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Market Trend Report

SILVER'S ROLE IN A FUTURE 5G CONNECTED WORLD

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Conducted By: Precious Metals Commodity Management LLC

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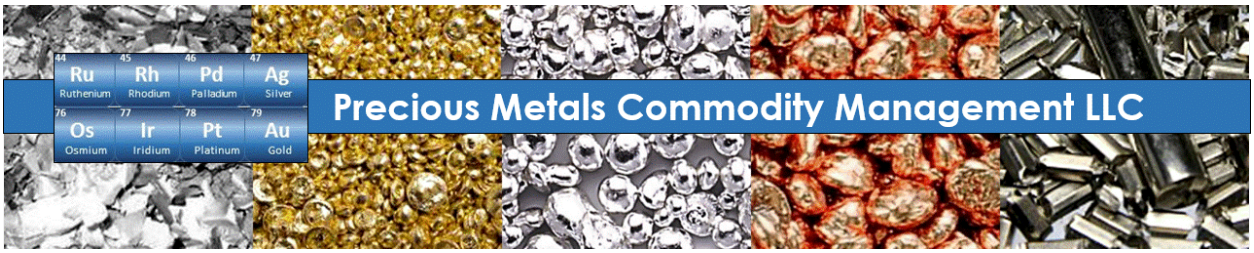


Precious Metals Commodity Management LLC

Precious Metals Commodity Management (PMCM) was founded by Matt Watson, who is an operations executive with over 30 years of international and domestic experience. PMCM supports clients with precious metals market research, risk management, trading/hedging, and design and process thrifting. It is working with a variety of clients across a broad range of industries, such as various electronics markets (i.e., hard disk drives, connectors, PVD target fabrication, etc.), mining and metals, and precious metals analytics.

Matt's expertise includes various fields of engineering, statistical consulting, and supply chain commodity management positions. In his previous roles, he spent 15 years of his career teaching and consulting in analytical methods in a wide range of industries. More recently, Matt led Tanaka's North American R&D and Marketing efforts for Tanaka America Inc.

INTRODUCTION

This report examines silver's role in a future 5G connected world and addresses the main differences of 5G compared to the previous generation of digital cellular networks. It also examines the five major technologies that make up the core of the 5G technology: millimeter waves, small cell networks, massive MIMO (multiple input multiple output), beamforming, and full duplex.

Additionally, the report looks at the hardware requirements and changes in this new environment. A massive amount of capital will be allocated to the new development and expansion of 5G networks, infrastructure, and other hardware and software globally. As such, many different companies are going to be involved at some stage throughout the supply chain.

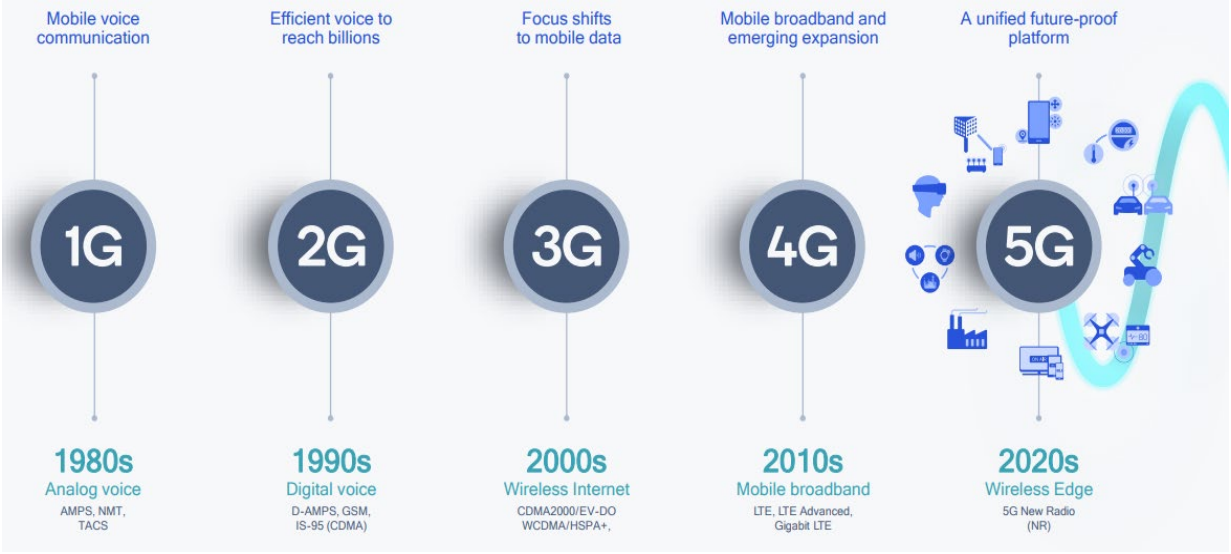
5G is going to be so much more than just another generation of a digital cellular network supporting digital consumer requirements, it will open up a whole new world of possibilities and will facilitate industries across the board to develop new groundbreaking technologies, which is also addressed in this report.

Lastly, the report examines the electronic components that will utilize silver to facilitate the implementation of 5G. It also provides a forecast on the demand split by different applications, including some end-use industries, and quantifies the projected silver demand growth over the next decade.

1. WHAT IS 5G?

In the early 1980s, analog mobile phones first appeared and were only used for voice calls. The second-generation (2G) digital mobiles came ten years later with GSM, offering text messaging (SMS) as the principal additional attribute, becoming the dominant technology worldwide. Around the turn of the millennium, 3G was introduced, which offered data download capabilities of around 1Mbps and could be described as 'mobile broadband,' while again ten years later, in 2010, the emergence of 4G (LTE) saw download speeds reaching 100Mbps.

Image 1: 1G – 5G Evolution



Source: Qualcomm

Built on the foundation of 4G LTE, 5G, the next-generation mobile network, will be ushering in a new wave of disruptive technological innovation with ubiquitous high-speed connectivity. 5G will transform entire industries and enable resilient, high-speed, high-volume internet connectivity from practically anywhere and on any device or sensor.

5G is not just an incremental improvement over 4G — it is the next major evolution of mobile communication technology with performance improvements of several orders of magnitude over today's networks. 5G enables a huge diversity of tasks that 4G cannot perform. 5G will have a 100% better capacity than 4G, which will dramatically improve internet speeds. According to the consumer technology association, the download of a two-hour film takes 26 hours on 3G, six minutes with 4G and will be as little as 3.6 seconds with 5G. But it's not just downloading speeds that will massively improve, response time, or latency, will be much faster too. 4G responds to commands with just under fifty milliseconds, which will drop to as little as one millisecond with 5G, or 400 times faster than the blink of an eye.

Table 1: 4G and 5G Comparison

Characteristics	4G (IMT-Advanced)	5G (IMT-2020)
Peak data rate (downlink)	1Gbps	20Gbps
User-experienced data rate	10Mbps	100Mbps
Latency	10ms	1ms
Mobility	350km/h	500km/h
Connection density	100k devices/sq km	1m devices/sq km
Energy efficiency	1x	100x
Spectrum efficiency	1x	3x
Area traffic capacity	0.1 Mbps/sq m	10 Mbps/sq m

Source: ZDNET, TechRepublic

5G will not only be an evolution of mobile broadband networks, it will bring new unique network and service capabilities. Due to its fast download speed and low latency, 5G can become the connective tissue for a whole host of applications and industries too. It will enable the evolution of the Internet of Things (IoT), which will be able to link and control robots, medical devices, industrial equipment, and agricultural machinery remotely, to name just a few applications. It will also facilitate autonomous driving technology, as well as augmented and virtual reality. It has, according to many, the potential to transform the internet.

2. THE FIVE KEY ENABLING TECHNOLOGIES OF 5G

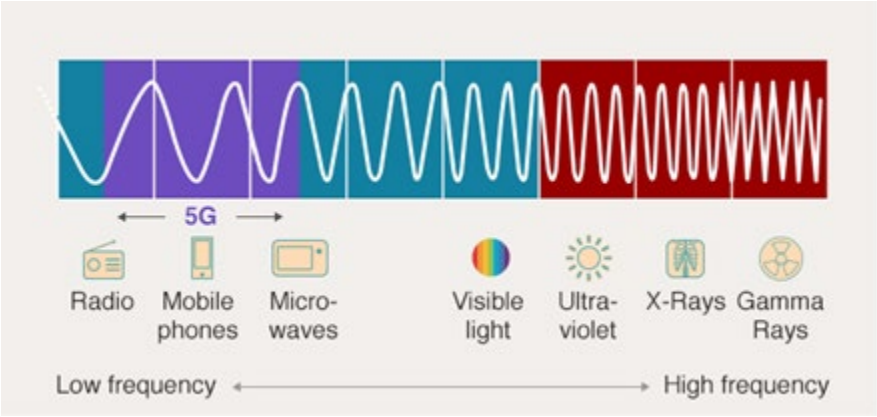
5G will be mainly leaning on five newly introduced and improved technology factors.

1. Millimeter waves

Consumer electronics with radio frequency (RF) use precise frequencies, typically under 6GHz (3kHz – 6GHz). Due to the rise in available devices, the frequency spectrum is becoming more crowded, while carriers can only process so much specific data on the same bandwidth. As more devices come online, services tend to get slower, and dropped connections increase.

The solution is to create more space. Researchers are testing shorter millimeter waves, typically between 3kHz – 100 GHz and reaching as far as 300 GHz, which have never been used for mobile devices before. Opening it up, however, would mean more bandwidth for everyone. Some of the main challenges millimeter waves present are their inability to travel through buildings and other obstacles.

Image 2: 5G in the Electromagnetic Spectrum Overview



Source: SCAMP/Imperial College London/EBU

2. Small Cell Networks

Small Cell Networks have now been introduced. Today, high power cell towers broadcast their signals over long distances. The presence of many small cell networks, also known as mini base stations, would allow 5G technology to get around the signal blockage from significant obstacles. Small cell network towers will be more closely grouped and form a relay theme that transfers signals around obstacles, something especially useful in cities.

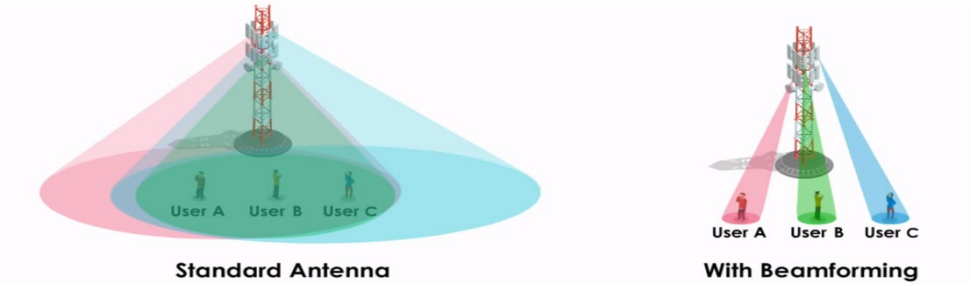
3. Massive MIMO (multiple input multiple output)

Today's 4G infrastructure has approximately a dozen ports antennas to handle all cellular traffic. With the roll-out of 5G, that will have to increase. Massive MIMO could handle a tenfold of that, which would increase the capacity of a network by a factor of 22+. The downside, however, is that today's cellular signals go in all directions at once, with many crossing signals causing serious interference with each other. Beamforming was developed to deal with this issue.

4. Beamforming

Beamforming makes the transmission between users and the base, or cell stations, more directional. It is like a traffic signaling system for cellular signals. Instead of sending signals in every direction it would allow a beam station to send a specific signal to a particular user. Since beamforming is much more directed, it prevents interference and is much more efficient in transmitting data. This means stations would be able to handle more incoming and outgoing data streams at once.

Image 3: Standard Antenna Reception vs Beamforming



Source: Sunny Classroom

5. Full Duplex

The final main 5G technology improvement element is called full duplex. A basic antenna can only do one job at the time, which is either transmit or receive data. This is because of the reciprocity tendency of radio waves to travel backward and forward along the same frequency, like two trains running in the opposite direction on the same tracks. To overcome this limitation, a signaling method was developed that can momentarily reroute two signals on the same frequency so they can get past each other, which resulted in significant data volumes and time handling efficiency improvements.

3. INFRASTRUCTURE, HARDWARE AND INDUSTRY

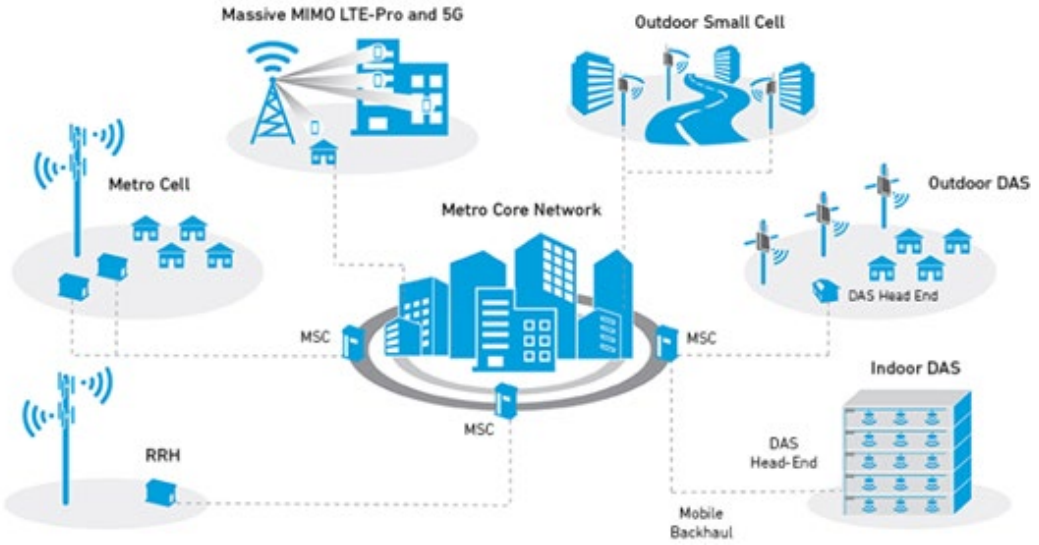
5G will mainly cover the 'last mile' problem, delivering digital connectivity from carrier to customer without drilling another hole in the wall. It describes a range of new technologies underpinned by a fundamentally unique architecture, different from all previous wireless infrastructure.

5G infrastructures will also be much more efficient compared to 4G. To reduce costs, 5G operators will allow for smaller transmitters that consume less power but will cover much smaller service areas than the typical 4G towers. Estimates vary, but a carrier will need at least 400 more, which will be integrated into the landscape. More base stations are just one part of the extra hardware required for a successful 5G rollout.

Some of the main components required for a 5G rollout consist of:

- Base stations – Including compute, storage, and communication capabilities
- Home devices (to replace wireless broadband)
- 5G Smartphones
- (Beamforming) Antennas
- Radio frequency front-end module components
- Optical transceivers

Image 4: Wireless Infrastructure: A Heterogeneous Network



Source: Qorvo

Note: DAS = Distributed Antenna System; RRH = Remote Radio Head

With these components, 5G infrastructure will be a heterogeneous network of a host of different collaborating hardware and software technologies.

Carriers will have to add between 3 to 10 times more sites to their networks to utilize large blocks of contiguous spectrum and higher frequencies. Most of this additional infrastructure will likely be built with small cells that use lamp posts, utility phones, or other structures of a similar size that are able to host more modest, less obtrusive radios required to build a densified network.

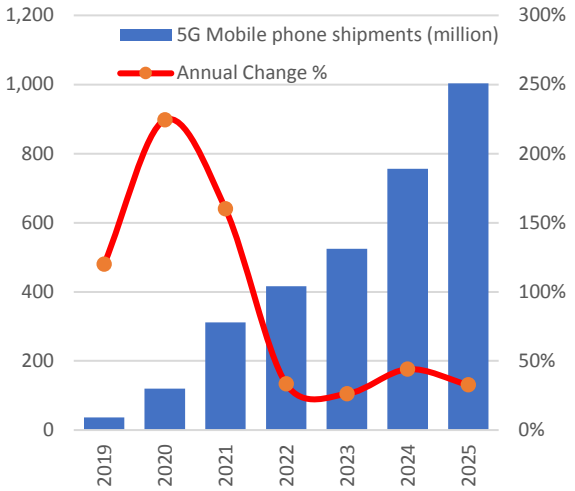
5G SMART PHONES

All this infrastructure build is done to facilitate one of the main features that will be actively using this technology: smartphones. As of 2019, fifteen smartphone manufacturers had already released their latest versions including 5G compatibility, and more manufacturers are expected to follow this year. Apple is the most notable laggard but is expected to launch its 5G-enabled iPhone in 2020.

By the end of January 2020, GSA had identified 62 new 5G enabled phones, with at least 35 already commercially available. With all the various brands introducing their respective new handsets, smartphone shipments are poised to rise significantly in the coming years, from a mere 37 million first-generation 5G smartphones in 2019 to over one billion devices by 2025, representing a CAGR of 73%. This represents an accumulated total of 3.1 billion devices over the 2020-2025 forecast horizon.

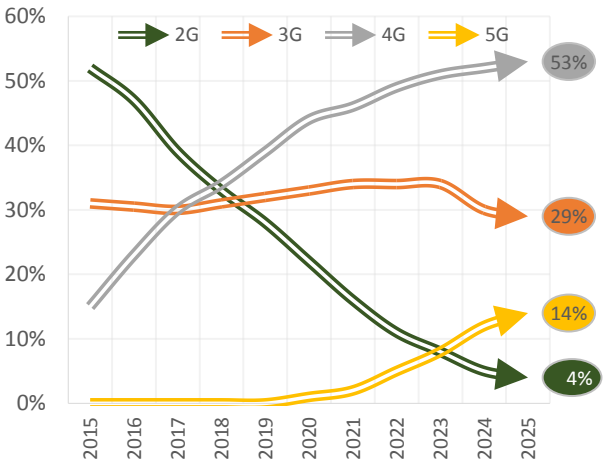
5G is anticipated to make significant inroads on the other providers, such as 3G and 4G, but will not replace all other networks overnight. By the year 2025, 5G is still expected to make up only 14% of the global network behind 3G at 29% and 4G at 53%. Despite the 5G rollout, 4G LTE and 5G are expected to work alongside each other simultaneously for quite some time to come.

Chart 1a: 5G Mobile Phone Shipments



Source: IHS; Ericsson; MLCC

Chart 1b: Mobile Subscription by Technology

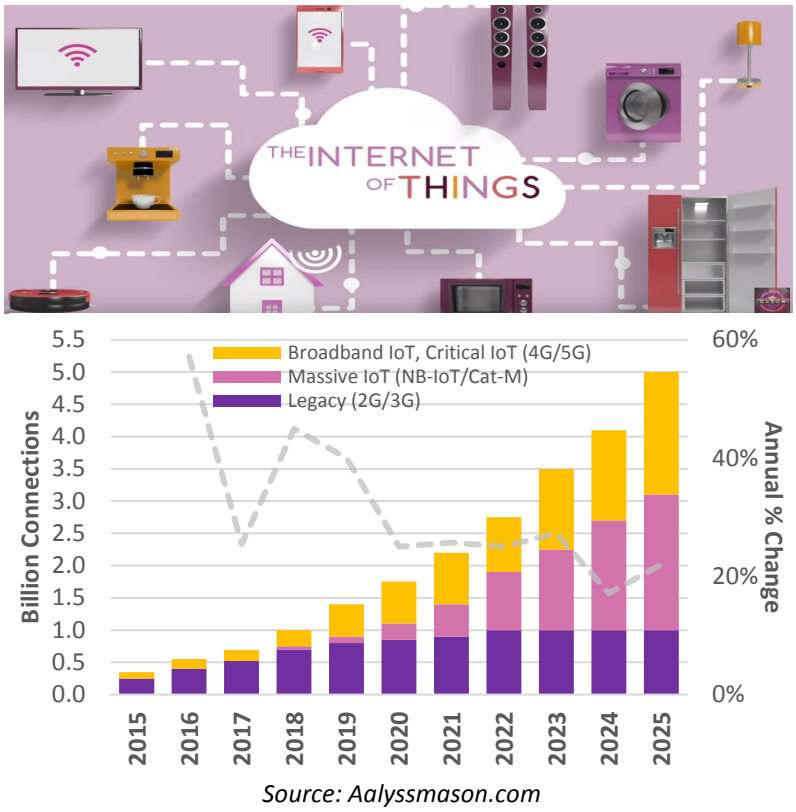


Source: GSMA Intelligence

Internet of Things (IoT)

In addition to a rise in 5G-enabled mobile phones shipments and the infrastructure rollout, the introduction of 5G is expected to be a huge enabler of the IoT. IoT devices will begin to penetrate all aspects of our business ecosystems, stretching along the following industries: Agriculture, Construction, Info and Communications, Manufacturing, Mining, Professional Services, Public Service, Real Estate, Transport (all vehicles) & Storage, Utilities, and Wholesale & Retail. As such, the number of connected devices is expected to increase from approximately 400 million in 2015 to 5 billion by 2025. China is set to dominate IoT connections throughout the forecast.

Chart 2: Expected Internet of Things Connections



Source: Aalyssmason.com

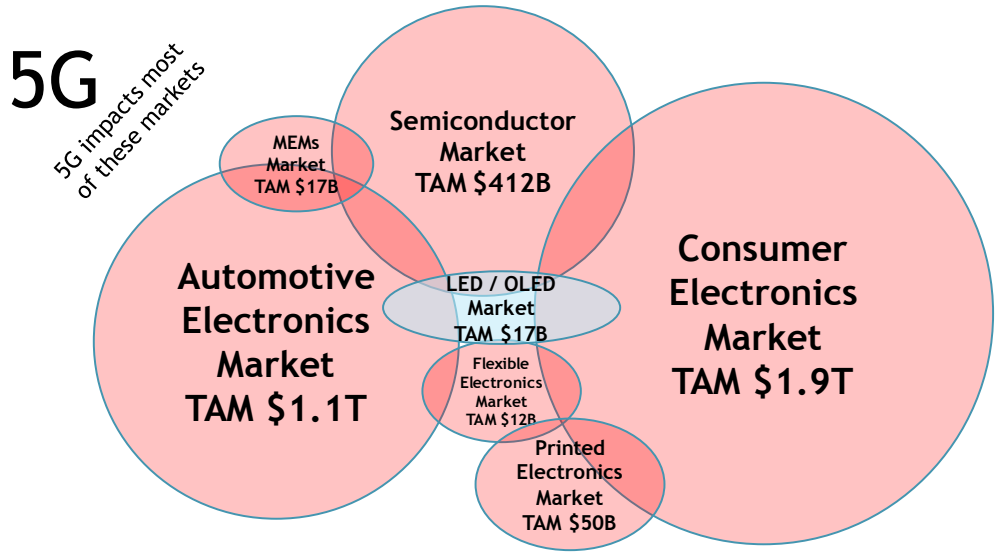
4. 5G, ELECTRONICS AND THE USE OF SILVER

Electronics Market Segments

A range of silver products are used in different electronics market segments, including Semiconductors (integrated circuits & printed circuit boards), MEMS (micro electro-mechanical systems), Automotive Electronics, Consumer Electronics, Flexible Electronics, LED/OLED and Printed Electronics.

Tracking of materials spend in each market helps us understand silver and other precious metals electronics demand trends. Although there is some overlap across these segments, we have identified seven markets where we estimate silver demand will be most significant in the coming years based on the implementation of 5G. An overview of the various electronics markets, and examples of the silver products used in each market segment, follows.

Diagram 1: Electronics Markets Affected by 5G



Source: Precious Metals Commodity Management LLC

Silver Products Are Used Across the Electronics Industry

The table below highlights some of the primary silver products used in the various electronics market segments, including their respective 5G-enabled growth potential in each segment indicated in two shades of green. Automotive electronics has the second largest TAM (Total Available Market revenue) and the biggest dispersion across the widest range of silver products. Consumer electronics comes second in terms of silver products usage strongly supported by the rise of IoT but has by far the largest TAM. In third place is semiconductors.

Table 2 – Silver Use In Different Electronics Markets

Silver Products Used In Different Electronics Markets

Market TAM	$412 Million	$ 1.1 Trillion	$ 1.9 Trillion	$17 Million	$45 Million	$12 Million
Electronics Market	**Semiconductor**	**Automotive Electronics**	**Consumer Electronics**	**MEMS**	**Flexible Electronics**	**Flexible / Printed Electronics**
Electro Conductive Adhesive (ECA) / Die Attach Materials						
Silver Solder / Reflow						
Paste						
PVD Targets and Materials						
Bonding Wire						
Wet Chemistry						
Passive Components (MLCC's)						
Glass Coating						
Silver Compunds						
Rivet and Spring Contact Materials						
Spark Plugs						
Connectors & Cables						
Silver Oxide Batteries						
Inks / Jetable Materials						
Nano-Silver Materials						

Note: Dark green indicates strong growth, light green medium to low growth.
Source: Precious Metals Commodity Management LLC

Semiconductor Market

The Semiconductor Market is producing Integrated Circuits and Memory. This is a $412 billion TAM segment that is spending ~1.5% of its total size on precious metals products, including silver solder materials, die attach materials, silver pastes, silver conductive films/materials, and silver bonding wire. As electronics continue to miniaturize, also stimulated by the help of 5G technology, there will be increasing use of denser packing technologies that will encourage the use of silver conductive materials.

Automotive Electronics & Electrification Market

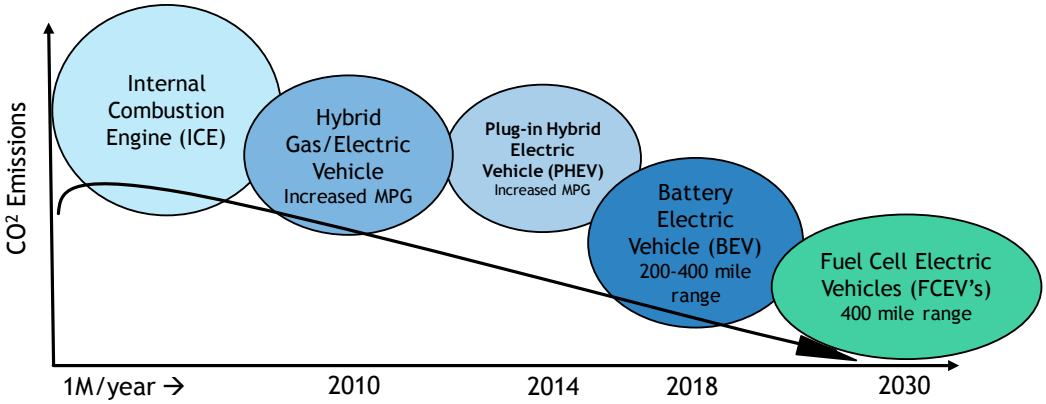
The current global automotive electronics market is $1.1 trillion. Despite its current size, it still is a fast-growing segment**.** This is driven by two primary demand drivers: first, a rising use of electronics used per vehicle, and second, the electrification of vehicle drivetrains. Both of these trends carry their own silver demand growth opportunities supported by the rise of 5G enabled technology.

Automotive Electronics Market: At present, auto-electronics represent on average 45% of a vehicle cost and are expected to continue to increase as we approach fully autonomous vehicles. As more printed circuit boards populated with integrated circuits, logic devices, memory, display drivers, and passive components make their way into the vehicle, silver demand is set to benefit. Also, printed electronics for OLED, lighting and display devices all printed on unconventional flexible substrates, will also soon be making their way into our vehicles, including LED headlamps.

Automotive Electrification Market: Hybrid Vehicles, Plug-In Hybrid Electric Vehicles (PHEVs), Battery Operated Vehicles (BEVs), and Fuel Cell Electric Vehicles (FCEVs) all come with more electronics and electrical and power distribution systems. Simply put, electric vehicles have higher rates of electronics.

Legislation in the EU, and in other parts of the world, is driving rapid adoption of electric vehicles to enable automotive OEMs to meet vehicle CO_2 emission standards. Every OEM in the EU has rapidly introduced a range of electric vehicles in recent years. This comes in addition to the previous EU trend to migrate away from light duty diesel vehicles in favor of gasoline ICEs and hybrids.

Diagram 2 – Automotive Electrification



Source: Precious Metals Commodity Management LLC

Consumer Electronics

The global consumer electronics (CE) market has a $1.9 trillion-dollar TAM. This includes products such as laptops, tablets, desktop computers, displays, smartphones, TVs and DVDs. Consumer electronics use various silver products including contacts, wiring, and power distribution related products. CE growth in emerging Asian and African markets present large global growth opportunities. Even silver oxide batteries used in hearing aids and small CE devices is also a growing demand sector. Through the IoT, consumer electronics will offer great growth potential with the rollout of 5G.

The MEMS – Micro Electro-Mechanical System

Similar to consumer electronics, the MEMS device market will explode as the number of IoT connected devices under 5G rapidly rises over the next couple of decades. Today the MEMs market has a TAM of $17 billion. Many of these IoT devices will incorporate remote low-cost sensors for use in everything from agricultural to medical, logistics, smart city sensors, and utilities. All of the semiconductor silver products are applied in MEMS processing and packaging.

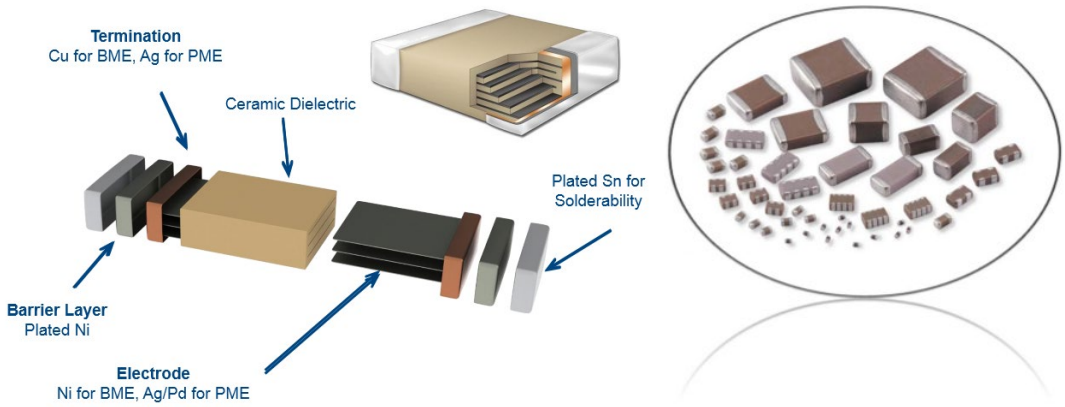
Printed & Flexible Electronics

Printed & flexible electronics are both emerging markets with a high CAGR. Printed electronics has a TAM of ~$50 billion/year, and Flexible Electronics $12 billion/year. Printed OLED display devices lead the way for volume applications, but the growth opportunities into various lighting, display, and automotive markets will provide an upside demand potential for both gold and silver. Printed Electronics spending on conductive materials is 5% of the overall TAM. Many of the lower cost IoT devices will start to use printed electronics within the next decade.

Passive Components: Multi-Layer Ceramic Capacitors (MLCCs)

Passive components are another strongly rising market segment, particularly **multi-layer ceramic capacitors (MLCCs)**. MLCCs come in two categories; capacitors that contain base metals, such as copper and nickel, and those that have precious metals in them. Precious metals MLCCs can be further divided into high-fire and low-fire ceramics. The high-fire ceramics have a higher sintering temperature at approximately 1,350 C. Palladium and platinum are usually used as electrodes here. Low-fire sinters, between 950-1,050 C, typically consist of silver or silver70/palladium30 electrodes.

Image 5: Ag, Pd & Ni Electrodes used in Multi-Layer Ceramic Capacitors (MLCCs)

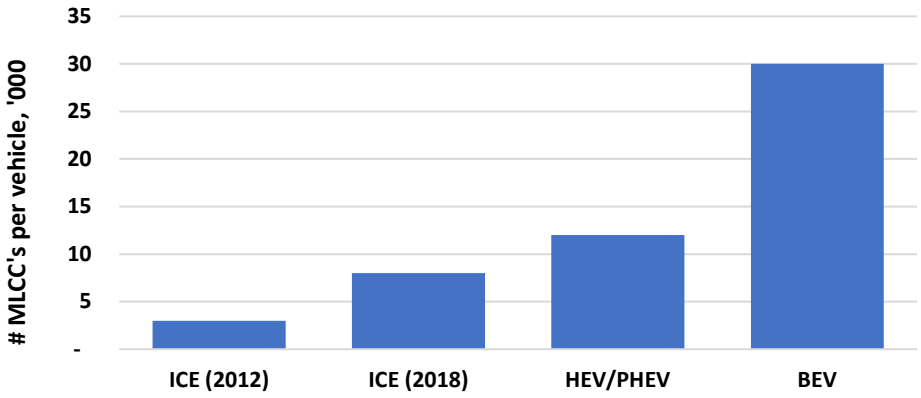


Source: TTI

5G enabled products use higher volumes of these MLCCs, as does automotive electronics and electrification. Due to thrifting and substitution, we estimate that the share of MLCCs containing precious metals has fallen to 13% in 2019 but is likely to stabilize over the forecast period. What is expected to rise is the sheer volume of MLCCs used in automotive.

The required number of automotive MLCCs, for example, rose from 3,000 units in 2012 to 8,000 units in 2018 and, due to the rising commercialization of autonomous driving and BEVs, is expected to boost demand for MLCCs even further to as much as 30,000 in case of BEVs.

Chart 3: MLCC count per Vehicle and Powertrain



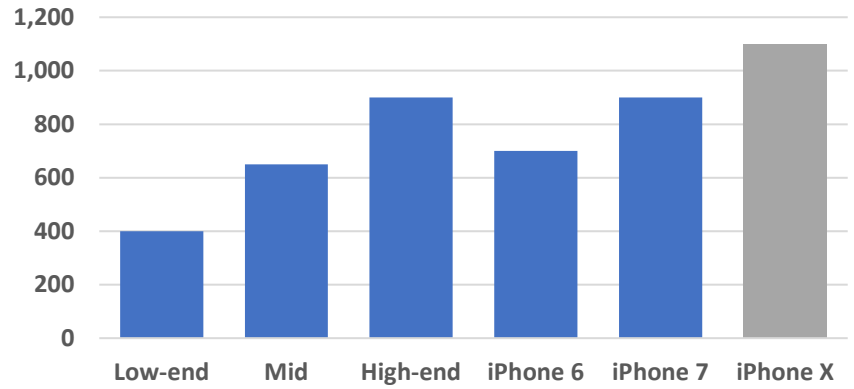
Source: TTI

Silver consuming passive components, such as MLCCs, will not only be extensively used in automotive applications. Mobile phone applications will become another significant source of demand driven by, among other things, the growing popularity of new designs of MLCCs, with higher capacitances, improved bypassing, filtering, and decoupling capabilities, which is expected to positively influence the growth of the global market.

A standard 4G iPhone 6, for example, has approximately 730 capacitors. With the introduction of 5G, this is expected to rise to above 1,000 per device. The power-hungry devices that will be able to download more data quicker require a larger battery, which leaves less space for other components. Capacitors offer a solution, as they store more energy in a smaller footprint.

In terms of silver use in this application, we estimate that of the low-fired MLCCs, silver-containing capacitors make up approximately 70% of the total. We calculated that silver used in MLCCs might have been as much as almost 7 million ounces (Moz) per annum in the 90s, which has been reduced in the years following due to thrifting and substitution pressures. The year 2017 was the low point for silver use in MLCCs, representing a mere 0.5 Moz, but we forecast that volumes are likely to reach 1 Moz again in 2025 and keep rising beyond that point, coupled with the rollout of 5G.

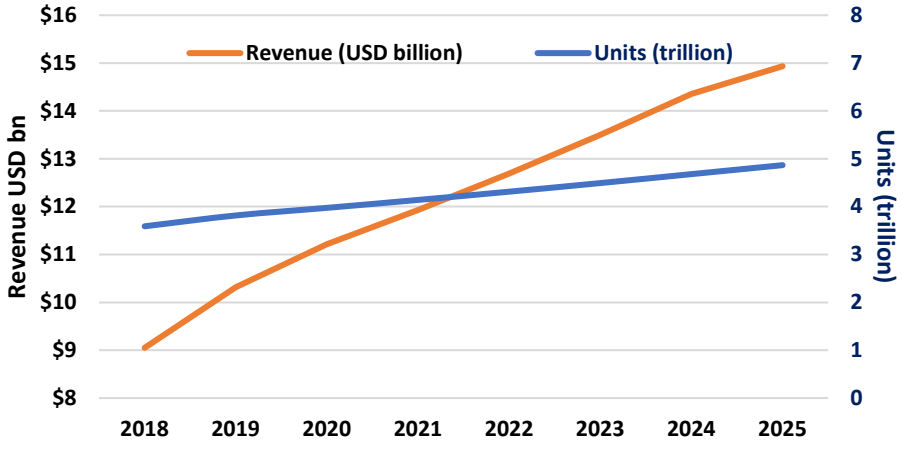
Chart 4: MLCC count per Mobile Phone



Source: TTI

The global MLCC market is currently valued at approximately $12 billion in revenue, generating 4 trillion units. 5G modems consume more power than 4G modems, and 5G phones require, on average, 30 percent more capacitors. New technologies such as IoT, EVs, and 5G are highly dependent on MMLCs and expected to boost the market revenue towards USD 15 billion and 5 trillion in volume by 2025.

Chart 5: Expected Revenue and Units sales of MLCC



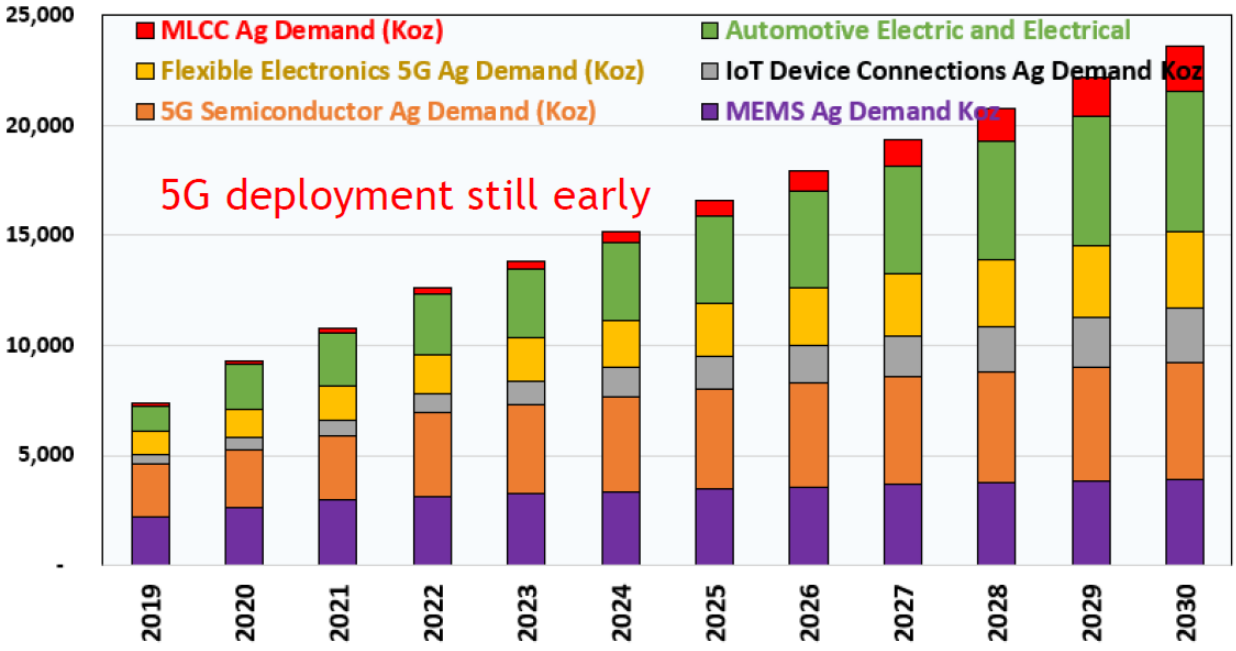
Source: Business wire

5. 5G IMPACT ON SILVER DEMAND

Some of the main components required for a 5G rollout consist of base stations, home devices (to replace wireless broadband), 5G Smartphones, 5G Antennas, Radio frequency front-end module components, and optical transceivers. Despite all that, the rise in silver demand from the 5G revolution will not so much be driven by the direct rollout of 5G enabled hardware, but will manifest itself particularly through an expanded range of capabilities in which silver can play a significant role. This new 5G enabled ecosystem will create incremental demand for semiconductor ICs/chips, memory, passive components, cabling, power distribution, IoT devices, and MEMS sensors, each of which uses silver products similar to the semiconductor segment.

We briefly discussed MLCCs and their past and expected silver demand from 5G technology. But MLCCs are only one segment where we foresee silver demand growth due to a 5G rollout. We have identified many other applications as discussed previously that can roughly be grouped into six segments. At present, the 5G deployment is still in its early days, and as such, demand for silver constitutes approximately 7.5 Moz or 0.75% of current annual supply. With the rollout of 5G in the coming years, all the above segments are expected to benefit and push 5G enabled silver demand from these electronic applications to approximately 16 Moz by 2025 and as much as 23 Moz by 2030, or approximately 2.3% of annual supply.

Chart 6: Silver Demand Across 5G-Enabled Market Segments



Source: Precious Metals Commodity Management LLC

SUMMARY & CONCLUSION

The rollout of 5G will not just be another migration from one generation to the next; it will require significant upgrades on infrastructure and the introduction of other hardware, such as mobile phones and IoT devices. Millimeter waves, small cell networks, massive MIMO, beamforming, and full duplex will be the five key 5G enabling technologies that will largely make up the 5G architecture. Due to the large data transfer capabilities, cloud computing and storage is set to significantly increase too.

Transformation will be the name of the game in many other industries too. 5G will facilitate not only increased download speeds, fewer delays, better connectivity with less energy consumed, but it will also indirectly facilitate the development of many industries, such as automotive, manufacturing and healthcare, just to name a few, to reach the next level. 5G will be the glue in an ecosystem of improved connectivity between all sorts of devices, and as such, it is expected that connected devices, such as the IoT, will significantly increase over the next five years.

Silver will benefit from this development over the forecast horizon. Everything 5G related will be based on electronic devices, such as semiconductors, MLCCs, MEMS, and many more, which to one degree or another consume various amounts of silver. Thrifting and substitution pressures are always present in electronic applications and we expect that particularly in the case of gold to continue. Silver, on the other hand, will be one of the go-to metals for future 5G enabled electronic applications.

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