I-Connect007

DECEMBER 2018

PCB007 MAGAZINE

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PCB007 MAGAZINE

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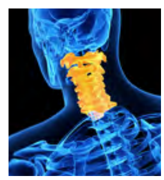

HIGHLIGHTS:

Can E-waste and Metals Recovery Efforts Lower Environmental Risks and Liability?

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Gold, palladium, silver, and other precious metals (PMs) in manufacturing wastes represent high value, but how PMs are recovered can pose environmental and liability issues. Aerospace and electronics manufacturers and suppliers, in particular, produce volumes of manufacturing wastes that contain varying levels of PMs. With U.S. growth projected at around 2% in 2019 [1,2], there may be an opportunity for more manufacturers and suppliers to review current methods and move to higher ground.

This would include printed circuit board (PCB) manufacturers. Although bookings for PCBs have fallen from recent peaks, shipments have been up about 10% through the third quarter of 2018 [3]. There are two waste streams for recycling and recovery for manufacturers to consider—the electronic waste (e-waste) from manufacturing operations and end-of-life (EOL) product recycling.

On the manufacturing side, a waste audit can identify areas where more PMs might be captured for recovery. This includes both high-level PM residuals from manufacturing operations—such as precious metals plating solutions, conductive pastes, filters, and sludges—and lower-level PM residual materials—such as syringes, wipes, rags, gloves, solder waste, and floor sweepings. Manufacturing wastes also include damaged parts and returns, as well as finished electronic components and PCBs that are outdated or obsolete. These items may also need to be handled according to industry and government standards.

Security is often a paramount concern. The design of PCBs may be proprietary, classified, or under International Traffic in Arms Regulations (ITAR) restrictions and sensitive components may need to be destroyed or obliterated to render information "irretrievable by any means." The environmental impact of recycling and recovery efforts is also a key consideration especially for government entities, consumer product companies, and other public corporations.

Beyond e-waste from manufacturing, EOL recycling is a growing concern for OEMs since it can impact operating costs as well as brands. As environmental issues grow, it also can impact PCB suppliers both directly through new quality or compliance requirements, or indirectly through a change in customer or public perceptions. Whether that is a threat or an opportunity depends on a variety of factors and how companies including recyclers choose to respond. Environmental considerations can often be downplayed, ignored, or simply overshadowed by the drive for maximizing returns, and smaller operations may be more vulnerable.

Of course, manufacturers, suppliers, and recyclers must comply with regulatory requirements and operate profitably in a competitive marketplace to remain in business, yet how companies respond can have long-term consequences. Environmental liabilities can surface years later from improper management and challenge a company's reputation or very existence. Liability can also lurk closer to home. When any recycler goes out of business and leaves a mound of hazardous waste behind, there can be finger pointing and a search for deep pockets [4]. For these reasons, it is important for manufacturers and suppliers to develop close, trusted downstream relationships and understand recycling and recovery processes and the ultimate fate of their products.

Baseline Value

The value of recycled e-waste can vary widely. Recent bans from China and Thailand on e-waste emanating from the U.S. further devalues recycled e-scrap in the U.S. and puts pressure on collection facilities, landfills, and tipping fees. At the same time, the value of recovered precious metals can gyrate, making planning difficult. The profitability of recovery and refining operations is often closely tied to metals commodity prices, and foremost among those is gold. Over the last 10 years, gold has swung from below $750/oz. in 2009 to a high of nearly $1,900/oz. in 2011 before settling into a range around $1,250/oz. ± $200 [5]. Palladium has seen even wilder swings with prices jumping over $1,100/oz. in the last month from $175/oz. a decade ago.

Manufacturers should seek waste recyclers that are financially stable. Those in a better position to withstand market fluctuations are also more likely to value their reputation and environmental responsibility and have programs in place to ensure environmental compliance and traceability.

There is also variability at the part level for electronic scrap. The amount of gold in a dynamic random access memory (DRAM) can easily vary by a factor of three or more depending on the exact part and manufacturer. Counterfeit parts in EOL waste streams can also confound expectations about returns. Fair pricing for e-scrap is often a matter of experience with a supplier and trust that builds over time. Speculators can acquire parts and either hold them for years hoping for market conditions to change for resale, or seek an immediate premium on the precious metals content, but may generate ill will.

Looking ahead, miniaturization, substitution, and advanced electronics manufacturing techniques will likely further reduce the already low levels of precious metals in key components, putting a further squeeze on the recycling industry. This means that while there are a variety of advanced recovery processes available or under development for precious, base, and rare earth metals—proven methods of recovery—and refining will likely continue to predominate for the foreseeable future.

Recycling Overview

Whatever the prevailing value of the underlying metals, electronic manufacturers often want to reduce the volume or bundle their scrap. Some recyclers offer one-stop services and may shred e-scrap on site before hauling it to another downstream vendor. On-site shredding can be advantageous for volume reduction to lower transportation costs and destroy intellectual property. However, it can make recovery of targeted PM components more difficult if not impossible. Closed-box services can offer an alternative with shipments directly to a PM recovery operation. Locked-box services go a step further with the secure shipment of high-value items. Secure transit can be accomplished through the use of seals, evidence tape, or lockable containers.

From the recycler's perspective, one of the biggest differences between manufacturing scrap and EOL scrap is that EOL scrap involves more plastic and base metals and typically more sorting. With either waste stream, for components that cannot be directly recycled or reused, the goal is to transform heterogeneous materials into one or more marketable commodities. PCBs are comprised of a complex mix of materials that includes fiberglass and epoxy resins, solder, and electronic components. They contain copper, and to a lesser extent gold, silver, palladium, steel, stainless steel, aluminum, and other base metals.

From the refiner's perspective, the best way to gauge how much PM there is any e-scrap stream or batch is by sampling and assaying. Due to the variability inherent in e-scrap, the more concentrated the level of PM in waste, the more important accurate sampling is and the higher the return. Of course, the value of the batch should cover the cost of sampling and assaying. It does not make sense to refine e-scrap worth $1 per pound in a process designed for $8–10 per pound PM residuals.

Primary E-scrap Recycling

Chart 1 shows a generalized flow diagram for metals recovery from e-scrap [6]. E-scrap recyclers may voluntarily certify to R2 or other in-

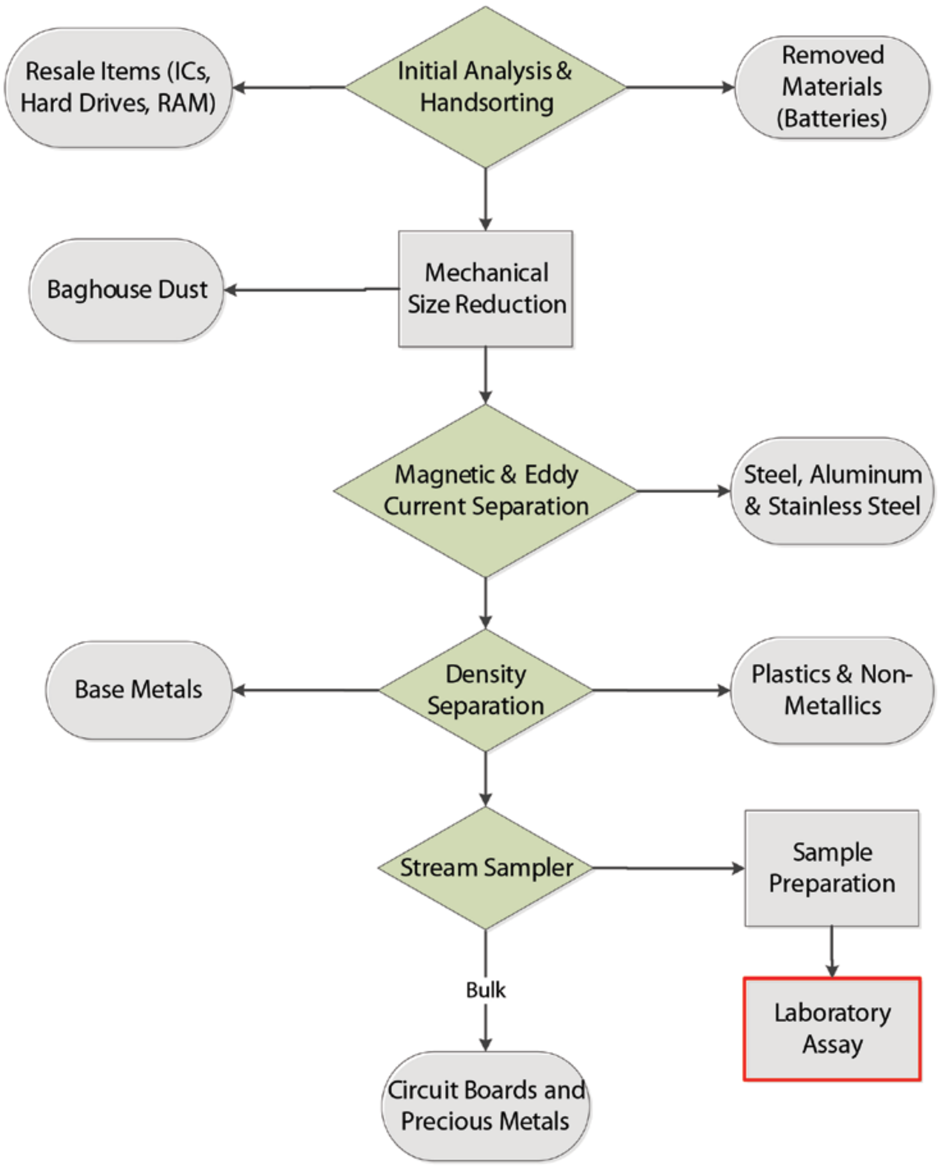

Chart 1: Primary e-scrap recycling.

Figure 1: High-value electronic scrap containing precious metals.

dustry standards, which are intended as an indicator of regulatory compliance and commitment to environmental procedures that follow a reuse-recover hierarchy and seek to reduce wastes to landfills and monitor transboundary movement. Resale of components typically offers the highest value and does not generate any new waste. After the initial sort, potentially hazardous components such as batteries must be removed. Components likely to contain recoverable levels of precious metals should also be targeted such as high-density PCBs, integrated circuits (ICs), memory chips, and PM connectors and pins (Figure 1).

Most recyclers serve primarily as collection points and include some type of sorting or shredding operations. They may shred or pulverize materials before sending them to further processing operations. A few are vertically integrated and incorporate chemical recovery and/or thermal reduction methods to prepare marketable metals for recovery.

Tight labor markets and rising wages put pressure on e-scrap recyclers to limit disassembly and/or rely more on automated methods. Along these lines, Phase II of a trial on a new method for disassembling PCBs is underway with the U.S. Environmental Protection Agency (EPA) and due for completion at the end of February. The equipment uses infrared (IR) to melt solder connections as PCBs travel on a conveyor and are then vibrated to loosen components [7]. This may improve recovery of reusable board-level components such as ICs, as well as improve returns by segregating devices containing precious metals for refining or further processing or refining. However, significant copper remains in the substrate with a requirement to process. Downstream charges are the same, or in some cases, more since both the per-pound value and attractiveness as a smelter feedstock are reduced.

Chemical Methods of Metals Recovery from PCBs

Chart 2 shows a generalized method of recovering metals from recycled PCBs via hydrometallurgy [6]. This wet chemical recovery process involves leaching followed by a concentration and purification step and may include further metal recovery. Leaching solutions may vary in their oxidation-reduction potential depending on the reaction. They may also require additional energy for heating to speed or extend the reaction, and may use chelating agents to extract certain metals selectively.

Recovery may proceed in sequence from the top, or leaching processes may be used for targeted materials. Leaching agents include nitric acid and hydrochloric acid (aqua regia). They also include salts such as sodium cyanide that form a strong base when dissolved in water. These are all hazardous chemicals and pose health and environmental risks if not properly stored and handled. Sodium cyanide solution reacts violently with acid and can produce highly toxic and flammable hydrogen cyanide gas.

Electrowinning selectively separates metals from an ionic solution using electrolysis. For example, with direct current, copper or gold can be electroplated from the solution. Electrowinning can be used in the solder leaching step to remove trace hazardous chemicals such as selenium and lead.

In the PM recovery process, chloride leaching may be used to recover palladium or potassium iodide used to recover platinum. Gold and silver are recovered by acid leaching, and the solution is then filtered. Activated carbon adsorption can also be used in a separate step to separate residual heavy metals such as nickel and zinc.

It should be noted that milder leaching chemistries such as glycine-peroxide solutions are being investigated [8] and have the potential to reduce environmental impact. Even mild acids such as white vinegar can be used for leaching gold [9]. However, a stronger acid and oxidant are still needed along with additional time or energy, and results are not suitable for commercial scale. When it comes to recovering precious metals, the goal is always 100% recovery. Some progress is also being reported on improving extraction from hydrometallurgical leaching solutions through the use of electroactive polymers. This requires additional active-bed processing but avoids the need for extraction reagents or additional energy [10].

In addition to hazardous wastes, hydrometallurgical processes generate non-metallic waste, which is typically a mix of different plastic compounds that are not recyclable. A fraction may find its way to waste-to-energy facilities, but the vast majority is trucked to landfills. More advanced chemistries may also generate waste that requires additional treatment for environmental disposal.

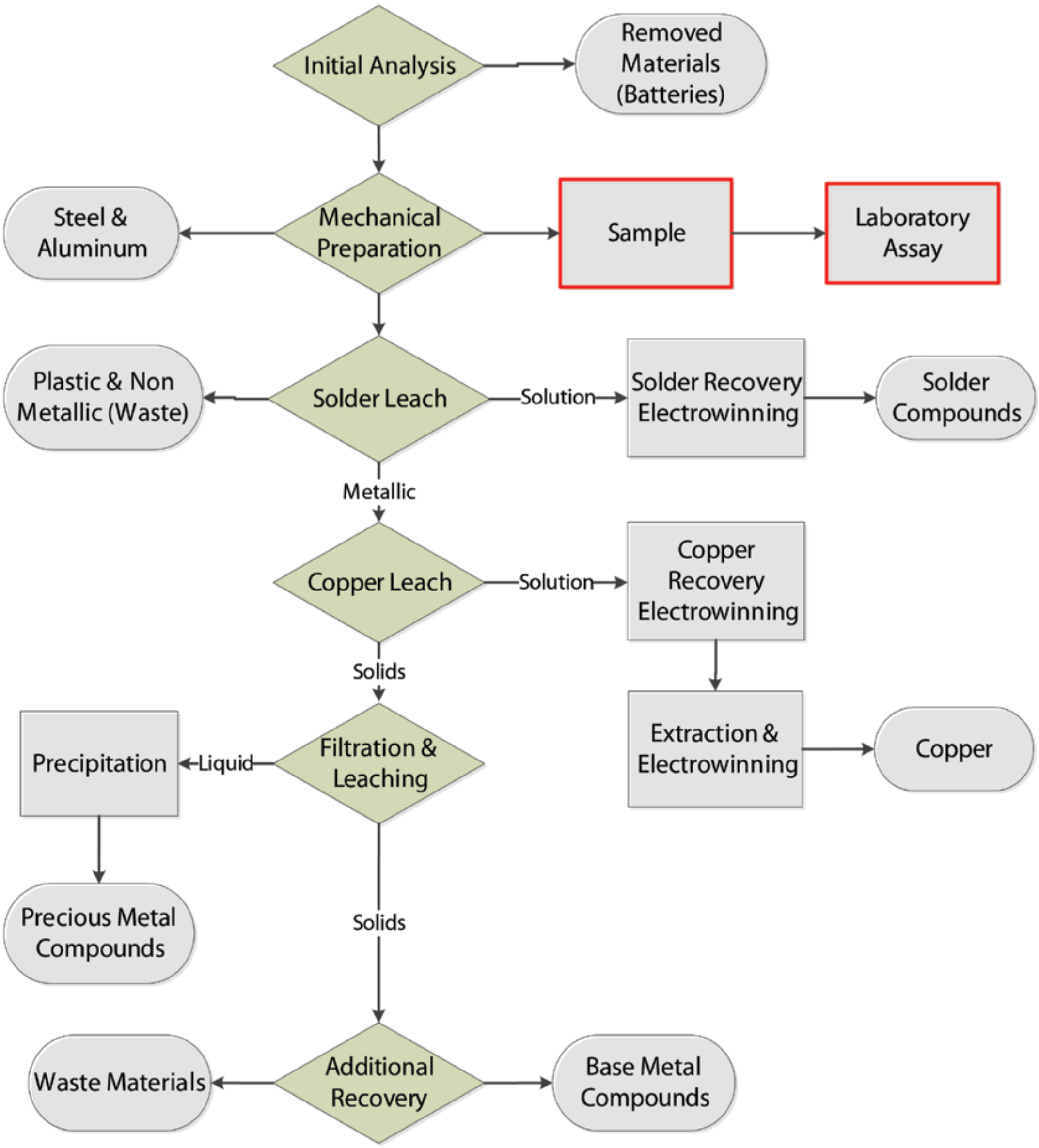

Chart 2: Chemical recovery of PMs.

Pyrometallurgical Recovery and Refining of PMs

Chart 3 shows a generalized diagram of the pyrometallurgical process for PM recovery. This method is ideal for e-scrap with high-levels of precious metals, such as the recurring wastes as noted from electronic manufacturing operations. It can also be valuable for recycled electronic components that have been segregated for potential residual value such as high chip density circuit boards.

Newer combustion processes typically use natural gas, which is cleaner and more cost-effective than other fuels. Pyrolysis greatly reduces the volume of non-metallic residue [11] but generates combustion byproducts which must be controlled. Newly constructed facilities and process upgrades typically incorporate more stringent pollution controls to meet government standards and permitting requirement.

Traditional incineration furnaces may operate at temperatures in excess of 2,500°F. These high temperatures contribute to the formation of toxic compounds when processing plastics and other organic compounds. Older furnaces may include a secondary afterburner to achieve more thorough burning of exhaust, but often lack other environmental controls or even basic filtration.

Controlled temperature processing and advanced controls can greatly reduce emissions

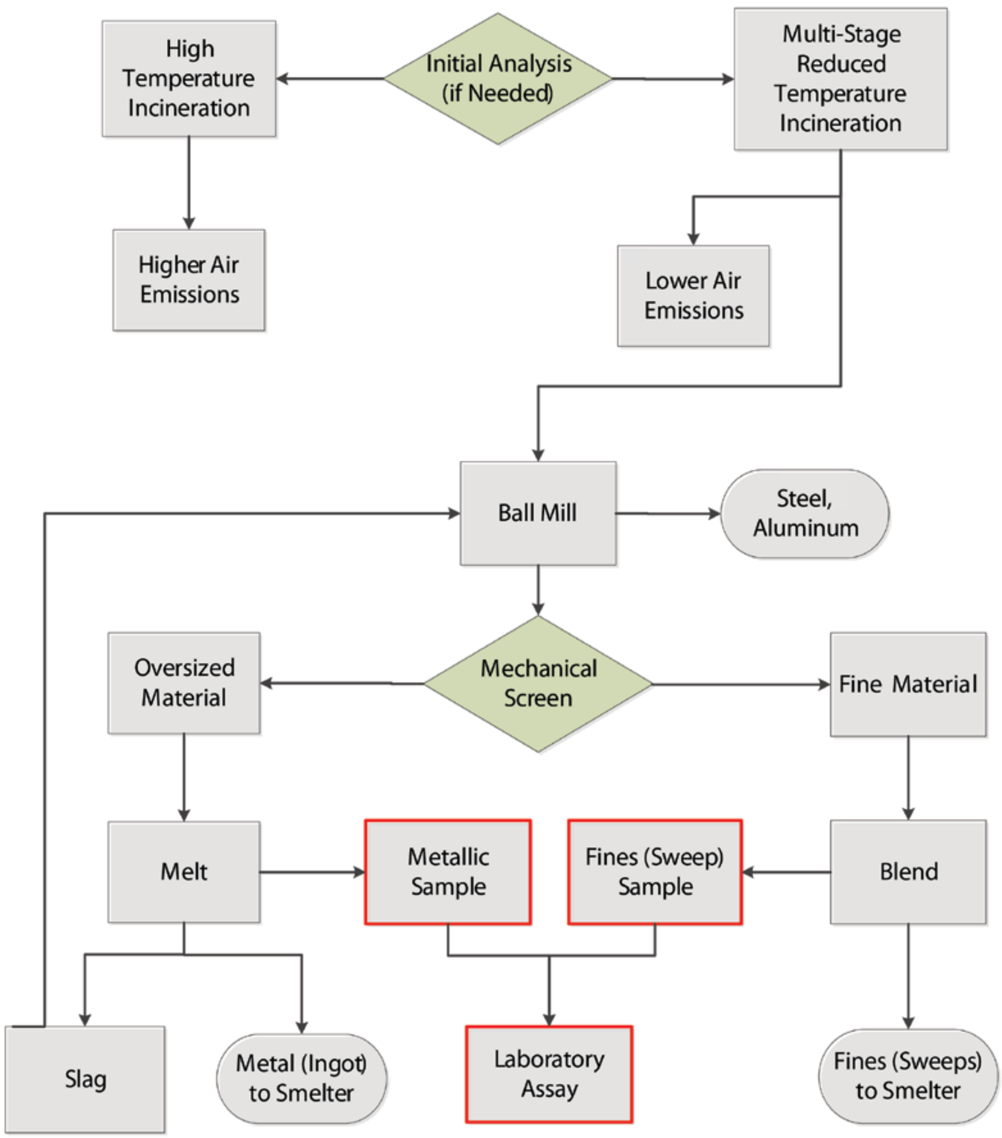

Chart 3: Thermal recovery of PMs.

while increasing the efficiency of subsequent milling or leaching operations. Recognizing the emerging needs in the electronics industry, Gannon & Scott designed a multistage thermal reduction system that essentially roasts combustible materials at temperatures around 1400°F. The company operates the TRu3Tec® thermal reduction system at processing plants on the West and East Coast—both of which are zero-discharge facilities (Figure 2).

Following combustion, gross metallics and primarily steel are removed before sending out for base metal recovery. The process also yields organic ash entrained with a combination of base and precious metals. The volume of organic content is much higher than high-temperature pyrolysis, which is evidence of much lower air emissions. The resulting ash is reduced to a powder by heavy ball milling, and the residue is screened by particle size. These two simple mechanical processes separate organic ash fines (also called sweeps) from the metallic (oversize), typically copper and precious metal alloys. Precious metals are also contained in the ash fines, which are then blended, sampled, assayed, and sold as a commodity. Metallics are melted, sampled, and poured into ingots.

The TRu3Tec system features advanced pollution controls including quenching, cyclonic separation, wet scrubbing of exhaust gases, and dust collection [12]. Quenching reduces exhaust temperatures to decrease the formation of hazardous byproducts. Cyclonic separation then knocks down carbons and other heavy particulate matter. Next, wet scrubbing removes acidic compounds, and the liquids are neutralized and air-dried in a separate process. Before exhaust is released to the air, it passes through a final series of filters which remove fine particles. All scrubber-solution entrapped solid salts from the air purification process and filtered dry particles are captured and converted on-site into sweeps. No hazardous waste is created.

There are other advanced electronic recycling technologies on the horizon including electromechanical and supercritical gas technologies, and even biometallurgical methods [13]. However, what may work in the laboratory must also be tested at a commercial scale, and be economically viable, profitable, and ideally, sustainable.

Figure 2: Lower temperature thermal reduction in combination with advanced environmental controls greatly reduces emissions. (Source: TRu3Tec system, Gannon & Scott Inc.)

In the final analysis, the two current paths for PM recovery following primary recycling operations remain chemical (hydrometallurgy) and thermal (pyrometallurgy). Both are proven methods that exist today. Nevertheless, there can be wide variation in process equipment and efficiencies, and residual waste byproducts. In addition, market pressures can negatively impact recycling channels. For this reason, electronic manufacturers and suppliers concerned about data security or environmental liability should carefully evaluate downstream processes and relationships. Those who do will likely discover fresh opportunities for growth. **PCB007**

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Andrew McManus joined Gannon & Scott as general manager in 2016. Previously, he spent 15 years at a recycling company that processed electronic waste and precious metal scrap. Early in his career, McManus worked in environmental and operations positions at manufacturing facilities involving precious metals at metal-finishing shops and a flexible-circuit operation. Andrew also served over 30 years in the U.S. Army and Reserve retiring as a lieutenant colonel. He earned an MBA in operations management from Bryant University and a B.S. in chemical engineering from the University of Rhode Island.

Gannon & Scott has been a precious metal processor since 1919.

Researchers Unveil Breakthrough in Human-machine Cooperation

Researchers at KTH Royal Institute of Technology reported new progress working within the framework of the Horizon 2020 European research project, Co4Robots. The project has developed functionality that enables real-time robots to move in a dynamic situation while collaborating with other robots and people.

The new functionality the project has developed has since been assigned to the TIAGo robot from PAL Robotics in Spain. TIAGo has gained a sense of observation that it can use to navigate in a changing landscape such as an office. As the robot steers itself around a workplace, it can identify things that must be moved. When a human co-worker wants the robot to help them pick up an object, the worker gives the robot a hand signal. Another signal tells the robot to release the object so it can be set down.

Professor Dimos Dimarogonas, coordinator of the project at KTH's Department of Automatic Control, says that the functionality is not platform-specific, so it can be transferred to other robots during the next phase when tests continue with Bosch.

"The robots will be in a larger dynamic office environment and collaborate with more robots and people. They will get more advanced tasks, and with different types of agents," Dimarogonas says. Other uses for the technology will eventually include healthcare facilities.

(Source: KTH Royal Institute of Technology)