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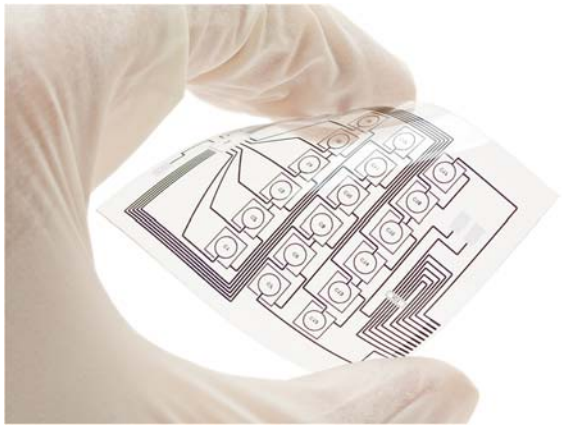
Market Trend Report

Silver in Printed & Flexible Electronics



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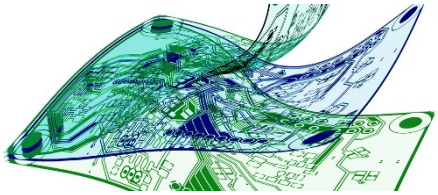
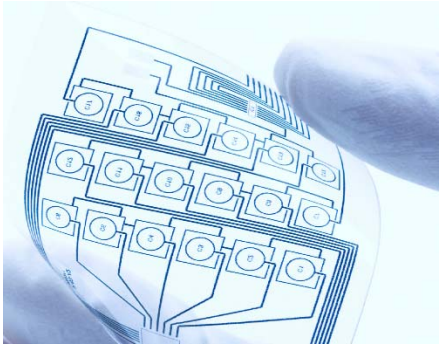


E^{X}ponent Flexible Electronics

Organic Light Emitting Diode (OLED) Flexible Display



Bühler Metalizing Film Capacitor

Executive Summary

This Market Trend Report for the Silver Institute examines silver's growing role in printed and flexible electronics. According to our research, 33.9% of the annual silver global supply in 2020 ended up in electronics. This is a total of 327 million troy ounces (Moz) that finds its way into various electronics markets every year. Given the projected growth of electrification, we are confident that this will continue to grow over time since silver is the world's most conductive material.

Adding to this growth will be an expansion in the solar photovoltaic segment, which already consumes 10% of the global silver supply. According to our forecasts, the amount of silver consumed in solar photovoltaics (solar PV) will climb to 15% (155 Moz) by 2025, and 19% (197 Moz) by 2030. The International Renewable Energy Agency is now calling for a growth to 14,000 GW of installed solar PV globally, or approximately 2,000 GW/year by 2050.

Growth in 5G wireless, automotive electronics and the Internet-of-Things (IoT) are well documented electronics growth opportunities as well.

Our research reveals that a critical application for silver is its use in printed and flexible electronics. This market segment, although relatively small today, generates approximately US$59 billion USD in total revenue, and is achieving an 11% annual grow rate.

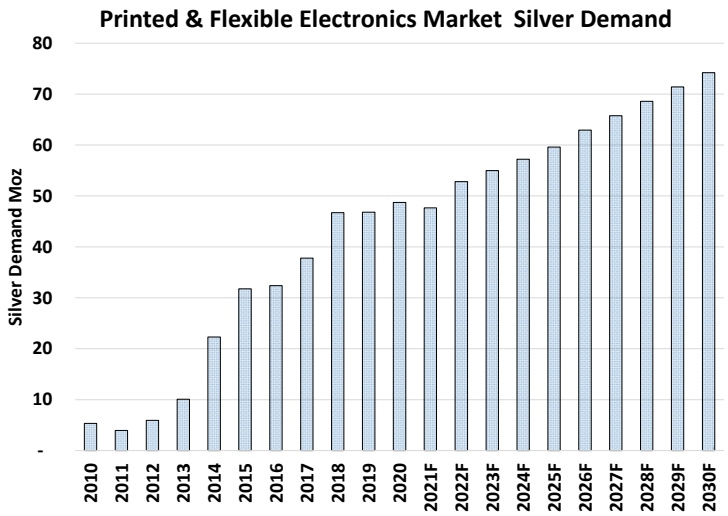
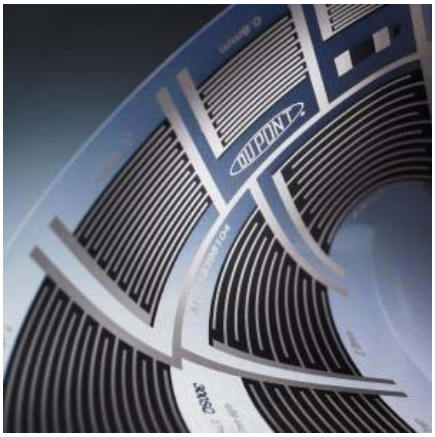


Chart 1: Printed & Flexible Electronics Market Silver Demand. Source: Precious Metals Commodity Management LLC

Silver is the ideal conductive material. It is relatively easy to screen print, inkjet dispense, aerosol dispense, and roll-to-roll print with numerous deposition and coating technologies. Nano-silver inks are one of the easiest to cure at a low temperature making them ideal for many flexible substrate applications as well. In addition, silver offers excellent corrosion resistance, easy bendability, and stretchability characteristics all while still retaining its conductive properties, making it ideal for this market segment.

In 2021 we forecast that 48 Moz of silver will be consumed in the printed and flexible electronics market. This is projected to grow to 74 Moz by 2030 and stands a good chance of accelerating its growth rate as more low cost and high-volume IoT connected devices, low-cost display technologies, and large area organic photovoltaic (OPV) technologies are successfully deployed.



Silver Conductive Inks For Printed Electronics - Dupont

Printing electronics is a faster means of mass-production in most cases, and also enables larger surface area substrates that include silver, such as large screen TV's and displays. Organic light-emitting diode (OLED) products for ambient lighting will become more commonplace in the future for use in residential, workplace and automotive segments as well, further leveraging this capability. Ultimately, the printing of films and materials can be integrated into building OPV products.

Additive manufacturing processes, where metals are printed onto irregular 3D surfaces -- like translucent headlight domes, mobile phone cases or embedded wiring in a plastic product housing -- can use printed silver and other conductive materials to reduce component counts and costs, while achieving the desired end product function.

The future is bright for silver in this printed and flexible electronics market. This is just one market that is adding to the continued proliferation of electronics and overall silver industrial demand.

Electronics Market Segments – Breaking It Down

We have broken down precious metal's use for the following electronics markets:

- Consumer Electronics – includes laptops, desktops, tablets, displays, smartphones, appliances, and other electronics
- Automotive Electronics and Electrification
- Semiconductor
- Solar Photovoltaics
- Power Distribution Components – includes cables, connectors, electrical contacts, and silver-oxide batteries
- Light-emitting diode (LED) and organic light-emitting diode (OLED) lighting and displays

- MEMS (Micro Electro-Mechanical Systems)
- Printed & Flexible Electronics

To many, the word "electronics" denotes semiconductor markets, but there is so much more category revenue and precious metals spend going on in consumer electronics and automotive electronics compared to just the semiconductor segment. Most of these market segments are overlapped in one way or another.

Some of these segments include:

Flexible and Printed Electronics

According to our analysis, the **Printed and Flexible Electronics Market** is generating approximately US$57 billion in revenue annually. Two very key fundamental points about this market segment are that the revenue growth is projected at 11.1% through 2025, and that the conductive materials spend in this segment exceeds 5% of the total revenue, much higher than the other electronics markets. Precious metals and silver are used in printed and flexible electronics applications with higher loadings.

Additionally, there is the prospect for an acceleration of growth in printing technologies and mass-produced roll-to-roll processing in the electronics manufacturing. As more of these printed technologies are successfully deployed, an acceleration in this technology is anticipated. Many leaders in the printed electronics market believe they can capture most of the OLED display, organic photovoltaic and IoT device market share. All of this adds up to a promising future for printed and flexible electronics and the use expanding uses of silver.

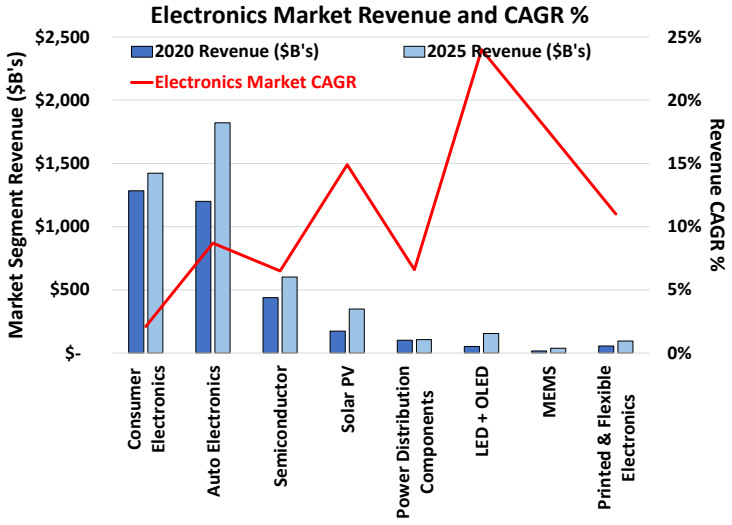


Chart 2: Comparison of Electronics Markets Revenue in 2020 & 2025
Source: Precious Metals Commodity Management LLC

Consumer Electronics Products

Automotive Electronics

Semiconductor

Solar Photovoltaic (PV) Array

According to our analysis, the **Consumer Electronics (CE) Market** is the largest of all of the electronics markets with a value approaching US$1.28 trillion per year but holds a relatively modest growth rate. Included in this category are laptops, desktops, tablets, televisions and displays, smartphones, appliances, DVR's, entertainment systems, gaming systems, and many other electronic devices. Silver finds its way into all of these CE device electronics.

Next in size is the expanding **Automotive Electronics Market.** According to new white paper from consulting firm Deloitte, on average, by 2030, 45% of a typical passenger vehicle production cost will be electronics according to Deloitte. To be more precise, in a typical internal combustion vehicle (ICE) 40% of the product cost is electronics, while 70% of a battery electric vehicle (BEV) of the vehicle cost is electronics. As the transportation segment is electrified and increasing percentages of hybrid electric vehicles (Hybrids), plug-in hybrid electric vehicles (PHEV's), full range BEV's, and fuel cell electric vehicles (FCEV's), it is no wonder that the average amount of electronics in these vehicles increases substantially and is expected to pass 50% of the vehicles cost content by 2030. Today's US$1.3 trillion automotive electronics market segment is enjoying nearly a 9% annual growth rate, and will overtake the consumer electronics market in size by 2028. The mid-January release of the Silver Institute's Market Trend Report entitled "Silver's Growing Role in the Automotive Industry" provides an excellent overview of this growing demand segment.

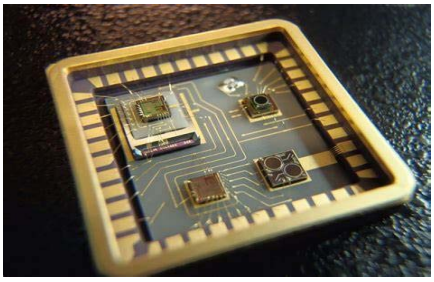
World Semiconductor Trade Statistics reports the **Semiconductor Market** surpassed US$439B in total 2020 revenue with a growth rate of 6.5% annually (Global Semiconductor Sales). Every form of electronics on silicon is captured in this segment including integrated circuits (IC's), and on-chip memory devices.

According to our research, the **Solar PV Market** generated US$174 billion in 2020 total revenue growing at a 14.9% annual growth rate on average from 2015 to 2020. The solar PV market in 2020 registered 115 Gigawatt (GW) of new installations and is expected to double in size by 2025 to a projected 230 GW. Then, in March of 2021, the International Renewable Energy Association, in its report entitled "World Energy Transitions Outlook: A 1.5°C Pathway," mapped out the need for the global PV market to grow to 14,000 GW of active installations by 2050 (World Energy Transitions Outlook: 1.5°C Pathway (Preview) (irena.org)). The near term forecast silver demand for solar PV new installations can be summarized as follows:

- 2020: 10% silver supply for 115 GW
- 2025: 15% silver supply for 230 GW
- 2030: 20% silver supply for 356 GW

Power Distribution Components

LED and OLED TV



MEMS Package

According to the firm Global Market Research, the **Power Distribution Component Market**, which includes cables, connectors, and electrical contacts, makes up the next market block at over US$95 billion in revenue, growing 6.6% per annum over 2019. A broad range of precious metals are used in this segment in a number of different forms including silver, and silver-oxide batteries.

According to Market Research Future, the **LED and OLED Lighting and Display Markets** are generating US$53 billion in revenue, growing 24% year over year. These markets have enjoyed a decade of growth already and will continue to grow for several more years to come. OLED technologies have now become the dominant television and display technology and have also now achieved majority share in the mobile phone market.

According to Yole Development, the **MEMS (Micro-Electro-Mechanical Systems) Market** is generating US$17.4 billion a year in revenue in 2020, with an anticipated growth rate of 17.5% per year. MEMS technology is defined as the miniaturized mechanical and electro-mechanical elements, such as devices and structures, which are manufactured and fabricated using the techniques of microfabrication. The types of MEMS devices vary from relatively simple structures with no moving elements, for some of the extremely complex electromechanical systems, with multiple moving elements under the control of integrated microelectronics. MEMS devices and sensor will continue to grow as the Internet-of-Things (IoT) continues to flourish. Most electronics are accomplishing more dense and low power designs through much more complex packaging.

Precious Metals Used in the Electronic Markets

Electronics is one of the biggest combined industrial segments of demand for all precious metals. E-waste recyclers have known this for years. The challenge is understanding what metals are used, and where they are used. Summarizing the extensive market research that we have accumulated to date, we arrived at the following summary of precious metals electronics demand as a percent of the overall mineral supply.

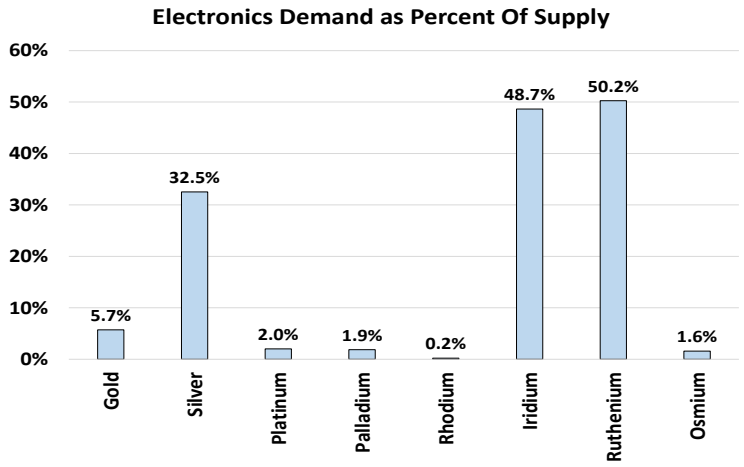


Chart 3: Electronics Precious Metals Demand % of Total 2020 Supply
Source: Precious Metals Commodity Management LLC

According to our analysis, a total of 32.5% of the global silver supply ends up in electronics. Given silvers overall abundance, you can see in Chart 4 below how dominating silver is in the electronics markets. Platinum group minor metals ruthenium and iridium use 48.7% and 50.2% respectively. Gold sends 5.7% of its global supply into electronics. Platinum sends 2.0% and palladium 1.9% of their respective overall global supply into electronic. Rhodium and osmium have very small contributions to electronics.

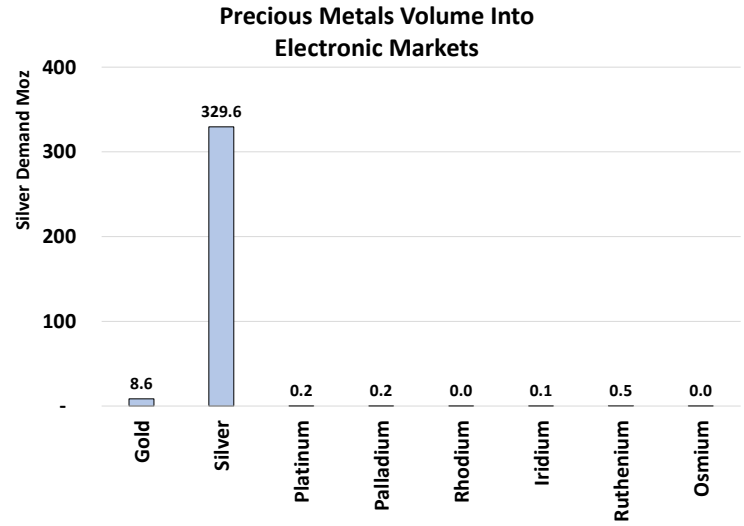


Chart 4: Electronics Precious Metals 2020 Demand
Source: Precious Metals Commodity Management LLC

Chart 4 above, indicates the various metal's loadings in the different electronics markets. Again, this is what sets the printed and flexible electronics market apart from the others with their higher loadings.

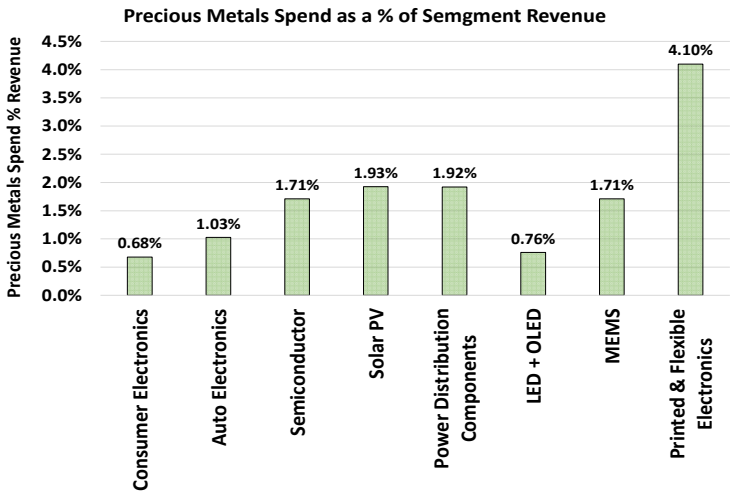
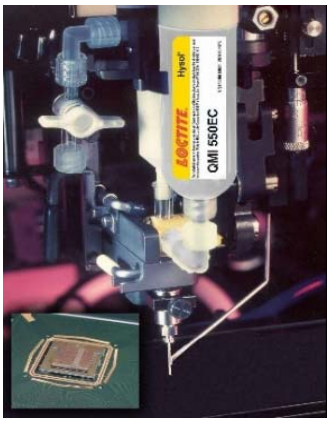


Chart 5: Electronics Precious Metals Spend as % of 2020 Market Revenue
Source: Precious Metals Commodity Management LLC

We have endeavored to study each of these electronics markets separately mapping their respective uses of all of the precious metals. The semiconductor industry, for example, spends approximately 1.71% of its total market revenue, or over US$7 billion on precious metals products used in semiconductor front-end manufacturing and back-end packaging materials.



Silver Die Attach Material

Silver Bonding Wire

Precious Metals Products

How much precious metal is used in the different electronics markets, and in what form is it used?

Silver

Silver is a natural thermal and electrical conductor and is therefore used in numerous electronics such as electrical switches, superconductors, batteries, televisions, etc. It resists corrosion and oxidation, though not as well as gold. Because silver is the best thermal and electrical conductor of all the metals, silver is ideal for electrical applications. Silver has excellent bonding and solderability characteristics, and is often used to conductively mount or bond devices to printed circuit boards, or to packages that need to be conductively mounted to other devices or substrates. Most touch screen device functionality is enabled by the use of silver.

Silver is used extensively in the solar PV cells and modules as an electrical connector or conduit of the energy collected from the sun.

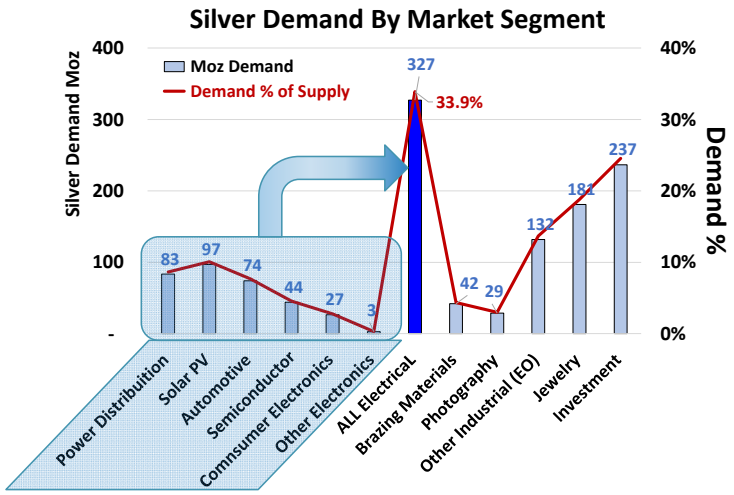
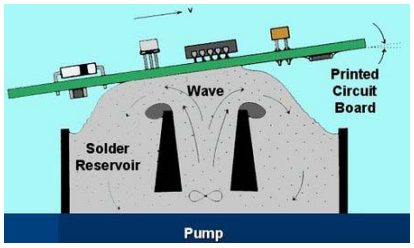
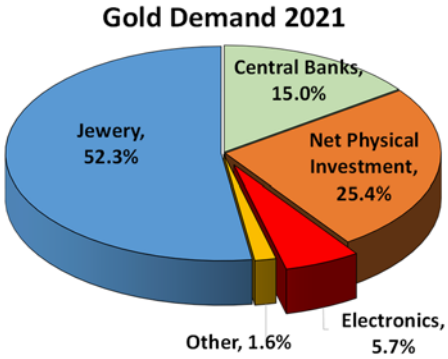
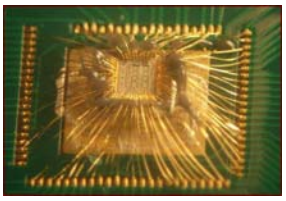


Chart 6: 2020 Silver Demand by Market Segment
Source: Precious Metals Commodity Management LLC

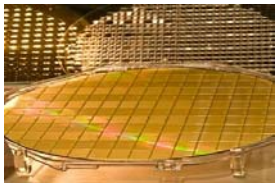


Silver Solder Wave Reflow





Gold Bonding Wire



Gold Plated Wafer

Silver Products Used in Electronics include:

- Silver and silver/alloy pastes
- Silver alloys die attach materials and electrically conductive adhesives
- Silver alloy conductive tapes and ribbons
- Silver and silver/alloy bonding wire
- Silver wet chemistries
- Silver solder materials
- Silver-oxide battery materials
- Silver alloys in contact materials
- Silver inks and aerosol products
- Silver nanoparticles
- Silver and silver alloy coatings
- Silver physical vapor deposition sputter targets

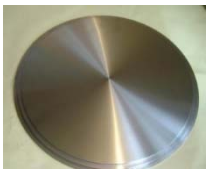
Gold:

Our research found that less than 5.7% of the supply of gold finds its way into electronics, a surprisingly low percentage at first glance. Of course, electronics scrap processors effectively target this high value metal. Gold currently is 60 to 70 times more expensive than silver, so of course it is targeted by recyclers. But in terms of troy ounces consumed in electronics, gold is indeed a vastly lower consumption volume product compared to silver.

Gold is used in electronics for three primary reasons: It has high electrical conductivity; it is malleable; and it's resistant to tarnishing. Small amounts of gold can be found in several electronic devices, including cell phones, televisions and computers. Gold has a very high density, and is therefore resistant to corrosion, making it ideal

for bonding and conductively connecting components to one another and to substrates.

Platinum



Platinum PVD Sputter Target

Often mixed with cobalt, platinum is used to get strong permanent magnets. Electrodes inside of glass are usually sealed with platinum because its thermal coefficient of expansion is almost equal to that of glass. Platinum can also be used in low voltage electrical contacts and electrical resistance wires.

Platinum products used in electronics includes physical vapor deposition (PVD) sputter targets, atomic layer deposition (ALD) and chemical vapor deposition (CVD) materials, electrodes, wires, spark plug tips, electrical contact materials, and wet chemistries.

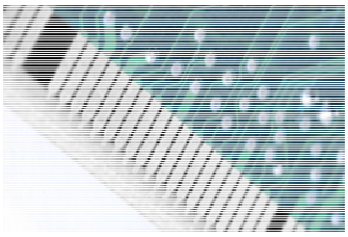
Platinum Resistance Thermocouple

Palladium

Palladium was used extensively as a paste in multi-layer ceramic capacitors (MLCC's) up until the year 2000 when a peak 2.1 Moz of palladium was consumed in this one single electronics product. These capacitors and their palladium continue to show up in e-waste recycle to this day.

Palladium/Silver Conductive Paste

Palladium is frequently used in the electronics industry as a plating for connectors and contacts. This is because of its low surface contact resistance. Often, a palladium-nickel alloy is plated on a connector surface before adding a flash of gold, this combination provides a low-cost, yet highly effective solution.



Palladium-Nickel Plated Connector

The Fundamentals of Printed & Flexible Electronics

Printed electronics enable the production of flexible and large-area components and complement silicon electronics. The substrates used are often thin, lightweight, and low-cost to manufacture. Printed electronics technology also enables products that can be directly integrated into low-cost reel-to-reel processes. This also enables production on larger area substrates including displays.

Fighting Food Waste With Printed Intelligent Expiry Date Label

Printed and flexible electronics rely on conductive or dielectric inks and a range of pastes using a range of coating, printing, dispensing and deposition of conductive materials. There are over a dozen technologies used to deposit these materials depending on what the producer needs. Some methods are higher resolution requiring tighter process control, while others are more geared for speed and throughput.

Thinfilm teams with Xerox so it can print a billion chips a year for the Internet of Things

There is no standard technique for producing printed electronics. Exactly which method is being used depends on the application, ink and substrate. The producer needs to consider whether a high resolution, throughput or homogeneity is the primary requirement. Nearly all types of industrial printing processes are being used, ranging from gravure and flexographic printing to screen and inkjet printing. However, these techniques need to be modified to allow the printing of electronics. Furthermore, it is possible to apply known processes from the classical semiconductor manufacturing, such as vapor deposition. The combination of all these types of process technologies with the knowledge from other industry sectors, such as material development and electrical engineering, has enabled the mass production of printed electronics.

Inkjet Printed Electronics

According to our research, the printed and flexible electronics market is approximately a $US57 billion-dollar total market revenue today and will enjoy an 11.0% CAGR over the next 5 years. This year 48 Moz of silver will be consumed in this segment. By 2025, the printed and flexible electronics market should enjoy US$96 billion in revenue, consuming with an estimated silver consumption of 60 Moz. A breakdown of the printed/flexible electronics market share is provided in below. Printed displays dominate this mix, along with printed organic photovoltaics.

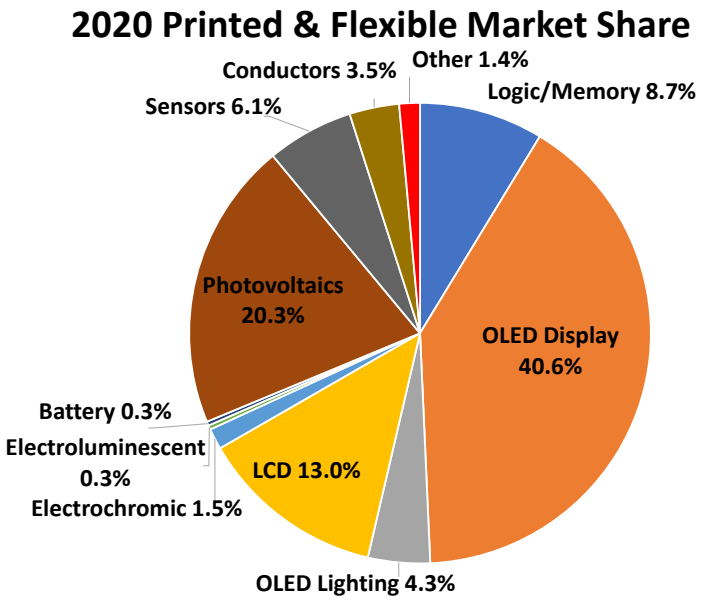
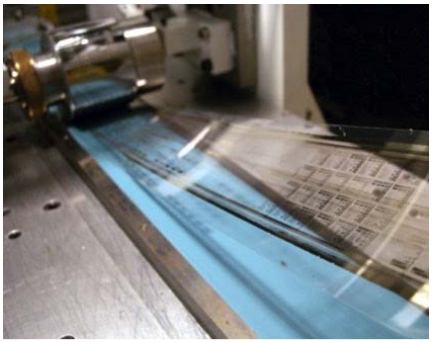


Chart 7: 2020 Printed & Flexible Electronics Market Share
Source: Organic and Printed Electronics Association (oa-e)



Gravure Roll Printed Electronics

A very informative comparison of market growth can be seen in the market comparisons chart below that contrasts the historical growth of the mature semiconductor market with the flat panel and printed electronics markets.

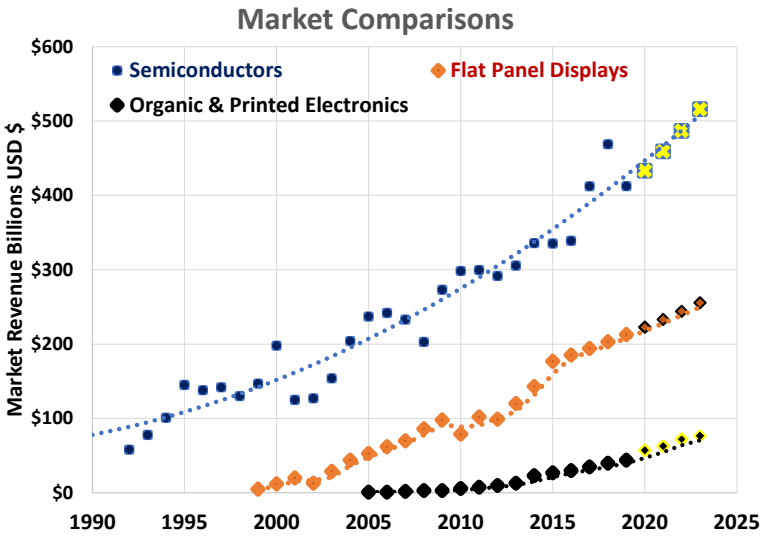
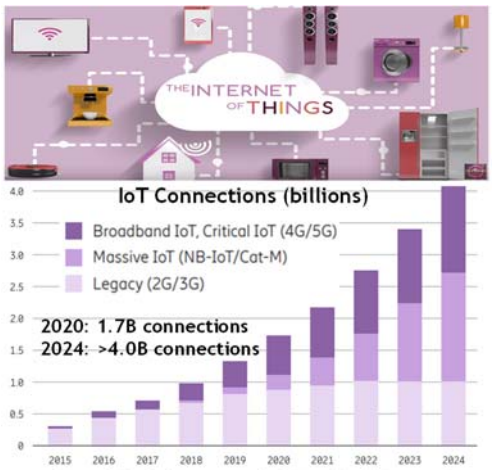


Chart 8: Electronics Market Trajectory Comparison
Sources: WSTS, Display Search, IDTechEx, Smithers Pira, Displaybank, Konica Minolta, Yole Development, and forecasts from Precious Metals Commodity Management LLC



Number of Global Internet-of-Things (IoT) Connections
Source: ericson.com

Visualizing the Future: Printed and Flexible Electronics Roadmap

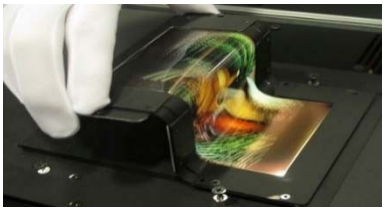
Display growth will continue to penetrate everything from appliances to automotive to residential and commercial lighting systems. Much of this has to do with cost, where producers are looking to scale low-cost and fast to produce roll-to-roll printing.

Consider the number of connected devices in our world today, largely made up of computers, tablets, and smartphones. As the world continues its migration into 5G wireless (5th generation wireless connections), most analysts realize there will be an explosion in the number of connected IoT devices. Ericsson estimates that globally there are 1.7 billion connected devices in 2020, and that will very quickly grow to over 4 billion devices by 2024. This is a stunning rate of growth that will pull more precious metals demand along with it.

Future Auto Panel OLED Lighting

The Organic and Printed Electronics Association has defined their roadmap OE-A Roadmap 8th Edition as follows:

Automotive: OLED lighting for exterior and interior style elements; curved displays; touch sensors; energy harvesting using organic photovoltaics (OPV); 3D and flexible surface integrated sensor applications for smart user interfaces.



Foldable OLED Screen

Printed Electronics Improve Patient Safety

Printed NCF Smart Labels

Flexible Wearable Displays

Building Integrated Organic Photovoltaics

Consumer Electronics: Foldable and flexible displays for phones, tablets, or wearables; EPD (Electronic Paper Device is a technology that uses an electrically charged surface replicating the look and feel of ink on paper) as second display; displays as decorative applications; OLED luminaires; sensing and signage for white goods; touch and functional surfaces; wearable technology.

Healthcare: Displays for use in wearables, smart watches; bio sensors; OLEDs for light therapy; biocompatibility of materials and substrates; monitoring and diagnostics, self-monitoring for preventive care, and for wellness purposes.

Internet-of-Things: Integration and embedding of displays in Internet-of-Things and in everyday objects; OPV-power sources for autonomous devices; smart labels, including temperature logging; printed / hybrid near field communication (NFC) and radio frequency identification (RFID).

Printing and Packaging: Low-cost and low-power displays for price labels and enhanced packaging; smart labels and tickets; smart packaging combining sensor systems, energy harvesting and storage, HMI input devices and displays; printed / hybrid NFC and RFID.

Smart Buildings: EPD for signage and decoration; electronics chart display wallpaper and information labels; building integrated organic photovoltaics everywhere (facades, windows, roof s); organic photovoltaics for energy autonomous sensors; OLED lighting as decorative, architectural, and/or functional lighting; sensor systems for use during and after construction, and for energy management including smart windows.

Conclusions

The printed & flexible electronics market is the most exciting electronics market segment. Silver in particular serves this segment extremely well due to its natural characteristics including excellent conductivity, solderability, flexibility, corrosion resistance, and modest comparative costs. Printed and flexible electronics markets routinely spend over 5% of the total market's revenue on conductive materials, the heart of the technology. This is the highest ratio of conductive materials and precious metals out of all of the various electronics segments. Given the massive growth in the number of IoT devices, sensors, and displays, printed electronics will become a central market to the overall electronics industry.

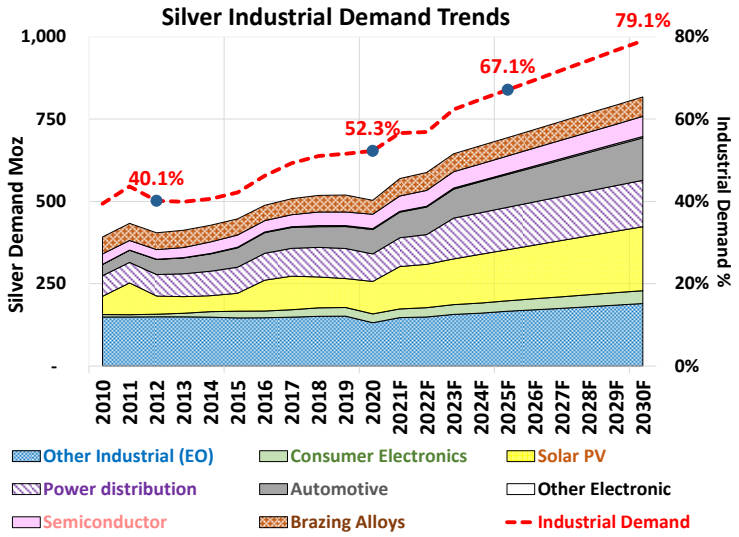


Chart 9: Silver Industrial Demand Forecast
Source: Precious Metals Commodity Management

Note that printed and flexible electronics is a portion of several of these other industrial demand categories including consumer electronics, automotive, solar PV, and semiconductor as shown in Chart 9.

Silver is becoming increasingly an industrial and electronics-based metal. Chart 9 above illustrates the industrial demand sources of the silver market forecast out through 2030.

The future of silver in printed and flexible electronics is bright, growing from 48 Moz of demand in 2021, to an estimated 74 Moz of demand by 2030.

Matt Watson is the Founder and Principal of Precious Metals Commodity Management LLC, based near California's Silicon Valley. Specializing in precious metals markets and its supply chain, Matt assists clients ranging from Mining, Investors, Industrial Precious Metals Users, Processors, and Recyclers and coaching industrial clients how to reduce costs, design thrift, and anticipate market changes. Matt has also worked with the Silver Institute in studying the ever-increasing industrial demands in silver.

Our ongoing mantra is that this will be the century of clean energy and mineral constraints. Silver's use as a key conductive energy collecting vehicle for the Solar PV market is an example of one of these potentially constraining clean energy mineral limits.