Emissions, Energy and Waste Assessment

PhotonAssay and Fire Assay

Chrysos Corporation Limited

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Executive summary

This report is subject to, and must be read in conjunction with, the limitations (refer to section 1.2) and the assumptions (refer to section 1.4 and Appendix A).

Background

This emissions, energy and waste Assessment, prepared by GHD for Chrysos Corporation Limited (Chrysos), evaluated the environmental performance of PhotonAssay™ (PA) technology in comparison to the traditional Fire Assay (FA) method for gold analysis. The purpose of conducting this assessment was for Chrysos to understand the emissions, energy and waste differences between these two analytical technologies.

The assessment focused on operational impacts, specifically energy consumption, greenhouse gas (GHG) emissions (Scope 1 and 2), and hazardous waste generation (lead/Pb waste), exclusively using data collected from the SGS Kalgoorlie Facility Laboratory (SGS Kalgoorlie) between June 2024 and March 2025 and that shared by Chrysos. To calculate these operational impacts a Calculation Tool, specific to the SGS, Kalgoorlie, Western Australia, was developed (refer to Appendix B).

Key Findings

- **Energy Efficiency:** PA routine analysis (analysis) demonstrated greater energy efficiency as compared to FA analysis, estimated to consume ~9.81 times less energy per sample (~0.78 kWh and ~7.64 kWh, respectively). The average monthly energy consumption for PA analysis was found to be ~6.71 times less than FA (~48,351 kWh and ~324,300 kWh, respectively). When including all pre-analysis stages (drying, crushing and pulverising), PA remains more energy efficient than FA, consuming ~5.12 times less energy per sample (~1.73 kWh and ~8.87 kWh, respectively) and ~5.06 times less energy per month (~70,808 kWh and ~358,236 kWh, respectively).
- **Emissions Profile**: PA analysis was estimated to produce ~4.17 times less CO_2-equivalent emissions per sample than FA analysis (~0.40 kg CO_2-e and ~1.66 kg CO_2-e, respectively). The average monthly CO_2-equivalent emissions from FA analysis were ~5.32 times lower than those from PA analysis (~13,206 kg CO_2-e and ~70,282 kg CO_2-e, respectively). When including drying, crushing and pulverising, PA remains less emissions intensive than FA, producing ~2.58 times less CO_2-equivalent emissions per sample than FA (~ 0.88 kg CO_2-e and ~2.29 kg CO_2-e, respectively) Notably, PA produced no scope 1 emissions, while FA's emissions were heavily influenced by natural gas combustion in furnaces during analysis.
- **Hazardous Waste**: FA was estimated to produce ~215g of hazardous lead waste from contaminated cupels and silica slag per sample. FA was estimated to produce ~9 tonnes of hazardous lead-contaminated waste per month (comprised of ~0.02 tonnes of discarded lead-contaminated crucibles, ~5.03 tonnes of lead from silica slag and ~3.98 tonnes of lead from contaminated cupels). In contrast, PA produced zero hazardous lead waste, eliminating the associated operational HSE impacts of this substance.
- **Operational Trends**: Emissions per sample for both methods are sensitive to operational factors like pre-treatment duration, system uptime/ downtime and the equipment selected to undertake sample preparation. PA stands to benefit more from grid decarbonisation efforts through its reliance on electrical power. PA's use of electricity makes it well-positioned to achieve net-zero emissions. This is especially relevant in Western Australia where local power grids (specifically the SWIS) is scheduled to reach net-zero by 2050.[1]

Conclusion

PhotonAssay technology presented a more sustainable alternative to Fire Assay, offering the following benefits from routine analysis:

- Lower energy consumption - ~0.78 kWh per sample (~90% lower than FA)
- Reduced GHG emissions - ~0.40 kg CO_2-e (~76% lower than FA)
- Elimination of hazardous waste - ~0 g per sample (100% lower than FA)

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[1] https://www.wa.gov.au/system/files/2023-05/swisda_report.pdf

These advantages position PA as a forward-looking solution aligned with priorities to reduce GHG emissions, energy and lead waste. These characteristics might be relevant to PA users wanting to reduce their own carbon footprint for the benefit of their own business sustainability and client customers.

Glossary

Abbreviation	Description
CO_2	Carbon dioxide
CRM	Certified reference material
EEW	Emissions, Energy and Waste
FA	Fire assay
FAAS	Flame Atomic Absorption Spectroscopy (FAAS)
FEA	Fluke Energy Analyze Plus (version 3.11.2) software
GJ	Gigajoule
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
kJ	Kilojoule
kL	Kilolitre
kW	Kilowatt
kWh	Kilowatt hour
LINAC	Linear Accelerator
LPG	Liquefied Petroleum Gas
MP-AES	Microwave Plasma Atomic Emission Spectroscopy
PA	PhotonAssay
QA	Quality assurance
QC	Quality control

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1. Introduction

1.1 Scope and purpose

GHD Pty Ltd (GHD) was engaged by Chrysos Pty Ltd (Chrysos) to provide an Emissions, Energy and Waste (EEW) Report (the Report), as detailed in GHD proposal ref: ‘12649535 – GHD Proposal to Chrysos – FINAL’ document and terms of agreed consultancy agreement signed 30 January 2025.

The purpose of the Report was to conduct an analysis of the current GHG emissions, energy and lead waste impacts of PhotonAssay™ (PA) technology against the incumbent Fire Assay (FA) technology during their operation. The emissions, energy and waste Assessment (the assessment) considered each technology’s technological parameters, including waste, energy consumption and material emissions during the entire operational process. The material emissions for this assessment are defined as the following:

- Scope 1: direct emissions from sources owned or controlled by SGS Kalgoorlie Facility Laboratory (SGS Kalgoorlie)
- Scope 2: indirect emissions from purchased energy from the local power grid only

A bespoke model for PA and FA was generated to allow an analysis of these parameters – for information on the Calculation Tool (refer to Appendix B).

1.2 Reliance Statement

Disclosure of and reliance on the Report prepared by GHD Pty Ltd

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1.3 Limitations

The Report is provided on the basis of the following limitations:

- An understanding that GHD is not responsible for any qualitative or quantitative errors in the Report resulting from errors in the material provided by Chrysos or vendor or other third parties.
- The site visit was limited to a preliminary visual validation of issues identified in the facility and discussions with key employees available at the time of visit.

Specific limitations to emissions, energy and waste scope are as follows:

- The emissions, energy and waste reported are not a detailed assessment of corporate governance, compliance with corporate regulations or individual environmental, social or governance issues.
- The assessment was restricted to and based on ten months (June 2024 to March 2025) of data.

1.4 Assumptions

In preparing the Report, GHD has assumed the following in relation to the material it received, unless otherwise specifically stated, and the Report is therefore subject to the below assumptions and to the other limitations and assumptions which appear in the body of the Report.

Nothing has come to the attention of GHD that has led it to believe that assumptions detailed in this section are not correct or that it would be unreasonable to rely on the assumptions in the circumstances. However, if any of our assumptions are not accurate or the advice GHD has relied on is incorrect, the opinions GHD has expressed will need to be re-examined and may need to be changed. GHD disclaims liability arising from any of the assumptions being incorrect.

A detailed list of all assumptions is provided in Appendix A.

1.4.1 Key project assumptions

The key assumptions apply to the overall project delivery and this report include:

- The assessment was isolated to assume a location of Kalgoorlie (Western Australia) for both PA and FA – within Australia, Chrysos currently operates their PA technology primarily in Western Australia, hence for the purposes of this assessment, this was considered to be the most appropriate location.
- All documents examined by GHD were genuine, complete and up to date and there are no defaults or contraventions under any permit or license conditions, agreement or instrument other than those set out in the material reviewed by GHD.
- This assessment only assessed the gold-assaying operations. The assessment results should not be taken as a representing assaying of all mineral sample types.
- The staff who provided information to GHD and/or assisted at the site visit were competent to answer the questions that they answered.
- The assessment completed has been based on a particular point in time and has used data from FA and PA technologies at SGS Kalgoorlie as the basis for comparison.
- All employees of Chrysos, SGS and shareholders who were aware of any information which has not otherwise been specifically made known to GHD and which could affect the correctness of the opinions expressed in this Report, have communicated that information to GHD.
- Chrysos and SGS have current licences to operate PA and FA and complies with applicable laws and regulations and both PA and FA are operated without contravening any laws and industrial health and safety and environmental regulations.

1.4.2 Key calculation assumptions

The key assumptions apply to the operational models developed (refer to Appendix B):

- The calculations are based off information provided which was true and accurate in all respects and contained no errors or omissions.
- The assessment assumed an analysis of only scope 1, scope 2, energy and waste (lead and contaminated silica slag) emissions.
- The most up-to-date emissions factors, obtained from the National Greenhouse Account Factors (NGAF) 2024 were used at the time of preparing the report.
- For the purposes of calculating electricity emissions factors, small-scale solar generation was assumed to be exported to the grid. Electricity was imported from the South-West Interconnected System (SWIS) grid. The SWIS grid factor at the time of conducting the assessment was used. Refer to section 3.4.
- The calculations were based on ~39 weeks (June 2024 to March 2025) of data provided. For PA, the early months post-commissioning (June 2024 – December 2024) were running well below the SGS contract rate. Therefore, data from June 2024 – December 2024 were excluded from the PA calculations. The months of January 2025 – March 2025 provide a fairer estimate (at ~33,000 samples per month on average).
- Waste products of PA included non-hazardous waste, a plastic jar and sample material. For this assessment, only hazardous lead-waste products were considered for FA, which included lead contaminated cupel waste, lead waste from silica slag and lead contaminated crucible waste.

2. Description of technologies

Assays are analyses of material such as ore to determine the presence, absence or quantity of one or more mineral components. Assays are a critical part of the mining process, undertaken either by a mining company at on-site laboratories, or by independent commercial laboratories at off-site facilities.

The most common assay technique in gold mining is FA. However, PA has emerged as a new technology that offers a number of advantages over the incumbent FA. These two types of technologies are described in the section below and the process of each technology is illustrated in Figure 1.

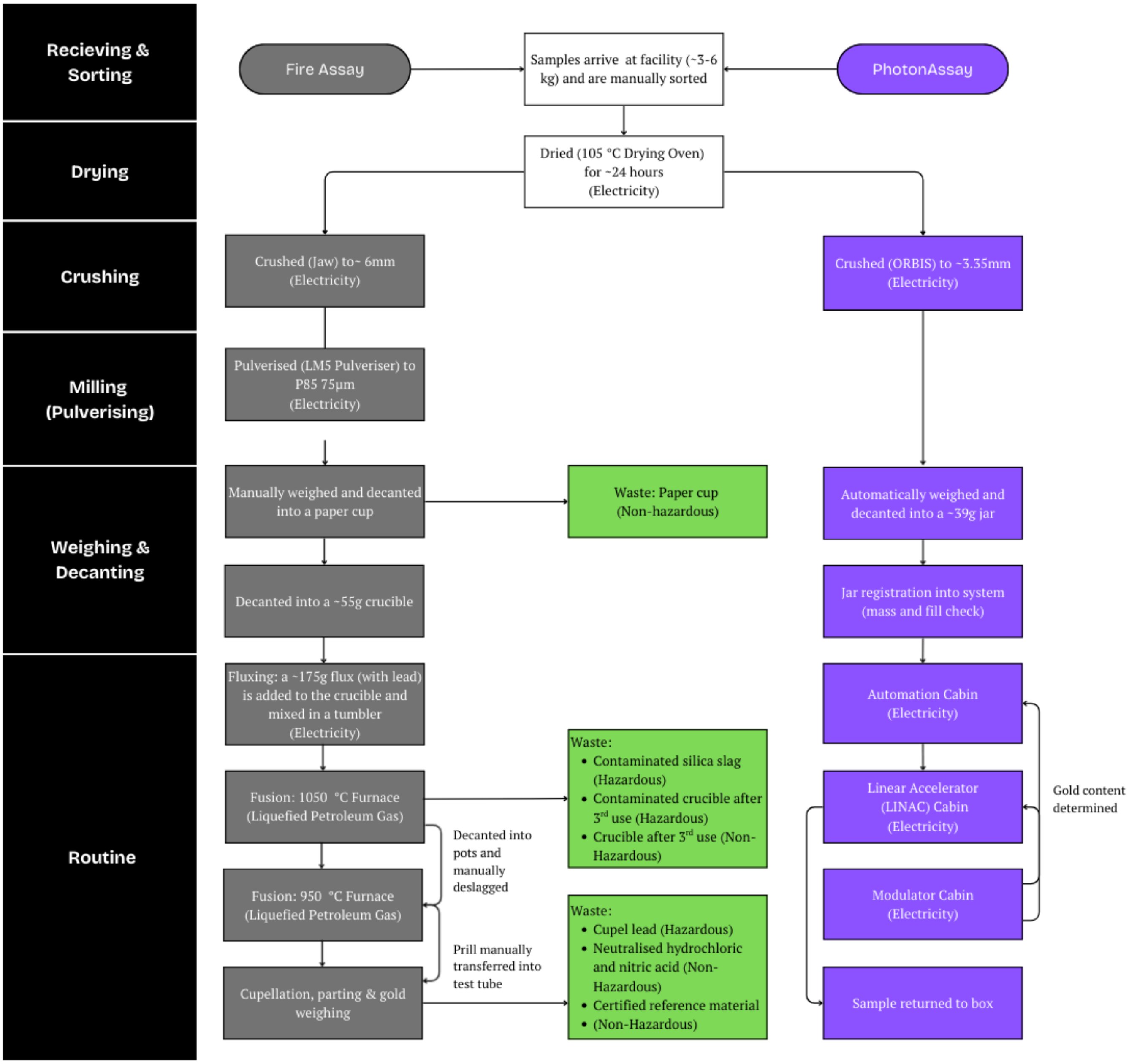

Figure 1 Technology process flow diagram

2.1 Sample preparation

The receiving, drying and crushing process is the same for both FA and PA. However, milling is only required for FA. This is because FA requires a finely ground sample to ensure a uniform distribution of gold. Coarse particles may lead to inaccurate results, where gold is unevenly distributed. As FA involves melting the sample with fluxes in a furnace, a fine powder ensures complete and efficient reactions during the fusion process. In contrast, each PA sample volume is ten times larger than FA (500 g and 50 g, respectively). The larger sample volume of PA may help mitigate the ‘nugget effect.’ This effect refers to the variability caused by gold particles being unevenly distributed in the sample (Pitard, 1994). By examining a greater volume, PA can provide a more representative measure of the sample’s gold content. However, the effectiveness of this approach is highly dependent on the quality of the initial sample preparation – a large volume will not compensate for a poorly split or non-representative sample. Therefore, rigorous sampling protocols remain essential to ensure that the material analysed accurately reflects the overall gold composition of sample. Unlike FA, the PA samples are not required to be chemically altered (i.e., lead additive in FA) or melted.

The sample preparation process is as follows:

1. **Receiving**: Samples are transported to the facility in labelled bags of 3-6 kilograms (kg). All received sample bags are systematically sorted, weighed and recorded in the database.
2. **Drying**: Samples are placed in an ESSA ® Series Drying Oven (electric oven) for 24 hours to dry the samples at 105 degrees Celsius (°C). During the drying process, samples are taken out and weighed again to check for differences in moisture before being placed back in the oven.
3. **Crushing**: All samples are crushed to 71-90% particulate matter (for gold) with the crushing process for 3 kg client samples taking ~2-4 minutes. A different crusher is used for PA and FA:
    a. For PA, each sample that arrives at the facility (~3-6 kg) is crushed using the Orbis Crusher (OM100) (electrically powered) to ~3.35 mm particle size. A 300-500 g sample is required for PA.
    b. For FA, each sample that arrives at the facility (3-6 kg) is crushed using the Jaw Crusher (Alsto JC2513 Mk2) (electrically powered) to ~6 mm particle size.
4. **Milling (pulverising)**: Once crushed, the FA samples are then milled using a LM5 Pulveriser (pulveriser). Milling is not required for PA. Milling for ~3 kg samples take ~5-6 minutes for FA samples. It should be noted that sample size does not influence modelling outcomes for either PA or FA.

For FA, after pulverising, a 250 g sub-sample is created, of which 50 g is used as the required final mass to be analysed, and the remaining 200 g spare is used for any repeat FA analysis (if required).

2.2 PhotonAssay

PA is an advanced automated, non-destructive assaying technology developed by Chrysos that revolutionises mineral analysis in the mining industry. PA is seen to be safer and more environmentally friendly, producing less hazardous lead waste and requiring reduced sample preparation. Its ability to analyse large sample sizes (up to 500 g) makes it especially effective for coarse gold systems, and its non-destructive nature allows for further testing or retesting of samples. All PA samples are retained for quality assurance (QA)/ quality control (QC). Containers can be reused, hence there is minimal waste generated as part of the process. PA also has a faster processing time compared to the FA, providing mining companies with faster access to data, with the intent of helping miners recover more gold and improve decision making throughout the value chain. The entire PA process (excluding pre-processing) takes ~1.5 minutes. The process for PA is outlined below.

Weighing

Boxes from the sample preparation are scanned in the system and weighed on a precision scale to get a weight value and fill level measurement. Jars that are less than 50% full are rejected from the system due to insufficient sample. They are placed on an infeed conveyor comprising five rows (one being an express lane for high priority samples). The infeed conveyor has capacity for ~160 jars (~32 per lane) and the PA unit generally processes ~72 jars per hour. Each empty jar weighs ~39 g (comprised of a ~22 g jar body and a ~17 g lid). If a jar with a measured mass and fill that is too small is put into the infeed conveyor the system will reject it, and the sample will process through the FA process. A sample of between 300 g and 500 g is typically used for PA.

Gamma Ray Activation

The jars are passed through the automation cabin to the linear accelerator (LINAC) cabin, where gamma x-rays excite the precious metal (gold) particles. The energy emitted by the activated gold (gold atoms) are measured and counted to produce a gold concentration value for each sample. During this process, the cabins are fully enclosed and shielded with automated safety interlocks to protect workers.

For a standard gold assay, the sample is irradiated and measured through two cycles. Each cycle consists of 15 seconds of irradiation by the LINAC followed by 15 seconds of measurement by the detector system. Up to three jars can be cycled through the system in sequence (one jar can be irradiated while another is in the detector station).

During the process, no acids or hazardous reagents are used. No lead fumes or solid wastes are generated.

Certified reference materials (CRMs) (homogenous manufactured materials whose gold concentration is accurately known) are used in ~1/20 samples, and are reusable for PA.

The samples are then returned the original box to be reused.

Post-processing

Following processing, a cooling conveyor is used to store the sample away from operators while any potential residual activation is present. For some elements the sample can take up to approximately ~1 hour to return to background levels. The cooling conveyor has ~2 hours of capacity ensuring that all samples have returned to background levels of radiation when fed out from the PA system.

The jars and sample material used for PA are single use at present (as of May 2025). No hazardous waste is generated in PA process as the high-energy X-ray analysis technique (outlined below) used eliminates the need for lead-containing fluxes and the hazardous waste associated with them.

2.3 Fire assay

The FA is a well-established method for determining the mineral (i.e. gold) content of ores and other materials. It is a complicated procedure, requiring a trained operator to conduct the analysis. The process takes ~3 hours, can be labour-intensive and includes some lead emissions due to the use of lead as a consumable, which requires additional safety measures. The process for FA is as follows:

Weighing

Once FA samples (~250 g), are weighed manually, they are placed in cups (~10 g in mass, with a capacity of ~300 g) within tray racks. However, only 30 g or 50 g are used in a single FA sample. A total of 84 samples (cups) can fit into one furnace. As part of QA and QC, standards (CRMs), replicates and duplicates are included with each batch. This helps to identify any technical issues, such as contamination within the process.

Decanting and fluxing

The FA samples (in cups) are decanted into crucibles (~55 g). According to the cupel material safety data sheet provided, the cupel is comprised of 90-96% magnesium oxide and 4-10% inorganic nuisance binder.

Prior to fluxing, each crucible is comprised of the following ingredients:

- Silica (60-65%)
- Magnesium Oxide (<0.2%)
- Calcium Oxide (<0.6%)
- Aluminium Oxide (30-34%)
- Ferric Oxide (<2%)
- Titanium Oxide (<2%)
- Sodium Oxide (<0.1%)
- Potassium Oxide (<0.5%)

A ~175 g flux along with lead is added to the crucible. Each crucible is then mixed in a flux mixer for ~10 minutes. The lead inside each crucible acts as a collector to collect gold from the sample. Each crucible is reusable for up to three times, however crucibles with gold particles are discarded (as non-hazardous waste).

Fusion

There are five furnaces in total at SGS Kalgoorlie; three which are heated at 1050°C (however, only two of these are ever used at one time, whilst the remaining is in downtime or maintenance), and two which are heated at 950°C (Figure 8). As FA requires high temperatures, there could be potential safety risks such as burns, fires and equipment failure. All furnaces are powered by natural gas (provided by an external liquified natural gas tank refilled by a third-party). The process of transferring samples into the furnace takes ~30 minutes.

The fusion process is outlined below:

1. Crucibles (up to 84 samples) are placed inside the first furnace (heated at 1050°C) for ~1 hour, which separates precious metals (such as gold), creating a liquid melt. In this furnace, lead sinks to form a concentrated button at the crucible's base. Above this button, unwanted materials float as silicate slag. The button holds the valuable metals (such as gold) from the original sample.
2. Crucibles are transferred from the first furnace into moulds (one tray has a capacity of 84 moulds), taking ~30 minutes. These moulds are required to cool down for ~1 hour (shattering occurs as the silicate slag cools and the metal mesh tray on top of the samples stops projectiles from injuring workers).
3. The silicate slag is hammered off after cooling and solidifying. As the silicate slag contains elevated levels of lead due to the use of lead oxide (litharge) in the flux mixture, it is placed in a hazardous waste bin.

Cupellation

Cupellation takes place (duration of ~1.5 hours). The lead cupel is removed from the precious metal (such as gold). The lead button is placed into an unused porous cupel (~56 g) and transferred into the second furnace (heated to 950°C) for ~1 hour where oxidising fusion takes place. The oxides then move away from the precious metal (such as gold) during cupellation. The separation works as precious metals resist oxidation under the specific temperature and pressure conditions of a cupel. The product of this process is a precious metal bead (known as a prill, which is silver in colour).

Cupels turn yellow when the lead button inside oxidises, creating lead oxide. Cupels are single use and discarded as hazardous waste because they become contaminated through absorption of lead used in the process. Cupel lead waste refers to the total mass of the used cupel after absorbing lead (resulting in an increase in mass) during the FA process. The cupels and silica slag are disposed of at a Class IV (Prescribed Premises Category 4) licensed secure landfill facility in Perth.

Parting

The parting process, which takes ~30 minutes, involves placing the silver prill into nitric acid contained in test tubes. This step dissolves the lead, while the gold remains intact, effectively separating and isolating pure gold. This process is performed for 99% of samples – as the remaining ~1% of samples containing very high gold content are gravimetrically analysed.

Following this, a dilute aqua regia solution is used in sample digestion – a chemical process used to further breakdown and dissolve the sample, particularly to isolate and analyse trace amounts of precious metals (such as gold). Because aqua regia is highly corrosive and toxic, any residual acid remaining after sample digestion is carefully neutralised.

Once in the aqua regia solution, gold is analysed at SGS Kalgoorlie using the Microwave Plasma Atomic Emission Spectroscopy (MP-AES) method. MP-AES uses a microwave-induced nitrogen plasma to excite the gold atoms, which emit light at characteristic wavelengths. Gold can also be analysed by using the following methods when in the aqua regia solution (Llaver et al, 2021):

- Flame Atomic Absorption Spectroscopy
- Inductively Coupled Plasma-Optical Emission Spectrometry
- Inductively Coupled Plasma-Mass Spectrometry

The test tubes used are single use and discarded as non-hazardous waste.

Gravimetric Analysis

For samples identified to have a very high gold content (only ~1% of samples), the gold in the prill is determined gravimetrically by weighing it directly on a high-precision balance. Gold concentration is expressed as parts per million (ppm), equivalent to grams per tonne (g/t). This process reveals the exact gold content and purity of the original sample.

For FA, the CRM used is discarded as non-hazardous waste. As part of QA and QC, replicates and duplicates are also processed.

3. Methodology

GHD has developed a Technology Comparison Tool (TCT) for the purpose of comparing the scope 1 and 2 emissions from the operation of PA and FA as well as calculating hazardous waste consumption.

3.1 Defining model boundaries

Representative system and analytical boundary

The first step was to determine which facility would be chosen as the representative system and analytical boundary for the assessment. A site visit was completed to SGS Kalgoorlie on 2 April 2025 for the purpose of understanding information about the operation of PA and FA at this specific location (refer to Appendix C).

Emissions assessment basis

The direct emissions (scope 1) and indirect emissions (scope 2) within the analytical boundary were identified for the assessment. This is described in section 3.2 below.

3.2 Identifying emission sources

The components of each technology were separated out into the appropriate emissions type. This involved identifying, based on energy input, what equipment generated scope 1 and 2 emissions. Table 1 below provides a comparison of the different emission sources identified for PA and FA within the boundaries of the assessment.

Table 1 Technology comparison of emissions sources

Technology	Source – Scope 1 Emissions	Source – Scope 2 Emissions
PA	N/A	These were the indirect emissions from the generation of purchased electricity, used in sample preparation and operation, including the following machinery: – Electric oven – Orbis crusher – PhotonAssay unit (Automation, LINAC and Modulator cabins)
FA	These were the direct emissions from on-site combustion of natural gas used to heat the furnaces (950 – 1050 C) during fusion and cupellation.	These were the indirect emissions from the generation of purchased electricity, used in sample preparation and lab operations, including the following machinery: – Electric oven – Jaw crusher – Pulveriser – Flux mixer

3.3 Calculating energy use

To quantify electricity and natural gas used, utility bills, metering and logger data were provided to GHD by SGS and Chrysos.

From the utility bills, logger data and sample output spreadsheets, electricity and natural consumption per sample (kW per sample and GJ per sample, respectively) were determined.

For all equipment, the days per month (i.e., 30 in June) were multiplied by (a) how long (in hours; hrs) each equipment took to process a sample, and (b) the number of hours the technology was operational for in any 24 hour period (either 20 hours for FA or 22 hours for PA), to determine the monthly operating duration. This allowed for a direct comparison with the supplied monthly sample throughput data.

An example calculation is as follows for the number of hours a FA sample was processed for in the pulveriser in June 2024:

$$\boldsymbol{Sample\ duration\ for\ June}\ (\boldsymbol{\sim 98\ hrs/\ month}) \\ = Number\ of\ samples\ processed\ in\ the\ pulveriser\ per\ month\ (35{,}343)\ /\ Days\ in\ June\ (30\ day \\ /\ month) \times\ Pulveriser\ operation\ duration\ per\ sample\ (0.083\ hrs/sample)$$

3.3.1 Electric oven

As outlined in the Appendix A, due to the absence of information stating the power rating of the electric oven used at SGS Kalgoorlie, the estimated power rating (~9.5 kW) of the electric oven had been calculated based on the volume of similar models of the same brand (ESSA Series DO).

The electric oven had the capacity to fit four trolleys (holding 125, ~3 kg sample material bags received from the client), equating to 500, ~3 kg bags (1,500 kg). Each ~3 kg bag was processed down to one FA or one PA sample. Noting that, energy use per sample of FA and PA processed within the electric oven had been calculated as follows:

$$\boldsymbol{Electric\ oven}\ \textbf{energy use per sample}\ (\textbf{kWh}) = Electric\ oven\ power(9.5\ kW)\ \times \\ (Electric\ oven\ duration\ (24\ hours)\ )/(Electric\ oven\ samples\ per\ cycle\ (500\ preprocessed\ samples)).$$

3.3.2 Fire assay

Furnaces

Energy use per sample of FA processed within each of the two furnaces (950°C and 1050°C) was calculated using the following steps, where the fuel source for FA at SGS Kalgoorlie was liquefied petroleum gas (LPG) (refer to Appendix B):

1. Convert monthly LPG (provided in tonnes) to daily usage (in tonnes):

$$\boldsymbol{Tonnes\ per\ day}\ = (Tonnes\ per\ month)/(Days\ in\ the\ month)$$

2. Convert tonnes to kilolitres (kL) using the conversation factor of 1.96:

$$\boldsymbol{KL}\ =\ Tonnes\ \times 1.96$$

3. Calculate energy content (in GJ) using the energy contact factor of 25.7 GJ/kL for LPG:

$$\boldsymbol{Energy\ content}\ (\boldsymbol{GJ}) =\ KL\ \times\ 25.7\ GJ$$

4. Determine energy use per hour (GJ/h), based on FA running for 20 hours per day:

$$\boldsymbol{Gj\ per\ hour}\ (\boldsymbol{GJ/h}) =\ \ (Daily\ GJ)/20\ hrs$$

5. Calculate monthly energy use:

$$\boldsymbol{GJ\ per\ month}\ (\boldsymbol{GJ/\ month})\ = GJ/h \times\ Monthly\ operating\ hours$$

6. Calculate LPG user per sample:

$$\boldsymbol{GJ\ per\ sample}\ (\boldsymbol{GJ/\ sample}) =\ (Monthly\ GJ\ )/(Number\ of\ monthly\ samples)$$

Crusher – JAW

Based on the model specifications for the jaw crusher (Altso, n.d.), the power rating of the jaw crusher used at SGS Kalgoorlie was 7.5 kW. Energy use per sample of FA being processed in the jaw crusher has been calculated as follows:

$$\textbf{Jaw crusher energy use per sample}\ (\mathbf{0.5\ kWh}) \\ =\ Jaw\ crusher\ power\ rating\ (7.5\ kw)\ \times\ \ Jaw\ crusher\ duration\ (0.067\ hrs)$$

Flux mixer

Based on the model specifications for the Westref Pty Ltd (Westref) Flux Mixer (Westref, 2019), the power rating of the flux mixer used at SGS Kalgoorlie was 0.37 kW. Energy use per sample of FA being processed within the flux mixer has been calculated as follows:

$$\begin{aligned}&\mathbf{Flux\ mixer\ energy\ use\ per\ sample}\ (\sim\mathbf{0.001\ kWh})\\&= Flux\ mixer\ power\ rating\ (0.37\ kw) \times\ Flux\ mixer\ duration\ (0.167\ hrs)\end{aligned}$$

Pulveriser

The pulveriser was switched off (for two minutes) approximately every three minutes from 10:08 pm to 11:17 pm on Monday 26 May 2026. From 11:18 pm onwards the pulveriser was switched off. Therefore, ~35 minutes of operational data (across 10 cycles) was assessed. The average power (~3.36 kW) across the operational period was determined and used for the following calculation:

$$\begin{aligned}&\mathbf{Pulveriser\ energy\ use\ per\ sample}\ (\sim\mathbf{0.28\ kWh})\\&= Pulveriser\ power\ rating\ (\sim 3.36\ kw) \times\ Pulveriser\ duration\ (0.083\ hrs)\end{aligned}$$

3.3.3 PhotonAssay

PhotonAssay Unit

The power supply specifications of a PA unit (specific to Australia and United Kingdom) (Appendix D) combined with logger data provided by SGS were used to determine the power rating of each component during standard operation and at standby (idle power load).

Data from a logger placed on a PA distribution board (between 19 to 26 May 2025) capturing all PA components (Appendix D) was used as the basis of calculation to understand the distribution of energy throughout the PA unit. Power data (in watts) was extracted from the Fluke Energy Analyze Plus (version 3.11.2) software (FEA) (Fluke, 2025), models Fluke 1732 (used on the PA distribution board) and Fluke 1738 (used on the Orbis Crusher and pulveriser).

The Fluke 1732 logger captured 12 recordings per minute (every five seconds) from 10:40 am on 19 May to 9:07 am on 26 May 2025, equating to a total of 119,839 recorded data points. However, the data for 19 May and 26 May 2025 only captured a portion of the day. For a more accurate and fair assessment, calculations are based on 20 May – 25 May 2025 (from 12:00 am to 11:59 pm each day) as the logger captured 24 hours of data across these six days.

The monthly maintenance period for PA was incorporated into the results. The logger data indicated that on 22 May 2025, maintenance activities were performed for ~6 hours (between 11:15 AM and 5:05 pm).

From analysing the FEA ‘RMS Power Graph’ and extracting the power data, the standby consumption could be determined. For this assessment, ‘standby’ power rating was identified and defined as standby load at <20 kW. ‘At operation’ power rating was identified and defined as ≥20 kW. Across the six-day period, the average ‘standby’ power ranged from ~3.6 to ~22 kW, with an average of ~15.46 kW. This was calculated using the following formulas:

$$\begin{aligned}&\boldsymbol{Average\ 'standby'\ power\ of\ the\ PA\ unit\ (kW)}\\&= \ (Standby\ power\ rating\ recording\ 1\ (kW) +\ Standby\ power\ rating\ recording\ 2\ (kW)\\&+\ Standby\ power\ rating\ recording\ 3\ (kW)\ \ldots))/\ Number\ of\ standby\ power\ recordings)\end{aligned}$$

The same calculation was run for the ‘at operation’ power periods to determine the average power rating (~40.62 kW). The ‘at operation’ power rating ranged from ~20 to ~66.89 kW.

To calculate, the average ‘standby’ energy consumption per sample (kWh), the following calculation was run:

$$\begin{aligned}&\boldsymbol{Average\ 'standby'\ energy\ consumption\ per\ sample}\ (\sim\boldsymbol{0.22\ kWh})\\&= \frac{Average\ standby\ power\ rating\ (\sim 15.46\ kW)}{Number\ of\ samples\ processed\ per\ hour\ (\sim 72)}\end{aligned}$$

The number of samples per hour (~72) was calculated by analysing the Acceptance Report (refer to Appendix B), showing the number of cycles run between 19 May and 26 May 2025.

The same calculation was run for ‘at operation’ to determine the average energy consumption per sample (~0.56 kWh).

Crusher – Orbis

Based on the model specifications for the Orbis Mining Pty Ltd (Orbis) OM100 Crusher (Orbis, 2017), the power rating of the Orbis crusher used at SGS Kalgoorlie was 7.5 kW. Energy use per sample of FA being processed within the Orbis crusher has been calculated as follows:

$$\mathbf{Orbis\ Crusher\ energy\ use\ per\ sample}\ (\sim\mathbf{0.05\ kWh}) \\ = Orbis\ crusher\ power\ rating\ (0.37\ kw) \times Orbis\ crusher\ duration\ (0.167\ hrs)$$

3.4 Applying emission and energy factors

Standardised emissions factors were identified from the Australian National Greenhouse Accounts Factors 2024 (NGAF) (DCCEEW, 2024) and applied by converting energy use into carbon dioxide (CO_2) equivalent emissions (CO_2-e). The factors used are detailed in Table 2 below.

Table 2 Emissions and energy contact factors

Factor	Value	Unit	Source
Electricity (Australia – Southwest Interconnected System (SWIS)) (located-based method):	0.51	kg CO_2-e/kWh	Section 2.2 of National Greenhouse Account Factors (NGAF) 2024
Consumption of liquefied petroleum gas (LPG)	60.2	kg CO_2-e/GJ	Table 5 of NGAF 2024
LPG – Energy Content	25.7	GJ/kL	Table 5 of NGAF 2024
Conversion – Tonnes to kL	1.96	kL/t	LPG Product Information – Gas Cylinder Sizes and Applications (LPG1020 V1 (Origin Energy, 2015)

3.5 Calculating emissions

Scope 1 and 2 emissions for FA and PA were calculated by using the following formula: $Emissions\ (kg\ CO_2 - e)\ = Energy\ (kWh\ or\ GJ)\ \times\ Emission\ Factor\ (kg\ CO2 - e/kWh\ \ or\ GJ)$ and expressed per sample.

The following calculation was run to determine emissions per sample, depending on the fuel source:

- Based on GJ per sample and the emission factor of 60.2 kg CO_2-e/GJ: $\mathbf{Emissions\ per\ sample\ (kg\ CO2 - e)}\ = Energy\ use\ per\ sample\ (GJ) \times\ 60.2$
- Based on kW per sample and the emissions factor of 0.51 kg CO_2-e/GJ: $\mathbf{Emissions\ per\ sample\ (kg\ CO2 - e)}\ = Energy\ use\ per\ sample\ (kWh) \times\ 0.51$

To calculate monthly emissions, the following calculation was run: $\mathbf{Monthly\ emissions}\ = Emissions\ per\ sample\ \times\ Monthly\ samples.$

3.6 Calculating hazardous waste

3.6.1 Hazardous cupel and silica slag waste

For hazardous waste (lead/Pb), SGS weighed the contaminated cupel and contaminated silica slag waste of one sample of FA on 28 May 2025. This hazardous waste was appropriately disposed of at a licensed waste facility, Sandy Ridge Facility, located in a remote location ~240 km north-west of Kalgoorlie. The Sandy Ridge Facility uses air dome technology so end of lifecycle hazardous waste can be safely contained and permanently disposed of in the world’s only geological repository, owned and operated by Tellus Holdings (Tellus, n.d.).

A total of 120 g of contaminated silica slag and 95 g of contaminated cupel was determined. To calculate the amount of hazardous contaminated cupel and silica slag waste per sample the following calculation was run:

$$\boldsymbol{Total\ contaminated\ cupel\ and\ silica\ slag\ waste\ (215\ g)} = Silica\ slag\ (120\ g) + \ contaminated\ cupel\ (95\ g).$$

Silica and other fluxing agents help dissolve contaminants, but they generally do not produce direct emissions like CO_2. However, indirect emissions of silica slag are derived from the energy required to produce and process it. Silica may also decompose or interact with other chemicals at high temperatures (present inside the furnaces) to produce trace gases (Safe Work Australia, n.d.). Due to this being immaterial, these trace gases have not been considered in the calculation of waste emissions.

3.6.2 Hazardous crucible waste

Each time a crucible is used, lead is absorbed as the furnaces are at high enough temperatures to melt litharge and allow potential penetration of molten lead into the porous ceramic crucible. Based on industry practices, a ceramic crucible has an average porosity of ~23% (IPS Ceramics, n.d.). Based on a study titled "*Ascertaining the Potential of Lead Mobilisation into the Geo-Environment by Spent Fire Assay Crucibles*" (Koomson et al, 2020) that analysed the chemical composition of crucibles before and after use in fire assay, the amount of hazardous waste per contaminated crucible discarded was calculated.

The difference in the percentage of lead mass of an unspent (crucible lead prior to fusion) and spent crucible (crucible lead post-fusion) was calculated as follows:

$$\begin{aligned}&\boldsymbol{Crucible\ lead\ mass\ difference\ between\ before\ and\ after\ fusion\ (\sim 1.58\%)}\\&= Spent\ Crucible\ (\sim 1.61\%)\ -\ Unspent\ crucible\ (\sim 0.03\%)\end{aligned}$$

To calculate the lead absorbed by each crucible during fusion (after one use) the following calculation was run:

$$\begin{aligned}&\boldsymbol{Lead\ absorbed\ per\ contaminated\ crucible\ (\sim 0.87\ g)}\\&= Mass\ of\ crucible\ (\sim 55\ g)\\&\times\ Crucible\ lead\ mass\ difference\ between\ before\ and\ after\ fusion\ (\sim \frac{\sim 1.58}{100})\end{aligned}$$

Therefore, to calculate the cumulative lead absorbed after the crucible was reused 3 times, the following calculation was run:

$$\begin{aligned}&\boldsymbol{Cumulative\ lead\ mass\ per\ contaminated\ crucible\ (\sim 2.61\ g)}\\&= Lead\ absorbed\ per\ crucible\ (\sim 0.87 g)\ \times\ Number\ of\ uses\ before\ being\ discarded\ (3)\end{aligned}$$

To calculate the total quantity of crucible hazardous waste discarded, the following calculation was run:

$$\begin{aligned}&\boldsymbol{Total\ crucible\ hazardous\ waste\ when\ discarded\ (\sim 57.61\ g)}\\&= Mass\ of\ crucible\ (\sim 55 g\ ) +\ cumulative\ lead\ mass\ per\ contaminated\ crucible\ (\sim 2.61\ g)\end{aligned}$$

Out of every 3^{rd} crucible that are discarded, only ~3% are considered hazardous (refer to Appendix B) as they contain lead contamination. To calculate the assumed number of contaminated crucibles per month, the following calculation was run:

$$\begin{aligned}&\boldsymbol{Number\ of\ contaminated\ crucibles\ per\ month}\\&= (Number\ of\ samples\ going\ through\ the\ fusion\ process\ /\ Number\ of\ crucible\ uses\ (3))\\&\times\ Percentage\ of\ hazardous\ crucibles\ (\sim 3\%)\end{aligned}$$

Using the above, to calculate the total quantity of hazardous crucible waste discarded per month, the following calculation was run:

$$\begin{aligned}&\boldsymbol{Total\ hazardous\ crucible\ waste\ per\ month\ (g)}\\&= Total\ crucible\ hazardous\ waste\ when\ discarded\ (\sim 57.61\ g)\\&\times\ Number\ of\ contaminated\ crucibles\ per\ month\end{aligned}$$

To calculate the total hazardous waste per month, the following calculation was run:

$$\begin{aligned}&\boldsymbol{Total\ hazardous\ waste\ per\ month\ (g)}\\&= Hazardous\ crucible\ waste\ per\ month\ (g)\\&+\ Hazardous\ silica\ slag\ waste\ per\ month\ (g)\ +\ Hazardous\ cupel\ waste\ per\ month\ (g)\end{aligned}$$

4. Results

This section provides an overview of the total sample throughput, energy use, emissions and hazardous waste for both FA and PA (refer to Figure 2). A detailed version of the results is provided in Appendix B.

4.1 Energy consumption

The energy consumption for each stage of the FA and PA process are outlined in Table 3 below.

During analysis, PA consumed ~9.81 times less energy per sample (~0.78 kWh) than FA (~7.64 kWh) on average. Across all stages, PA consumed ~5.12 times less energy per sample (~1.73 kWh) than FA (~8.87 kWh) on average.

The average monthly energy consumption for PA across all stages (~70,808 kWh) is ~5.06 times less than FA (~358,236 kWh). The vast majority (~91%) of the FA average monthly energy consumption was from the operation of the furnaces (~324,300 kWh). In contrast, the average monthly energy consumption for PA was distributed more evenly across all components and equipment, with the PA unit (automation, LINAC and calibration cabins) accounting for ~68% of the average monthly energy consumption across all stages.

Table 3 Summary – energy consumption

Stage	Technology	Average energy user per sample (kWh)	Average energy use per month (kWh)
Receiving and Sorting	FA	-	-
	PA	-	-
Drying	FA	0.456	6,931.200
	PA	0.456	6,840.000
Crushing	FA	0.500	17,311.950
	PA	0.500	15,617.008
Milling (Pulverising)	FA	0.280	9,694.132
	PA	-	-
Decanting and Weighing	FA	-	-
	PA	-	-
Routine Analysis	FA	7.637	324,300.053
	PA	0.778	48,350.898
Total Average	**FA**	**8.873**	**358,236.335**
	PA	**1.734**	**70,807.906**

4.2 CO_2-Equivalent emissions

The CO_2-e emissions for each stage of the FA and PA process are outlined in Table 4 below. During analysis, PA was estimated to produce ~4.17 times less CO_2-e emissions per sample (~0.40 kg CO_2-e) than FA (~1.66 kg CO_2-e). The average monthly CO_2-e from PA analysis was ~5.32 times lower (~13,206 kg CO_2-e) than those from FA (~70,282 kg CO_2-e).

When including drying, crushing and drying, PA remains less emissions intensive than FA, producing ~1.65 times less CO_2-e emissions per sample (~0.88 kg CO_2-e) than FA (~2.29 kg CO_2-e).

Although PA had ~30% higher scope 2 CO_2-e emissions, PA produced no scope 1 CO_2-e emissions. The CO_2-e emissions of FA were heavily driven by LPG combustion in furnaces during analysis, accounting for ~80% of the average monthly CO_2-e across all stages.

Table 4 *Summary – CO_2-e emissions*

Stage	Technology	Average Scope 1 Emissions Per Sample (kg CO_2-e/ sample)	Average Scope 1 Emissions Per Month (kg CO_2-e/ month)	Average Scope 2 Emissions Per Sample (kg CO_2-e/ sample)	Average Scope 2 Emissions Per Month (kg CO_2-e/ month)	Average Emissions (Scope 1 + 2) Per Sample (kg CO_2-e/ sample)	Average Emissions (Scope 1 + 2) Per Month (kg CO_2-e/ month)
Receiving and Sorting	FA	-	-	-	-	-	-
	PA	-	-	-	-	-	-
Drying	FA	-	-	0.233	3,534.912	0.233	3,535.912
	PA	-	-	0.233	3,488.400	0.233	3,488.400
Crushing	FA	-	-	0.255	8,828.585	0.255	8,829.585
	PA	-	-	0.255	7,964.674	0.255	7,965.674
Milling (Pulverising)	FA	-	-	0.143	4,944.007	0.143	4,944.007
	PA	-	-	-	-	-	-
Decanting and Weighing	FA	-	-	-	-	-	-
	PA	-	-	-	-	-	-
Routine Analysis	FA	1.655	70,282.307	-	-	1.655	70,282.307
	PA	-	-	0.397	13,205.884	0.397	13,205.884
Total Average	**FA**	**1.655**	**70,282.307**	**0.630**	**17,307.504**	**2.285**	**87,589.811**
	PA	**-**	**-**	**0.884**	**24,658.958**	**0.884**	**24,658.958**

4.3 Hazardous waste

The total quantity of hazardous waste (lead) estimated for FA and PA are outlined in Table 5 below.

Table 5 *Summary – hazardous waste*

Technology	Average hazardous lead waste from cupel and silica slag per sample (g/ sample)	Average hazardous lead waste from cupel and silica slag per month (g/ sample)	Average hazardous lead waste from contaminated cupels per month (t/ month)	Average hazardous waste per month (t/ month)
FA	215.000	9.004	0.024	9.028
PA	0	0	0	0

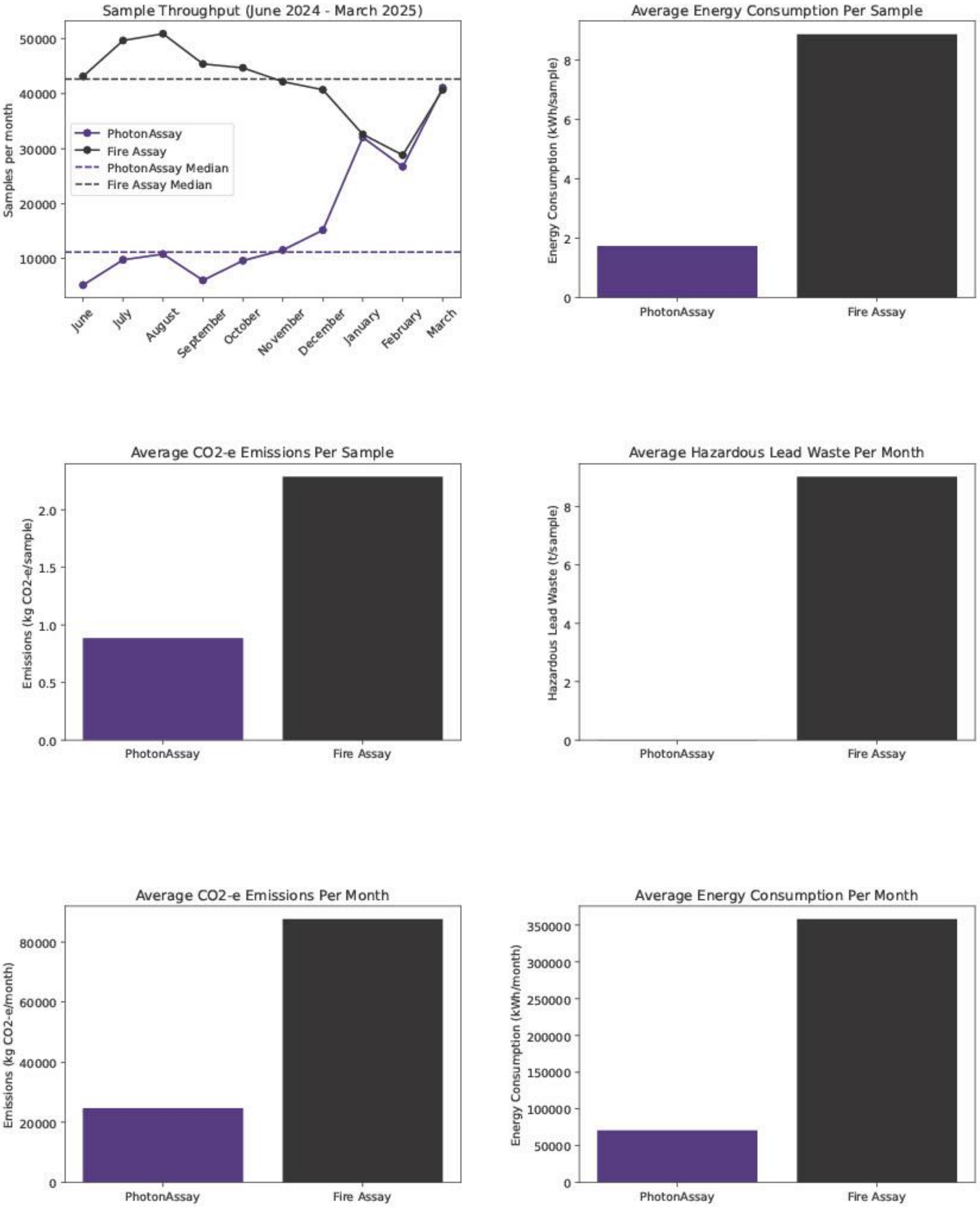

Figure 2 Visual summary of energy consumption, emissions and hazardous waste across the entire FA and PA process

5. Discussion

5.1 Energy efficiency

The results suggested that on a per-sample basis, the FA operation has larger environmental emissions and energy consumption, given FA consumes approximately five times more energy per sample than PA. FA's energy consumption was heavily skewed towards the furnaces (~91%), highlighting a potential area for optimisation.

5.2 Emissions impact

PA was estimated to emit ~4.17 times less CO_2-e emissions per sample than FA during the analysis stage and average monthly CO_2-e emissions during this stage were estimated to be ~5.32 times lower than FA's, reinforcing FA's larger environmental footprint (refer to Table 4 and Figure 2).

The average monthly CO_2-e emissions from the preparation stages (drying, crushing) excluding pulverising (as it is only for FA) only varies by ~7%. Therefore, it does not substantially contribute to the difference in CO_2-e emissions between the two technologies. When considering all stages, PA was found to have ~3.55 times less CO_2-e emissions (scope 1 and 2) on average per month than FA.

FA had significant scope 1 CO_2-e emissions across all stages (~80% of total CO_2-e emissions) from LPG combustion of the furnaces, while PA had none (refer to Table 4). That makes PA more favourable, particularly in jurisdictions with strict scope 1 regulations or those with limitations on stack emissions for other environmental reasons – e.g., nitrogen and sulfur oxide reductions, environmental thermal emissions limitations, or aspect or site-line limitations preventing flue gas stacks. PA's CO_2-e emissions were entirely scope 2 CO_2-e emissions (indirect from electricity use of the PA unit and associated equipment), which could be further mitigated by sourcing renewable energy (i.e., solar panels or renewable PPAs).

5.3 Hazardous waste generation

FA was estimated to produce hazardous lead waste, while PA produces none, making PA a zero hazardous waste technology during its operation. This is a critical environmental and health advantage for PA, especially in regions with strict hazardous waste disposal regulations.

5.4 Implications of operational changes

With PA's lower energy use, CO_2-e emissions, zero hazardous waste and faster processing time (~1.5 minutes for PA and ~3 hours for FA), the technology is seen to be superior across these parameters. Sample throughput data provided (refer to Figure 2) suggests that SGS Kalgoorlie's client demand has been transitioning from FA to PA potentially capitalising on the benefits seen in this study.

From June 2024 to March 2025, ~2.5 times more FA samples have been processed (418,789 for FA compared to 167,682 for PA). However, it was identified from the sample throughput data received that FA operations have been slowing down since January 2025 (refer to Figure 2). If FA operations continue to decrease output, while PA operations steadily increase, it may result in a larger difference in the CO_2-e emissions and energy consumption, per month, between the two technologies. In contrast, PA operations increased from January to March 2025 (sample throughput increased by 64%, from 15,157 to 41,066 samples processed) (refer to Figure 2), which could suggest higher demand for PA by clients.

The CO_2-e emissions and energy usage per sample for the PA have been calculated based on the pro-rata number of monthly samples 9,394 processed (18,788 cycles) during the logger data collection period (19 – 26 May 2025). It is noted that if an individual PA unit processes a higher or lower number of samples per month, this will affect the amount of standby time of the unit over the month and the average CO_2-e emissions and energy usage per sample accredited to the standby time of the unit. A greater amount of sample throughput would likely lower the overall CO_2-e emissions and energy usage per sample for an individual month.

Modelling of both technologies' processes suggest that CO_2-e emissions per sample is very sensitive to operational changes, including:

- Altering pre-treatment duration time (e.g., shorter crushing duration) could reduce scope 2 CO_2-e emissions further
- Altering operational uptime, such as increasing operational uptime and throughput (to minimise idle emissions) of the PA system could further reduce scope 2 CO_2-e emissions per sample

However, differences in grid electricity (which are location-dependent), equipment types, type of material assayed (i.e., gold vs. copper) and fuel sources play a large role in contributing to energy use and therefore, CO_2-e emissions generated. Therefore, the CO_2-e emissions from SGS Kalgoorlie may vary significantly from another facility in a different location or indeed for another analytical facility proximally located to the SGS Kalgoorlie site.

Importantly, PA stands to benefit more from 'grid greening', further reducing CO_2-e emissions. Both FA and PA use electricity for pre-processing, with an emissions factor of 0.51 kg CO_2-e/kWh. However, PA's analysis process runs entirely on electricity, positioning it well for future reductions in CO_2-e emissions. According to the SWIS Demand Assessment (2023-2042) (Government of Western Australia, 2023) PA operations in Western Australia could potentially reach 'net-zero' emissions by 2050, in line with grid decarbonisation. This transition to net-zero could be accelerated through renewable energy solutions such as power purchase agreements or onsite solar prosumer integration (e.g., rooftop solar or battery energy storage systems installed at the client site), which also could potentially enhance energy reliability in remote locations.

Overall, PA is identified from the results as a more advanced technology with growing market share that is a viable and energy efficient alternative to FA.

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Appendices

Appendix A

Detailed Assumptions

Table A1 Detailed Assumptions

Relevance	Assumption	Justification / Comments
Calculations - Fire Assay	GHD assumed lead was the only hazardous waste product of FA. Waste products of PA included non-hazardous waste, a plastic jar and sample material. Waste products for FA included contaminated cupel waste (silica slag and lead), a crucible and sample material.	Confirmed by SGS.
Calculations - Fire Assay	On average, 3% of every third crucible discarded contained lead contamination.	The average percentage of every crucible discarded containing lead was confirmed by Chrysos.
Calculations - Fire Assay	Lead absorbed per crucible was estimated to be 0.689 based on the calculation: crucible mass (55 g) x (1.61%-0.03%), where unspent crucibles contain 0.03% lead by weight and spent (used) crucibles contain 1.61% lead by weight.	Lead input into FA crucibles was not able to be provided by SGS. Therefore, an assumption of calculated lead absorbed was determined based on the study, https://conference.umat.edu.gh/wp-content/uploads/2020/08/Ascertaining-the-Potential-of-Lead-Mobilisation-into-the-Geo-environment-by-Spent-Fire-Assay-Crucibles.pdf.
Calculations - Fire Assay	The energy consumption of the post-processing laboratory used for fire assay (where parting and gold weighing occurs) was not included in the calculation.	GHD assumed this to not be material and as it was difficult to ascertain the energy consumption given all electricity consumption came from the grid and a logger was not able to be setup for the post-processing laboratory.
Calculations - Fire Assay	Based on the model specifications for the Jaw Crusher (Alsto JC2513 Mk2), the power rating of the Jaw Crusher used at the SGS Kalgoorlie was 7.5 kW.	A logger was not able to be installed by the electrician at SGS. Therefore, based on the model specifications obtained from review of https://alsto.com.au/product/jc2513-mk2-jaw-crusher/, the power rating (kW) of the Jaw Crusher was determined.
Calculations - Fire Assay	Given that the Flux Mixer has a power rating of only 0.37 kW, resulting in an emission per sample of <0.001 kg CO2-e (0.03% of the total average emissions per sample), the Flux Mixer was excluded from the calculations.	Confirmed with Chrysos.
Calculations - Fire Assay	Based on the LM5 Pulveriser logger data provided by SGS (from 10:08 pm - 11:18 pm on 26/05/25), an average of 3.357 kW was calculated.	Logger data was provided by SGS.
Calculations - Fire Assay	Three (3) furnaces are operated at any given time for FA. Each sample only went into the 1050 °C furnace and then the 950°C furnace once for the same duration in each.	Information on operation of furnaces was provided to GHD by SGS during the site visit.
Calculations - Fire Assay	The Lead Process Engineer from GHD calculated the difference in the amount of LPG combusted between the 950°C and 1050°C degree furnaces. An LPG composition of 40 vol% propane, 50 vol% butane and 10 vol% propylene was used. LHV = 45,941 kJ/kg (according to HYSYS). Assuming that the flue gas volume remains the same and the furnaces are similar in operation with the exception of temperature, the following was calculated: – Combusted 1 kg of LPG with a 10% excess air to generate the flue gas volume in HYSYS, resulting in 17.93 kg of flue gas/kg LPG combusted. – Additional energy required = mCpdT = 17.93 kg flue gas x 1.733 kJ/kg°C x 100°C = 3,107 kJ.	The allocation of LPG between each furnace was not able to be provided by SGS. Therefore, the GHD Lead Process Engineer calculated and provided the difference in the amount of LPG combusted between both furnaces.

Relevance	Assumption	Justification / Comments
	– Additional LPG required = 3,107 kg / 45,941 kJ/kg = 0.068 kg / kg or 6.8 mass % more. For every 100 kg LPG combusted to get the temp to 950°C, 106.8 kg LPG would need to be combusted to get the temp to 1050°C, or split 48.35%:51.65%. To summarise, 106.8 kg LPG is combusted in the 1050°C furnace for every 100 kg LPG combusted in the 950°C furnace (1.068: 1 ratio).	
Calculations - Fire Assay	Each sample was pulverised in the LM5 Pulveriser for ~5-6 minutes. An average of 5.5 minutes was used for the calculation (0.083 hours). The LM5 Pulveriser processes one (1) sample during this period, regardless of sample size (up to 3 kg). This produces one fire assay sample (0.25 kg) in a packet for fire assay and the remaining mass is stored for return or disposal after job completion.	Information on LM5 Pulveriser duration per sample was provided to GHD by SGS during the site visit.
Calculations - Fire Assay and PhotonAssay	For the purposes of calculating electricity emission factors, all small-scale solar generation was assumed to be exported to the grid. Electricity came from the SWIS grid.	Grid connection was confirmed by Chrysos.
Calculations - Fire Assay and PhotonAssay	PA and FA operational emissions were based only on the same material being assayed, being gold. Standard Gold Assay (PAAU02) was used for PA. The assessment results were not taken as a representation for all mineral assaying.	Material (gold) was confirmed by Chrysos.
Calculations - Fire Assay and PhotonAssay	Waste products of PA included non-hazardous waste, plastic jar and sample material. As, this assessment only assessed hazardous waste, PA waste was deemed to be outside the scope of works. Lead was selected as the hazardous waste product for fire assay.	Waste products were confirmed by Chrysos.
Calculations - Fire Assay and PhotonAssay	Samples for PA and fire assay arrived at the lab at 3-4 kg and then were crushed to 3.35 mm (~3 g) for PA and 6 mm (~6 g) for fire assay. The energy used to crush the samples to the required final mass was accounted for in the calculations.	Sample size was provided and agreed on with Chrysos and SGS.
Calculations - Fire Assay and PhotonAssay	The assessment assumed an analysis of only Scope 1 and 2 emissions.	Confirmed by Chrysos.
Calculations - Fire Assay and PhotonAssay	The ESSA Model DO2 (5.2 m^3) has a power rating of 12kW (3 phase), a DO4 (10.1 m^3) has a power rating of 24 kW (3 phase). Given this, GHD estimated that a 4 m^3 oven (the size of the oven in SGS Kalgoorlie), has an estimated power rating is 9 - 10 kW (3 phase). An average of 9.5 kW was used for the calculation.	SGS Team provided the model information. GHD reviewed https://chromatech.co.za/brochures/essa/Drying%20Ovens%20DO1%20DO2%20DO4.pdf to determine an estimated power rating (kW).

Relevance	Assumption	Justification / Comments
Calculations - Fire Assay and PhotonAssay	The ESSA Electric Oven has the ability to up to ~500 (3 kg) pre-processed samples (material received from clients) in 24 hours. The SGS team mentioned that the ESSA Electric Oven can process up to ~500 (3 kg) pre-processed samples (material received from clients) 24 hours. For the purposes of this calculation, GHD assumed that the electric oven is maximally filled at all times. Each 3 kg pre-processed sample from the client equates to one FA or PA sample.	SGS Team provided model capacity information.
Calculations - Fire Assay and PhotonAssay	The most up-to-date emissions factors, obtained from the National Greenhouse Account Factors (NGAF) 2024 were used at the time of preparing the report.	The NGAF represent the most current and authoritative emissions factors available in Australia.
Calculations - Fire Assay and PhotonAssay	The calculations were based off information provided being true and accurate in all respects and contained no errors or omissions.	GHD did not independently verify every data point (e.g., utility bills, equipment specifications, throughput logs). The Emissions, energy and waste assessment was not an audit. It was a comparative analysis based on operational data.
Calculations - Fire Assay and PhotonAssay	Early months after commissioning (June 2024 to December 2024), PA was run well below the SGS contract rate. Therefore, June 2024 to December 2024 data were excluded from the calculation, as January 2025 to March 2025 data provides 33000 samples per month on average – a fairer estimate of typical sample throughput.	GHD developed the operational model based on data for this duration of time to ensure there is enough data to complete the assessment.
Calculations - PhotonAssay	Based on the PA logger data provided by SGS, an average of 40.62 kW ('at operation') and 15.46 kW ('at standby') was calculated and used as the power rating (kW) across January 2025 - March 2025 on the basis that logger data was only able to be provided for a full six-day period. The SGS team mentioned that PA has a monthly maintenance period. The data within the 'PhotonAssay Logger - 19-26 May' sheet indicated that on 22 May, maintenance activities were performed for ~6 hours (between 11:15 am and 5:05 pm). This was incorporated into the average calculated.	Logger data was provided by SGS.
Calculations - PhotonAssay	Based on the Orbis logger data provided by SGS (from 6:36 pm - 9:15 pm on 26/05/25), an average of 3.65 kW was calculated and used as the power (kW) across June 2024 - February 2025 on the basis that logger data was only able to be provided for a one-day period.	Model was provided by SGS.
Delivery	The calculations assumed a location of Kalgoorlie (Western Australia) for both FA and PA.	Chrysos intended to operate their Assay technology in Perth (Western Australia). Therefore, for the purpose of this calculation this location was the most appropriate. This was agreed during the fortnightly project catch-up meeting between Chrysos and GHD on 12/02/2025.
Delivery	The calculations relied on Chrysos and SGS supplied data. GHD assumed this data provided was the most up to date.	GHD relied on process, design and specification details of infrastructure, key equipment lists, and waste management units provided (where applicable).

Appendix B

Calculation Tool

Refer to excel calculation tool – *Calculation Tool Chrysos Assay Technology Comparison*

Appendix C

Site Visit Memorandum

Site Visit Memorandum

A meeting was held at the SGS Laboratory (the Laboratory) in Kalgoorlie, Western Australia on 2 April from 9:30 am to 4:00 pm. In-person attendees were from GHD, SGS and Chrysos. Two GHD attendees and attended virtually for part of the site visit.

The purpose of the site visit was to validate parameters (i.e., sample capacity) of operational emissions models for PA and FA developed by GHD.

1. Introduction

The Laboratory is located at 17 Stockyard Way, Broadwood, Kalgoorlie, Western Australia (Figure 1). The Laboratory in Kalgoorlie is part of the global SGS network and receives client's samples from across Western Australia. The Laboratory is a trusted partner for mining companies, offering a wide range of services, including mineral analysis, environmental and metallurgical testing. The Laboratory operates 20 hours per day typically (over two, 10-hour shifts), with 24/7 operations on case-by-case basis. PA (commenced operation in June 2024 at the Laboratory) can assay gold, copper and silver. However, GHD notes that the scope of the work is for gold assaying only.

Figure 1 Site Visit Location – SGS Laboratory, Kalgoorlie

2. Sample Preparation – process

The sample preparation process is the same for PA and FA. Further details on the sample preparation process are outlined in section 2.2 of the EEW Report (the report). Refer to Table 1 for an overview of the process.

Table 1 Overview of sample preparation

Process	Description / Photograph
Receiving	 *Figure 2 Samples arrived at the SGS Kalgoorlie laboratory*

Process	Description / Photograph
Drying	 *Figure 3 Electric ovens (dry and feed)*

Process	Description / Photograph
Crushing	 *Figure 4 Orbis crusher used for PA samples*

Process	Description / Photograph
Milling (pulverising)	 *Figure 5 Milling equipment (LM 5 Pulveriser) for FA samples*

3. FA – process

Refer to Table 2 for an overview of the FA process. Further details on the FA process are outlined in section 2.3 of the report.

Table 2 Overview of the FA process

Process	Description
Weighing	Samples (~250g) are weighed and decanted into crucibles.  *Figure 6 Photo of (A) ~250g FA samples post-milling, and (B) FA racks*

Process	Description
Decanting and fluxing	Flux and lead are added to the crucibles with the sample.  *Figure 7 Crucibles used for FA*

Process	Description
Fusion	1. Crucibles are heated in furnaces (950–1050°C) to melt the sample.  *Figure 8 Three furnaces (left) heated to 1050°C and two furnaces (right) heated to 950°C*

Process	Description
	2. Lead collects gold, forming a button beneath silicate slag.  *Figure 9 Silicate slag (hazardous waste) bin*

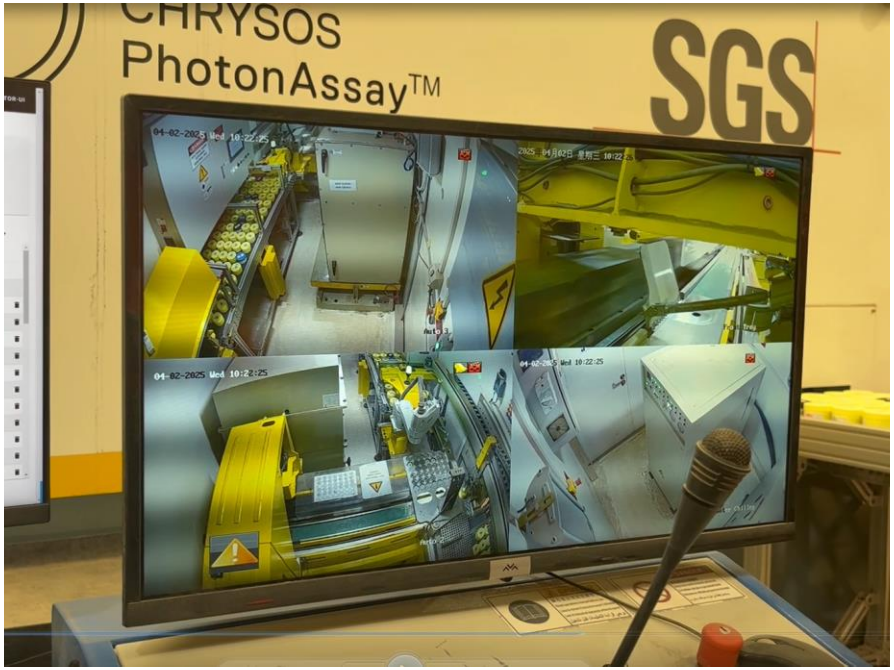
Process	Description
	3. Between fusion and the next stage (cupellation), the samples are cooled for approximately one hour.  *Figure 10 Cooling rack for the FA samples*

Process	Description
Cupellation	The lead button is transferred to a cupel and reheated to oxidize and remove lead, leaving a gold prill.  *Figure 11 (A) a small prill in the bottom of each cupels, and (B) discarded cupels post-cupellation*
Parting	The prill is treated with nitric and hydrochloric acid to dissolve remaining lead, isolating pure gold.
Final weighing	Gold is weighed gravimetrically or analysed via AA, ICP-OES, or ICP-MS.

4. PhotonAssay – process

Refer to Table 3 for an overview of the FA process. Further details on the FA process are outlined in section 2.4 of the report.

Table 3 Overview of the PA process

Process	Description
Weighing	Coarse crushed samples (~500g) are weighed and placed in single-use jars. If the sample is too small, it is redirected to FA.  *Figure 12 Automation cabin, showing feeder valves*
Gamma Ray Activation	Samples pass through a linear accelerator (LINAC) cabin where high-energy X-rays excite gold atoms. The emitted energy is measured to determine gold concentration. Each sample undergoes two 40-second LINAC cycles, with a 15-second LINAC irradiation period, subsequent 15-second detection period and cooldown period between the first and second irradiation period (up to ~60 seconds) to ensure full sample excitation. No acids or hazardous reagents are used. Minimal emissions (trace SF_6), and no hazardous waste is generated.

5. Maintenance

5.1 FA

There is no shutdown period for FA. The fusion furnaces are replaced when required (i.e., they reach the end of their product life). Out of the three 1050°C furnaces, there is one furnace shut down for maintenance and two that are operational. There is no scheduled maintenance for FA.

5.2 PhotonAssay

There is regular monthly maintenance for PA. This involves inspecting/ checking the automation and LINAC cabins as well as calibration. Maintenance takes up to eight hours for gold and up to 12 hours for other metals. During maintenance, the air conditioning and chillers are running 24 hours a day.

The chillers are comprised of the following refrigerants:

- 4 x Fujitsu 7.1 kW Air Conditioner R32 (at 1.27 kg each)
- 1 x Chiller – R407C (at 18 kg charge)
- 1 x Cabinet Air Conditioner 3384500 – R134a (at 700 g)

For newer PA units, the chiller is R410A. Chrysos mentioned that starting in 2026, R32 chillers are planned to be used for all PA units.

Note that there is a backup generator (powered by petrol) used only for the detectors and air conditioning unit on top of the unit the detectors are stored in. The PA system backup only lasts for 30 minutes before the backup generator is required. The detectors are used to ensure temperature control. If due to a loss of power for sufficient time the PA High Purity Germanium (HGPe) Radiation Detector crystal increases above -175°C then the system is shut down for ~2 days to allow for a full thermal cycle of the detector crystal in order to prevent damage to the detector.

One in every ~14 months there is target failure, requiring infrequent (one-off) maintenance.

6. Energy requirements

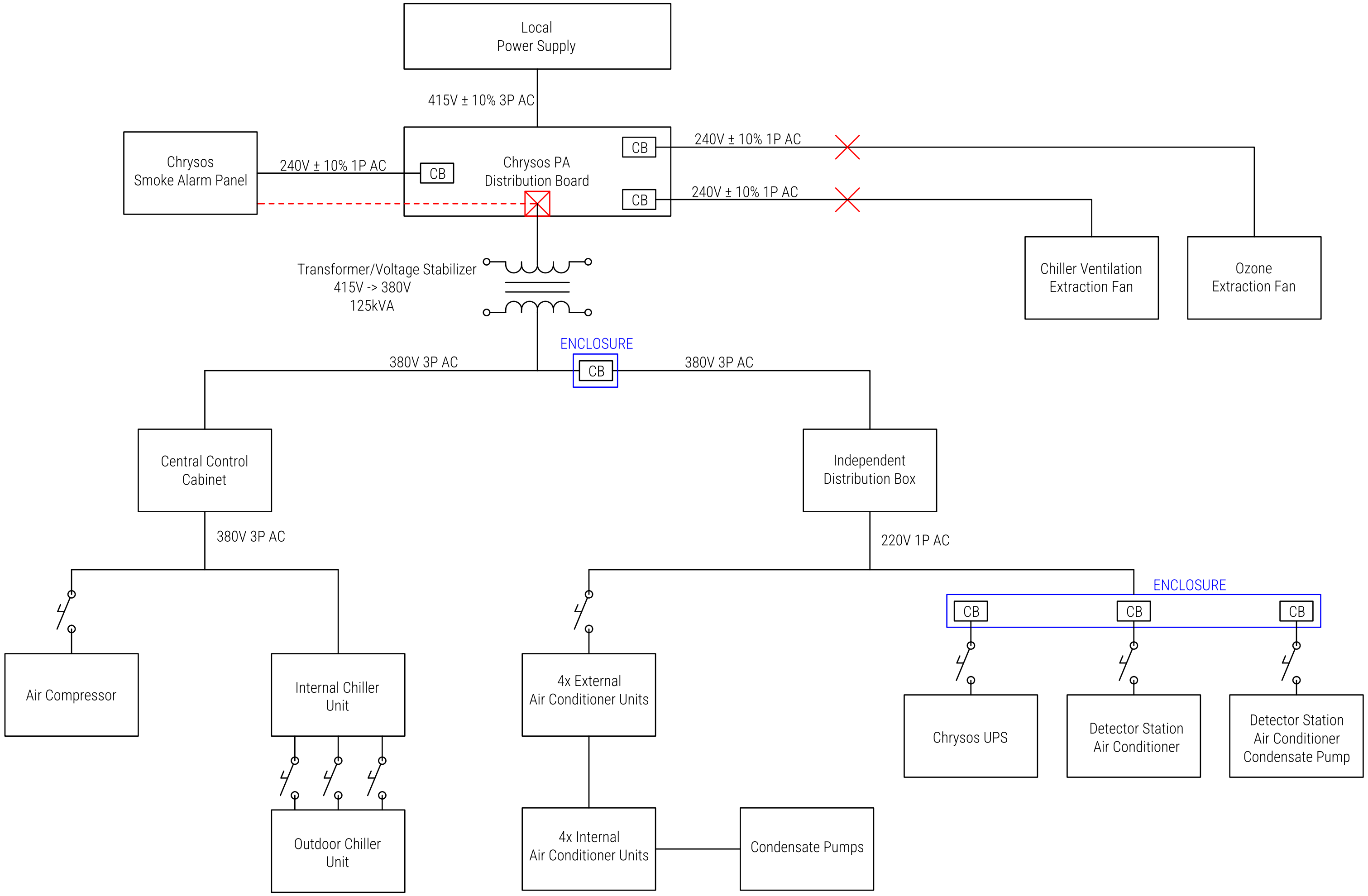
For FA, a combination of electricity and natural gas is used. Natural gas is used for the furnaces. Two cylinders are refilled weekly by Origin Energy.

Electricity is used to power all other equipment in the Laboratory, including all the infrastructure used for PA. There is a distribution board behind the PA (Figure 13) unit that powers the entire PA unit and entire Laboratory (excluding the furnaces).

Forklifts are used within the site. This is estimated by SGS to involve a 70/30% usage split between PA and FA, respectively.

Appendix D

Chrysos PhotonAssay Unit Specifications (Australia/New Zealand)



Legend

- ☐ SHUNT BREAKER
- ✕ IN THE EVENT OF FIRE, CUT POWER HERE
- ┆ FIRE ALARM SIGNAL CABLE
- CB CIRCUIT BREAKER
- ⏚ EXTERNAL LOCKABLE ISOLATOR

Notes:-

1. Chrysos Smoke alarm test procedure - WHS-PRO-055 must be performed upon completion of all the electrical wiring.
2. Refer to PRO-118 Chrysos Electrical Specification - Africa for detailed information on the work to be done and the cables/parts/equipment to be supplied.
3. Refer to S120-01-01 Electrical Installation Schematic - CE Units for electrical schematics of the connections to be made.

REFERENCES

REFERENCE NUMBER	REFERENCE TITLE
S120-01-01	Electrical Installation Schematic - CE Units
PRO-120	Electrical Specification - Australia/UK

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REVISIONS

REV	DESCRIPTION	PCO	DRN	APP	DATE
E	Updated AC, D/S & Ozone Fan Connections	PC220	VT	KH	29/02/2024
D	Updated Atomtex Connections & General Cable Specifications	-	VT	AS	08/05/2023
C	Added Dose Sensor	-	VT	AS	20/01/2023
B	Added Isolators for Air Conditioner and Chrysos UPS	-	VT	AS	05/12/2022
A	Initial Release	-	VT	AS	13/10/2022

INITIAL REVISION

DRAWN: V. Tibrewala
APPROVED: A. Stabile
DATE: 13 OCT 2022

Power Supply Drawing - Australia/UK

Single Line Diagram

SHEET SIZE	SCALE	DOCUMENT No.:	REVISION	SHEET
A3	NTS	C101-45-101	E	1 of 1

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