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Thermoelectric Recovery on H_2 DRI + EAF Mills

TEG as the complement to ORC across the H_2 DRI buildout – five specific heat pockets, modelled mill-level economics.

v3 · 2026-05-15 · micropower-global.com

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TEG as the complement to ORC across the H_2 DRI buildout – five specific heat pockets, modelled mill-level economics.

The global steel industry is in the early innings of its biggest process-route change since the Bessemer converter. Blast-furnace / basic-oxygen-furnace (BF-BOF) capacity is being displaced by hydrogen direct reduction of iron (H_2-DRI) feeding electric arc furnaces (EAFs). HYBRIT, Stegra (formerly H2 Green Steel), Midrex HYFOR, Energiron ZR, ArcelorMittal's Hamburg trial, and Thyssenkrupp's Duisburg Direct Reduction plant are each moving from pilot to commercial scale between 2025 and 2030. The transition opens exhaust and top-gas streams that look fundamentally different from a BF-BOF mill. The incumbent heat-to-power technology at 300–500 °C is Organic Rankine Cycle (ORC). For utility-scale duty on DRI top gas or EAF waste-heat boilers it is very likely the right primary answer. H_2-DRI sites also present multiple mid-temperature heat pockets where ORC either does not scale down economically, is constrained by water or permitting, or leaves a residual tail after primary recovery. That is where solid-state thermoelectric modules – MicroPower's PbTe / TAGS PowerRing – become complementary.

What this paper covers

- The H_2-DRI capacity buildout – who, where, and when, through 2030.
- Thermal streams on a typical H_2-DRI + EAF mill: temperatures, mass flows, recovery options.
- ORC as the incumbent at utility scale.
- The five specific heat pockets where TEG is the right answer, complementary to ORC.
- Mill-level economics: what 1.5–3% incremental recovery is worth per tonne of green steel.
- Go-to-market: OEMs (Midrex, Tenova, Primetals), EPCs, and mill owner-operators.

1 · The H_2-DRI transition

Why the process route is changing. A BF-BOF mill emits roughly 1.8–2.2 tonnes of CO_2 per tonne of crude steel. The Paris-aligned IEA Net Zero scenario requires that figure to fall below 0.4 t CO_2/t by the 2040s. No efficiency tweak to the blast furnace closes that gap – the coke-based chemistry is the emissions source. H_2-DRI + EAF, once the hydrogen is clean, approaches 0.1 t CO_2/t.

Policy is accelerating this: EU CBAM now applies embedded-emissions tariffs at the border; the US IRA 45V provides up to $3/kg for clean hydrogen; and major steel buyers (automotive, appliances, construction) are signing green-steel offtake contracts at premium pricing.

The commercial fleet.

Project	Location	Technology	Target start
Stegra (H2 Green Steel)	Boden, Sweden	Midrex H_2-DRI + EAF	2026
HYBRIT (SSAB / LKAB / Vattenfall)	Gällivare, Sweden	Proprietary H_2-DRI + EAF	2028
ArcelorMittal Hamburg	Hamburg, Germany	Midrex H_2-DRI pilot	2027–29
ArcelorMittal Sestao	Sestao, Spain	Green-H_2 DRI + EAF retrofit	2028
Thyssenkrupp Duisburg	Duisburg, Germany	Tenova Energiron ZR H_2-DRI	2027
Salzgitter SALCOS	Salzgitter, Germany	Midrex H_2-DRI + EAF	2026 onwards
Voestalpine Linz	Linz, Austria	Midrex / Primetals H_2-DRI	2027–30
POSCO HyREX	Pohang, South Korea	Fluidised-bed H_2 reduction	2030

Announced H_2-DRI capacity in Europe alone passes 25 Mt/yr by 2030 – each a greenfield or major-retrofit opportunity for integrated heat-recovery design. Dates are target start-up dates published by the operators; actual first-commercial-heat dates regularly slip 12–24 months across this class of project, so treat the 2025–2030 ramp as the realistic design-in window, not a fixed calendar.

2 · The thermal streams on an H_2-DRI + EAF mill

Stream	Typical temp	Typical mass flow	Primary recovery route
DRI shaft top gas (after scrubbing)	~300–450 °C	Large, continuous	Feed preheat / ORC
DRI reformer flue gas (where used)	~350–500 °C	Large	Feed preheat / steam / ORC
EAF off-gas (post-dedusting)	~200–400 °C	Cyclic, per-heat	ORC / scrap preheat
EAF off-gas (primary, before quench)	1,200–1,600 °C	Very high peak, cyclic	Quench tower + scrap preheat
Reheating furnace flue gas	~800–1,100 °C (tail 300–500 °C)	Continuous at rolling	Recuperator + ORC tail
Ladle / tundish heaters	~200–400 °C surface	Local, per-heat	Typically unrecovered today
Compressor / blower intercoolers	~80–200 °C	Continuous	Typically unrecovered today

Compared with a BF-BOF mill, the H_2-DRI route produces far less very-high-temperature gas (no coke oven, no blast furnace), but it produces a larger, steadier mid-temperature flow from the shaft reformer and top-gas streams. That mid-band is where heat-to-power economics get interesting.

3 · ORC as the incumbent – where it wins

Modern 1–5 MWe ORC packages from Turboden, Exergy, Ormat, and ENOGIA are mature, bankable, and deliver 10–15% net electrical recovery from a 400 °C gas stream at the right flow rate. For a 2 Mt/yr DRI module the ORC case is strong and the vendor ecosystem well established.

Where ORC is the right primary answer on an H_2-DRI mill.
• DRI top-gas after scrubbing – large, continuous, 300–450 °C, utility-scale duty.
• Reformer flue gas on steam-methane-hybrid routes – large and steady.
• Reheating furnace flue tail – where existing recuperators leave a 300–500 °C tail.

For those streams, the right engineering conversation is ORC sizing and integration. MicroPower's role on those primary streams is not to displace ORC.

4 · The five heat pockets where TEG is complementary

TEG earns its place on an H_2-DRI + EAF mill in five specific pockets that ORC either cannot reach economically or that sit downstream of an ORC cycle as a residual tail.

4.1 The ORC exhaust tail (250 → 120 °C). After an ORC extracts work down to its condenser temperature, the remaining stream typically still carries useful thermal energy. A PowerRing TEG array on the ORC exhaust captures that tail with no rotating machinery and no water addition – incremental kWe at zero parasitic cost.

4.2 EAF off-gas intermediate band (350 → 250 °C). EAF off-gas is cyclic (one heat ~50–75 minutes; peaks for 15–25 minutes, then trails). The cyclic duty punishes ORC economics at mill scale because the turbine has to ramp. TEGs have no moving parts and ramp instantaneously with ΔT. For the 350–250 °C window between the initial quench and the dedusting line, TEGs capture a share that would otherwise be lost to cycle mismatches.

4.3 Decentralised streams under 1 MW thermal. A modern mill has dozens of smaller thermal sources: ladle heaters, tundish dryers, hot-metal transfer routes, compressor intercoolers, auxiliary burners. Below ~1 MW thermal, ORC is uneconomic. These streams are currently unrecovered on most mills. TEG modules, modular and maintenance-free, close that long tail.

4.4 Water-constrained sites. Green-steel projects in water-stressed regions (Spain, Morocco, Mexico, Western Australia) face scrutiny over ORC condenser cooling. TEGs need no process water. For those sites, TEG displaces rather than supplements the ORC in the project balance.

4.5 Early-deployment pilot streams. Pilot H_2-DRI modules at 0.2–0.5 Mt/yr (ArcelorMittal Hamburg, POSCO HyREX) are below the scale at which a full ORC is capex-justified. TEG is the right match: a mill can instrument the pilot streams now, gather operating data, and design ORC in for the commercial scale-up.

5 · A worked example – 2 Mt/yr green-steel mill

This section shows what the incremental economics look like when TEG is stacked on top of a primary ORC recovery cycle at a 2 Mt/yr H_2-DRI + EAF mill. All figures are modelled from literature-range values and published mill-level statistics; they are not a site-specific quote.

Parameter	Assumption / source	Value
Reference mill	Stegra / SALCOS / Sestao class	2 Mt/yr green steel
Mill electricity demand	Published H_2-DRI + EAF intensity (IEA 2023)	3–4 TWh/yr
DRI top-gas thermal duty	~1.5 GW thermal at full capacity, modelled	~1.5 GW_{th}
Primary ORC electrical recovery	Vendor-published 10–15% net, 400 °C band	~8–12% heat-to-power
Primary ORC output share	Modelled share of mill electricity	~5–8% of demand
TEG polishing on ORC tail	PbTe / TAGS at 250 → 120 °C, literature band	~3–5% system-level
TEG on decentralised sub-MW streams	Modular PowerRing across ladle / intercooler / small auxiliary	~0.5–1% of mill electricity
TEG on cyclic EAF intermediate band	Per-heat capture across ~3,500 heats/yr	~0.5–1% of mill electricity
Incremental TEG contribution	Sum of the three pockets above	~1.5–3% of mill electricity
Incremental GWh/yr	1.5–3% × 3–4 TWh/yr	~45–120 GWh/yr
Gross revenue at €80/MWh	Modelled avoided-cost proxy	~€3.6–9.6 M/yr
Retrofit capex (incremental TEG only)	Literature first-of-kind TEG retrofit band	~€8–22 M
Simple payback (incremental)	Gross revenue ÷ capex	~2–6 years
Green-steel lifecycle premium	€80–120/t premium on offtake	~€160–240 M/yr potential on mill output

The incremental 1.5–3% of mill electricity is small at the corporate P&L level, but it is structurally significant for two reasons: first, every one of those incremental MWh is produced at near-zero variable cost once installed, so gross margin is high; second, and more important, the lifecycle CO_2/t figure goes down across the whole mill output, which is what green-steel offtake contracts are actually priced against. For a mill competing for a €100/t premium on 2 Mt/yr, a 1–2% CO_2/t reduction is worth far more than the raw MWh revenue suggests.

What is load-bearing in the example, and what is not.
Load-bearing: mill electricity demand (IEA 2023), ORC primary 8–12% figure (vendor published), PowerRing module performance window.
Assumed: 1.5–3% incremental TEG contribution (literature-band stack), €80/MWh avoided-cost price, €80–120/t green-steel premium range.
Out of scope: site-specific mill configuration, exact ORC package selection, local electricity and carbon pricing, offtake contract structure – resolved in structured dialogue with the mill engineering team.

6 · BF-BOF retrofit — the installed-base case

The global blast-furnace / basic-oxygen-furnace fleet remains the dominant steel-production architecture by tonnage and will be a brownfield retrofit case for the next two decades. MPG's chip envelope (300–1000 °C design, 440–550 °C lab- and field-proven) matches several BF-BOF heat streams.

BF-BOF heat stream	Temperature band	MPG fit
Hot stove flue gas	200–350 °C	BiTe on low tail; PbTe/TAGS on the hotter end
Slag granulation cooling (surface)	~150–500 °C	PbTe/TAGS across the mid-band; BiTe at the cold edge
BOF off-gas cooler exhaust (after primary cooling)	~300–600 °C	PbTe/TAGS — primary target band
Coke-oven flue gas / waste-heat boiler tail	~200–300 °C	BiTe on the tail; PbTe/TAGS where the WHB inlet is still hot

Engagement model. OEMs (Primetals, SMS, Danieli) for new-build BF-BOF balance-of-plant; EPCs (Tenova, Outotec) for retrofit packages; owner-operators with active brownfield programmes — including ArcelorMittal Dofasco, where MicroPower has a Phase 1 outline already on file (CS-D).

BF-BOF retrofit is a slower commercial path than H_2-DRI design-in — the installed base is engineered, the operator has owned the asset for decades, and the change-control bar is high. But it is the larger pool by tonnage and is where the bulk of TEG-relevant waste heat sits today, not in 2030. A measured retrofit programme on a single mill establishes the per-stream economics and the engagement model for fleet rollout.

7 · Go-to-market

Channel priorities.

- DRI technology OEMs – Midrex, Tenova (Energiron), Primetals Technologies. Each is designing the shaft furnace and top-gas cleaning package; TEG as an optional balance-of-plant line wins on design-in, not retrofit.
- EAF and melting OEMs – Tenova Melt Shops, Primetals EAF, Danieli. Their off-gas quench and dedusting packages own the EAF thermal stream.
- EPCs – Tecnimont, Tata Consulting Engineers, SMS group, Worley – the integrators for utility-scale mill balance-of-plant.
- Mill owner-operators – Stegra, ArcelorMittal, Thyssenkrupp, Salzgitter, Voestalpine, Tata Steel Europe, POSCO. Direct conversations viable where their engineering teams run their own sustainability innovation tracks.
- Strategic partners – Turboden, Exergy, Ormat. A joint ORC + TEG package offered to the OEMs and EPCs reads cleaner than either alone.

Timing. 2026–2028 is the design-in window for the European H_2-DRI wave. Stegra is already commissioning; HYBRIT commercial scale, Thyssenkrupp Duisburg, SALCOS, Sestao and Hamburg are all in FEED or early construction. Later entrants will retrofit, which is slower and more expensive.

MicroPower engages selectively with DRI OEMs, EPCs, ORC partners, and mill owner-operators interested in first-deployment TEG integration on H_2-DRI sites. Introductions and structured enquiries are welcome via the MicroPower Global contact page.

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