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**Case Report**

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# Industrial Scale Thermal Consolidation of Heterogeneous Mixed Plastic Waste with Integrated Combustion Support and Exhaust Gas Treatment

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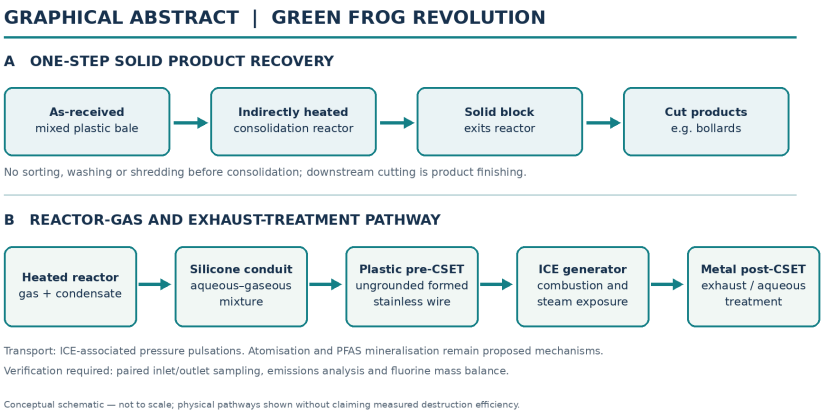
## Abstract

The principal objective of this research is to demonstrate the technical feasibility of converting intact bales of heterogeneous, contaminated mixed-plastic waste into cohesive solid blocks through controlled thermal consolidation, without conventional washing, shredding, sorting or polymer separation. Heterogeneous contaminated mixed-plastic waste is difficult to recover using conventional routes requiring sorting, washing, shredding or feedstock homogenisation. This study evaluates an author-developed industrial-scale system combining one-step indirect thermal consolidation and gravity-assisted compression with integrated process-gas extraction, combustion support and exhaust treatment. The combustion support and exhaust treatment module (CSET) is connected to an internal combustion engine (ICE): reactor gases, vapours and condensate are conveyed through a manifold and pre-CSET modules to engine air intakes, while engine exhaust passes through a post-CSET assembly. The engine also drives the generator supplying electricity to the heaters. This integrated configuration provides a proposed pathway for transport and high-temperature treatment of potentially PFAS-associated material; PFAS mineralisation and exhaust-treatment efficiency were not demonstrated. Full-scale developmental trials recorded temperature, vertical settlement, electrical consumption and physical cohesion. In the principal quantified trial (Bake 5), 351.6 kg of incoming material was processed for 213 h using 296.50 kWh of measured electrical energy. The recovered solid weighed 275.2 kg (78.27% mass retention), corresponding to 0.843 kWh/kg incoming material. A discrete 194 mm settlement was associated with strap release and cannot be attributed solely to thermal consolidation. Recovered sections were cohesive but heterogeneous, with an irregular upper face and loose peripheral material. The experimental findings demonstrate that full-scale mixed-plastic bales can undergo measurable thermal consolidation while retaining sufficient cohesion to permit removal and subsequent cutting. The research does not seek to establish the structural certification of manufactured products or experimental proof of PFAS mineralisation, which represent separate stages of development requiring dedicated material-performance and analytical validation. The central research question is whether heterogeneous, contaminated plastic waste can be consolidated into a manageable solid form without conventional preprocessing. The full-scale trials provide preliminary experimental

evidence that this is technically achievable. The potential relevance to Sustainable Development Goals 9 and 12 lies in reduced-preprocessing resource recovery, subject to further validation.

Keywords: heterogeneous plastic waste; thermal consolidation; combustion support; exhaust treatment; CSET; PFAS fate; industrial-scale processing; SDG 12

Figure 1. Conceptual graphical abstract: one-step thermal consolidation and integrated process-fluid pathway. This schematic is illustrative, not evidence of PFAS mineralisation.




Graphical abstract — integrated process and proposed treatment mechanism

Panel A. Conceptual illustration of one-step consolidation and the integrated reactor–CSET–engine gas-handling pathway. The illustrated equipment and products are schematic, not photographs of the tested apparatus.

Panel B. Hypothesised pre-combustion conditioning and PFAS mineralisation pathway. This illustration presents a research hypothesis; the depicted conversion products and treatment efficiency were not established by Bake 5 emissions measurements.

Panel C. Annotated photograph of the installed reactor-to-generator gas-handling arrangement, showing the reactor outlet, 25 mm collection conduit, distribution manifold, pre-CSET modules, engine air-intake connections and post-CSET exhaust assembly. This documents equipment configuration, not measured contaminant removal or PFAS mineralisation.

Interpretive note: The reactor, CSET and engine are an integrated operating arrangement. The presence of a combustion pathway is not evidence of complete pollutant removal or demonstrated PFAS mineralisation.

# 1 Introduction

Mixed industrial plastic waste can contain multiple polymers, moisture, food residues, films and non-polymeric inclusions. Conventional mechanical recycling generally benefits from controlled composition and preprocessing such as sorting, cleaning and size reduction [1–3]. These steps may complicate recovery of difficult mixed waste streams. Alternative approaches, including plastic lumber production, compression and intrusion moulding, thermal densification and plastic building blocks, also process mixed plastics. The present study does not claim invention of heating or compressing mixed plastic waste generally.

The specific question examined here is whether intact, heterogeneous industrial bales can be thermally consolidated at full scale by indirect upper and lower heating under mechanical load, without conventional sorting, washing or shredding. The novelty under investigation is the combined process configuration, full-bale thermal history and measured performance in an industrially relevant feedstock, rather than an assertion of uniquely originating plastic consolidation. The system boundary includes the connected CSET–ICE generator used for process-fluid handling and electricity generation; environmental treatment effectiveness is examined as a distinct, as-yet unquantified question.

The study relates principally to United Nations Sustainable Development Goal (SDG) 12, responsible consumption and production, through investigation of an alternative pathway for difficult waste, and SDG 9, industry and innovation, through full-scale process development. Potential relevance to SDG 13 requires comparative greenhouse-gas evidence and is not claimed as an achieved benefit. The hypothesis is that one controlled heating-and-compression stage can produce a physically coherent recovered solid from an intact bale. Whether the product is durable, safe and environmentally preferable is a separate hypothesis requiring testing.

The principal objective of this research is to demonstrate the technical feasibility of converting intact bales of heterogeneous, contaminated mixed-plastic waste into cohesive solid blocks through controlled thermal consolidation, without conventional washing, shredding, sorting or polymer separation. The research addresses a fundamental industrial waste-management challenge: processing mixed and contaminated plastic waste that is difficult or economically

impractical to recover through conventional mechanical recycling. The research does not seek to establish the structural certification of manufactured products, as such applications represent a separate stage of development requiring additional material-performance testing. Similarly, the integration of the CSET system does not constitute experimental proof of PFAS mineralisation, which requires separate analytical validation. The central research question is whether heterogeneous, contaminated plastic waste can be consolidated into a manageable solid form without conventional preprocessing. The full-scale trials provide preliminary experimental evidence that this is technically achievable.

# 2 Materials and methods

Figure 2. As-received intact heterogeneous mixed-plastic bale before processing.




## 2.1 Feedstock and study design

This is a developmental case study, not a controlled replicated experiment. Earlier Bakes 3 and 4 informed the operating configuration; the principal newly documented quantitative case is Bake 5, undertaken 24 October–3 November 2026. Bake 5 used an intact heterogeneous bale of mixed, contaminated soft plastic from industrial waste handling. Polymer fractions, initial moisture, ash, PVC content and contaminants were not analytically determined; accordingly polymer-specific mechanisms cannot be assigned.

The incoming scale reading was 359.6 kg including an 8.0 kg pallet, giving a net incoming feedstock mass of 351.6 kg. A corresponding recovered block weighing used the same pallet.

Feedstock sampling and independent composition analysis are required before generalising the result to other waste streams.

Figure 3. Full-scale reactor and bale-handling arrangement during developmental trials.



## 2.2 Reactor and operating conditions

The full-scale consolidation apparatus uses a containment shell (referred to in this study as the reactor) to enclose the intact bale and provide a controlled passage for process-generated gases and vapours. Unlike a conventional high-temperature chemical reactor, this shell is not intended to undergo extreme temperature excursions or serve as the principal direct-heating surface. Heat is supplied indirectly by separate upper and lower electric heating assemblies; the

lower plate supports the bale and the upper assembly rests on it and follows settlement under dead-weight loading. The approximately 8–10 mm open clearance between the heating assemblies and shell wall provides a gas/vapour migration passage. The upper and lower heater thermostat settings were approximately 150°C and 200°C, respectively; these are controller setpoints, not measured shell-wall, bale-core or combustion temperatures. Temperatures measured on the outer surface of the containment shell, or at externally accessible middle/top positions, must not be interpreted as measurements of the internal bale core. The shell operates nominally near ambient pressure. Transport of extracted process fluid through the connected treatment pathway is associated with internal combustion engine (ICE) intake/exhaust pressure pulsations rather than sustained reactor vacuum. The ICE-driven generator supplies electrical power to the heaters and receives extracted process fluid through the upstream combustion support and exhaust treatment module (CSET). The ICE and generator are integral to the gas-handling arrangement, not an unrelated electricity source. Apparatus integration alone does not establish gas capture efficiency, complete oxidation, regulatory compliance or exhaust safety.

Bake 5 heating began 24 October 2026 at 10:04 AEST and stopped 2 November 2026 at approximately 07:04 AEST, a duration of 213 h. Heater operation was intermittently cycled, with adjustments during the trial. The original time-series log should accompany a final submission to document the complete duty-cycle history; the applied compressive force was not instrumented and cannot be reported as a measured pressure. Manufacturer, heater serial numbers and sensor calibration records were not available in the present source report.

Figure 4. Photographic record of the integrated generator and CSET-related equipment. The image documents configuration and historical observations, not verified emissions performance.




## 2.3 Integrated process-fluid extraction and combustion arrangement

The current CSET configuration integrated with this apparatus is described in Australian Standard Patent Application No. 2026200930, A Combustion Support and Exhaust Treatment Module, System and Method, filed in the name of Vapour Draw Systems Pty Ltd. The patent application documents the disclosed apparatus design and is not evidence of independently verified pollutant-removal performance.

Reactor-generated gas, vapour, aerosol and entrained or condensed liquid are collectively termed extracted process fluid, distinct from engine exhaust. The reported configuration conveys this mixture from the reactor towards an upstream CSET conditioning stage and the ICE intake. A downstream CSET/exhaust-contact arrangement is part of the broader system design. The engine simultaneously provides generator power and a high-temperature combustion environment for the transported mixture. Process-fluid movement is attributed to engine-induced pressure pulsations. This coupled configuration is relevant to reproducibility, mass and energy boundaries and hazard assessment; omitting it would inaccurately portray the experimental apparatus as an isolated heated vessel.

Figure 1. Installed process-fluid transport and CSET–ICE integration. The annotated photograph documents the reactor-to-manifold conduit, individual pre-CSET pathways to engine intake and downstream post-CSET assembly. Gas-flow arrows describe the intended operating route; quantitative flow, combustion completeness and exhaust-treatment performance require independent measurement.

In the photographed configuration, a nominal 25 mm PVC conduit connects the reactor outlet to a distribution manifold. Individual nominal 3 mm silicone lines feed pre-CSET modules, with a corresponding line from each module to an engine air-intake connection. Engine exhaust is routed through the post-CSET assembly before atmospheric discharge. This description concerns the installed arrangement; line dimensions and flow distribution should be verified against engineering records, and no inference of emission-control efficiency follows from the photograph.

The proposed pre-combustion mechanism involves controlled flow, gas–liquid contact and possible electrostatic effects on droplet transport. These are mechanistic hypotheses rather than measured aerosol size, charge density or PFAS fate. Neither nominal engine combustion temperatures nor the presence of an exhaust-contact stage prove mineralisation or removal of specific contaminants. No representative matched pre- and post-CSET gas, liquid and exhaust speciation was obtained for Bake 5. Generator diesel consumption and CSET stream-flow rates were not quantified in the reported electrical-energy total.

Supplementary Information S1 contains the fuller trial narrative, instrument observations and photographic record. Its technical observations are incorporated here only to the extent supported by measurements and documented specimen inspection.

### 2.3.1 CSET gas–liquid conditioning and condensate pathway

The CSET architecture incorporates a condensation chamber containing a body of fluid through which incoming gas can interact with the liquid phase. The incoming pathway extends below the fluid level through a submerged inlet arrangement containing apertures. Gas is therefore brought into direct contact with the liquid environment before progressing toward the module outlet.

Moisture entering with the gas/vapour stream can condense and contribute to the liquid inventory within the chamber. Compounds associated with the incoming vapour may also partition into or become associated with condensate. The liquid body therefore becomes both an operational component and a potential analytical record of material transferred from the upstream process.

Incoming gas dispersed through the fluid body increases contact between gas and liquid phases. Possible physical processes include gas cooling, vapour condensation, gas-liquid mass transfer, moisture exchange and entrainment of fine liquid droplets. Their relative contributions depend on operating conditions and should be measured rather than assumed.

Following initial gas–liquid interaction, the CSET architecture incorporates a baffle arrangement intended to influence the subsequent gas/vapour pathway and provide additional opportunity for entrained liquid droplets and condensable material to separate from the moving stream.

Condensate generated or accumulated within the system is treated as a material stream. The pathway is process gas/vapour → condensation → CSET liquid → sampling, controlled removal or secondary treatment. If a compound decreases in the gas phase but appears in the liquid phase, the evidence supports phase transfer or capture, not necessarily destruction.

The physical configuration provides the experimental boundary Pre-CSET → CSET → Post-CSET. Where a constituent decreases across that boundary, the investigation should also consider the liquid and retained fractions, converting a simple removal test into a material-fate experiment.

### 2.3.2 Combustion support and exhaust-treatment boundaries

Conditioned gas/vapour may subsequently interact with the combustion system. Process-derived combustible constituents may potentially provide supplemental combustion support. The energetic contribution must ultimately be quantified experimentally rather than inferred solely from engine operation.

Conditioned process-derived gas or vapour can enter an internal-combustion engine as supplemental combustion support. The system also defines a downstream exhaust-treatment and sampling boundary. Engine operation alone does not establish fuel displacement or contaminant destruction.

The engine performs a dual operational role in the integrated configuration: it drives the electrical generator and receives conditioned reactor-derived gas or vapour at its intake. The pre-combustion conditioning pathway and post-combustion exhaust pathway must be distinguished. Their inclusion describes the apparatus, not a verified emission-reduction

efficiency. Engine pulsation and pressure differentials may contribute to flow; actual stream flow, composition, residence time and fuel displacement require direct measurement.

### 2.3.3 Proposed PFAS transport and mineralisation mechanism

Condensate recovered within the integrated system may undergo atomisation. For an ideal spherical droplet, A/V = 6/d. As droplet diameter decreases, surface area relative to liquid volume increases and characteristic heat-transfer distance decreases. The pathway can therefore extend Condensate → atomisation → rapid heating → phase transition → steam/elevated-temperature exposure. Its effect upon PFAS chemistry remains an experimental question.

Temperature, residence time, pressure, droplet characteristics, mass flow, contaminant concentration and chemical composition may all affect the outcome. A maximum measured temperature cannot independently define the thermal history of every contaminant-bearing droplet.

The presence of a high-temperature combustion environment does not, by itself, demonstrate complete destruction of persistent contaminants. Effective thermal transformation depends upon the combined effects of temperature, residence time, mixing, oxygen availability and the physical and chemical form in which a contaminant enters the combustion zone.

Under incomplete or non-uniform combustion, parent compounds, transformation products or other fluorinated species may potentially survive or pass into the exhaust pathway. This possibility must be tested rather than presumed.

These are testable hypotheses. Droplet-size distribution, thermal histories, residence time, oxygen availability, process-gas composition, combustion products and exhaust chemistry have not yet been characterised sufficiently to attribute the downstream water result to PFAS transformation.

The CSET pathway is intended to transport potentially PFAS-associated material within aqueous droplets and a gas–vapour mixture to a high-temperature combustion environment. Electrostatic conditioning, if present, is considered a possible transport influence, not evidence of PFAS chemical transformation. Mineralisation would require demonstration of conversion to inorganic fluorine end products, supported by paired sampling, transformation-product analysis and fluorine mass balance. No such quantitative efficiency is claimed for Bake 5.

### 2.3.4 Historical analytical observation and experimental limitations

IOHC Pty Ltd was engaged to undertake PFAS water sampling at the GFR installation at Caboolture, Queensland. The specific methodology records that a two-part PFAS sample was collected by an occupational hygienist using sterile water bottles supplied by the laboratory. The sample was obtained from the tank at the rear of the diesel generator by separating the

water-feed hose. The generator displayed 13,236.9 operating hours at the time of sampling. The sample was refrigerated during transport and submitted to Envirolab Services Pty Ltd for analysis.

Envirolab Certificate of Analysis 404075 identifies one water sample received on 12 March 2026, prepared on 17 March 2026 and analysed on 18 March 2026. Envirolab states that PFAS analysis was performed using LC-MS/MS under Method Org-029. The laboratory documentation describes direct injection and/or concentration/extraction using solid-phase extraction as applicable, correction using extracted mass-labelled internal standards, and monitoring through surrogates and laboratory quality-control procedures. Envirolab operates under NATA Accreditation No. 2901 for the reported testing.

The reported results for water sample 404075-1 were PFBS, PFHxS, PFOS, PFOA and 6:2 FTS each <0.01 µg/L; 8:2 FTS <0.02 µg/L; and the laboratory's Total Positive PFAS <0.01 µg/L. These are analyte-specific reporting limits, not zero concentrations. The original evidence composites from both source papers appear in Figures A6–A7.

These controls strengthen confidence in the analytical measurement. They do not overcome limitations in the experimental design, particularly the absence of a matched pre-treatment sample.

The result demonstrates that the selected PFAS compounds were below the applicable PQLs in the sampled downstream water at the time of sampling.

It does not demonstrate that the water contained absolutely no PFAS. It does not establish the PFAS concentration entering the treatment pathway. It does not establish a percentage reduction. It does not independently establish the mechanism responsible for the downstream analytical condition. It does not demonstrate complete PFAS mineralisation.

We classify this as a post-treatment analytical condition (Level 0). No matched pre-CSET laboratory result was collected at the same event. The sample therefore cannot establish a percentage reduction, a destruction efficiency, an operating mechanism or mineralisation. The 13,236.9 h generator reading identifies the equipment's cumulative operating history; it is not the residence time of the sampled water or a duration of verified PFAS treatment.

The sampled generator-associated water was part of the integrated CSET–engine arrangement, not an unrelated generator experiment. Nevertheless, the March 2026 sampling event is distinct from the Bake 5 material-consolidation trial and cannot be treated as a contemporaneous Bake 5 emissions measurement.

### 2.3.5 Proposed verification of whole-system performance

Generator fuel consumption and emissions depend on load. Baseline and CSET-assisted tests should therefore be conducted at approximately equivalent electrical output and with engine speed, exhaust temperature, ambient conditions and sampling duration documented.

Final exhaust is a critical downstream checkpoint. The question is not simply whether combustion occurred, but what matter remains in or has formed within the gas stream after combustion and CSET treatment.

The strongest design is a paired comparison of the same generator under a defined baseline condition and a comparable CSET-integrated condition. For each emission parameter, both concentration and exhaust mass flow should be reported.

If PFAS-associated matter enters combustion, absence of the original parent compound downstream does not establish disappearance of fluorine. Possible pathways include remaining organic fluorine, different fluorinated compounds, gas-phase products, condensed material, deposits and terminal inorganic fluorine products. Future research should therefore extend beyond water analysis.

Fuel-displacement experiments should hold engine speed and electrical load constant, measure baseline and CSET-assisted primary-fuel mass flow, and quantify process-derived gas composition and flow. Final exhaust must be sampled at representative operating conditions. Any change in gas concentration must be converted to mass emission using flow and time, with condensate and deposits measured as potential transfer pathways.

For a defined boundary and period, total input equals measured outputs plus accumulation and an explicitly unaccounted fraction. The same principle applies to feedstock mass, water, hydrocarbons, individual PFAS and elemental fluorine. A drop in a sampled gas-phase concentration may indicate capture in water or deposition; loss of a parent PFAS signal may indicate transformation into another fluorinated compound.

For a defined PFAS compound, the experimental objective is to account for input mass across relevant output and retained fractions. Parent PFAS disappearance from one phase should trigger investigation of other phases and transformation products.

A stronger endpoint follows fluorine rather than only parent PFAS:

$F_{input} = F_{organic} + F_{inorganic} + F_{gas} + F_{liquid} + F_{solid} + F_{deposited} + F_{unaccounted}$.

A future instrumented trial should record feedstock mass and representative composition, retained-solid mass, condensate quantity and composition, process-gas composition/flow, primary-fuel use, electrical output, temperature/time history, relevant pre/post treatment samples, exhaust composition/flow and internal residues where material accumulation is significant.

Every balance contains measurement uncertainty. Instrument accuracy, sampling representativeness, analytical PQLs, temporal variability and unmeasured fractions should be reported rather than hidden within a single closure number.

A large decrease in parent PFAS concentration may coexist with poor fluorine closure. In that circumstance, disappearance has been observed but mineralisation has not been demonstrated. Destruction efficiency and balance closure answer different questions and must not be substituted for one another.

The March 2026 PFAS result supplies a downstream concentration condition but lacks the matched input concentration and complete output fractions required for a PFAS or fluorine mass balance. It therefore remains Level 0 evidence while informing the design of the next experiment.

## 2.4 Measurements and calculations

Electrical consumption was obtained from the trial kWh meter; external middle and upper reactor temperatures and height changes were observed during operation. Local post-shutdown temperature readings were taken at exposed cut surfaces and must not be interpreted as full three-dimensional internal thermal maps. Net material mass was calculated by subtracting the same 8 kg pallet mass from incoming and recovered weighings.

Mass retention (%) = 100 × recovered net mass / incoming net mass. Specific electrical energy (kWh/kg incoming) = metered electrical energy / incoming net mass. Height reduction is reported separately from volume reduction because complete, uniform final dimensions were not established. A final average recovered height of approximately 350 mm was recorded, but nonuniform shape and incomplete final length/width measurements preclude a defensible final bulk-density calculation.

# 3 Results

Bake 5 is the principal quantified full-scale trial in this manuscript. Supplementary Information S1 provides the corresponding technical report and images, including later removal and lower-section examination.

Figure 5. Bake 5 mass-record photograph, retained as supporting observational evidence; consult original scale record for verified net mass.

StripScale



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Weight

283.2kg

3.1 Quantitative results for Bake 5

| Parameter | Measured or reported value |
|---|---|
| Net incoming material | 351.6 kg |
| Net recovered solid | 275.2 kg |
| Net mass difference | 76.4 kg (21.73%) |
| Mass retained | 78.27% |
| Electrical energy | 296.50 kWh |
| Heating duration | 213 h |
| Specific electrical energy per incoming mass | 0.843 kWh/kg |
| Specific electrical energy per recovered mass | 1.077 kWh/kg |
| Mean electrical input over elapsed heating time | 1.392 kW |
| Approximate recovered height | 350 mm average; irregular geometry |

The 76.4 kg difference is a net mass-balance observation, not an identification of chemical species or a measurement of emissions. It may include water, food residue, volatilised material and other transferred or retained fractions. No complete mass closure of condensate, gas and residue streams was performed.

Figure 6. Recovered block following consolidation, illustrating geometry and surface irregularity.



## 3.2 Settlement, consolidation and thermal observations

A height change from approximately 1,089 mm to 895 mm (194 mm) occurred near 98.5 kWh when bale retaining straps released, with a middle sensor reading of approximately 62°C. This discrete event is classified primarily as mechanical settlement. Later gradual height reductions occurred as middle-region measurements approached approximately 65–70°C. Such changes are consistent with heat-assisted deformation under load but cannot distinguish softening, viscoelastic creep and stress relaxation without controlled unloading or in-bale sensors.

The post-shutdown observations represent measurements taken at different times and sampled locations, not a single uniform bale-core temperature. Approximately 31 h after shutdown, four readings at a cut inspection region about 300 mm inward from an edge and 150 mm below the upper face were reported at approximately 67–68°C. A separate photographed handheld reading shows 61°C. Later, approximately 50 h after shutdown, exposed-section infrared readings were approximately 50.6–55.6°C. The time-stamped photographic sequence is consistent with gradual heat loss over many hours; these readings cannot be treated as simultaneous or used to calculate a controlled cooling rate. In particular, temperatures recorded at the outer containment shell or other accessible exterior locations are not direct measurements of the bale internal core.

Figure 7. Recovered consolidated block with heterogeneous upper surface and visible peripheral material.



## 3.3 Recovered solid and heterogeneity

The recovered material formed a cohesive consolidated mass, and lower-region sections remained coherent during handling. Inspection and cutting showed heterogeneous plastic constituents and entrained foreign materials physically incorporated within the consolidated structure, providing a promising route towards long-term physical encapsulation. Photographs

also document layered formations, local irregular edges and an upper-face cavity. A comparatively loose peripheral region, estimated at approximately 100–200 mm in observed locations, is consistent with the intended thermal-barrier strategy and should not automatically be classified as failed consolidation. Visual incorporation does not by itself establish long-term immobilisation, leach resistance or product mechanical performance; spatial testing remains necessary.

# 4 Discussion

Figure 8. Internal section of recovered plastic showing heterogeneous bonding and local temperature-probe observation.




## 4.1 Mechanistic interpretation and limitations

Indirect heating can cause spatially nonuniform thermal histories in a bale containing folded films, air gaps, moisture and contaminants. Upper and lower heating both contribute; therefore upward heat migration is plausible but not exclusive. The upper heater may help maintain warmer headspace surfaces and reduce premature condensation, but no quantitative dew-point or vapour-composition measurements were available. The upper face cavity and discolouration could be associated with local overheating or material displacement; photographs alone cannot identify the cause.

The study supports the limited hypothesis that an intact industrial bale can form a physically coherent solid after prolonged heating and compression. It does not demonstrate uniform consolidation, a certified engineering product, controlled emissions, or repeatable results across compositionally matched replicates. Earlier development bakes were operated under different conditions and should not be presented as independent statistical replicates.

## 4.2 Environmental and sustainability implications

Avoiding conventional washing, sorting and shredding in this trial may reduce the number of process stages, but reduced stage count does not by itself establish lower energy, cost, greenhouse-gas emissions or environmental impact. Electricity was generated by diesel equipment; the reported 296.50 kWh measures electrical input and excludes upstream diesel energy and other site inputs. Comparisons with landfill, incineration with energy recovery, and conventional recycling require a consistent functional unit, system boundary, allocation assumptions and measured emissions.

Mixed plastics may contain PVC and other constituents capable of generating hazardous emissions during heating. No representative off-gas testing for HCl, VOCs, PAHs, dioxins or furans is provided here; no standardised leachate, abrasion or microplastic-release testing has established product safety. Consequently the study makes no claim of PFAS mineralisation, contaminant immobilisation, environmental compliance or climate benefit. A historical PFAS-containing-water analysis associated with the integrated CSET investigation is described separately; without paired inlet/outlet samples and a fluorine mass balance, it cannot establish treatment efficiency or mineralisation.

The intended use of coherent cut sections in bollards or similar durable goods is a proposed resource-recovery route. The fate of offcuts, loose outer layers, eventual wear and end-of-life disposal or reprocessing remains unresolved. Potential use of loose material as aggregate is a development possibility rather than a validated recycling pathway. These constraints are important for SDG 12 and for transferability across jurisdictions with different waste, product and emissions regulations.

## 4.3 Comparison with prior work and industrial feasibility

Research reviews identify sorting, washing and size reduction as common operations in mechanical recycling, while also noting difficulties posed by polymer incompatibility and contamination [1–5]. Conventional remelting and extrusion generally require more controlled feedstock than the intact heterogeneous bales investigated here. Plastic lumber, compression moulding, intrusion moulding and densification are related product-forming pathways; they are not claimed as new in this study. The specific investigated distinction is consolidation of an intact industrial bale by indirect heating and mechanical loading, with connected process-gas handling. Published energy or environmental comparisons are not treated as directly equivalent because feedstock quality, functional unit, product specification and system boundaries differ. The present 0.843 kWh/kg is measured electrical energy at the heater/generator output boundary, not total primary energy or a life-cycle result [4,5].

| Pathway | Typical preparation / output | Comparison limitation |
|---|---|---|
| Conventional mechanical recycling | Sorting, cleaning and size reduction; reprocessed flakes or pellets | Requires comparable contamination and material specifications. |
| Plastic lumber / moulded composite | Often size-reduced feedstock; moulded or extruded product | Performance depends on composition, additives and mechanical testing. |
| Pyrolysis / gasification | Thermochemical conversion to fuel, gas or chemical feedstocks | Different product function and emissions/energy boundary. |
| Intact-bale indirect consolidation (this study) | As-received bale, indirect heating and load; cuttable heterogeneous solid | Product strength, whole-system energy and emissions remain unverified. |

Table 2. Qualitative comparison of recycling pathways; not a comparative life-cycle assessment.

The recorded electrical intensity provides an initial engineering input for future cost modelling. A screening cost comparison would also require diesel consumption, labour, equipment depreciation, maintenance, yield of saleable product, emissions controls and disposal of residual fractions. The trial alone does not establish economic viability.

Figure 9. Recovered block cross-section illustrating the variable consolidation of the material.



## 4.4 Additional cross-trial evidence and operating lessons

Bake 3 processed approximately 550 kg of mixed plastic. Initial heating produced substantial height reduction but inspection following cooling showed incompletely bonded regions. The material was reheated from near-ambient conditions with revised upper-heater settings. Despite additional thermal exposure, the expected improvement in uniform gelling was not achieved.

Condensation in the upper region and heat migration through the insulating bale were important observations. The experiment supports a working preference for a single sufficiently controlled continuous heating cycle rather than interrupted heating and reheating, without proving the polymer-scale cause. A consolidated energy figure of approximately 285.6 kWh appears in later records and requires reconciliation against the phase-specific meter log before calculation of specific energy.

Bake 4 was conducted in a square reactor of approximately 1200 × 1200 mm footprint. Cumulative metered electrical energy reached approximately 428.8 kWh before shutdown. Height declined substantially from the corrected initial measurement of approximately 1200 mm, then approached a plateau near 930 mm. Post-process inspection found a well-consolidated underside but incomplete peripheral bonding; clear plastic enclosed within black bags had bonded in places while the surrounding black material remained separable. A central top-face defect and local surface degradation were also observed. These results demonstrate spatially nonuniform consolidation and do not establish that colour alone caused the bonding difference.

Bake 3 and Bake 4 are developmental comparisons rather than controlled replicates. Their initial feedstock masses and operating histories are not uniformly measured, so they are not pooled with Bake 5 to estimate statistical repeatability.

Figure 10. Detailed section with depth scale illustrating the heterogeneous internal material structure.




## 4.5 Thermal transport and peripheral material behaviour

The operating strategy intentionally retains a comparatively soft and loose peripheral plastic region around the primary product-forming mass. This region is intended to act as a thermal barrier that limits outward heat transfer while the central material consolidates; identical bonding across the entire bale is not the process objective. The observed peripheral thickness was

approximately 100–200 mm in some locations, rather than a uniformly measured design dimension. The containment shell primarily encloses the bale and provides a process-fluid boundary, rather than acting as a conventional high-temperature reaction vessel. Measurements taken at its outer surface or other accessible exterior points describe local conditions and cannot be equated with the internal bale-core temperature.

The peripheral material may have experienced heating despite limited visible bonding. Its proposed insulating function is consistent with the observed temperature differences and material condition, but direct heat-flux, thermal-conductivity and spatial core-temperature measurements are still required to quantify that function. The softer peripheral material is an intentional aspect of the operating approach, not by appearance alone a process fault.

After cooling and demoulding, the softer peripheral plastic can be separated and retained as secondary manufacturing feedstock. Potential downstream products include plastic aggregate, pavers, cementitious or polymer-composite fillers, and other manufactured articles. Such applications may require further heating, size reduction, blending or forming; they are proposed utilisation pathways rather than demonstrated product qualifications. Mechanical performance, contaminant characterisation, environmental leaching and application-specific standards must be assessed before commercial claims are made.

The resulting intended material strategy comprises (i) primary recovery of a consolidated block for products such as bollards and (ii) secondary recovery of peripheral feedstock for subsequent manufacturing. The “one-step” description refers to the primary bulk-consolidation operation and does not imply that secondary aggregate or paver manufacture requires no additional steps.

The peripheral-layer explanation is an operating interpretation, not a directly measured thermal-conductivity result. Product claims require spatially resolved mechanical and environmental testing.

## 4.6 Proposed methods for quantitative validation

Approximate one-dimensional conductive flux: $q'' = -k_{eff} \partial T/\partial x$ (W/m²). Both $k_{eff}$ and the temperature gradient may vary during compaction and moisture release.

Compaction ratio by measured height: $C_h = (H_0 - H_t)/H_0$; height reduction alone is not evidence of uniform bonding.

Mark top, bottom and side faces and establish a specimen coordinate system before drilling. Collect both vertical cores (along the compaction direction) and horizontal cores (transverse to it) from defined central, intermediate and peripheral locations where practicable. For each core record identifier, extraction position and direction, diameter, length, depth, appearance, voids, delamination, coolant use and recovery condition. Photograph the block and cores with scales and orientation marks. Preserve failed cores and record possible drilling-induced damage. The

extraction direction must not be confused with the direction of load applied during subsequent strength testing.

A complete material balance should separately measure incoming feedstock, consolidated product, loose peripheral fractions, condensate, captured residue and off-gas where technically feasible. A full energy balance should include diesel consumption, delivered electrical energy, heating time and auxiliary equipment. These are proposed measurements, not results of Bake 5.

## 4.7 Integrated gas management, historical PFAS observation and safety limitations

The experimental configuration requires distinguishing apparatus integration from analytical provenance. The generator and internal combustion engine (ICE) are physically and operationally connected to the reactor process-fluid extraction and CSET pathway. Their roles include electrical generation and providing an intake and combustion route for extracted gases and vapours. The engine is therefore not a separate, unrelated experimental system: it is relevant to the experimental method, gas-handling architecture and emissions boundary. This physical integration does not establish that a historical sample was collected during Bake 5.

A historical CSET-associated water sample (Envirolab Certificate of Analysis 404075; sample 404075-1, March 2026) was collected in association with a generator recorded as having 13,236.9 operating hours. In the available analytical account, PFBS, PFHxS, PFOS, PFOA and 6:2 FTS were each reported below 0.01 micrograms/L, and 8:2 FTS below 0.02 micrograms/L. These are reporting-limit observations for one sampled liquid matrix, not a paired before-and-after comparison and not a Bake 5 emission result. No matched upstream concentration, fluorine mass balance or final exhaust analysis accompanies this observation. Consequently the sample cannot establish PFAS removal efficiency, destruction or mineralisation; it is retained only as historical context for the integrated CSET research programme, not as a consolidation outcome. The sampling location and its relationship to the integrated process should be confirmed against the original certificate and sampling records before final submission.

Potential hazardous constituents from heterogeneous plastics include acid gases, volatile and semi-volatile organics and combustion by-products. Routing gases to an ICE is a safety-relevant design measure but does not, without stack measurements and operating controls, establish that the experiment has reduced risk. Verification requires inlet and outlet sampling at defined locations, engine-load and fuel measurements, combustion/exhaust monitoring, condensate analysis, and independent laboratory evaluation of contaminants and fluorine fate. The apparatus should not be operated on the assumption that unmeasured contaminants are rendered harmless.

## 4.8 Whole-system accounting and research boundaries

The 296.50 kWh reported for Bake 5 is metered electrical energy delivered during the trial. A whole-system energy inventory would additionally require generator diesel use, fuel calorific value, electrical generation efficiency, any recovered process-fluid energy, auxiliary power and start-up/shutdown loads. A whole-system material balance must quantify the 76.4 kg difference between incoming and recovered weighed material across water, condensate, volatile outputs, deposits, offcuts and uncollected fractions. The present dataset does not permit assignment of this difference to individual chemical or physical pathways.

The complete Bake 5 operating record, source photographs and additional observations are provided as Supplementary Information S1 (Full-Scale Bake 5 Technical Report). The principal quantitative results are reported above; the supplement is the detailed traceable supporting record, not an independent replicated trial.

# 5 Conclusions

Bake 5 demonstrated the technical feasibility of one-step bulk thermal consolidation of an intact 351.6 kg heterogeneous industrial mixed-plastic bale into a recovered 275.2 kg cohesive solid mass over 213 h, with 296.50 kWh of measured electrical consumption (78.27% mass retention; 0.843 kWh/kg of incoming waste, excluding generator fuel). Visual inspection and cutting documented the physical incorporation of heterogeneous plastics and entrained foreign materials within the consolidated structure. This provides a promising pathway towards long-term physical encapsulation and the development of value-added manufactured products, subject to durability and environmental validation. A large discrete height change was associated with bale-strap release and is distinguished from gradual heat-assisted settlement.

An intentional feature of the process is the comparatively loose peripheral region, approximately 100–200 mm thick at observed locations, intended to act as a thermal barrier around the primary consolidated mass. This region is potential secondary feedstock rather than necessarily a failed product zone; its thermal performance remains to be quantified. The reactor functions principally as a containment shell for the bale and process-generated fumes, vapours and gases, while separate heating assemblies provide controlled indirect heat. External shell or accessible wall temperature measurements must not be represented as direct measurements of the bale core. The integrated CSET–ICE arrangement is an essential process-fluid management pathway, with treatment effectiveness requiring further verification. The trial establishes a positive engineering basis for continued development; planned mechanical, durability, composition, leaching, emissions, fluorine mass-balance and controlled-repeatability studies will assess product suitability and environmental performance.

# Declarations

## Ethical approval

Not applicable. The study involved industrial waste processing and no human or animal participants.

## Consent to participate

Not applicable. No human participants were involved.

## Consent to publish

Not applicable to human-subject consent. The author consents to publication of the manuscript and author-supplied experimental images.

## Competing interests

The author is affiliated with Vapour Draw Systems Pty Ltd and is involved in developing the Green Frog Revolution process described in this article. This constitutes a relevant commercial interest.

## Funding

The author reports no external research funding for this study.

## Use of generative AI

ChatGPT (OpenAI) was used to assist with language, structure and editorial preparation. The author is responsible for checking all technical claims, calculations, references and final content.

Supplementary Information S1. Full-Scale Bake 5 Technical Report (24 October–4 November 2026), accompanying this submission; includes trial narrative, measured mass and energy, temperature and settlement observations, and photographic evidence.

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# Appendix A Original manuscript photographs

Source images reproduced from the original author-supplied document. Captions identify image sequence; exact scale, measurement context and photographic descriptions should be verified against the source before submission.

Figure A1. As-received compressed heterogeneous plastic bale secured by lifting straps before processing.

Figure A2. Transport of multiple compacted waste bales to the processing site; logistical context rather than evidence of consolidation performance.

Figure A3. Full-scale reactor and handling arrangement during bale loading or removal.

Figure A4. Recovered consolidated material showing irregular external surface and heterogeneous appearance.

Figure A5. Cut sections of recovered plastic displaying variable cohesion and internal texture.

Figure A6. Composite of integrated CSET equipment and historical analytical documentation; included for apparatus context, not proof of PFAS removal.

# Appendix B Bake 5 technical report photographs

Source images reproduced from the original author-supplied document. Captions identify image sequence; exact scale, measurement context and photographic descriptions should be verified against the source before submission.

Figure B1. Initial Bake 5 bale on weighing equipment; recorded gross mass 359.6 kg including approximately 8 kg pallet.

Figure B2. Bake 5 recovered material showing heterogeneous surface and partially consolidated peripheral material.

Figure B3. Recovered Bake 5 block viewed from the side, showing uneven exterior and loose outer material.

Figure B4. Post-processing weighing record of recovered material; reported net recovered mass 275.2 kg.

Figure B5. Post-cut surface temperature measurement adjacent to a ruler; local measurement only, not a full internal thermal map.

Figure B6. Ruler placed into the recovered block to document depth and irregular surface geometry.

Figure B7. Temperature measurement on exposed cut region; reading reflects a local post-heating condition.

Figure B8. Further local temperature and depth measurement at an exposed surface.

Figure B9. Repeat measurement at a nearby location illustrating spatial variability in the cut material.

Figure B10. Additional local temperature measurement and ruler placement on the recovered block.

Figure B11. Upper face of recovered Bake 5 material showing a prominent cavity and nonuniform consolidation.

Figure B12. Documented post-cut temperature measurement and instrument display; measurement conditions are described in Supplementary Information S1.

Figure B13. Infrared temperature reading from an exposed section during cooling; not an in-situ core measurement.

Figure B14. Additional infrared surface-temperature record during cooling.

Figure B15. Recovered section with ruler and thermal measurement record illustrating irregular geometry.

Figure B16. Ruler and infrared measurement record on a recovered section during post-processing inspection.

APPENDIX A — EXPERIMENTAL PHOTOGRAPHS AND PROCESS SCHEMATIC

The following figures are reproduced from the illustrated developmental manuscript. Conceptual diagrams do not constitute experimental proof of PFAS mineralisation or exhaust-treatment efficiency.

Figure A1. Graphical abstract of the one-step consolidation and integrated CSET pathway (conceptual schematic).

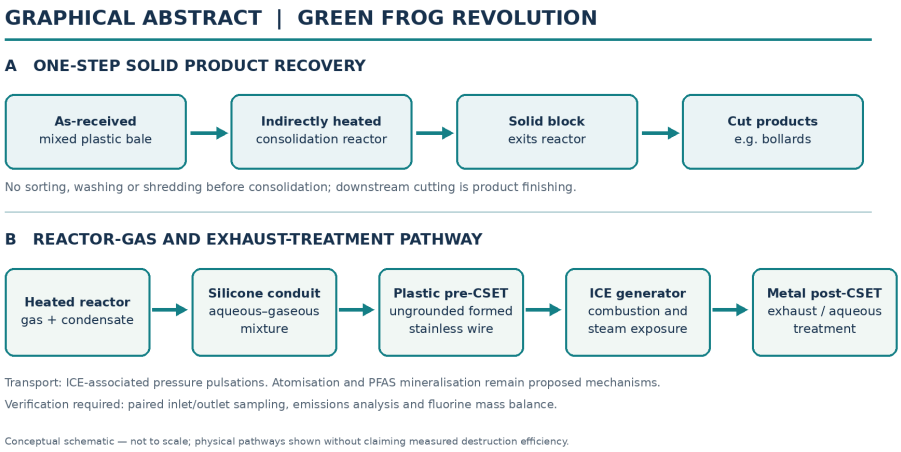



Figure A2. Full-scale reactor assembly used in developmental trials (equipment photograph).



Figure A3. As-received heterogeneous plastic bale before thermal consolidation (photograph).




Figure A4. Recovered consolidated material showing heterogeneous structure and cut sections (photograph).



Figure A5. Recovered block surface after processing (photograph).



## Supplementary Files

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- Screenshot20261113054457Chrome.jpg