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Glistening particles of industrial silver

A report prepared for The Silver Institute

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Executive Summary

This report seeks to identify and understand new trends in silver demand across different sectors and regions with a focus on the recent developments in silver industrial applications, particularly those driven by technological innovation.



Silver-oxide battery



Medical care



Bearings



Laptop batteries



Solar cells

Silver in established industrial applications

Silver in new industrial applications



Brazing alloys/solders



Silver catalyst



Electrical contacts



Nanosilver



RFIDs

Source: CRU Consulting

From watch batteries to massive solar energy systems, the special properties of silver are often indispensable in industrial applications, including silver coated bearings, catalysts, medical care and many products in our daily lives. Along with technological improvements, more and more applications of silver have been invented, and more importantly, commercialized; such as nanosilver, solar cells and printed inks. In this paper, we will look at demand for silver in the following selected industries:

- Batteries
- Ethylene oxide (EO)
- Anti-bacterial uses
- Bearings

Silver-containing **batteries** have long been an established industrial application of silver. Thanks to new technologies, these batteries have now expanded from the traditional usage in military and aerospace applications to everyday use, especially in developed countries, but

increasingly within developing countries. CRU Consulting expects silver consumption in batteries to reach 36 Moz in 2018, up 13% from 2013.

In the **EO** industry, silver catalysts help combine ethylene and oxygen into EO which is widely used in a variety of products from anti-freeze to cosmetics. As the global EO capacity increases rapidly, silver demand for EO applications will continue to grow by 21% to 63 Moz by 2018 compared with the 2013 level.

Considering silver applications in our daily lives, we cannot overlook the critical development of **nanotechnology**, from silver coated medical equipment, food contact materials and textiles to potentially many more novel applications as the technology develops. Nanosilver uses a miniscule amount of silver per application and the potential volume should not be over-estimated. It is still a minor component of overall silver volumes, comprising 8-10 million ounces of silver in a market that has over a billion ounces a year of supply and equal demand. The nanosilver market has expanded from North America and Europe to many developing economies, such as China and other Asian Pacific countries and supports an expanding market in the long run. This supports a bullish outlook for silver demand in this application in the long run, reaching 12 Moz by the end of forecast period vs. 9 Moz in 2013

In **bearings**, silver bearing liners have long been providing safety and longevity to jet engines and heavy-duty equipment. Supported by a resurgent construction industry, demand for silver coated bearings is expected to grow in parallel with these markets in the short to medium term. CRU estimates this sector to consume between 2 and 3 Moz by 2018.

In addition, we will also highlight some other industrial applications with high growth potential, including photovoltaic (PV), automotives, brazing alloys/solders and printed inks. We will look at how increasing **PV** capacities worldwide support silver consumption in the coming years despite decreasing unit consumption. CRU Consulting expects silver consumption in PV industry will rise by 19% to 109 Moz by 2018.

Another promising market for silver demand is **automotives**. In particular, accelerating automotive production in China and India has and is expected to continue to boost the demand for silver-coated contacts in these countries, driving silver consumption in this sector at a CAGR of 4.6% to reach 71 Moz in 2018. The growth rate is slightly slower than 4.9% in the period of 2008-2013 as the Chinese economy is expected to slow down.

In the **brazing alloys/solders** sector, demand for silver is driven by industrial activity and is expected to benefit most from the gradual recovery of housing and infrastructure both in developed regions and developing economies.

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Printed silver inks are a relatively new technology that has not yet been fully commercialized. One application, within radio frequency identification devices, has already been accepted by the market but another application in the printing of electric circuits, is still at a trial stage.

Overall, CRU is generally optimistic with regards to silver demand for industrial applications. Although silver consumption in industrial sectors has experienced a slowdown in the past two years, it is expected to rally from 2014 on the back of a continued recovery of the global economy. Moreover, along with technology innovation, new applications of silver will continue to emerge.

CRU Consulting forecasts that the silver consumption in other industrial sectors will increase by a CAGR of 4.5% to 386 Moz by 2018 supported by Automotives, PV and EO industries.

The table below summarizes our forecast increase in silver consumption from these industrial applications. Also included below is our estimate of the risks and opportunities for these different sectors.

Thrifting risk: for some applications the technology continues to drive the intensity of use down and hence although the number of units utilizing silver may be rising strongly, the quantity of silver per unit is being driven down.

Technology reliance: the confidence of the forecast is reduced when there is a high reliance on the continued development / acceptance of technology associated with applications.

Opportunity: This represents CRU Consulting's estimate of the markets where the opportunities may be highest for over performance in terms of silver consumption.

Table E1: Silver consumption in other industrial sectors, 2013 and 2018F, Moz

	Consumption 2013	Consumption 2018F	CAGR 2013-2018	Thrifting risk	Technology reliance	Opportunity
Batteries	32	36	2.7%	M	H	M
EO	52	63	3.9%	M	M	H
PV	88	109	4.4%	H	H	H
Automotives	56	71	4.9%	L	M	H
Brazing & Alloys	70	88	4.7%	L	M	M
Bearings	2	3	8.4%	L	M	L
Printed silver inks	2	4	14.9%	L	M	L
Others (medical, w water purification)	9	12	5.9%	L	L	L
Total	310	386	4.5%	–	–	–

Data: The Silver Institute, CRU Consulting

Notes: H-High, M-Moderate, L-Low

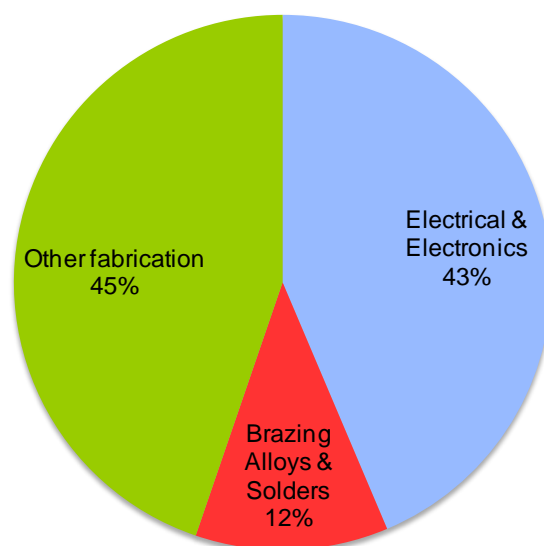
Notes: 2013 consumption data based on the Silver Institute data. Totals may not match individual figures due to rounding.

Chapter 1 – Introduction

Silver, a soft, white and lustrous metal, is usually found in native form as an alloy with other metals and in minerals, such as argentite and chlorargyrite. Among all metals, its malleability and ductility offer high levels of optical reflectivity as well as excellent thermal and electrical conductivity.

With these unique properties, silver is seen both as a precious and an industrial metal and its consumption can be categorized into the industrial, investment and jewelry/decor sectors. Over the past decade, physical silver demand has seen strong growth, of which industrial demand for silver has contributed the largest share. Between 2004 and 2013, total physical demand for silver grew from 917 Moz to 1,081 Moz, with industrial fabrication (note that CRU has excluded photography from our industrial fabrication numbers) demand accounting for roughly half of the total. In 2013, the sluggish global economic recovery along with further substitution and thrift had a negligible impact on silver industrial fabrication demand globally. Industrial fabrication (excluding photography) consumption in 2013 was 536 Moz, effectively flat compared to 2012, though this still constituted over half of the global demand for physical silver.

Share of different industrial fabrication demand, 2013

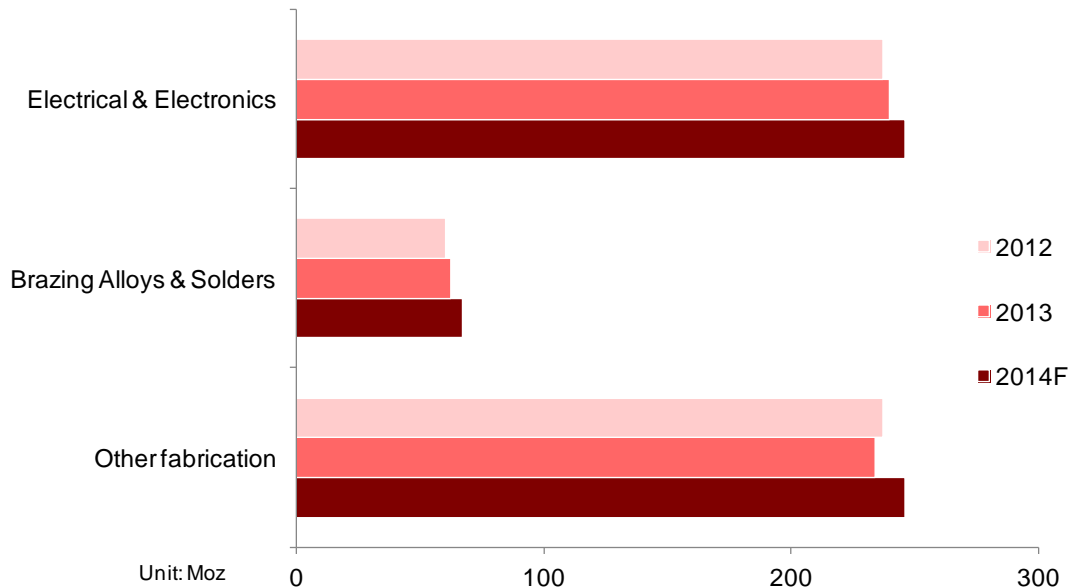


Data: The Silver Institute

The electrical and electronics sector accounts for the largest share of total industrial fabrication demand, as silver has a wide range of applications in this sector, ranging from consumer electronics to automobiles. The brazing alloys and solders sector has also contributed to the increase of silver demand as demand correlates strongly with world GDP growth. Losses from the photography sector have been offset by increasing demand from other sectors as well as new

applications, such as silver-zinc batteries, clothing and hygiene industries. As a result of the ongoing recovery of the global economy and continuous technology development of silver applications, industrial demand for silver is expected to rally in the coming years. It is forecast that total silver consumption in industrial fabrication in 2014 will be 4.4% larger than in 2013.

Silver industrial demand by sectors



Data: The Silver Institute, CRU Consulting

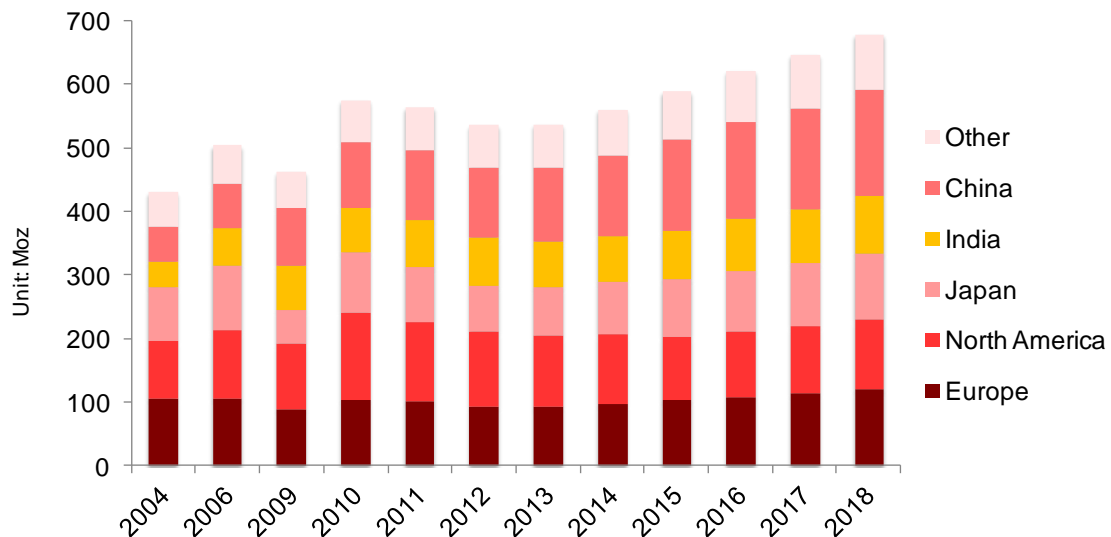
This growth will be partly due to the expansion and commercialization of applications in a variety of new territories. Accordingly, we will focus on future demand for silver in technological applications in the industrial sector, such as photovoltaic (PV), pharmaceutical, brazing and solders, electrical and electronics, ethylene oxide catalysts (EO), automobiles and several niche applications using nanotechnology, including printed inks and biocides. Although they use small amounts of silver per application, they have the potential to be rolled out extensively and positively impact silver demand.

It is worth observing how silver industrial demand (excluding photography) can shift among its key geographic locations. Over the past decade, the most significant change was the shift of silver demand towards the emerging markets, particularly in China. In 2004, while silver industrial demand in Europe reached 105 Moz, China consumed merely 56 Moz. In contrast, when demand in Europe fell to 91 Moz in 2013, Chinese industrial consumption had increased to 117 Moz. This shift has not only been driven by market evolution over time but also technology innovations. Increasing demand for silver in solar panels, automobiles and in anti-bacterial applications has influenced consumers in developed and developing countries to different degrees.

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We will observe how the silver market has evolved by timeline and region in Chapter 2. Technological demand varies across continents, not only in its intensity but also by its precise applications. In Africa, we note that car ownership has been increasing significantly, whereas in China, silver has been used not only in a wide range of auto sector applications but also anti-bacterial and military uses.

Silver industrial demand by region



Data: The Silver Institute, CRU Consulting

In Chapter 3, we will focus on four selected markets with high expectations: batteries, EO, anti-bacterial and bearings. In particular, we will consider demand elasticity, substitution effects and scenarios for each market. Industrial demand for silver is less price-sensitive than, for example, the jewelry sector, but it is still influenced by price volatility. How silver prices and volatility affect potential growth and substitutions need to be investigated in order to understand how silver demand develops in the future. We will also discuss the main drivers of demand growth and fundamental shifts.

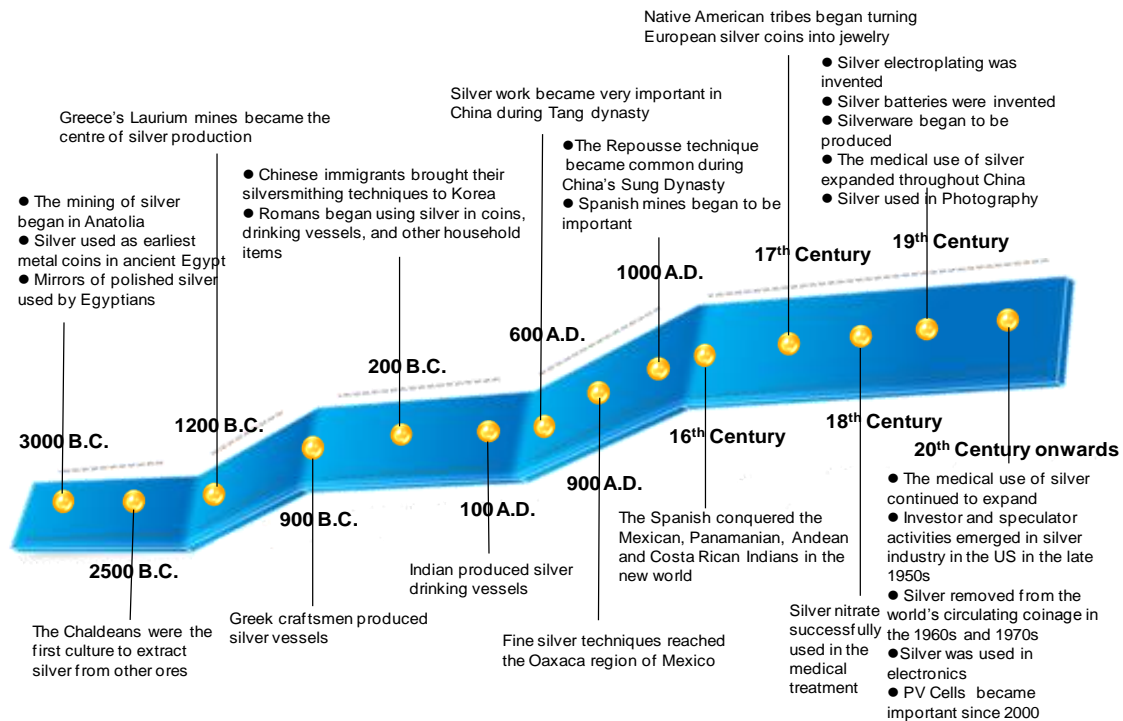
Finally, we will highlight some other important silver applications within the industrial sector. Silver has started gaining momentum in some key markets, such as PV. Other markets, such as automotives and printed inks, still have potential in driving silver demand. The upside potential of silver use in these applications will also be discussed.

Chapter 2 – Silver market evolution

2.1 The development of silver demand

Silver has been used for thousands of years in vessels, silversmith ware, jewelry, and as a basis for monetary systems of many nations throughout history around the world. Electrum, a natural alloy of gold and silver, was used as the earliest metal coins in ancient Egypt as early as the 3000 B.C. In China, silver was firstly used as an official currency during the Han dynasty (206 B.C.-220 A.D.). In 1794, the first official U.S. silver dollar was minted. As introduced earlier, silver has a variety of usages today and considered as a store of wealth by investors. The chart below maps the usage development of silver over time.

The development of silver demand



Source: CRU Consulting

Many technologies we use today have long histories. The US and European countries led silver application technologies through history, and then technologies spread to Asia, Africa, and South America. It is reported that nanosilver was first synthesized in 1889. In the early 20th century, the commercial sale of medicinal nanoscale silver colloids began under different names such as Collargol, Argyrol, and Protargol, and their uses became widespread over a 50-year period in the US. These nanosilver products were used to treat various diseases, such as syphilis and other bacterial infections, and were sold as over-the-counter medications across the world. In addition, nanosilver products can also be used as a biocidal in swimming pools.

Just after 1900, Johnson Matthey began to produce experimental silver solders for its silversmith customers. In 1932, silver solders began to be sold in America. During the 1930s,

silver brazing became an established process in Europe. Demand for brazing alloys and electrical contact materials grew dramatically during the World War II, driving companies such as Johnson Matthey to develop many new products, including a cadmium-free silver brazing alloy. More recently, silver soldering became a substitute to traditional tin-lead soldering after the Restriction of Hazardous Substances Directive came into effect in July 2006 which restricted the use of six hazardous materials in the manufacture of electronic and electrical equipment, namely lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers.

Although Alessandro Volta invented the first battery using silver and zinc as the electrodes at the beginning of the 19th century, silver batteries were not developed until military requirements for high energy density batteries emerged in the 1940s. Silver batteries are now used in a wide range of applications in everyday life all over the world, such as watches, calculators, electronics, photography, etc. Japan is now one of the world's biggest battery producers, with silver batteries accounting for over 20% of all primary battery sales in Japan in 2013.

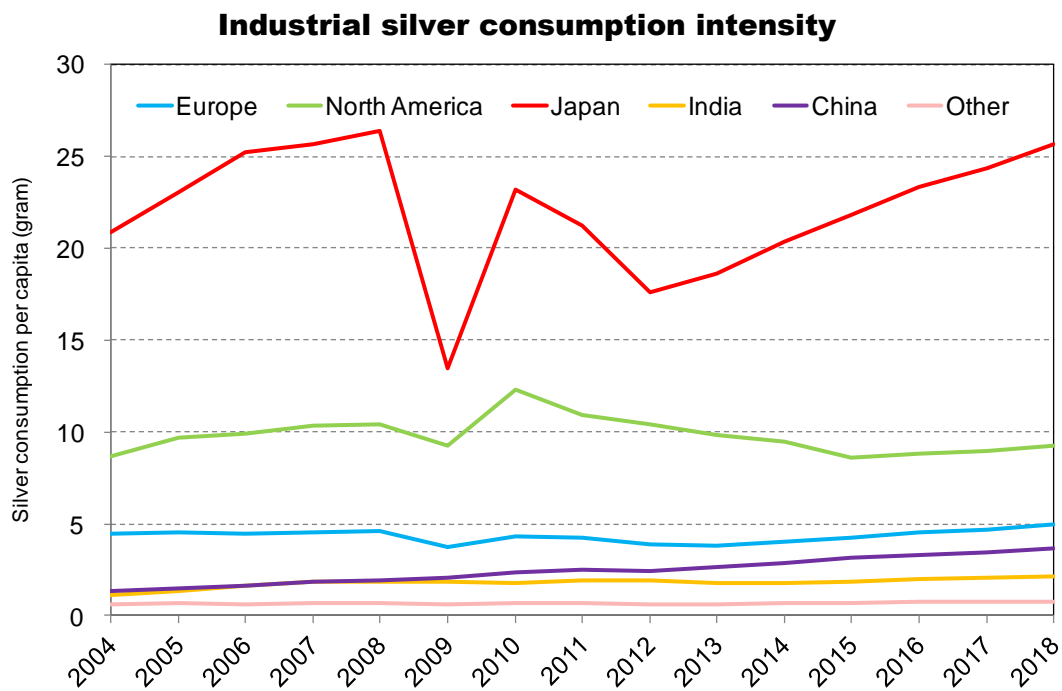
Silver bearings, as with silver batteries, were developed in the 1940s for high performance military aircraft engines. Silver bearings are used extensively throughout the heavy industries where superior resistance to corrosion and fatigue is needed. The ethylene oxide (EO) industry emerged as an important end use sector in the mid-20th century. Silver catalysts used in the oxidation of ethylene were initially discovered by French chemist Theodore Lefort in 1931. Together with the demand growth of polyester, the EO industry experienced rapid growth during the second half of the 20th century. Developed regions like the US, Japan and European Union dominated the EO industry until the 1980s, but then the center of the industry shifted to the developing regions, such as Middle East and China.

More and more industrial silver end-use sectors have become established in recent years. One in particular is the PV industry, which has developed into a promising end-use sector since 2000. Germany was a leading consumer from 2000 to 2012 due to increasing installed PV capacities. Silver consumption in this sector rose by an average of nearly 50% per year between 2000 and 2008, reaching 19 Moz by 2008 and exceeding 47 Moz in 2012. The largest end user of solar panels in 2012 was Germany. Unsurprisingly, the future of PV demand doesn't rely on Europe but on the emerging giants, like China, who generated about 54% of global silver PV demand in 2012. Growth rates will be tempered by increased efficiency in the silver contained products driven by cost reduction pressures. These forces have already started reducing unit consumptions of silver per installed gigawatt of solar power.

Per capita silver consumption has changed dramatically across continents over the last decade. Specifically, Chinese silver consumption per capita has increased by 281% since 2000; while

the per capita consumption in the developed regions has matured during the same period of which Europe, North America and Japan declined by 3.9%, 0.8% and 3.6% respectively.

The chart below shows per capita silver consumption over time, with a forecast to 2018. As a whole, silver consumption intensities are higher in the developed regions, such as Europe, Japan and North America. Although developing economies have lower per capita consumption, many regions have been accelerating during the past decade. Still, we expect the developed regions to remain higher intensity in the coming years while China has a much faster growing rate with the silver consumption intensity reaching 3.6 gram per capita in 2018 soaring 28.3% compared to 2014. Furthermore, Japan’s consumption intensity is forecast to rise to 25.7 gram per capita on a combination of recovering silver demand supported by electrical and electronics sector and declining population between 2014 and 2018. CRU Consulting expects thrifting and substitution away from silver usage in the electrical and electronics sector to slow down. This means that increasing demand for electronic and electrical devices should translate to increasing use of silver. With the economy recovering after European debt crisis, Europe is also expected to be in positive growth territory given growing demand in the electrical and electronics and brazing alloys and solders sectors.



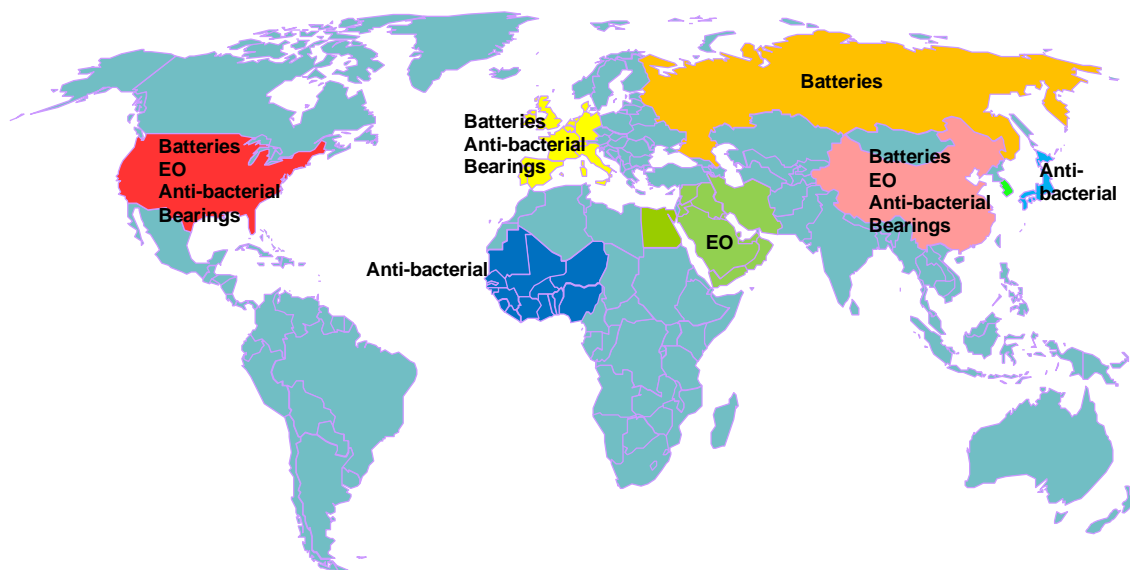
Data: The Silver Institute, CRU Consulting

Looking ahead, we are bullish on the industrial applications of silver, which will support the total silver demand in the long run. As technologies develop, a variety of new applications are emerging that have the potential for mass consumption, bringing with them prospects for augmenting industrial silver demand. CRU Consulting forecasts that the industrial applications of silver (excluding photography) will increase from 535 Moz in 2013 to 677 Moz in 2018 with the electrical and electronics sector contributing 66 Moz to this growth.

Chapter 3 – Markets with high expectations

In this chapter, we will discuss four selected markets for silver with high expectations: batteries, EO, anti-bacterial uses and bearings. We will particularly focus on the growing regional markets highlighted in the map below.

Potential growing regions for silver demand



Source: CRU Consulting

3.1 Silver in batteries: from specialized areas to mainstream markets

Silver oxide-zinc system batteries (or simply ‘silver-oxide’ batteries), first commercialized in the 1960s, are a major contributor to miniature power sources. A silver-oxide battery, which uses silver oxide as the positive electrode and zinc as the negative electrode, is a primary cell with a very high energy to weight ratio. Silver-oxide batteries can take the form of small-sized button cells which are used in hearing aids, photographic applications, toys, medical instruments, watches and other low power devices; or large cells for military applications, including missiles, torpedoes and submarines. Notably, traditional silver-oxide batteries are non-rechargeable and as silver prices increased in recent years, they have been substituted by other batteries in many areas.

A second type of silver-containing battery - silver-zinc batteries - also has a wide range of applications. Silver-zinc batteries are rechargeable secondary batteries which share most of the

characteristics of the silver-oxide batteries. These cells are able to deliver one of the highest specific energies of all presently known electrochemical power sources, making it widely used in high energy density applications. However, the cost of large capacity silver-zinc batteries is extremely high because of the silver content and therefore they are mostly used in aerospace and military applications where the superior performance of the battery outweighs the cost of manufacture, typically in spaceships, satellites and rockets. CRU Consulting expects the cost of silver-zinc batteries to decline in the coming years which could help to slow down thrifting and substitution effects; and boost demand.

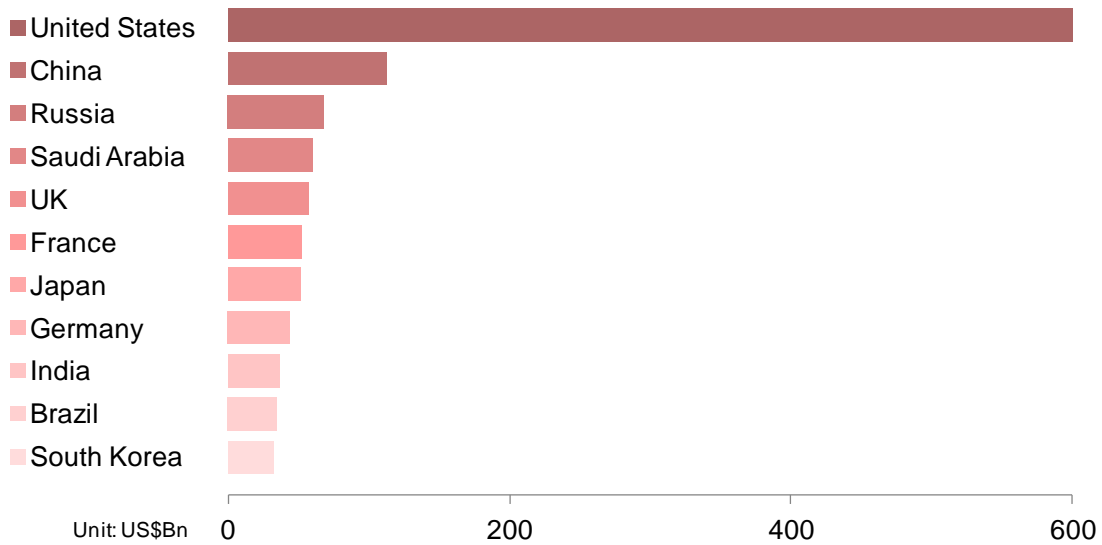
In order to target mainstream markets, silver-zinc batteries have developed into smaller units applicable to applications where lithium-ion technology cannot be accommodated. Compared with lithium-ion batteries, silver-zinc batteries can store about 30-40% more energy in the same volume and are much safer and environment-friendly. Recently, a new type of portable batteries, particularly designed for hearing aids and wearable electronic devices, were released by a US producer. Their aim is to provide at least 50% of all rechargeable hearing-aid batteries globally in the coming five to ten years, which will utilize silver consumption in small batteries.

At present, most portable electronic devices, such as smart phones, tablets, and laptops use lithium ion batteries and face the problem of power endurance, as their battery lives shorten with frequent recharges. Although silver-zinc batteries are more expensive than lithium ion ones, they are fully recyclable so that initial high costs can be mitigated. However, silver-zinc batteries also have relatively short cycle lives, typically less than 100 cycles per battery. Once the scientists break through this technology bottleneck, silver-zinc batteries are expected to replace lithium ion batteries in many expensive electronic devices. As yet, the technology remains unproven on a commercial scale. ZPower, a company based in the US, was the first to develop rechargeable silver-zinc batteries which have already been used in hearing products and they remain bullish about the commercialization of this battery technology and are backed by Intel. We are reasonably bullish about silver demand in batteries which, although facing a technological risk, has upside potential. Demand is estimated to reach up to 15 Moz per year by 2018.

Another positive prospect for silver-contained batteries demand comes from increasing demand from military hardware. Silver-zinc batteries used for military purposes tend to be one-time use, as they are impossible to recycle. The US and UK have been discussing the planned deployment of a missile defense system for Eastern Europe and considering other regional geopolitical and strategic factors, a handful of countries have been looking to invest in more sophisticated missile defense systems. Additionally, many missiles and missile-defense systems globally are approaching the end of their life cycles or are nearly obsolete. This is expected to

bolster demand for missile defense replacements and upgrades even without the specter of regional military conflicts.

Major countries' defense budget in 2013



Data: International Institute for Strategic Studies (IISS), CRU Consulting

The chart above shows the defense budget of major countries in 2013. The global total defense budget in 2013 was \$1,538 billion. China's defense budget is estimated to reach \$132 billion in 2014; Russia's budget is planned to increase by more than 10% year-on-year for the next three years, and Japan also aims to lift its budget by about 2.8% in 2014. Similar expansions are expected to happen to India, Saudi Arabia and South Korea. With robust growth of national defense budgets, more expenditure will be spent on defense systems and missile weapons, which in turn will boost the demand for silver-contained batteries.

3.2 Silver in EO: stable increase to continue

A fast-growing industry that consumes silver is the production of ethylene oxide (EO). EO, a chemically reactive material, is primarily used as an intermediate in the production of ethylene glycol (76%) and ethoxylates for surface active agents (14%) and other applications (10%). During the production process, silver works as a catalyst that helps combine ethylene and oxygen into EO. Although catalysts are unaffected by the reaction they support and are therefore almost completely recoverable after being used, the EO capacity is forecast to continue to grow.

EO products are widely used in the production of anti-freeze, polyester, heat transfer liquids, gas dehydration, solvents and many daily products, such as cosmetics, pharmaceuticals, lubricants, soaps, detergents, gas purification, emulsifiers and dispersants. Imagine a sportsman training in his favorite track suit with his lightweight unbreakable bottle - all of these items contain or require silver in their production. A small yet important amount of EO is consumed

in the sterilization of healthcare products and medical supplies, such as bandages. Demand for silver has grown continuously in the past decade along with the development of the EO industry. According to IHS, a leading market and information provider, current global EO capacity has reached over 26Mt, which means the consumption of silver catalysts is around 53-56 Moz per year.

Demand for EO is mainly driven by the Asia-Pacific region, Middle East, Latin America and Central Europe. Asia-Pacific is the largest consumer of EO, supported by rapidly increasing demand for polyester fibers. China is at the forefront of the Asia-Pacific region and is expected to see robust growth both in demand as well as production in the next few years, thanks to the rapid development of surfactants and polyester sectors. In contrast, EO consumption in North America, Japan and Europe has started showing signs of maturity. Notably, a demand risk exists in spent catalyst recycling. Usually EO plants replace the catalysts every two or three years, and spent catalysts will be recycled. When silver prices rise rapidly, plants are inclined to extend the service life of the catalysts, even if the efficiency of catalysts drops.

Production of EO is concentrated in the Middle East, China and the United States. These three regions account for about 80% of total world capacity. Shell is one of the leading EO process licensors with production units in Singapore, the US, Canada and Netherlands. Other top players of global EO industry include Dow Chemical Company, BASF, SINOPEC Corp., Honam Petrochemical Corp, etc. In the next few years, Asia-Pacific and the Middle East are expected to witness a rapid increase in EO capacity. Total EO capacity in China is expected to reach 7.6Mt by the end of 2017, adding another 6 Moz of demand for silver catalysts. Several big players in the Middle East have also announced expansions and plans for new plants. North America also expects to see increasing EO capacity with a number of planned large scale ethylene and derivatives (including EO) plants. For example, Shell is considering constructing a new crude EO unit in Louisiana, United States; INEOS, a petrochemicals producer, has also confirmed that it is considering plans to expand its EO capacity as part of its strategy to grow its global business over the next few years.

Table 3.1: Announced expansion plans of major EO producers

Company	Expansion plan	Estimated silver consumption	Start-up date
Shell	To build new petrochemicals production units on Jurong Island with High-purity EO capacity 140,000 tpy in 2013	0.32 Moz	2014
	Joint venture with SABIC to expand various projects at the Saudi Petrochemical Company (Sadaf)	–	Unknown
Dow Chemical Company	Joint venture with Saudi Arabian Oil, to build a 300,000 tpy of EO plant in Middle East	0.7 Moz	2016
BASF	Joint venture with Sinopec to expand 50,000 tpy capacity existing Chinese EO plant	0.12 Moz	2015

Data: Shell, The Dow Chemical Company, BASF and CRU Consulting

As global capacity for EO grows continuously, demand for silver catalysts will keep a steady upward trajectory in the next five years. In addition, more and more EO plants are installed with silver catalysts, especially the newly added capacities in developing countries, which will lead to a robust demand for silver catalysts. CRU expects annual silver consumption in EO to reach 63 Moz by 2018, up from 52 Moz in 2013.

3.3 Silver in anti-bacterial uses: supported by new technologies

Usage of silver in anti-bacterial applications has a long history and can be traced back to ancient times. The Phoenicians stored water and other liquids in silver coated bottles to discourage contamination by microbes. Silver dollars used to be put into milk bottles to keep milk fresh. Out of all the metals with antimicrobial properties, silver has the most effective anti-bacterial action and the least toxicity to human cells, so it is unsurprising that silver is commonly used to deter bacterial growth in a variety of medical applications as well as in our daily lives, including wound and burn care, consumer appliances, water purification, food packaging and so on.

Silver can also be used as a biocide in hospitals and other health care facilities to help reduce or remove the presence of antibiotic-resistant ‘superbugs’. Small amounts of silver can coat hospital surfaces and medical equipments to prevent the spread of pathogens. A technology emerging during the 21st century has permitted the production of silver on a very small scale, one nanometer (nm); equivalent to a billionth of a meter. The far higher surface area of nanoparticles greatly enhances reactivity, making it more suitable for long-term anti-bacterial applications. Silver is now used in hospital equipment such as water systems, catheters and almost all equipment in operating theatres, including surgical threads and bandages. Silver bandages have been widely used in the US and Europe to treat burns, prevent infections and promote healing. In developing countries, such as China, these bandages are still rare due to a lag in technology. Governments are now encouraging R&D on silver containing dressings; CRU expects to see such bandages capturing a much larger share of global demand in the near future.

Antimicrobial products bring benefit to millions of consumers every year. Products such as plastics, textiles, and cosmetics last longer and provide better value for money and increased utility to consumers. This is a market that has been served by many different synthetic and inorganic materials over multiple decades, only a small portion of which is served by silver additives, of which nanosilver is just one form.

Antimicrobial treatments can bring a number of functionalities to consumer articles, including longer shelf life (e.g. cosmetics) giving more safety, less waste and ultimately lower prices for consumers; plastics that are protected against the degrading action of bacteria (e.g.

discoloration); and textiles that are protected against colonization of bacteria that can lead to odors (e.g. sports clothing), ultimately giving greater comfort and prolonged use. Additional benefits such as reduced washing frequency at lower temperatures can give significant water and energy savings. Antimicrobial treatments, of which nanosilver represents less than 0.1% of the numerous materials available for this purpose, therefore serve a broader purpose giving benefits to numerous consumer goods every day.

Although nanotechnology has made silver popular in everyday life, the increasing usage of nanosilver in anti-bacterial applications has aroused concern over its impact on the environment and human health. The assessment of risk is a balance between potential for harm (toxicology) and exposure. An analysis of exposure patterns for nanosilver would reveal that most products employ minuscule amounts of nanosilver (tens of parts per million by weight of treated article) and in all cases this is employed in forms that are bound and secured in plastic matrices and/or coatings. Nanoparticles cannot exist as discrete particles, since they will agglomerate and they therefore need to be in a matrix to allow them to exist discretely and react appropriately. Furthermore, an exposure analysis in comparison to conventional silver products and synthetic chemical antimicrobials shows significantly lower quantities of active substance are required for nanosilver to achieve an equivalent effect. Such analysis shows a compelling potential for less chemicals to be used to treat consumer products and less pollution of the environment.

3.4 Silver in bearings: as yet unsubstitutable

Silver-coated bearings are used extensively throughout industry for heavy-duty equipment and hi-tech applications in which superior resistance to corrosion and fatigue is needed. With its high temperature strength, thermal conductivity, lubrication and corrosion resistance, silver bearing liners offer some of the highest load bearing specifications in the industry. During World War II, every US ‘Superfortress’ aircraft was coated with a layer of silver on its main shaft bearings of the 9,000 horsepower reciprocating engines. Nowadays, silver-coated bearings continue to develop to meet the needs of ever-increasing speeds and loads. The fan/compressor/turbine rotating components that push the air through the jet engines are all attached to the main shafts which rotate on steel ball bearings. All those parts rotate at much higher speeds than ground-based machineries. Placing a layer of silver between steel balls and steel cages can reduce the friction, increasing the performance and longevity of engines and accessories.

In addition, silver plays another important role in jet engine fail-safe lubrication. Usually bearings are lubricated with synthetic engine oil. In the event of an oil interruption, for instance a pump failure or oil shortage, the silver plated bearings can provide adequate lubrication to allow a safe engine shut-down before any more serious damage can occur. Therefore, all major jet engine manufacturers depend on silver-coated bearings for their performance and safety.

Glistening particles of industrial silver

The newest forecast by Airbus shows that in the next twenty years, the total passenger carrying capacity is expected to increase with an average annual growth rate of 4.7%, bringing a demand for 31,400 new airplanes. Moreover, given ever-increasing freight volume, airline companies are inclined to use larger airplanes that need stronger engines. With fast development of the aviation industry, we believe demand for silver-coated bearings in jet engines will see continued stable growth.

The European authorities have now removed lead from virtually all areas of road-based automotive applications. Hence, the development of lead-free bearings is set to increase silver consumption. Lead-free bi-metal bearings are now common. For high-performance tri-metal units, especially in high-performance diesel engines, silver's properties matched those required in terms of strength, melting point, thermal conductivity and adhesion to crank-joining surfaces.

Global demand for bearings is expected to rise 7.8% per year to \$96 billion by 2016. In mature markets, such as Western Europe, Japan and the US, demand growth of bearings is driven by rebounding automobile production and construction. In countries where the bearing market is still developing, demand is driven by rapidly increasing durable goods manufacturing and the growth in demand for home appliances and automobiles. The Asia-Pacific region is expected to record the fastest growth of any region, with demand in China rising the most rapidly. However, given its limited amount of usage per application, demand for silver in bearings is likely to grow at a slower speed compared to silver demand in other applications. CRU expects that silver use in bearings will reach 3 Moz per year by 2018.

Chapter 4 – Other industrial applications

Besides the four markets we discussed in Chapter 3, silver has also been used in many other industrial applications. Here we will look at four growing markets: photovoltaics (PV), automotive, brazing alloys/solders and printed inks.

4.1 PV industry

One of the most established industrial end-uses for silver is PV. A PV system, essentially a power system, is designed to convert light directly into electricity. It consists of several components, including solar panels to absorb and directly convert sunlight into electricity, a solar inverter, a mounting system, cables and other electrical accessories. Silver is a primary component in solar panels. Despite the high cost of silver, it is used in the most of crystalline silicon PV cells. On average, a 1MW solar module uses about 90kg of silver pastes. The electricity generated by PV cells is highly reliable. As soon as sunlight strikes, power begins to flow, and it does not need direct sunlight to work, as they can still generate electricity on a cloudy day.

As an effectively limitless source of clean energy, the PV industry has gained government support in many countries. Germany was the first and largest consumer of solar energy, followed by many other European countries. The US government has also subsidized domestic energy producers to develop solar energy. The PV industry entered into a period of rapid development since 2008. Based on data provided by the European Photovoltaic Industry Association (EPIA), the world's cumulative installed PV capacity jumped to 138.9 GW by 2013 vs. 23 GW by the end of 2009.

As the PV market is heavily policy-driven, government subsidies continue to be a critical driver of industry growth. During the global economic slowdown in 2011, demand for PV cells declined significantly and a high level of stock arose throughout the supply chain. The market stabilized in 2012 and then quickly recovered in 2013, restoring growth in demand for silver paste used in PV cells. To cut production costs, many large producers have been trying to reduce the usage of silver pastes in the cells. For instance, DuPont has invented a silver paste in which the content of silver is reduced by 15% compared to traditional pastes.

Since 2013, there has been rapid development in PV use in Asia-Pacific region. China has dominated the production of PV cells, growing to 11.8 GW in 2013, followed by Japan and the US. Germany now ranks the fourth largest of the new installation of PV capacity. India is

expected to experience one of the biggest increases in silver demand from its domestic PV market. The Indian government aims to become a global leader in solar energy over the next three decades. It plans a massive expansion which will upgrade the installed capacity of solar power from the current capacity of nearly 2.5GW to 20GW by 2020. In late 2013, India announced plans for the world's largest solar plant in the northern state of Rajasthan. The 4,000MW capacity plant is expected to boost demand for silver by 20 Moz annually, i.e. it will lift regional silver demand from PV cells by almost 40% from 50 Moz in 2013.

The Middle East and North Africa region will represent untapped potential for the PV market. The PV industry also shows great potential in South America and Africa, where electricity demand will grow significantly in the coming years and a large number of projects that have started will lead to installations from 2014 onwards. According to EPIA, even in the low scenario, the global market could add between 35 and 39GW of new capacity annually in the five coming years. The combination of an European slowdown and the difficulty of establishing durable new markets in emerging countries could cause this market stagnation. In the high scenario, the European market would first grow around 13GW in 2014 before increasing slowly again to around 17GW in the next few years. Annual growth will be between 52 and 69GW from 2014 to 2018. Indeed, new installations of PV capacity are going into households in Europe. For example, IKEA UK has been selling solar panel packages for houses since 2014, following a successful pilot project at the Lakeside IKEA store in which one PV system was sold almost every day in 2013.

As a result, no matter which way the market develops, global PV capacities will continue to expand and silver consumption in PV cells is expected to increase accordingly. However, the growth rate might be negatively impacted by declining intensity of silver use – i.e. new cells that consume less silver are expected to be widely used in the future. CRU expects global silver consumption in PV to increase to 109 Moz by 2018, up from 88 Moz in 2013.

4.2 Silver in automotive

As silver is conductive and corrosion-resistant, it is used in electrical and motor control switches universally. The special properties of silver make it valuable in automotive industry. Every single electrical action in automobiles is activated with silver coated contacts. A fully-equipped automobile may have over 40 silver-tipped switches to start the engine, activate power steering, brakes, windows, mirrors, locks and other electrical accessories.

Although the exact consumption of silver contacts in automobile is uncertain, the demand outlook is bullish. In the past few years, global car production has seen a steady increase, especially in China where production showed a two-digit growth rate except for 2011 and 2012.

By the end of 2013, the global production of cars and commercial vehicles was 87 million units, representing 2.8% of growth year on year.

Though impacted by stagnation in European countries, we are still optimistic that global car production will be supported by the gradual economic recovery in the US, a stabilizing European market and strong growth in China and India. Therefore, we forecast worldwide output growth to accelerate from 2014 and reach 110 million units by the end of 2018. As a result of technological improvements and customers' increasing demand for medium- and high-end models, more and more electrical contacts will be used in cars. Therefore the use of silver in automotive industry could in fact grow faster than the growth in car production as a result of greater usage of silver-coated contacts.

CRU predicts that silver consumption in the automotive sector will grow from 56 Moz in 2013 to 71 Moz in 2018.

4.3 Silver in brazing alloys/solders

Silver brazing, also known as silver soldering, is brazing using silver alloy based fillers. These silver alloys consist of silver and other metals at different percentages, such as copper, zinc, tin and cadmium. Silver soldering typically contains 1 to 3% silver and works at temperatures below 600 degrees Celsius. Silver brazing may have 30% and 60% silver and it works at temperatures above 600 degrees Celsius. Silver brazing/soldering is a popular method for joining or bonding ferrous and non-ferrous metals, like steel, stainless steel, copper and brass, as it produces joints with excellent strength, conductivity, leak-proof and corrosion-resistance. Silver brazing alloys are used in a wide range of sectors, from home appliances to power distribution, and from automobiles to aerospace industries.

Demand for silver in brazing/soldering is driven by industrial activities. Silver consumption in brazing alloys/solders recorded 73 Moz in 2011 but fell back quickly in 2012 by 5.5% year on year, mainly because of the slowdown of housing and construction activities in Europe and North America. In 2013, the market rebounded a little on the backdrop of mild economic recoveries, particularly in the US, and the total consumption of silver in brazing/soldering reached 70 Moz. At the same time, brazing alloy manufacturers have tried to reduce the level of silver usage in order to save production costs. The new silver brazing alloys introduced by BrazeTec in 2013 saves up to 10% of silver compared to similar products. Although silver content is reduced in each alloy, the total consumption is likely to increase given the lower unit prices.

Indeed, demand for silver in brazing alloys and solders is expected to grow following the gradual recovery of housing and infrastructure in the developed and developing regions.

Moreover, silver soldering is likely to gain some additional market share due to the gradual phasing out of lead solders in the industry. By the end of 2018, the demand for silver brazing alloys/solders is forecast to achieve 88 Moz, adding more than 18 Moz of demand to current level.

4.4 Silver in printed inks

As electronic devices, (e.g. mobile phones, tablet computers and smart sensors) become smaller, more pervasive and more powerful, manufacturers have been developing new technology for printing electronic components to replace conventional manufacturing technologies. Printed inks based on silver nanotechnology are designed to utilize the superior conductivity of silver. With silver printed inks, a printer can easily print electronic circuit board on paper and plastics, or even textiles. Until now, bringing low-cost electronics to the masses has been hindered by the logistics and costs associated with silicon chip manufacturing. The breakthrough of silver inks, which overcame the cost hurdle, has removed time-consuming and capital-intensive thermal curing and other additional processes during conductor production. This helps to unlock the huge potential of printed electronics.

At present, silver printed inks are still at the stage of research and lab trials. Several research labs and big companies, such as Mitsubishi and Xerox, have successfully developed silver inks to print plastic circuits. Early this year, Archipelago Technology Group, a start-up UK business, has developed a new ink manufacturing process by combining precision chemistry with the physics and engineering of inkjet printing. The key issue is to make the nanoparticles into the same size and shape. Now they are working on commercializing these new techniques.

Another application of silver inks is used in the radio frequency identification devices (RFIDs) which transmit information using radio frequency. The technology tracks high volumes of goods without requiring intensive manual labor to sort individual items. Silver inks, which are printed on a paper substrate, are used as a transmitter. Many companies who handle massive goods, such as supermarkets, have adopted RFIDs. As early as 2003, Wal-Mart first announced its plan to implement RFID technology in its supply chains. In the US, many chain stores, including Target, Best Buy and Kroger have either officially announced plans or are in the process of installing RFID system. Currently, RFIDs have not been widely used in developing countries, but they are expected to expand to developing markets soon. For example, the Chinese government is now promoting 'the internet of things' and such a network will need RFID system to connect everyday objects, devices and services. RFIDs tags have even been used in livestock management, so any unusual health conditions will be detected at early stage to prevent further losses. As consumers get increasingly concerned about the origin and quality of the meat they purchase, many governments, including Australia, the US and the European

Council of Ministers, have introduced the electronic identification and registration of goats and sheep using RFID system.

Each RFID tag contains an estimated 10.9mg of silver. RFID tag market has seen a rapid increase in recent years and current total demand for the tag was over 4 billion pieces. According to IDTechEX, between 2012 and 2022, the market size will increase four times with market value reaches US\$26.2 billion. We can image that along with the higher standard of identification, RFIDs could be applied in more territories including transportations, IDs and animal quarantines. It seems likely that the huge RFID tag market will boost the demand for silver.

In total, CRU expects silver demand in printed inks to double from 2 Moz in 2013 to 4 Moz by 2018.