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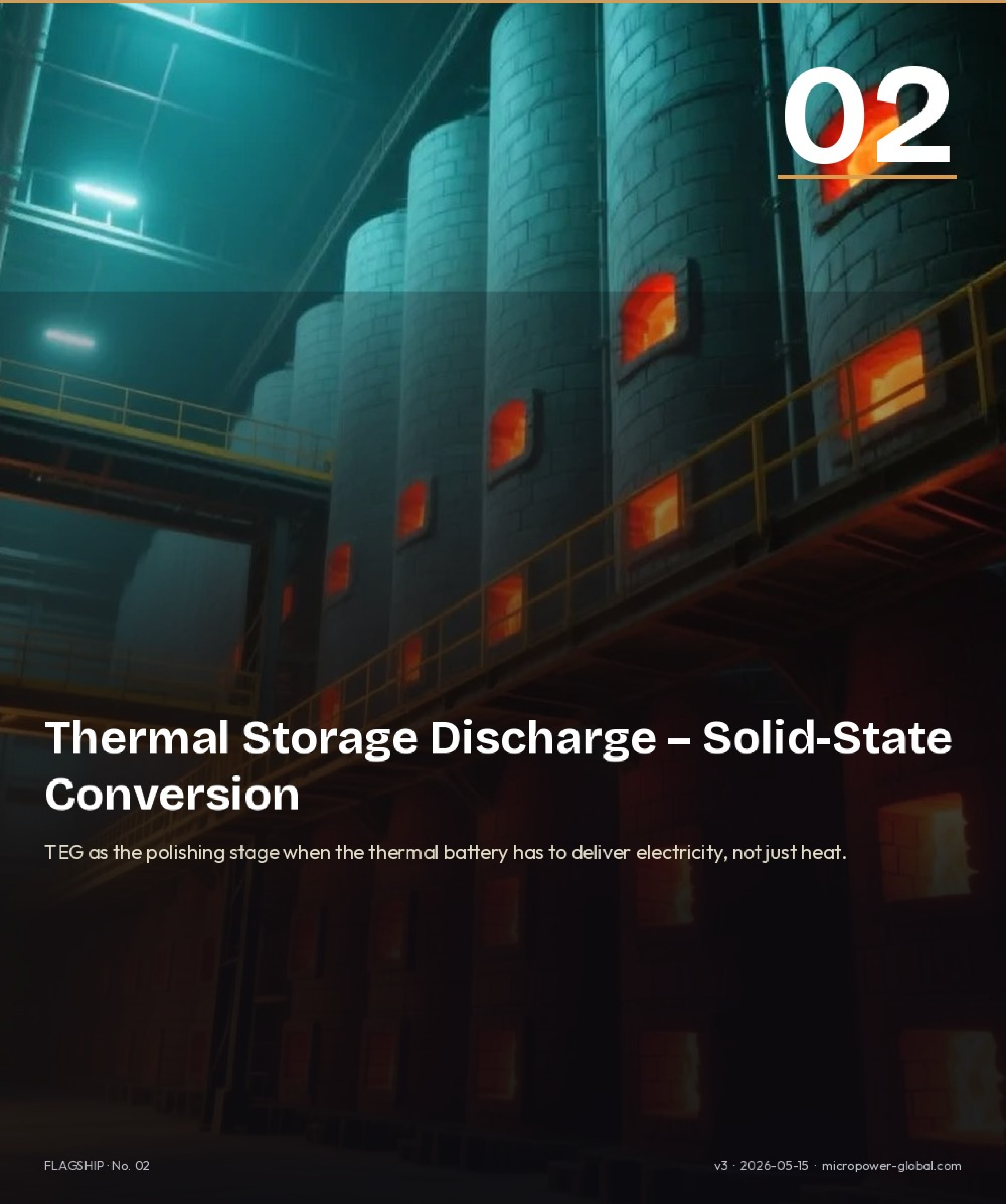

02

Thermal Storage Discharge – Solid-State Conversion

TEG as the polishing stage when the thermal battery has to deliver electricity, not just heat.

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Thermal Storage Discharge – Solid-State Conversion

TEG as the polishing stage when the thermal battery has to deliver electricity, not just heat.

The thermal battery sector has moved from demonstration to first-of-a-kind commercial builds in under five years. Rondo Energy, Antora, Electrified Thermal Solutions, Fourth Power, Kyoto Group and MGA Thermal are each shipping or commissioning units that store electrical energy as heat at 400–2,400 °C and discharge it over hours to days. The economic thesis – soak up curtailed renewable power, release steady process heat – is in operational data from the first commercial deployments. The technical question in front of every developer is the same: when the customer wants electricity back, not just process heat, what is the best conversion layer? Steam Rankine and supercritical CO_2 cycles dominate the conversation at utility scale. Both impose water, rotating machinery, and complex permitting on a thermal battery's otherwise solid, quiet, modular footprint. MicroPower's solid-state thermoelectric generators offer a complementary discharge path: no water, no moving parts, no minimum viable scale, and a discharge profile that matches the near-constant hot-face temperature these storage media deliver.

What this paper covers

- The thermal-battery market, sized by technology, developer, and commissioned capacity through 2026.
- Discharge temperature profiles: refractory brick, carbon block, molten salt, silicon, MGA alloy.
- Why TEG fits the steady high-temperature discharge regime better than low-power ORC.
- The complementary stack: primary steam / sCO_2 cycle plus TEG polishing the tail.
- A worked example – molten-salt polishing layer on a 50 MWh_{th} Kyoto-class unit.
- Go-to-market: developer co-development, then EPC design-in, then OEM partnership.
- Performance framing grounded in peer-reviewed literature, with calibrated claims only.

1 · The thermal-battery market has arrived

From demo to commercial in five years. Between 2020 and 2025 the thermal-battery category moved from lab benches to named, financed, utility-scale commercial projects. The drivers are well understood: zero-marginal-cost curtailed wind and solar, hard-to-decarbonise industrial heat (cement, glass, lime, food, chemicals), and policy tailwinds (IRA 45Y/48E tech-neutral credits, EU Innovation Fund, UK industrial decarbonisation bands). What changed is the capex curve: refractory brick, carbon block, and molten-salt designs are now quoted at $15–40 per kWh thermal – an order of magnitude below equivalent battery storage for the same duration.

The developer landscape.

Developer	Storage medium	Peak temp	Primary discharge
Rondo Energy	Refractory brick + resistive heating	~1,500 °C	Process steam, hot air
Antora Energy	Solid carbon block	~1,800 °C	Radiant heat + TPV
Electrified Thermal (E-ThOS)	Conductive refractory	~1,800 °C	Process heat, power cycle
Fourth Power	Molten tin + graphite	~2,400 °C	TPV cells
Kyoto Group (Heatcube)	Molten salt	~415 °C	Steam, hot water
MGA Thermal	Miscibility-gap alloy	~550–700 °C	Steam, Rankine cycle
Brenmiller bGen	Crushed rock	~600 °C	Steam, hot water
1414 Degrees (SiBox)	Molten silicon	~1,400 °C	Process heat

Announced commissioned capacity across this cohort exceeded 1 GWh thermal by end-2025, with visible pipeline north of 10 GWh through 2028. The US Department of Energy's Industrial Demonstrations Program has backed multiple units in this list directly. Capacities and timelines are developer-published and move with commercial reality; treat them as a snapshot of public statements at early 2026, not a fixed forecast.

2 · The discharge-side gap

Heat out is easy; power out is harder. For industrial process-heat customers – steam, hot air, direct radiant – thermal batteries are already solved: the media is hot, insulation controls losses, and a blower or heat exchanger does the rest. But a growing share of developers need to deliver electricity back – either because the anchor offtaker is a utility or IPP, or because the business case requires optionality to arbitrage power markets during peak hours.

The conversion options each carry real constraints:

- Steam Rankine (sub-critical or supercritical): efficient at >10 MWe, but requires water, condensers, a boiler train, and turbine maintenance – a heavy overlay on a solid thermal core.

- Supercritical CO_2: higher efficiency at high temperature, but turbomachinery still in first-of-a-kind phase, with very few vendors shipping in the 1–10 MWe band.
- Organic Rankine Cycle: works at lower temperatures (Kyoto, Brenmiller), but not well-suited to the 1,000 °C+ refractory and carbon systems; economics also collapse below 500 kWe.
- Thermophotovoltaics (TPV): promising at >1,800 °C (Antora, Fourth Power), but still ramping cell yields and requiring extremely hot radiating surfaces.
- Stirling engines: elegant fit, but the installed base of industrial-grade Stirlings in the 100 kWe–1 MWe range is small and OEM support thin.

Where TEG earns its seat at the table. MicroPower's PbTe / TAGS thermoelectric modules hit a specific combination of properties that thermal batteries value more than any other application:

- Steady, predictable discharge: thermal batteries hold near-constant hot-face temperature across most of their discharge curve. TEG output depends on ΔT – and ΔT here is unusually stable.
- No moving parts and no water: matches the fundamental appeal of a thermal battery – quiet, solid, low-maintenance. A steam loop or turbomachine undoes much of that value.
- Modularity: from single-kWe polishing loads up to multi-MWe arrays. No minimum viable size.
- Temperature fit: PbTe / TAGS operates cleanly in the 300–800 °C band where molten salt, MGA alloy, and first-stage refractory discharge all sit.
- Cascade-friendly: extracts work from the exhaust tail of a Rankine or sCO_2 cycle without adding a second rotating machine or working fluid.

3 · Lead architecture — HEX-integrated TEG

HEX-integrated TEG is the lead deployment architecture for thermal-battery discharge. TEG modules are embedded directly inside the discharge heat exchanger — the modules carry both the heat-transfer surface and the electrical output. Higher area-density, higher ΔT across the module, and significantly more power per square metre than wrapping a downstream duct. The thermal-battery developer's storage-medium HEX becomes the TEG host: one piece of hardware does what would otherwise be two.

Secondary architecture — PowerRing retrofit on existing discharge ducts. Where HEX-integration is not viable — typically retrofit on an already-built unit, or where the developer's HEX vendor is locked in — MicroPower's PowerRing form factor wraps the discharge duct downstream of the HEX. Lower area-density than the integrated case, but installable without redesigning the host HEX.

Where the material-fit table that follows refers to PowerRing geometry, read it as the secondary retrofit path; the lead path on any new commercial unit is the HEX-integrated module described above.

4 · Material fit by storage medium

Storage medium	Discharge temp to TEG	MicroPower module fit
Molten salt (nitrate) tail	200–250 °C	BiTe – correct low-tail material
Molten salt (nitrate) bulk	250–400 °C	PbTe / TAGS – mid-band
MGA alloy	400–600 °C	PbTe / TAGS – optimal
Crushed rock / concrete	300–550 °C	PbTe / TAGS – good
Molten silicon (SiBox)	500–800 °C secondary loop	PbTe – excellent
Refractory brick (Rondo, E-ThOS)	500–900 °C via HX	PbTe – primary target band
Carbon block (Antora)	TPV primary; TEG tail to ~250 °C	PbTe (mid-band) → BiTe (low tail)
Molten tin (Fourth Power)	TPV primary; 400–800 °C tail	PbTe – complementary tail

In all cases the lead architecture is the HEX-integrated TEG described above; PowerRing — a ring or sleeve that wraps a hot exhaust or discharge duct — is the secondary retrofit geometry. Hot oil, steam, or direct hot-air discharge loops are all amenable to PowerRing wrap without redesigning the host heat exchanger.

5 · The complementary stack, not a substitution fight

Rondo's published roadmap, Antora's public technical briefings, and Kyoto's commercial sales all point the same way: these developers are not looking for a monolithic single-conversion technology. They are looking for the right discharge mix for the customer. TEG is not competing with steam Rankine, sCO_2, or TPV – it extends them.

An illustrative stack on a 1,400 °C refractory battery.
Primary discharge: sCO_2 cycle extracts bulk electrical output from 1,400 → 400 °C.
Secondary discharge: process-steam heat exchanger covers 400 → 250 °C process customers.
Polishing layer: PowerRing TEG array extracts residual electrical output from 250 → 120 °C tail.
Net effect: every joule of stored heat ends either as shaft power, process heat, or TEG electrical output – no rejected-heat tail.

For developers selling to industrial anchors with hard decarbonisation targets, eliminating the rejected-heat tail is as valuable as the primary cycle efficiency number. Lifecycle tonnes of CO_2 displaced per MWh of electrical input goes up across the whole stack.

6 · A worked example – molten-salt polishing on a 50 MWh_{th} unit

This section models a PowerRing polishing layer on a Kyoto Heatcube-class molten-salt thermal battery in the 50 MWh_{th} size band. Molten salt is chosen as the worked-example medium because its discharge temperature band (250–400 °C) sits squarely in MicroPower's TAGS sweet spot and because Kyoto has the most commercial units in the field today. All figures are modelled from literature-range values and published developer data; they are not a Kyoto-specific quote.

Parameter	Assumption / source	Value
Reference unit	Kyoto Heatcube Rx class, published	~50 MWh_{th}
Hot-face discharge temperature	Molten-salt nitrate, operator-published	~400 °C
Primary discharge pathway	Steam loop to customer	~85% thermal efficiency
Tail heat available to TEG	After steam extraction, modelled	~10% of stored heat
TEG operating band	BiTe on the 250 → 120 °C tail (PbTe handles the 400 → 250 °C bulk via the steam HX)	~5–7% system-level
Gross TEG electrical output per cycle	Tail × TEG efficiency	~0.25–0.35 MWhe
Cycles per year	Daily discharge, 330-day availability	~330
Annual TEG generation	Modelled	~80–115 MWhe/yr
Annual revenue at €100/MWh	Modelled avoided-cost proxy	~€8–12k / yr / unit
Retrofit capex (TEG only)	Literature first-of-kind TEG band, modular	~€35–65k / unit
Simple payback	Modelled	~3–7 years
Effect on lifecycle CO_2/MWh	TEG output is extra GHG-free	Reduces anchor-site MWh carbon intensity

The business-case logic, not the absolute MWh. €8–12k/yr per unit is modest in isolation. The reason a developer should care is two-fold: first, the payback is inside the developer's typical 5–8-year warranty window, so this is a low-risk add-on line item; second, on a fleet rollout of 50–100 units (which is where Kyoto, Rondo, and Brenmiller are headed), the fleet-level incremental revenue is €0.5–1.2 M/yr at near-zero variable cost. For developers competing on cost-of-energy versus batteries or direct electrification, that margin pick-up compounds.

What is load-bearing in the example, and what is not.
Load-bearing: molten-salt discharge temperature window, BiTe operating band on the 250→120 °C tail, MicroPower module performance at low-tail conditions.
Assumed: 10% tail-heat fraction, 5–7% system-level TEG efficiency (literature band), 330 cycles/yr, €100/MWh avoided-cost price, modular capex inside the first-of-kind TEG band.
Out of scope: specific developer hardware configuration, proprietary heat-exchanger geometry, site-specific off-take contract – resolved in structured dialogue with the developer.

7 · Performance basis

The performance numbers in this paper trace to two anchors. Material- and module-level: MicroPower's PbTe / TAGS production-spec chip platform. The chip's high-temperature contact and thermal-interface structures were informed by an early MicroPower collaboration with the U.S. Army Research Laboratory and have been substantially evolved internally since. The 14% module conversion efficiency at 550 °C is extrapolated from the U.S. Army Research Laboratory's evaluation of MicroPower's standard modules. NREL subsequently confirmed independently that production modules met datasheet specification. Geometric: a PowerRing form factor that has been simulated and prototyped for 300–1,000 °C exhaust ducts in turbine and engine applications. The system-level efficiency framing draws on the peer-reviewed TEG literature (Champier 2017, Rowe's CRC Handbook of Thermoelectrics, Applied Energy reviews), which places PbTe-class system-level electrical efficiency in the 5–8% range at 500–800 °C hot-side / 50–80 °C cold-side. On a thermal-battery discharge tail that would otherwise be rejected, 5–8% is almost all incremental revenue, not a bulk conversion figure – and that is the correct way to size it in the business case.

8 · Go-to-market

Channel priorities.

- Direct developer co-development – the named thermal-battery developers in the developer landscape table. Each has a small engineering organisation and a short path from pilot to spec.
- EPC design-in – major utility-scale EPC firms working balance-of-plant on thermal-battery projects.
- OEM integration – gas-turbine and steam-cycle OEMs assembling bundled thermal-battery + power-cycle packages.
- Industrial offtaker pilots – cement, glass, and chemicals anchors that have already bought a thermal battery.

Timing. The 2026–2027 window is the right inflection point. Leading developers are moving from first-of-a-kind to second-of-a-kind commercial units, where engineering is re-opened and the balance-of-plant specification is being standardised. This is the moment to win design-in – retrofit later is slower and more expensive.

MicroPower engages selectively with thermal-battery developers, EPCs, and utility offtakers interested in first-deployment TEG integration on the discharge side of a commercial unit. Introductions and structured enquiries are welcome via the MicroPower Global contact page.

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Worked-example outputs are modelled from literature ranges and developer-published data, not firm quotations. Thermal-battery discharge is a new MicroPower application; no installed reference at any named developer at time of publication. For site-specific modelling, contact MicroPower via www.micropower-global.com/contact.