEM students
    - Graduating 6,000 students/yr. in STEM and 2,500 students/yr. in target engineer and technician programs
  - 3 major university hubs (SUNY Poly, Syracuse, and Cornell) within a 90 mile radius
  - 5 SUNY colleges (ESF, Morrisville, Oneonta, Adirondack, and Cobleskill) within a 50 mile radius
  - 3 private colleges (Utica, Hamilton and Colgate) within 20 mile radius
  - 7 community colleges (Cayuga, MVCC, HCCC, FMCC, SCCC, Onondaga, and HVCC) within a 90 mile radius
- Marcy Nanocenter site is now part of SUNY campus
  - 428 acres, 220 acres to be developed
  - Site is fully permitted (includes final site plan approval for 3 mega fab development
  - Improvements underway for Ring Road, stormwater, wetlands mitigation, clearing & grubbing, and on-site utilities
  - Water/sewer extended to site
  - Extension of two OH transmission lines from Edic Substation to Customer Substation

  - National Grid extending 12” gas main to Marcy
  - PILOT Allocation Agreement in place with PILOT Increment Financing Option
- Other attractive tech offering nearby
  - Phase 1 of Quad C
- Large number of engineering graduates
  - Within 90 miles of Marcy 1,239 graduate surplus per year
  - Within New York State 2,380, graduate surplus per year
- Large number of technicians graduates
  - Within 90 miles of Marcy, 162 graduate surplus per year
  - Within New York State, 1309 graduate surplus per year
- Good infrastructure in place or under development to support semiconductor fabs
- Transportation infrastructure in place
- Reliable utilities infrastructure in place
- Attractive rural lifestyle – family friendly

Weaknesses

- Perceived as highly unionized, high cost location
- Harsh winters

Opportunities

- Ample land and utilities to attract new and expand of existing facilities
- Continued support from local government and existing businesses
- Government/defense business. i.e. trusted manufacturing (Made in USA)

Threats

- Increased competition from other global locations such as Singapore, Taiwan, Japan, China and India
  - Strong government support in China
    - Has $20 billion investment fund for match private to acquire or develop semiconductor eco-system in China
  - India government helping to fund a 300mm analog fab. This initiative is to support a locate company Cricket Semiconductor.

New York Summary

When deciding to locate a manufacturing, R&D or administration center, there are, of course, additional subjective issues taken into consideration. But overall, Upstate New York fares very well in a comparison to other established areas.

New York has benefited from many high technology focused facilities. Some of these include but are not limited to:

- The Albany NanoCollege,
- International Sematech
- GLOGALFOUNDRIES including IBM’s facilities, patents and research
- Marcy Nanocenter

- SUNY Polytechnic Institute
- Innovation Center
- World class (first tier) universities
- A region known for developing leading technology

Economics: Upstate New York

New York State has an active program to attract new technology to the region. The semiconductor industry outreach and attraction efforts offer a unique opportunity to prospective companies.

Residential Market

- Mohawk Valley represents 0.1% of the nation's households
- Cost of living 9% below national average
- Median income is 97% of the national average, while the median home cost is 62% of the average
- Average 2 bedroom apartment rent is 86% of the national average
- Water quality is one of the highest in the nation ranking 60% above the national average based on EPE water quality index
- K-12 Pupil/Teacher Ratio is 91% of the national average
- 5 higher education schools, two 4-year and three 2-year institutions

Business

- Downtown and suburban lease rates are 69% of the national average
- Industrial lease rates and 67% on the national average
- Construction cost for industrial space is 98% of the national average
- Construction cost of office space is 93% of the national average

The upstate New York counties involved in this project do not have a developed electronics/semiconductor base; however, during the past 10 years the State of New York has established a significant foothold in nanoelectronics with a 300-acre NanoCenter at the State University of New York Institute of Technology. The state program, NY♥Nanotech, has given New York world recognition as premier center for the development of innovative technology.

Upstate New York can capitalize on the success of New York's nanoelectronics program and the synergy with the semiconductor industry with the building of a second 300mm wafer fab.

Economic Development Multipliers

Economic development activities to attract new manufacturing jobs to a community are viewed as important and beneficial because of the jobs that the new business adds to the work force. However, it is not just the new manufacturing jobs that contribute to the economic activity of the area. One new manufacturing job can translate into several additional jobs due to the increased need for housing, food, retail operations and both private and government services. In addition, the materials and services that are part of the product being produced results in the growth of existing supplier businesses or new support businesses moving into the area. The additional jobs and economic activity related to one new manufacturing job is generally referred to as the Multiplier Effect.

Economic multipliers are applied at several different levels. The table below provides a list of the multipliers that will impact the ams manufacturing project.

Table 18: Types of Economic Multipliers Used for ams Project Impact Analysis

	Earnings Multiplier	Job Multiplier	Output Multiplier
Construction			
Direct Jobs	X	X	
Bldg Materials/Services	X	X	X
Fab			
Direct Jobs	X	X	
Material & Service Inputs	X	X	X

Source: Semico Research Corp.

Direct effects multipliers are applied to the earnings associated with the ams project. For example, the jobs related to the construction of the ams fab totaled $66 million. That number was multiplied by 1.3986 to determine the additional earnings that would be generated from the construction jobs created to complete the ams fab.

Final demand multipliers are applied to the value of the materials and services used to produce products. For example, concrete, copper pipes, and other construction materials were purchased to build the ams fab. Many of the inputs used in the fab infrastructure will be supplied by local construction companies. The sale of the construction materials adds to the jobs, tax revenue and general health of the area. In addition, once the fab is running, the wafers that are produced will utilize chemicals and other material inputs, a small portion of which will be supplied from local distributors or direct suppliers.

Table 19: Economic Multipliers

	Direct Effect		Final Demand		
	Earnings (dollars)[1]	Employment (Jobs)[2]	Output (dollars)[3]	Earnings (dollars)[4]	Employment (Jobs)[5]
Construction new mfg structures	1.36986	1.59528	1.54811	0.69414	10.63895
Semiconductor & rel. device mfg	2.76702	3.97917	1.49442	0.28708	4.53996

Source: IMPLAN Group, LLC, Monroe County, IRIMS Total Multipliers

1. The Direct Effect Earnings Multiplier represents the dollar change in earnings of households employed by all industries due to the additional earnings paid directly to households employed by the new company.
2. The Direct Effect Employment Multiplier represents the change in number of jobs in all industries for each additional job added by the new company.
3. The Final Demand Output Multiplier represents the dollar change in output that occurs in all industries for each additional dollar spent to create the products manufactured by the new company.
4. The Final Demand Earnings Multiplier represents the dollar change in earnings of households employed by all industries for each additional dollar spent to create the products manufactured by the new company.
5. The Final Demand Employment Multiplier represents the change in the number of jobs that occurs in all industries for each additional 1 million dollars spent to deliver a final product manufactured by the new company.

These multipliers provide a way to estimate the total impact that a change in economic activity has on an economy. Multipliers are based on assumptions related to how communities and individuals adjust their labor supply, saving, and consumption decisions when their income changes. These multipliers are also based on estimates of the relationships between broad measures of economic activity, such as income and consumption.

The magnitude or impact of multipliers is closely linked to the marginal propensity to consume, which quantifies the relationship between changes in personal income and consumption. In extended models, the size of the multipliers is influenced by the degree to which individuals shift their consumption, labor supply, and savings across time in response to anticipated changes in taxes, interest rates, or asset prices that may make them feel wealthier or poorer. Regional multipliers are based on a detailed set of industry accounts that measure the goods and services produced by each industry and the use of these goods and services by industries and final users. This detail allows for estimates of the impact of an initial change in economic activity on industries in a region. These multipliers assume that resources are readily available in an economy through training or importation of labor.

Economic Impact Analysis

The ams semiconductor manufacturing fab will have a positive financial impact on the state starting from the site development, construction and progressing to the operation of the fab along with future expansion projects. Following is a description of the factors impacting the increased economic activity of Oneida County, New York due to the building and operation of a semiconductor fab in the area.

Project Costs

The site and infrastructure preparation along with the actual construction of the 300mm semiconductor manufacturing facility will be the first investment into the area. The model assumes that the site preparation work, gas and electric expansion will occur in the fourth quarter of 2015 and Fab construction stars in the first quarter of 2016. If the site preparation does not start until the fab construction commences, this will have no material impact of the project's ROI.

Over the course of the following ten years there are grants and discounts that are available from economic development programs and utility companies. Table 1 provides a recap of the expected project costs. It does not include the expenses that are anticipated by the private entity expected to ramp and operate the semiconductor facility.

There is a total of $500 million available for the building of the semiconductor facility and site preparation. $367 million is expected to be used for the construction of the building, including construction labor. The remaining $133 million will be used for site preparation for the ams property. Any cost savings will be used for the purchase of equipment.

There is also $114 million available for additional site preparation. The site preparation includes items such as the 12" natural gas and 115 KV transmission lines. The analysis also includes $50 million for R&D spread over five years ($10 million/year) and a $36 million NYS Tooling Grant spread over 3 years.

Job training grants, tax credits, and utility discounts are also available. See table below.

Table 20: Project Costs

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Site Preparation	$50,800,000	$158,100,000	$38,100,000							
Fab Construction Brick & Mortar	$71,408,031	$211,939,999	$17,446,305							
Construction Labor	$15,717,105	$46,648,580	$3,839,980							
NYS Tooling Grant		$12,000,000	$12,000,000	$12,000,000						
R&D Grant			$10,000,000	$10,000,000	$10,000,000	$10,000,000	$10,000,000			
National Grid Utility Discount	$0	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
NYS Excelsior Refundable Tax Credit	$1,139,746	$982,377	$836,725	$700,198	$572,796	$454,518	$344,328	$244,559	$153,915	$72,395
EDGE Job Training Grant $2M		$1,000,000	$500,000	$500,000	$0					
Total	$139,064,882	$431,670,956	$83,723,010	$24,200,198	$11,572,796	$11,454,518	$11,344,328	$1,244,559	$1,153,915	$1,072,395

Note: Any savings from fab construction can be used for equipment purchases

Source: M&W, MVEdge and Semico Research

Project Benefits

As previously mentioned, economic development activities to attract new manufacturing jobs to a community are viewed as important and beneficial because of the jobs that the new business adds to the work force. However, it is not just the new manufacturing jobs that contribute to the economic activity of the area. This section provides a review of the benefits gained from the increased jobs and economic activity added to the area from the construction and operation of the semiconductor facility.

The most visible impact from the new semiconductor facility is the jobs that are created from the construction of the building and infrastructure and the ramp and operation of semiconductor production. These jobs are referred to as direct employment/jobs. Each new job that is created such as electrician or fab operator results in additional economic activity in the form of higher retail sales, more housing needs, more classroom space, etc. The jobs created from the additional economic activity are referred to as indirect job creation.

The next table presents the direct and indirect jobs associated with the new semiconductor facility.

Table 21: Project Jobs

Direct Jobs	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Property Prep	33	75	38									
Construction	193	709	225									
Fab Operation	0	3	38	93	273	468	506	510	603	742	940	1000
Total Direct Jobs	227	787	301	93	273	468	506	510	603	742	940	1000
Multiplier Jobs												
Property Prep	254	791	191									
Construction	309	1,131	360									
Fab Operation	0	12	151	370	1,086	1,862	2,013	2,029	2,399	2,953	3,741	3,981
Construction Materials	190	564	186									
Fab Inputs	0	0	26	65	392	686	726	726	840	1,072	1,384	1,471
Total Multiplier Jobs	752	2,497	913	435	1,479	2,549	2,739	2,755	3,239	4,024	5,125	5,452
Total Jobs	979	3,283	1,214	528	1,752	3,017	3,245	3,265	3,842	4,766	6,065	6,452

Source: M&W, MVEdge and Semico Research

The construction of a 300mm manufacturing fab will bring construction laborers to the area along with some of the families for the two years required to build. Because additional construction of new homes and businesses will occur for the increased population, a large percentage of the construction workers will stay in the area. Additional employment of workers moving/migrating to the area will also include support for the fab. Increased economic activity and population require increases in the services. Doctors, teachers, lawyers, accountants, sanitation workers, etc. are added to the required job support base. Real estate demand is projected to increase about 15% in three to four years. Direct and multiplier jobs will total 898 in 2016 from site development and fab construction and will grow to 6452 by 2027 with the addition of the fab operations employees and multiplier jobs.

The semiconductor manufacturing facility provides the following employment opportunities:

- Entry level personnel
  - Skill set required, one year's experience
- Salaries
  - Wafer operators (starting salaries) $45,000
  - Average salaries for fab workers $60,000
- Skill set salaries for fab workers
  - 57 fab engineers 70% moving to area

- 31 facility engineers 70% moving to area
- 31 R&D engineers 70% moving to area
- 18 management 70% moving to area
- 18 Administration 10% moving to area
- 30support staff 40% moving to area
- 750 fab operators 30% moving to area
- 54 wafer probe technicians 30% moving to area

- Salaries
  - Engineers' average salary $85,000
  - Management average salary $130,000

For purposes of this analysis, we used an average of $60,000 for all fab employees received from M+W.

In addition to the actual jobs created for fab operations, there are a number of jobs that are created in order to support the fabs. Support jobs for the fab include the following. Jobs are not limited to this list.

- Fab garment cleaning
- Computer sales maintenance
- Warehousing
- Delivery service
- Chemical disposal
- Satellite equipment offices
- Specialty products
- Maintenance
- Training
- Private security

Additional jobs revolving around the fab are the suppliers of equipment, materials and services.

The earnings associated with the jobs created are provided in the table below.

Table 22: Jobs Earnings

Direct Earnings	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Site Prep	$2,210,000	$6,630,000	$2,762,500									
Construction	$15,717,105	$46,648,580	$3,839,980									
Fab Operation	$0	$255,000	$2,850,000	$6,045,000	$16,380,000	$28,080,000	$30,360,000	$30,600,000	$36,172,746	$44,520,786	$56,403,903	$57,830,694
Total Direct Earnings	$17,927,105	$53,533,580	$9,452,480	$6,045,000	$16,380,000	$28,080,000	$30,360,000	$30,600,000	$36,172,746	$44,520,786	$56,403,903	$57,830,694
Multiplier Earnings												
Site Prep	$3,027,391	$817,033	$2,270,543									
Property Prep	$35,262,435	$109,743,916	$26,446,826									
Construction	$21,530,237	$63,902,035	$5,260,236									
Fab Operation	$0	$705,591	$7,886,015	$16,726,652	$45,323,832	$77,697,998	$84,006,810	$84,670,895	$100,090,810	$123,190,026	$156,070,881	$160,018,843
Total Multiplier Earnings	$59,820,063	$175,168,574	$41,863,620	$16,726,652	$45,323,832	$77,697,998	$84,006,810	$84,670,895	$100,090,810	$123,190,026	$156,070,881	$160,018,843

Source: Semico Research Corp.

In addition to additional jobs, the increase earnings equates to an increase in the tax base (property, sales, income, etc.). Increased incomes results in increased spending, improved property values and additional tax collections.

Table 23: Additional Government Revenue

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Income Taxes	$6,620,355	$19,981,532	$3,360,424	$1,444,566	$4,184,747	$7,187,672	$7,754,999	$7,810,644	$9,215,789	$11,379,790	$14,442,763	$14,859,440
State Sales Taxes	$3,310,177	$9,980,416	$1,564,537	$476,930	$1,427,546	$2,454,131	$2,645,254	$2,663,336	$3,139,723	$3,882,895	$4,932,072	$5,082,500
County Sales Taxes	$3,930,836	$11,851,744	$1,857,888	$566,354	$1,695,211	$2,914,281	$3,141,239	$3,162,711	$3,728,421	$4,610,938	$5,856,836	$6,035,469
Utilities Taxes		$6,959	$13,919	$31,317	$52,196	$59,155	$62,635	$73,406	$86,871	$100,335	$105,721	$108,414
Real Estate Taxes		$268,461	$777,243	$2,223,252	$2,728,742	$3,297,897	$3,925,795	$4,614,896	$5,365,547	$6,105,435	$6,842,055	$7,572,637
Total Additional Govt. Revenue	$13,861,367	$42,089,113	$7,574,010	$4,742,418	$10,088,441	$15,913,135	$17,529,922	$18,324,993	$21,536,350	$26,079,394	$32,179,447	$33,658,460

Source: Semico Research Corp.

New jobs and growth would stimulate local area schools and healthcare expansion. Assuming 1.5 children per household, there is a potential for an additional 4,500 children requiring community services.

Additional dollars are earmarked for workforce education and retraining programs needed to provide a long-term supply of skilled workers for the manufacturing jobs. Synergies with educational institutions and universities (R&D) such as SUNY will be coordinated to achieve increased employment levels.

Private company and small business investment occurs at a gradual incremental pace. This ranges from the expansion of chains to new shopping centers. Other investment, occurs with the support businesses to the fabs that were listed previously.

Expansion of infrastructure such as transportation (highways, airport, etc.), utilities (water, sewer, electric, gas, telecommunications, etc.), public services (police, fire, etc.), education (schools, universities), R&D centers – are all part of the expansion of employment and revenue generation for the area. Some of this expansion will be accomplished with companies and organizations presently in other locations in New York.

Table 24: Value of Increased Economic Activity

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fab Operation	$0	$255,000	$8,610,000	$20,445,000	$102,780,000	$179,280,000	$190,200,000	$190,440,000	$221,259,690	$280,619,683	$361,230,807	$381,830,694
Multiplier Effect on Economic Activity	$368,167,806	$1,119,987,864	$194,209,604	$21,857,367	$91,500,266	$158,506,758	$169,433,213	$170,097,298	$199,010,429	$249,372,956	$318,985,458	$333,180,471
Total Increase in Economic Activity	$368,167,806	$1,120,242,864	$202,819,604	$42,302,367	$194,280,266	$337,786,758	$359,633,213	$360,537,298	$420,270,119	$529,992,639	$680,216,265	$715,011,165

Source: Semico Research Corp.

The following is the ROI for the State of New York on the investment to build a semiconductor manufacturing plant.

The State investment is estimated at $500 million plus $114 million for site preparation plus $36 million for tooling and $50 million for R&D for a total of $700 million. In addition, there are discounts from the National Grid ($10 million over 10 years) and refundable tax credits from NYS Excelsior.

Benefits to the state are defined as the following:

- Additional State income taxes
- Additional State sales taxes

- Additional County taxes
- Jobs from construction activity to build the facility (9 quarters, both site prep and actual bldg)
- Jobs from the semiconductor manufacturing company
- Jobs to support the manufacture of semiconductor products on 300mm wafers
- Jobs to support workers of the manufacturing company and the support businesses
- Added economic activity to support the purchases made by the construction contractors building the facility such as concrete, copper pipes, etc.
- Added economic activity to support the purchases made by the semiconductor manufacturing operation such as chemicals and other material supplies, fab garment cleaning, satellite equipment offices, private security, etc.
- Added value to the community in the form of:
    - Stronger real estate market
    - More economic opportunities for the citizens

Significant manufacturing operations such as the ams facility also tends to stimulate the cultural aspects of a community like:

- Performing arts
- Museums
- Charities

Summary Data

The numbers show that the site development and construction of a semiconductor manufacturing plant would generate revenue and added economic value for the state.

Table 25: Five-Year Benefits

	Revenue
5-Year Tax Collection Increase	$78,355,350
5-Year Addition to Local Economy	$1,927,812,908
Total	$2,006,168,259

Source: Semico Research Corp.

An ROI is calculated in the following manner:

(Gain from investment – Cost of investment)/ Cost of Investment

The ROI for five years and ten years is:

- 5-yr = 191%
- 10-yr = 474%

The cost of jobs for New York State assuming $700,000,000 investment would be as follows.

- The cost per job at the 10th year is $146,874 which is calculated by dividing
    - Total investment including site Prep, construction, R&D and tooling
    - Divided by total jobs in year 10, including both direct and multiplier jobs.

Table 26: 10-Year Benefits

	Cumulative Revenues
10-year Tax Collection increase	$177,739,145
10-year Addition to Local Economy	$3,936,032,935
Total	$4,113,772,080

Source: Semico Research Corp.

Yearly Return on Investment

The State does not have to wait until Year Five to see a return on investment. Benefits of the site preparation and start of construction on the semiconductor fab begin in year one. The following table presents the State revenue and added GDP. Over a ten year period, over $177.7 million in tax revenues is generated for New York State and nearly $4.1 billion in added economic activity. The yearly detail is presented in the following table.

Table 27: Additional Yearly Tax Revenue plus Added GDP

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	10Yr Cumm
State Revenue	$9,930,532	$29,961,948	$4,924,961	$1,921,495	$5,612,293	$9,641,803	$10,400,253	$10,473,980	$12,355,511	$15,262,686	$110,485,462
County Revenue	$3,930,836	$12,127,165	$2,649,049	$2,820,923	$4,476,148	$6,271,332	$7,129,669	$7,851,013	$9,180,838	$10,816,708	$67,253,682
Added GDP	$368,167,806	$1,120,242,864	$202,819,604	$42,302,367	$194,280,266	$337,786,758	$359,633,213	$360,537,298	$420,270,119	$529,992,639	$3,936,032,935
Total	$382,029,173	$1,162,331,978	$210,393,614	$47,044,786	$204,368,708	$353,699,893	$377,163,135	$378,862,292	$441,806,469	$556,072,033	$4,113,772,080

Source: Semico Research Corp.

County Only View

A look at the impact of the site development, fab construction, fab operation and all the multiplier effects that go along with these investments and operations result in significant benefits to the local counties. The table below details the county data.

Table 28: County Benefits

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Site Prep incl. Multipliers	$1,250,432	$3,873,457	$937,824							
Fab Construction incl. Multipliers	$2,680,403	$7,955,473	$654,872							
Fab Operations incl. Multipliers	$0	$22,814	$265,191	$566,354	$1,695,211	$2,914,281	$3,141,239	$3,162,711	$3,728,421	$4,610,938
Incr in Real Estate & Property Taxes	$0	$268,461	$777,243	$2,223,252	$2,728,742	$3,297,897	$3,925,795	$4,614,896	$5,365,547	$6,105,435
Utility Tax Collections	$0	$6,959	$13,919	$31,317	$52,196	$59,155	$62,635	$73,406	$86,871	$100,335
Total County Taxes Collected	$3,930,836	$12,127,165	$2,649,049	$2,820,923	$4,476,148	$6,271,332	$7,129,669	$7,851,013	$9,180,838	$10,816,708
15% of added economic benefits stay in County	$55,225,171	$168,036,430	$30,422,941	$6,345,355	$29,142,040	$50,668,014	$53,944,982	$54,080,595	$63,040,518	$79,498,896
Total Taxes and Economic Benefit to the County	$63,086,842	$192,290,759	$35,721,039	$11,987,201	$38,094,336	$63,210,678	$68,204,320	$69,782,622	$81,402,195	$101,132,312

Source: Semico Research Corp

Breakeven

The breakeven period for the State of New York investment in the ams fab project will be achieved in less than 24 months. The breakeven calculation is based upon the following:

- Summing the value of additional tax collections
- Plus the value added to the local economic activity (local GDP)
- Includes fab operation and all multiplier effects

This report presents statistics and facts about the semiconductor industry. The number of jobs that can be created by the establishment of a semiconductor facility in the Oneida County area is impressive. Additionally, the enhanced levels of employment and income will be a definite plus to the tax coffers of the State.

Semiconductor Glossary of Acronyms

200mm: A size of silicon wafer approximately 8-inches in diameter.

300mm: A size of silicon wafer approximately 12-inches in diameter.

Abatement: A process where toxic or other hazardous substances are removed from a liquid or gas (e.g. removing copper particles from CMP slurry).

ADC: Automatic Defect Classification. Defects found by wafer inspection systems are classified by the system into several categories based on their physical and optical properties.

Advanced Patterning Films (APF): A strippable hardmask (an amorphous carbon/DARC stack film) that is designed to replace the spin-on ARC in typical trim procedures.

Aluminum Chemical Vapor Deposition (ALCVD): A CVD process that results in deposited aluminum on a substrate.

Aluminum Interconnect: Aluminum pathways within a microchip that connect the transistors.

Aluminum Low Pressure Seed (ALPS): ALPS was originally an aluminum process, now also used for other metal PVD processes.

Ambient Control Chamber (ACC): A Synexis chamber that stores and pressurizes in-process wafers. The chamber attaches to the side of the factory interface and is fed by the FI robots.

Amorphous silicon: A type of silicon deposited on a variety of surfaces (rigid and flexible) with thin homogenous layers. Amorphous silicon absorbs light more effectively than crystalline silicon, so the cells can be thinner. For this reason, amorphous silicon is also known as a "thin film" photovoltaic technology.

Angstrom (Å): A unit of length; one ten-billionth of a meter.

Anneal: A high-temperature processing step (usually the last one) designed to repair defects in the crustal structure of the wafer.

Anti-Reflective Coating (ARC): A light-absorbing metal layer (typically titanium nitride), deposited on top of metal or polysilicon, to improve photolithography performance.

APCVD: Atmospheric Pressure CVD refers to systems whose deposition environments operate at or near atmospheric pressure. Typically, wafers are placed horizontally on belt-driven flat susceptors that move through the deposition zone. Belt speed and gas flow determine the film thickness.

Aspect ratio: The ratio of depth to width of a via or contact structure.

Atomic Layer Deposition (ALD): A specialized CVD process required for <100nm deposition.

Automated Process Control (APC): A computer controller for gas panels used within semiconductor manufacturing.

Back-end of Line (BEOL): The series of process steps from contact through completion of the wafer, prior to electrical test. Also known as the back-end of semiconductor manufacturing.

Barrier: A physical layer designed to prevent intermixing of the layers above and below the barrier layer.

Bunny Suit: Special clothing worn by people working in clean rooms that reduce the amount of particles that could damage a semiconductor.

Capacitor: A device used to store electrical charge in a circuit and smooth out irregular current.

CD: Critical Dimension is the width of a patterned line or the distance between two lines of the sub-micron sized circuits in a chip.

Chemical Mechanical Planarization (CMP): A process that uses an abrasive, corrosive slurry to physically grind the microscopic topographic features on a partly processed wafer flat (planarization) so that subsequent processes can begin from a flat surface.

Chemical Vapor Deposition (CVD): A process for depositing thin films from a chemical reaction of a vapor or gas.

Chip: A small piece of a silicon wafer that contains a complete integrated circuit.

Circuit: The combination of many connected electrical elements to accomplish a desired function.

Cleanroom: The portion of a fab where semiconductors are manufactured. These rooms are strictly monitored to ensure successful manufacturing of semiconductors.

Color Filter (CF): The section of a flat panel display that is broken into areas of red, green and blue. Using a transistor, varying amounts of lights are transmitted through the color filter to create millions of colors.

Complementary Metal Oxide Semiconductor (CMOS): Any MOS device that incorporates both p-channel and n-channel transistors within the same silicon substrate. CMOS devices are noted for low power requirements, high immunity to electrical noise, and relatively slow speed.

Computer Integrated Manufacturing (CIM): Manufacturing supported by computers. It is the total integration of Computer Aided Design/Manufacturing and also other business operations and databases.

Conductor: A material that conducts current.

Contact: The portion of a microchip that is between the copper or aluminum interconnect and the transistor. This area is often filled with tungsten.

Contact diameter: The diameter of the metal structure used to connect the doped contact area formed in the silicon base material to the metal interconnect.

Copper Interconnect: Copper pathways within a microchip that connect the transistors. Copper interconnects provide better microchip performance when compared to aluminum interconnects.

Copper seed layer: A thin copper layer deposited by physical vapor deposition over the barrier layer. It acts as a wetting and nucleation layer for growth of the subsequent copper film deposited by electroplating.

Critical Dimension Scanning Electron Microscopy (CD-SEM): A type of Scanning Electron Microscope used to measure critical dimensions.

Crystalline: A material that has atoms arranged in an ordered periodic array.

Damascene: An integrated circuit process where a metal conductor pattern is embedded in a dielectric film on the silicon substrate, resulting in a planar interconnection layer. The creation of a damascene structure most often involves chemical mechanical planarization of a nonplanar surface resulting from multiple process steps.

Decoupled Plasma Nitridation (DPN): A method for creating an advanced oxynitride gate dielectric with high nitrogen incorporation at the oxynitride/poly interface and low nitrogen at the Si/oxynitride interface.

Decoupled Plasma Source (DPS): A technology used within conductor etch that separates the management of plasma density and bias power, resulting in the ability to provide a uniform high ion density over a large process window, maintain a linear plasma density dependence on the inductive RF power and apply a minimum bias power.

Deep Ultraviolet (DUV): The portion of the ultraviolet light spectrum with wavelengths below 300nm.

Defect Inspection: A process where defects are located on a patterned wafer.

Defect Review Scanning Electron Microscopy (DR-SEM): DR-SEMs classify defect types during the wafer manufacturing process at a very high magnification and determine whether these defects will affect chip yields. DR-SEMs are typically used in the critical layers of the device structure at 0.25 microns and below.

Deposition: A process used to deposit a thin layer of insulating or conductive material onto the wafer.

Design Rules: Rules that outline the allowable dimensions of features used in the design and layout of integrated circuits, such as limits for feature size, and layer-to-layer overlap.

Dielectric: A material that conducts essentially no current when it has a voltage across it: an insulator. Two dielectrics commonly used in semiconductor processing are silicon dioxide (SiO_2) and silicon nitride (SiN).

Dielectric Anti-Reflective Coating (DARC): A non-reflective, non-energy-absorbing, inorganic dielectric layer deposited on top of metal or polysilicon to improve photolithography performance. DARC layers make it possible to accurately transfer the mask pattern onto the photoresist and are typically used in advanced devices such as 256Mb DRAMs and beyond.

Dielectric Anti-Reflective Layer (DARL): Another name for dielectric anti-reflective coating (DARC).

Dielectric Film: A non-conducting film. In integrated circuits usually $Si0_2$ (Silicon Dioxide)

Dopants: An impurity added in controlled amounts to a material in order to modify some intrinsic characteristic, such as resistivity/conductivity or melting point.

Doping: Adding a controlled amount of impurities to a material in order to modify some intrinsic characteristic, e.g., resistivity/conductivity, melting point.

Double-layer Metal (DLM): The number of metal layers used to personalize an ASIC die.

Electrochemical Plating (ECP): A deposition process in which metals are removed from a chemical solution and deposited on a charged surface.

Epi or Epitaxy: A process technology used in some semiconductor designs where a pure silicon crystalline structure is deposited or "grown" on a bare wafer, enabling a high-purity starting point for building the semiconductor device.

Equivalent Oxide Thickness (EOT): A number used to compare performance of high-k dielectric MOS gates with performance of SiO_2 based MOS gates.

Etch: A process for removing material in a specified area through a chemical reaction.

Etch Stop Layer (ESL): A layer of film used to identify a place for etching to stop. For example, a nitride layer can be deposited over a poly layer to signal the etch process to stop before etching the poly layer.

Fab: A facility for manufacturing semiconductors.

Flat Panel Display (FPD): A consumer display device that uses advanced technologies to create televisions and computer monitors. Flat panel displays can be created using thin-film transistors, organic light emitting diodes or plasma technologies.

Flexible Printed Circuit Board (FPCB): A flexible dielectric substrate having circuit lines attached to one or more surfaces. The flexible printed circuit board is widely used and can be divided into four types according to function: lead line, printed circuit, connector, and integration function system.

Front-end of Line (FEOL): Front-end processes include: Thermal Processes, Implantation, Chemical Vapor Deposition (CVD), Photolithography, Etching, Physical Vapor Deposition (PVD), Polishing, Process Diagnostics and Control (Metrology), and Cleaning.

FSG: Fluorine-doped Silicate Glass is a reduced dielectric constant (k=approximately 3.5) material made by doping SiO_2 with fluorine.

Gate: An electrode that adjusts the flow of current in a metal oxide semiconductor transistor.

Gate Stack: The gate/oxide structure in a MOSFET/CMOS.

Geometry: A circuit line or etched feature on a chip.

Hard Mask: A hard nitride layer deposited on top of a polysilicon gate, increasing the adhesion of the resist at edges.

High Density Plasma (HDP): A plasma featuring a high concentration of free electrons, and hence, a high concentration of ions.

High Density Plasma Chemical Vapor Deposition (HDPCVD): A CVD process that incorporates high-density plasma.

High Temperature Oxide (HTO): A high temperature process that deposits an oxide layer on a wafer.

Implant: An abbreviation for ion implantation

Indium Tin Oxide (ITO): A transparent, conductive material often used when creating thin-film solar cells.

Insulator: Nonconductive dielectric films used to isolate electrically active areas of the device or chip from one another. Some commonly used insulators are silicon dioxide, silicon nitride, borophosphosilicate glass (BPSG), and phosphosilicate glass (PSG).

Integrated Circuit (IC): A fabrication technology that combines components of a circuit on a wafer.

Interconnect: The wiring in an integrated circuit that connects the transistors to one another.

Interlayer Dielectric (ILD): Films used between metal layers of an IC for insulation.

Intermetal Dielectric (IMD): Insulating films used between adjacent metal lines; typically silicon dioxide.

Ion Implantation: A process technology in which ions of dopant chemicals (boron, arsenic, etc.) are accelerated in intense electrical fields to penetrate the surface of a wafer, thus changing the electrical characteristics of the material.

Junction: The interface between two semiconductor regions of differing dopant types. Usually refers to a p-n junction, at which the conductivity semiconductor changes from p-type to n-type.

Lattice: An orderly arrangement of atoms in the crystal wafer.

Layering: A process of depositing thin layers of metal or insulators onto a wafer during the wafer fabrication process using deposition and oxidation techniques.

Linewidth: The width of a metal interconnect.

Liquid Crystal Display (LCD): A type of flat panel display that uses an array of backlit thin film transistors to control a display process.

Litho Enabling: A set of processes that enhance the lithography process.

Lithography: The transfer of a pattern or image from one medium to another, such as from a wash to a wafer.

Load Locks: Isolation chambers that allow a process chamber to be protected from ambient conditions.

Low k: A dielectric material having relatively greater insulating ability than silicon dioxide (SiO_2), usually with a k<3.5.

LPCVD: Low Pressure CVD refers to systems that process wafers in an environment with less than atmospheric pressure. LPCVD systems may be furnaces that process wafers in batches, or single-wafer systems.

Mask: A flat plate that is used to transfer desired geometries for one process layer onto the surface of a wafer.

Material Control System (MCS): A computer-controlled system that controls the flow of physical items in a manufacturing environment.

MEMS: Micro Electrical Mechanical System. These are mechanical devices fabricated with semiconductor technology. MEMS are considered electronic components. MEMS technology is used to make sensors and other components.

Metallization: The deposition of a layer of high-conductivity metal (such as aluminum) used to interconnect devices on a chip by CVD or PVD. Metals typically used include aluminum, tungsten and copper, etc.

Metrology: The science of measurement to ascertain dimensions, quantity, or capacity; the techniques and procedures for using sensors and measurement equipment to determine physical and electrical properties in wafer processing.

Micron (µm or micrometer): A unit of length; one-millionth of a meter or about forty-millionths of an inch. A human hair is approximately 100 microns wide.

Microprocessor: An integrated circuit that contains the basic arithmetic, logic and control circuitry required for processing.

Monocrystalline Silicon: A type of silicon that has a single and continuous crystal lattice structure with almost no defects or impurities.

Multicrystalline Silicon: A type of silicon that is cast into ingots using grains of monocrystalline silicon. The ingots are then sliced into wafers and used in the manufacturing of microchips and photovoltaic cells.

Nanomanufacturing Technology: Solutions for the semiconductor manufacturing industry that are focused on dimensions smaller than 100nm.

Nanometer (nm): A unit of length; one billionth of a meter.

NMOS: An n-channel MOS transistor; in an NMOS device the channel is negative during conduction.

Nucleation Layer: A thin layer of film that promotes the growth of the subsequently deposited film.

Organic Light Emitting Diode (OLED): A mechanism of light emission where radiation is emitted as a result of electron-hole interactions in a thin film organic semiconductor, leading to the formation of exciton; de-excitation of excitons results in photon emission.

Passivation: The final layer in a semiconductor device that forms a hermetic seal over the circuit elements. Plasma nitride and silicon dioxide are the materials primarily used for passivation.

PECVD: Plasma Enhanced Chemical Vapor Deposition is a process where plasma is used to lower the temperature required to deposit film onto a wafer.

Perflourocompound (PFC): A class of gas byproducts created in the manufacturing of semiconductors. PFCs are most commonly seen in CVD processes and can be reduced by an abatement solution.

Phase Shift Mask (PSM): A conventional mask that phase shifts the light passing through transparent portion of the mask. Phase shifting increases resolution of the pattern transfer with destructive interference, preventing resist exposure in the regions in which it should not be exposed.

Photolithography: A process by which a mask pattern is transferred to a wafer, usually using a "stepper."

Photoresist: A light-sensitive organic polymer that is exposed by the photolithography process, then developed to produce a pattern, which identifies some areas of the film to be etched.

Photovoltaic: A process where sunlight is converted to electricity.

Planarization: The process by which an uneven wafer surface is made relatively flat using a low-selectivity etch.

Plasma Display Panel (PDP): A type of flat panel display where visible light is created by phosphors excited by the discharge of an inert mixture of noble gases (typically neon and xenon).

Plasma: Ionized gases that have been highly energized—for example, by a radio frequency energy field.

PMD and Contact: The area of a semiconductor transistor that is made up of the pre-metal dielectric and contact plug.

PMOS: P-channel MOS transistor where the active carriers are holes flowing between p-type source and drain regions in an electrostatically formed p-channel in an n-type silicon substrate. The channel, the source, and the drain are made of a p-type semiconductor material. (HWDI series)

Polycide: A material formed by reaction of polysilicon with a metal.

Polysilicon (Poly): Polycrystalline silicon; extensively used as conductor/gate materials in a highly doped state. Poly films are typically deposited using high-temperature CVD technology.

Post Nitridation Anneal (PNA): An RTP process used within the creation of the gate stack.

Pre-metal Dielectric (PMD): Films that insulate between the wafer and first metal layer.

Process: A group of sequential operations in the manufacturing of an integrated circuit.

Process Chamber: An enclosed area in which a process-specific function occurs during wafer manufacturing.

Process Integration: Optimizing each process step to work correctly with the prior and subsequent steps in a sequential process flow.

PVD: Physical Vapor Deposition (also called sputtering) is a process technology in which molecules of conducting material (aluminum, titanium nitride, etc.) are "sputtered" from a target of pure material, then deposited on the wafer to create the conducting circuitry within the chip.

Radio Frequency (RF): Electromagnetic energy with frequencies ranging from 3 kHz to 300 GHz.

Reactive Ion Etch (RIE): A combination of chemical and physical etch processes carried out in a plasma.

Reticle: A flat, transparent plate, used in a stepper that contains the photographic image of wafer patterns to be reproduced on a wafer.

RF Generator: A device that creates radio frequency, often used to create plasma within the semiconductor industry.

RTP: Rapid Thermal Processing is a process in which a wafer is heated to a specified temperature for short periods of time.

SEM: A scanning electron microscope is a device that displays an electronically scanned image of a die or wafer for examination on a screen or for transfer onto photographic film.

Semiconductor: A material whose electrical conductivity is intermediate between that of metals (conductors) and insulators (non-conductors) and can be modified physically or chemically to increase or decrease its conductivity from a "normal" state by "dopants."

Sensors: Devices that detect some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing. Sensors can be manufactured using semiconductor materials and manufacturing processes or non-semiconductor materials. This report does not cover the non-semiconductor sensors.

Shallow Trench Isolation (STI): The STI isolates each transistor from its adjacent transistor in order to prevent current leakage. Traditionally this isolation was accomplished with a LOCOS (localized oxidation of silicon) field oxide process.

Silane (SiH_4): A gas that readily decomposes into silicon and hydrogen, silane is often used to deposit silicon-containing compounds. It also reacts with ammonia to form silicon nitride, or with oxygen to form silicon dioxide.

Silicide: A film compound of silicon with a refractory metal. Common silicide semiconductor films (used as interconnects) include tantalum, tungsten, titanium and molybdenum.

Silicon: A brownish crystalline semi-metal used to make most semiconductor wafers.

Silicon Dioxide (SiO_2): The silicon/oxygen film most often used for dielectric applications; can be deposited via silane or TEOS; often called "oxide."

Silicon Nitride (SiN): A silicon/nitrogen film dielectric deposited using plasma-enhanced or LPCVD.

Silicon-on-Insulator (SOI): A silicon wafer with a thin layer of oxide (SiO_2) buried in it. SOI substrates provide superior isolation between adjacent devices in an integrated circuit as compared to devices built into bulk wafers.

Sputtering: A method of depositing a film of material on a desired object.

Stepper: Equipment used to transfer a reticle (mask) pattern onto a wafer.

Strain Engineering: Processes used in semiconductor manufacturing that introduce stress into the underlying silicon structure by either compressing or expanding the silicon lattice structure, enabling electricity to move more easily through the transistor, increasing transistor performance.

Substrate: A wafer that is the basis for subsequent processing operations in the fabrication of semiconductor devices.

Thin-Film Transistor (TFT): A metal-oxide-semiconductor field effect transistor manufactured with thin film technology. It typically uses thin films such as polycrystalline or amorphous silicon with a variety of insulating substrates. Used primarily in the manufacturing of active matrix LCDs.

Throughput: The number of wafers per hour through a machine, assuming 100% equipment uptime and a fully-loaded machine.

Topography: Refers to the layering of features on a device structure causing contours on the surface. The degree of flatness and/or smoothness is very important in wafer fabrication.

Track: A track-like set up which integrates several instruments needed to process photoresist (deposition, soft bake, exposure, developing, hard bake) in advanced semiconductor manufacturing.

Transistor: An electronic device that controls current flow and serves as the basic element of a computer chip. It consists of three terminals: a source, a gate, and a drain. Applying a voltage to the gate controls current flow between the source and the drain.

Trench: A groove etched in a wafer to be used as part of a device structure.

Trench Capacitor: A capacitor built into an etched trench on the semiconductor substrate. The capacitance can be increased without increasing the area on the wafer needed to form the capacitor.

Tungsten: A refractory metal used as an interconnect material.

Ultra-shallow Junction (USJ): An area of semiconductor manufacturing that is focused on reducing the junctions on the silicon substrate through ion implantation and rapid thermal processing.

Ultraviolet (UV): The invisible part of the light spectrum with wavelengths between 250 to 400 nanometers.

Vias: Holes through dielectric layers, opened by etching. Metal will be deposited in the via to form a plug and create an interconnect between two metal lines.

Wafer: The thin, circular slice of pure silicon on which semiconductors are built.

Wafer and Mask Metrology: An area of semiconductor manufacturing that is focused on ensuring the consistency and success of a microchip through automated systems.

Wet Clean: A process for cleaning patterned wafers using a liquefied cleaning solution between process steps.

Yield: The percentage of wafers or die produced in a process that conforms to specifications.