Massmelt Continuous Thermal Extrusion System

Intrinsic Safety Architecture for Lithium-Ion Battery and Pressurised Gas Cylinder Containment & Anaerobic Compaction.

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Massmelt 400 with integral bin tipping machine.

1. Executive Summary

The proliferation of discarded consumer electronics—most notably single-use electronic nicotine delivery systems (disposable vapes) and portable power banks—has introduced severe fire hazards into municipal, commercial, and transport-hub waste streams [1]. In conventional mechanical compaction equipment, including rotary drum crushers, vertical balers, and portable compactors, mechanical force routinely breaches cell separators, initiating rapid exothermic thermal runaway. Because these conventional methods leave extensive interstitial air voids (50% to 70% trapped atmospheric oxygen) amidst dry paper and cardboard, short-duration cell failures reliably escalate into sustained, catastrophic facility fires [2].

Even with rigorous segregation at the point of generation, occasional hazardous inclusions may bypass source controls and screening. The Environmental Services Association (ESA) has warned about the serious consequences of lithium-ion battery fires in the UK waste sector. The Massmelt continuous thermal extrusion system offers an additional engineered layer of risk mitigation [3, 4, 5, 6]. Segregation remains the first line of defence; batteries and pressurised containers are not intended feedstocks.

By combining progressive-load auger compaction, reduced interstitial air, in-situ polymer binding, controlled cooling and the heat-absorbing capacity of residual moisture, Massmelt is designed to inhibit the propagation of isolated ignition events into sustained waste fires. The same consolidation mechanisms can reduce conditions that contribute to secondary or delayed yard fires. By deoxygenating and thermally consolidating the waste matrix and discharging a dense extruded log into a protected steel receptacle, the process significantly reduces the risk of fire propagation from lithium-ion battery failures and inhibits the conditions associated with spontaneous combustion during downstream storage and transport.

2. Characterisation of Battery Ingress in Transit and Packaging Waste

In public-concourse, rail, airport, and food-service waste streams, battery ingress conforms to a distinct, bounded energy distribution [7]. Crucially, the duration of these thermal runaway events is extremely rapid—often lasting under one minute for a standard vape cell and up to three minutes for a high-capacity power bank [8]. In a conventional compactor, this brief, intense energy release acts as the ignition source for the surrounding aerated waste, instantly escalating a one-minute cell failure into a facility fire that can take hours or days to extinguish.

Device Category	Cell Chemistry & Form	Electrical Energy	Runaway Energy (Max)	Approx. Event Duration
Single-Use Vapes (>95%)	Li-Po / 13340 cylindrical	1.3 – 2.5 Wh	~15 – 30 kJ	< 60 seconds
Smartphones / Compact Cameras	Li-Po pouch / Li-ion	11.0 – 17.5 Wh	~120 – 190 kJ	1 – 2 minutes
	Multi-cell 18650/21700	74.0 – 99.9 Wh	~800 – 1,080 kJ	2 – 3 minutes

3. Failure Modes in Conventional Mechanical Compactors

Standard rotary compactors, crush balers, and static skip compactors inadvertently assemble all three sides of the fire triangle along with an external ignition trigger. The mechanical vulnerabilities manifest in two primary modes:

3.1 High-Shear Point Puncture (Rotary Compactors)

Rotary compactor drums employ protruding hardened steel teeth to grab, pull, and shred bags. When a tooth impinges on a battery casing, it exerts concentrated point loads exceeding several hundred megapascals (MPa). This tears the 15–25 µm microporous polymer separator, potentially provoking an instantaneous internal dead short, localised Joule heating, and violent deflagration.

3.2 Elastic Spring-Back and Loose Packing (Balers and Portable Compactors)

While standard crush balers and portable static skip compactors successfully reduce initial waste volumes, the compression is strictly mechanical and elastic. This violent crushing action—whether from the steel ram itself or the intense friction between compacted waste particles—routinely breaches battery casings, initiating a hidden ignition sequence. Upon retraction of the hydraulic ram, the waste undergoes 'spring-back'. This loose-

packed matrix leaves abundant interstitial oxygen alongside highly combustible, high-surface-area tinder (paper, napkins, lightweight film). When the compromised lithium cell ultimately vents into this oxygen-rich environment, it rapidly feeds an open flame that can develop either immediately inside the compactor or later in the storage yard. Such conflagrations risk the wider facility and can destroy the compactor itself, melting critical hydraulic lines, drive mechanisms, and electronic control ancillaries.

4. The Massmelt Mitigation Architecture

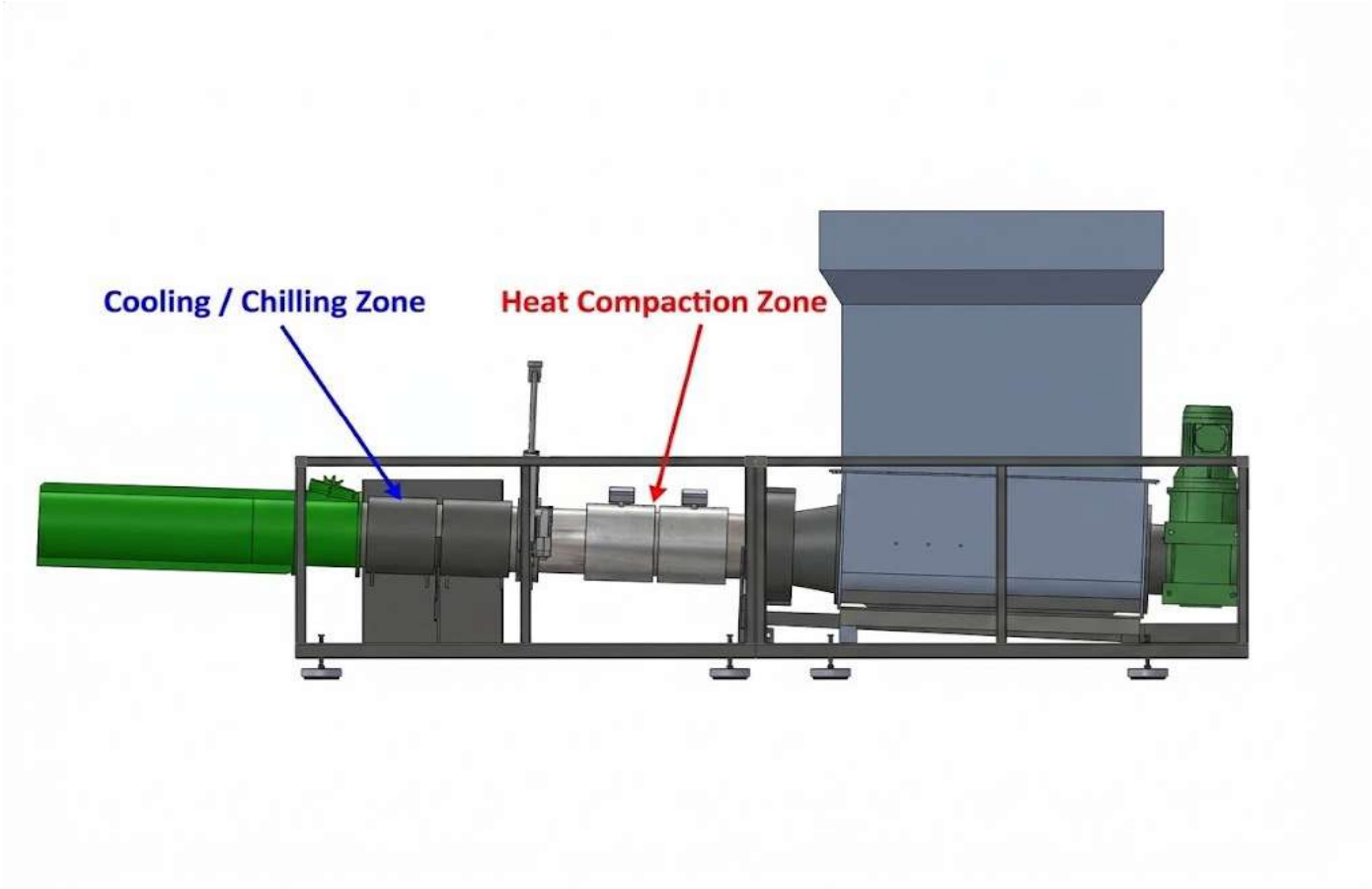

Figure 1: Skeletal Render of Massmelt System indicating Heat Compaction and Cooling Zones.

Underpinned by a progressive architectural lineage of international patents, the Massmelt system replaces destructive mechanical impact and elastic compaction with continuous, enclosed thermal densification.

4.1 Progressive Load Geometry and Cushioned Infeed

Waste entering the Massmelt feeds into a continuous auger with progressive flight geometry. Loose cardboard, food cartons, and flexible packaging form a protective cushion around the battery during entry. Forces are applied as distributed axial and hoop stresses. Cells are flattened progressively along their longitudinal axes rather than pierced across their cross-sections, preventing violent separator shredding.

Figure 2: Internal view of the Massmelt auger and progressive load geometry.

4.2 Empirical Void Elimination and Atmospheric Oxygen Starvation

As the auger drives waste through the heated barrel, the flight depth tapers, generating severe mechanical compaction alongside thermal softening. Trapped air is driven backward toward the low-pressure feed throat and safely extracted.

Empirical trials comparing fast-food station waste demonstrate the vast disparity in void elimination. Waste initially processed by a rotary compactor yielding a volume of 0.942 cubic metres was subsequently reprocessed through the Massmelt system, achieving a final extruded volume of just 0.157 cubic metres—an 83.3% absolute reduction in volume.

Figure 3: Empirical volume reduction. 0.942 m³ rotary compacted waste reduced to 0.157 m³ via thermal extrusion.

This extreme densification mathematically demonstrates the almost complete expulsion of interstitial air, validating the highly anaerobic nature of the Massmelt matrix. While a lithium-ion cell contains internal cathode oxidisers sufficient for its own internal decomposition, surrounding municipal waste cannot burn without atmospheric oxygen. Within the highly compacted, oxygen-depleted waste matrix, the conditions necessary to sustain and propagate conventional flaming combustion are substantially suppressed by the physical characteristics of the process.

4.3 Heterogeneous Matrix Binding and In-Situ Polymer Encapsulation

In open-air aerobic environments, hydrocarbon-based plastics are traditionally viewed as highly combustible fire accelerants. However, within the anaerobic confines of the Massmelt barrel, their physical behaviour fundamentally changes.

Transit and commercial waste streams are inherently heterogeneous, typically comprising paper, cardboard, organic matter, and an available thermoplastic fraction (such as LDPE, HDPE, and PP) of approximately 20% to 25%. At barrel operating temperatures (130°C–170°C), this available 20–25% plastic fraction does not combust; instead, it transitions into a highly viscous melt. Rather than forming a pure, homogeneous polymer slurry, it acts as a molten binder distributed throughout the diverse waste matrix. Under immense mechanical pressure, this molten fraction is mobilized, flowing into remaining micro-voids and encapsulating foreign bodies, including compromised battery casings.

As the material is extruded, this polymer fraction preferentially forms an approximately 4 mm plastic coating along the log's longitudinal surface. While the sheared ends of the log remain open, this smooth outer coating acts as a vital physical barrier, insulating the internal contents from external flame impingement and acting as a dielectric potting agent to prevent external electrical arcing.

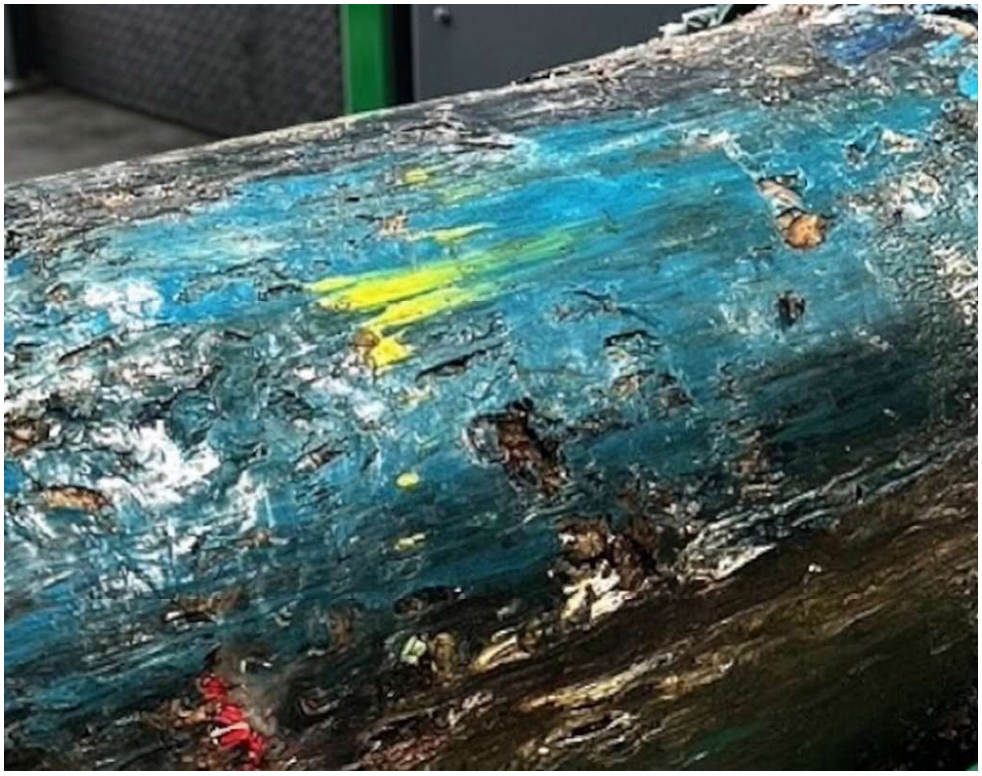

Figure 4: The 4 mm plastic coating formed during in-situ polymer encapsulation.

(See Figure 2 for source material)

4.4 Integrated Cooling and Solidification Zone

To ensure operational safety and maintain the structural integrity of the densified matrix, the extruded log immediately passes through an integrated cooling or chilling zone prior to discharge. If the log were to exit directly at the core processing temperature of nearly 200°C, it would present a severe burn hazard to operators and risk thermal expansion (spring-back) as internal gases attempt to escape.

The dedicated chilling zone rapidly cools and solidifies the molten polymer skin. This helps retain the high compaction density, limits re-expansion compared with conventional balers, and reduces surface-temperature risks before the log enters the discharge receptacle.

4.5 Moisture-Driven Endothermic Quenching

In transit waste, packaging is invariably contaminated with residual liquids, which serve as a high-capacity endothermic thermal heatsink. When a rogue cell initiates runaway, adjacent water flashes into micro-steam. Vapourising just 450 millilitres of ambient waste moisture absorbs the entire theoretical maximum 1,000 kJ energy spike of a 100 Wh power bank. The resulting micro-steam displaces any trace oxidisers and carries thermal energy smoothly out through the negative-pressure extraction system.

4.6 Active Fire Suppression via Conveyance and Anaerobic Quenching

In the event that an external ignition or a rogue battery vent establishes a fire within the aerobic infeed hopper (skip), standard fire suppression equipment is designed to activate to mitigate smoke generation. Crucially, the

Massmelt system does not rely solely on external suppression. Rather than halting and allowing the fire to persist in the hopper, the machine continues to operate, actively conveying the burning material forward.

The auger draws the ignited waste out of the aerobic hopper and forces it into the deoxygenated barrel. In this context, the entire barrel acts as an anaerobic quenching zone. Deprived of atmospheric oxygen and subjected to the severe compressive forces and endothermic dampening of the internal waste matrix, the conveyed fire is rapidly starved and extinguished, preventing structural damage to the machine.

5. Prevention of Secondary Yard Fires and Spontaneous Combustion

Beyond the immediate threat of lithium-ion point-punctures, conventional waste processing is highly susceptible to delayed yard fires and spontaneous combustion. The Massmelt system actively disrupts these failure pathways:

5.1 Reduced Flammability via Surface Area Modification

Loose, shredded, or finely divided organic materials possess an extremely high surface area-to-volume ratio, allowing for rapid heat transfer and quick oxygen access. The Massmelt extrudes waste into dense, solid logs. This dramatic reduction in surface area limits volatile release and creates a 'heat sink' effect, making it exceptionally difficult for localised external heat to propagate and sustain ignition.

5.2 Deoxygenation and Arrest of Aerobic Self-Heating

When organic matter is compressed under immense pressure, interstitial air is physically squeezed out. Oxygen is a mandatory component for aerobic microbial activity—the primary catalyst for exothermic self-heating in organic waste piles. By stripping the matrix of interstitial voids and simultaneously subjecting it to a 200°C skin thermal treatment, the microbial 'engine' responsible for spontaneous combustion is severely retarded.

While eventual oxygen ingress is inevitable over extended periods, the strict lack of interstitial voids strongly inhibits exothermic action. This structural density significantly delays microbiological activity, mitigating the risk of self-heating over a considerable storage period. In empirical observations, extruded logs have remained stable in storage without mishap for up to 12 months.

6. Regulatory Compliance and Insurance Viability (UK Context)

The National Fire Chiefs Council (NFCC) alongside compliance schemes such as Valpak report that lithium-ion battery fires now cost the UK economy well over £100 million annually. The sheer frequency of these events in waste streams—exacerbated by highly combustible environments in conventional rotary and RoRo compactors—has triggered a severe regulatory and insurance crisis. This risk profile applies universally across all major international waste handling operations. [11,12]

6.1 Operational Scrutiny and Business Interruption

Under enforcement by environmental regulators (such as the Environment Agency in the UK), a severe waste fire triggers immediate operational suspension pending EA investigation, site clearance, permit variation, and Fire Prevention Plan (FPP) re-approval [9, 10].

Because this regulatory recovery process rarely concludes within a year, specialist waste insurance brokers strongly mandate that operators carry business interruption indemnity periods of 24 to 36 months to survive the operational downtime, compounding the initial property losses and halting essential public infrastructure.

6.2 The Uninsurability Threshold

The Environmental Services Association (ESA) has highlighted the serious insurance and business-continuity implications of fires at waste-processing sites. A compactor fire can lead to property damage, higher premiums, additional risk-control requirements and interruptions to operations.

By reducing mechanical ignition hazards and limiting oxygen availability within the densified waste, Massmelt offers an engineering risk-control measure relevant to regulatory and insurance assessment. Its practical effectiveness and regulatory suitability remain dependent on appropriate source segregation, safe operation, site-specific assessment and supporting evidence.

7. Drive Train Efficiency, Insulation, and Thermal Dynamics

The mechanical and thermal efficiency of the Massmelt architecture provides significant operational advantages alongside its safety profile:

- High-Torque / Low-Energy Mechanics: The system incorporates a high-ratio reduction gearbox, generating immense operational torque while running at approximately 8% of the energy consumption of a comparably sized standard extruder machine. This low-speed, high-torque approach not only reduces overhead costs but ensures the slow, progressive deformation of batteries rather than violent, high-speed sheering.
- Thermal Insulation and Capacity: The Massmelt barrel and continuous auger represent a massive thermal capacitor. The total steel mass in the compaction zone is between 500 and 600 kg. Even under the theoretical assumption that the entire energy release of a 100 Wh cell was transferred exclusively to the steel barrel, the bulk temperature rise across the processing assembly is less than 4°C. The entire heated barrel is fully insulated to minimise external heat loss, heavily optimising thermal efficiency and ensuring the surrounding operational environment remains safe.

8. Discharge Phase: Attenuated Discharge and Hermetic Log Receiver

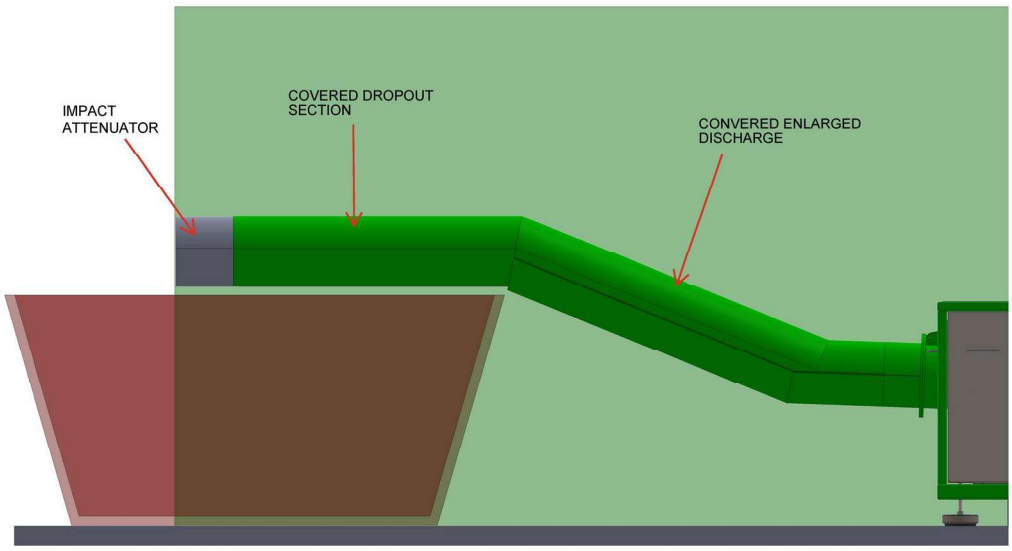

Figure 5: Discharge Chute with Covered Dropout Section and Impact Attenuator.

At the discharge end of the system, the extruded log passes through a covered, enlarged discharge chute equipped with a covered dropout section and a terminal mechanical impact attenuator. The manufactured attenuator is now a mandatory part of the revised machine specification, designed to absorb calculated discharge loads and reduce the consequences of abnormal pressure release or kinetic ejection.

Parameter	Conventional Compactors (Rotary, Ram, Portable Compactors)	Massmelt Thermal Extruder
Primary Mechanical Action	Shearing teeth / Elastic ram pressing	Continuous rolling auger
Discharge Kinetic Protection	None	Terminal Arrestor System (Massmelt 4 design)
Atmosphere Around Cell	Aerobic (50–70% air voids, spring-back)	Densified matrix with reduced interstitial air
Fire Damage Risk to Machine	High (destroying hydraulics/controls)	Reduced by steel-barrel containment; residual risks require assessment
Polymer State	Cold, dry, combustible loose film	Molten, encapsulating matrix
Water Content Role	Leachate pool (biological hazard)	Latent heat vapourisation sink
Thermal condition	Uncontrolled heating in a severe fire	Controlled external heating; internal cell reactions remain possible
Output State	Loose, aerated bags or blocks in skips	Rock-solid, impermeable log
Delayed Rekindling Risk	Critical operational hazard	Strongly inhibited by oxygen depletion and thermal consolidation.

Following the attenuation zone, the log shears or drops directly into a dedicated, heavy-duty steel collection bin. The log is mechanically isolated from ambient station air and loose packaging. The steel receptacle provides an additional physical barrier for controlled handling and onward transport to RDF or recycling facilities, subject to the installation's approved safety arrangements.

9. Conclusion

While conventional mechanical compactors, rotary crushers, and RoRo skip compactors successfully reduce initial waste volumes, they inadvertently act as accelerators for lithium-ion battery fires. By combining mechanical cell puncture with an oxygen-rich, dry-tinder environment caused by elastic spring-back, these traditional volume-reduction methods expose facilities and critical machine components to severe fire damage.

In contrast, Massmelt has demonstrated substantial further volume reduction of waste previously processed through a conventional compactor. Its enclosed thermal compaction architecture is designed to limit oxygen availability and inhibit fire propagation in compacted waste. Positioned at fixed facilities handling source-segregated commercial waste, it can also reduce the volume of loose material requiring onward transport to Materials Recovery Facilities (MRFs).

The containment architecture encountered an extreme, real-world incident in late 2025. Pressurised catering containers entered the waste stream and ruptured following prolonged heating during an abnormal operational blockage. The steel barrel remained structurally intact and no fire or operator injury was reported, although rapid pressure expansion ejected waste from the discharge chute. The incident informed the design and manufacture of the Terminal Arrestor System (Impact Attenuator), now a mandatory revision to the machine specification for all future deliveries.

The Massmelt process combines progressive feeding, high compaction density, controlled cooling and reduced oxygen availability to inhibit the spread of combustion within processed waste. Polymer-bound extruded logs may also reduce exposed surface area and limit conditions conducive to delayed self-heating. Together with the revised discharge safeguards now incorporated into the machine specification, these features provide a basis for mitigating the consequences of inadvertent hazardous inclusions, subject to feedstock segregation, operating controls and validation under representative conditions.

10. References

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