RONIN 8

# TECHNOLOGY INTRODUCTION
## Sonic Upgrading Facility

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# 1 SONIC UPGRADING FACILITY (SUF)

With a vision to create a circular economy for the electronics industry, Ronin8 has built a team that has successfully developed, distinct technologies that deal with printed circuit boards (PrCBs) in a fashion that supports responsible, environmental stewardship of these products, which have become obsolete in their current form.

The Sonic Upgrading Facility (SUF) processes printed circuit boards (PrCBs) by liberating and separating metals from non-metals efficiently and economically, enabling each stream to be processed in a manner which unlocks their maximum value. The SUF is a ground-breaking wet system that incorporates the re-purposing and retro-fitting of established technologies from other industries to the PrCBs vertical, as well as the application of in-house sonic liberation technology to enhance separation, which provides a competitive advantage over other options in the end-of-life electronics recycling industry.

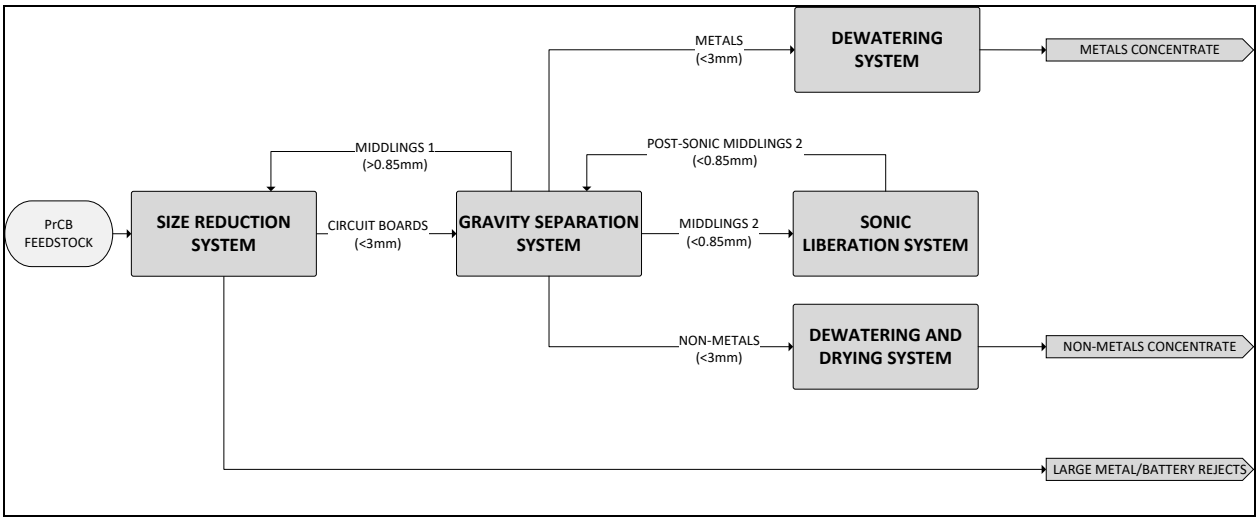


*Figure 2-1: High-level block diagram of SUF process*

## 1.1 Sonic Technology

Originally developed in the mining industry, the sonic liberation unit harnesses the intense kinetic energy produced from vibratory resonance of a massive solid steel bar (the “resonant member”) - analogous to a tuning fork, but at a much larger scale. Symmetrical in design, the sonic liberation unit is induced into its natural resonance frequency via a series of electromagnets on either end of the resonant member. Resonance chambers are attached to each end of the bar, and process slurries are conveyed through these chambers. Within the resonance chambers, the process slurries are subjected to the intense kinetic energy “in-line”, produced from the vibratory resonance of the resonant member.

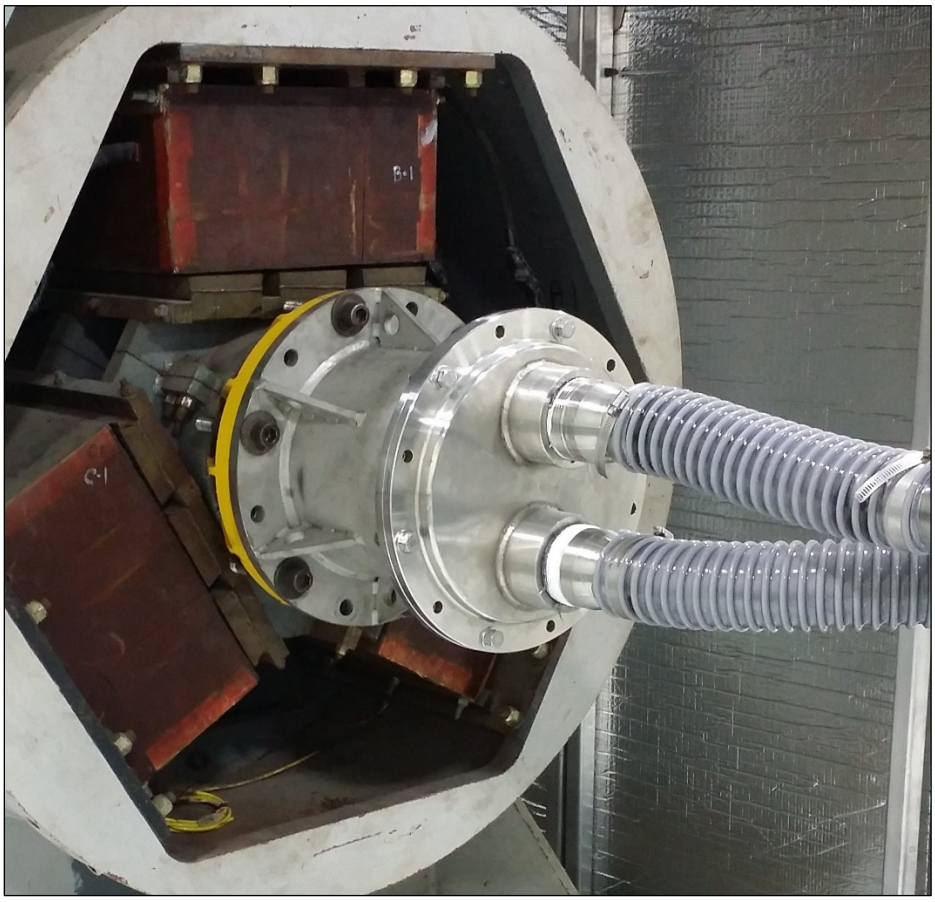

*Figure 2-2: Sonic liberation technology*

The sonic liberation technology provides a unique enhancement to the liberation of metals from non-metals in PrCB slurries, based on the efficient application of vibratory resonance to process

wet slurries through the resonance chambers. This patented technology delivers specific process enhancements and advantages due to the use and application of the resonance energy, as follows:

- Facilitates media/slurry movement and attrition without the use of a rotational mechanism, thus providing a unique “polishing” effect used to liberate and separate materials based on differences in material properties (i.e. malleability, friability) vs. pure impact energy
- Low-impact/high input energy wet attrition size reduction, thus avoiding the high-wear of high-impact attrition milling technologies;
- “In-line” size reduction in media-retained sonic chambers provides maximum control of residence time, thus minimizing the risk of gold smearing and subsequent loss in ultra-fine slimes produced in conventional media-based milling technologies; and
- The ability to both size reduce and condition a process slurry simultaneously due to the instantaneous mixing effect created by the resonance vibrations.

## 1.2 SUF Pilot Validation: P-Delta

The base SUF has been demonstrated in a 20,000 sq ft prototype plant known as the P-Delta pilot facility ("Delta" representing the development leap from preliminary concept to pilot implementation and operation), with the process being validated, from both technical and performance perspectives, by an independent technical auditor.

### 1.2.1 Background

With Canadian government support and investor equity, a prototype plant dubbed P-Delta was built in Richmond, BC, Canada with objectives that included:

- Showcase and validate the novel application of the sonic technology in a closed-loop facility with a nominal capacity of 1 tpd;
- Obtain RQO certification and cultivate relationships with regulatory and compliance representatives;
- Engage with suppliers of feedstock and metals concentrate refiners to prove supply and pricing;
- Generate and accumulate critical operational data and invaluable process expertise to support commercial scale-up; and
- Produce unique metals and non-metals concentrates to facilitate the development of innovative value adding enhancement of these products.

Fully commissioned in January 2016, the individual unit operations (equipment which perform a physical change or chemical transformation to the materials) at P-Delta each have a nominal processing capacity of 0.5-1 tonne/hr, and are operated in batch mode (materials are manually transferred between unit operations).

Such an operation limits the overall throughput of the facility, but has some important and deliberate effects:

- Gives Ronin8 the ability to showcase the closed-loop Sonic Upgrading Facility in a controlled, adaptable manner;
- Gives Ronin8 the ability to process individual batches of material and accurately assess recovery for potential clients/partners;
- Allows for maximum control of operating conditions, producing distinct operational data unique to each process step; and
- Allows for a cost-effective means to achieve process validation through a third-party.

With this in place, SGS Canada Inc., a global verification and validation firm, was retained to perform an independent technical evaluation and process assessment.

### 1.2.2 Third Party Technical Evaluation

Ronin8 commissioned SGS Canada Inc., a global verification and validation firm, to complete a third-party process review, to be completed in two phases:

- Preliminary process review and on-site audit
- Audited mass and material balance and sonic performance assessment

The first phase of the SGS audit involved a preliminary review of the process, sampling, and analytical protocols as well as an operational tour and audit of ongoing operations. This was performed by Steve Wilson, Global VP Mine and Plant Services, and Jake Lang, Global Metallurgical Business Manager.

The following excerpt from the Phase 1 Final Report clearly summarizes the results from this exercise with SGS:

> *"The Ronin8 plant has clearly demonstrated a successful proof of concept for liberating and separating a metallic product from recycled circuit boards. The plant is being well run as a semi-batch process."*

The second phase included an audited mass and material balance as well as a technical assessment of the sonic performance.

A full metals balance and a testing program was conducted to evaluate process design elements and allow Ronin8 to upgrade the facility to a commercial scale, continuous operation with appropriate material balance controls. This was performed by Dominique Lascelles, Metallurgy Manager (Vancouver).

Two full materials balances were performed on two separate feedstocks – one low-grade (~1 troy oz gold/tonne circuit boards) and one medium-grade (~4.5 troy oz gold/tonne circuit boards). The following excerpt from the SGS report for the low-grade feedstock trial summarizes the trial as follows:

> *"The mass balance results…show that the process was able to recover 79.6% of the gold, 88.7% of the palladium, 86.4% of the copper, and 84.5% of the silver in 34.4% of the*

*mass in the Combined Metals Concentrate. The gravity circuit middlings stream contains an additional 8.7% of the gold, 0.9% of the palladium, 8.1% of the copper and 1.1% of the silver, which would likely be recovered through recirculation to table feed in a continuous operation. Recirculation of these streams should not negatively impact the final concentrate grade."*

Expected results for the two separate feedstocks in an unoptimized, continuous operation follow.

| Type of feedstock (circuit board)<br>Feedstock grade<br>Troy oz. gold/tonne Feedstock | Shredded/Pre-processed<br>Low-grade<br>~1 | Manually Dismantled/full<br>Medium-grade<br>~4.5 |
|---|---|---|
| METAL RECOVERY (Audit) | | |
| Gold | 88.3% | 85.0% |
| Silver | 85.6% | 82.4% |
| Copper | 94.5% | 96.8% |
| Palladium | 89.6% | 82.7% |
| Overall metal value recovery | 89% | 84% |

Figure 2-3 Metals balance results from SGS audit trials

The above Figure 2-3 assumes the metals from the middlings stream will be recovered in a continuous operation. It follows that any additional increase in recovery must come from other output streams as represented in the audit trials at P-Delta. Figure 2-4 below summarizes the average metal unrecovered in unprocessed streams produced at P-Delta that will be eliminated or mitigated in the continuous operation:

| Type of output (P-Delta) | Dust | Combined Non-Metals |
|---|---|---|
| METAL UNRECOVERED (Audit) | | |
| Gold | 3.6% | 8.75% |
| Silver | 5.1% | 7.05% |
| Copper | 0.9% | 3.1% |
| Palladium | 6.8% | 5.25% |
| Overall metal value unrecovered | 5% | 7% |

Figure 2-4 Unrecovered metal from P-Delta output streams

Figure 2-5 shows the metal recovery improvements realized through the recommended modifications, validated with additional optimization trials and continuous mass balance simulations performed by SGS.

| METAL RECOVERY | Pilot, Unoptimized | Third-Party, Optimized |
|---|---|---|
| Gold | 86.7% | 91.7% |
| Silver | 84.0% | 95.3% |
| Copper | 95.7% | 97.1% |
| Palladium | 86.2% | 94.1% |
| Overall metal value recovery | 86.4% | 93% |

Figure 2-5 Forecasted initial metal recoveries in an optimized continuous operation

The third column, which represents work completed at the SGS pilot metallurgical laboratory in Burnaby, BC, Canada does not include the application of the sonic liberation technology as a recovery enhancement. From data generated from P-Delta operations, it is expected that the gold recovery will increase ~2% to 93.5%.

## 1.3 SUF Design Capacity

The SUF is designed to operate at a nominal throughput of 10,000 tpa/1.2 tonnes per hour (tph) of PrCB feedstock.

| Input | tpa | tph |
|---|---|---|
| Printed Circuit-boards (PrCBs) | 10,000 | 1.2 |
| Output | | |
| Large Metal & Battery Products | 916 | 0.11 |
| Metal Concentrate | 3,584 | 0.43 |
| Non-Metal Concentrate | 5,500 | 0.66 |

Figure 2-6: SUF Operating Parameters

## 1.4 SUF Mass Balance

The SUF produces the following consolidated output streams:

- Large Metal and Battery Products (9% by mass)
- Metals Concentrate Product (36% by mass)
- Non-Metals Concentrate Product (55% by mass)

Figure 2-2 shows the expected metal recovery rates (by mass) and organics concentration in the consolidated concentrate product streams, and mass % of product stream as a percentage of infeed material.

| | Metals Concentrate | Non-Metals Concentrate |
|---|---|---|
| Gold | 93.5% | 6.5% |
| Silver | 95.3% | 4.7% |
| Copper | 97.1% | 2.9% |
| Palladium | 94.1% | 5.9% |
| Organics (concentration) | 4.9% | 54.1% |
| Mass % (% of infeed) | 36% | 55% |

Figure 2-7: Consolidated concentrate products characterization

Each consolidated concentrate product stream comprises multiple distinct output streams and can be presented as a whole, or individually, such that the client can tailor these products for suitability for downstream operations

### 1.4.1 Metals

At its inception, one of the objectives of the P-Delta demonstration facility was to develop the basis for a unique and specialized metals refining process for concentrates produced from the Ronin8 Sonic Upgrading Facility. Using metals concentrates produced at P-Delta, Ronin8 has developed a design concept for a commercial-scale refining facility capable of extracting gold, silver, copper, palladium, and platinum, among other metals.

### 1.4.2 Non-Metals

With complete and non-destructive breakdown of PrCBs, P-Delta also provided a non-metals concentrate that has been used to identify further techniques for developing environmentally benign uses for the product. Working with third parties, and academia, Ronin8's investment in this has resulted in a design that is commercially scalable and closes the loop in eliminating waste from PrCBs.

Ronin8 has invested >CAD $150K on third-party analytical services and equipment testing since commissioning to support process optimization and validation, with a significant portion of this applied to learning more about the non-metals material, traditionally overlooked in comparable embodiments of this processing approach. This investment represents a significant differentiator for Ronin8, and we continue to perform prototype tests at our demonstration facility and invest in developing environmentally benign uses for our non-metals product.

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## 1.5 SUF Sampling and Analytical

Ronin8's sampling capabilities uniquely address current challenges in the e-waste collection and aggregation supply chain. Currently, collection of a demonstrative sample from a varied material like printed circuit boards requires a sampling system that operates at significant scale. Many E-waste recyclers generate insufficient quantities of PrCBs and other e-waste to do business directly with smelters, and are therefore required to aggregate with larger recyclers, brokers, and other intermediaries. For smaller recyclers this both reduces their margins and leaves them susceptible to large fluctuations in anticipated settlement and payment, making accurate cash flow predictions next to impossible.

Ronin8 Sonic Upgrading Facilities will implement a robust batch control, monitoring, and reconciliation system that will be able to demonstrate a comprehensive mass and materials balance of processed materials to potential suppliers and partners. Our novel approach to circuit board revitalization through enhanced size reduction and liberation delivers an analytical advantage for Ronin8 in the e-waste realm. Our ability to sample batches as small as 3 tonnes will attract business from the numerous smaller recyclers who must currently aggregate their material. And the great accuracy of sampling will reduce the risk to Ronin8 of overpaying for feedstock.

Ronin8 is committed to continually innovating its sampling technology to remain the market standard for sampling. As operations expand, Ronin8 will collect data from all feedstock sources and build a proprietary data set that will be used to support a machine-learning sampling process. Ronin8 will work towards using only non-destructive analytical methods (i.e. optical scanning, in-line XRF) to perform feedstock valuation and provide settlement to recyclers that eliminates the need for costly size reduction, sub-sampling, and chemical analysis. This approach will continue to give recyclers peace of mind that the process and results provide honest and fair representation of their materials, and help build long lasting and meaningful relationships.

## 1.6 Environmental Benefits

Major environmental benefits of Ronin8's process include:

- Low energy and water requirements
- A recirculated water separation process that uses no solvents
- No burning; no emissions
- Reduced transboundary flows of hazardous waste
    - By locating separation facilities in developed countries like Canada and the USA, we can ensure that the non-metal portion of e-waste (which contains hazardous chemicals) is treated responsibly within the developed world.
- Reduced transportation
    - Locating Ronin8 plants close to recycling hubs will allow for more efficient movement of the separated metal and non-metal streams for final processing.

Ronin8 commissioned Offsetters Clean Technology Inc. to quantify the environmental impact of Ronin8's upgrading process when compared to conventional gold mining.

Based on the findings of this study, a market rollout of the Ronin8 process would result in significant environmental benefits including reduced air emissions of Nitrogen oxides (NOx), Sulfur oxides (SOx), and greenhouse gases (GHGs), decreased water consumption, and reduced releases of solid waste for ground.

With just one Ronin8 Sonic Upgrading Facility operational in Canada by 2018 capable of processing 10,000 tonnes of PrCBs annually, the emission reduction totals compared to conventional gold mining would be:

- 21,013 tonnes of Carbon dioxide equivalent ($CO_2e$);
- 27 tonnes of Nitrogen oxides ($NO_X$);
- 33 tonnes of Sulfur oxides ($SO_X$);
- 296.5 million litres of fresh water saved; and
- 1.5 million tonnes of mined materials.

With an additional 160 Ronin8 Sonic Upgrading Facilities are operational in other countries by 2035, the annual emission reduction totals compared to conventional mining would be:

- 2.55 million tonnes of Carbon dioxide equivalent ($CO_2e$);

- 3,222 tonnes of Nitrogen oxides ($NO_X$);
- 4,050 tonnes of Sulfur oxides ($SO_X$);
- 36 billion litres of fresh water saved; and
- 183 million tonnes of mined materials.

With the changing climate and rapidly expanding human population, minimizing greenhouse gas emissions are of utmost importance. Many regions are facing water shortages, making the conservation of water a pressing issue as well. In addition to greenhouse gas emissions, conventional precious metals mining and smelting can produce highly toxic and environmentally-damaging substances such as dioxins and furans, which are not released using the Ronin8 process.