Decarbonising an Already-Green Plant

Acciaieria Arvedi, Cremona — Physical Scope 1 Baseline, 2030 Abatement Package, and Pathway to 2050

1. Executive Summary

Acciaieria Arvedi's Cremona works is among the lowest-carbon steel plants in the world, and in July 2022 it became the first steelmaker to hold a third-party-verified net-zero certification. This study asks the question; **what would it take to make it physically true?** To answer it, the analysis discards Arvedi's reported figure which accounting instruments have already reduced to approximately zero and rebuilds the baseline from the plant's EU ETS verified emissions record.

Verified Scope 1 baseline	**434,844 tCO_2** (CY2023, EU ETS)
2030 abatement package	**192,494 tCO_2/yr — 44.3% of baseline**
Capital cost	€58.0M total; €28.0M near-term
Cost per tonne of steel	**€11.44 — 1.8% of product value**
Sector 2030 range	–37% (MPP) to –50% (E3G/PNNL)
Carbon liability trajectory	€6.9M/yr (2026) → €32.6M/yr (2034)

The certified net-zero rests on one physical achievement and three accounting decisions. Arvedi genuinely drove direct intensity to 138 kg CO_2/t against roughly 2,100 kg/t for the integrated route. The remainder of the claim is constructed: Scope 2 is zeroed on a market-based basis, the residual is offset with voluntary forestry credits, and Scope 3 is excluded. The ETS record adds a fact that the absolute emissions have risen roughly fifteen-fold since 2005 and now sit within 1% of the plant's all-time peak.

A physically-real 2030 pathway exists, and it is affordable. Deploying every commercially available lever abates 44.3% of the verified baseline at €11.44 per tonne of steel which is under two percent of product value, and comfortably within reach of the green premium Arvedi already earns on its low-carbon line. The package clears the Mission Possible Partnership trajectory and falls short of the more demanding E3G/PNNL pathway.

But 59% of that pathway rests on a single measure. Biocarbon substitution alone delivers 113,494 tCO_2 which is 68% of the baseline process carbon and cannot be electrified away. It requires roughly 36,400 tonnes a year of certified biochar against a European market measured in tens of kilotonnes. Remove it and the package falls to 18% of baseline, where no combination of remaining measures approaches the sector range.

The commercial case strengthens as the regulation tightens. Cremona is already short of allowances (82,536 tonnes in 2023) so abatement is avoiding cost. As free allocation phases out, the plant's carbon liability rises to roughly €19M a year by 2030, which exceeds the entire near-term capital cost of the package. Against a blast-furnace competitor the same phase-out opens a cost advantage approaching €140 per tonne of steel by 2034.

Recommendation. Treat certified biochar procurement as a strategic programme beginning now; it is the gating constraint on three-fifths of the pathway, and staged substitution backed by long-term offtake is the only realistic route to the volumes required. In parallel, resolve whether the ESP lines are gas-fired or induction-heated. This determines whether the largest measure in the package exists at all. Defer tunnel-furnace conversion until power prices and grid capacity justify it, and replace market-based Scope 2 with physically additional supply before tightening standards render the current claim unsupportable. Looking beyond 2030, the constraints that bind are feedstock quality and firm clean power. Carbon is the tractable problem.

Independent case study. Figures are engineering estimates derived from public sources, not company disclosures; the Scope 1 baseline is the sole third-party-verified input. Assumptions and their bases are registered in Appendix C.

2. Plant and Process Profile

Acciaieria Arvedi. (2021). Acciaieria Arvedi, with its plant in Cremona, is one of the most important users of scrap in Italy. #economiacircolare #circulareconomy | Acciaieria Arvedi S.p.A.

2.1 Corporate and site context

Acciaieria Arvedi S.p.A. is the steelmaking core of the Arvedi Group, a privately held Italian producer headquartered in Cremona, Lombardy. Following the February 2022 acquisition of Acciai Speciali Terni (AST), Italy's principal stainless producer, the group employs over 6,000 people and operates at volumes of approximately 6 Mt across its production units. [src C]

This study is bounded to the **carbon-steel flat-product operation at Cremona**. The stainless (AST, Arinox, ILTA Inox) and welded-tube (Arvedi Tubi Acciaio, Metalfer) businesses are outside the analysis.

The EU ETS treats Cremona as a discrete installation, separate from Trieste. [EUTL] All Scope 1 figures in this study are therefore the Cremona installation only. The Cremona site holds EMAS registration IT-002004, first registered 27 May 2020 and valid to 10 October 2028. [EMAS] The underlying environmental declaration would provide plant-level process inputs (carbon-input rate, fuel inventory, flux and electrode consumption); it was not obtainable for this study, and its absence is the principal reason the Section 3 decomposition rests on allocated literature shares rather than measured plant data.

This study is bounded to the carbon-steel flat-product operation at Cremona

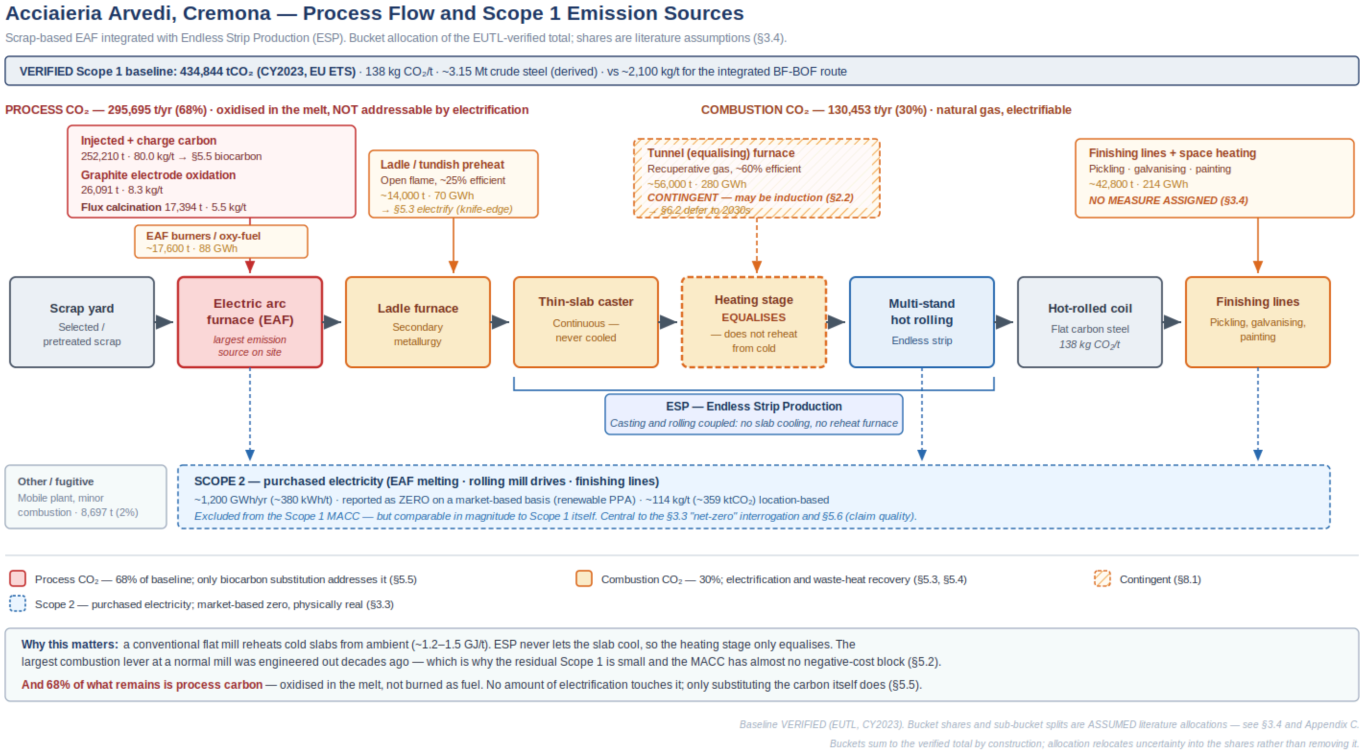
2.2 The production route

Cremona operates the scrap–EAF route: selected and pretreated steel scrap is melted in electric-arc furnaces, refined in secondary metallurgy, and cast. The distinguishing feature is the casting–rolling step. Arvedi's proprietary **ESP (Endless Strip Production) line couples thin-slab casting directly to hot rolling in a single continuous process**: liquid steel enters one end and hot-rolled coil exits the other, with the slab never allowed to cool. [src A]

In a conventional flat route, cast slabs cool, are stored, and are then reheated from ambient in a reheating furnace before rolling — a step consuming on the order of 1.2–1.5 GJ of fuel per tonne. Because ESP never lets the slab cool, the heating stage between caster and mill only **equalises** temperature rather than **reheating** from cold, cutting that thermal load by roughly three-quarters.

One further characteristic of endless processing bears on the 2050 feedstock argument. Because the strand spends roughly one minute in the heating stage rather than the prolonged residence of a conventional tunnel furnace, the route tolerates close to double the copper content in the charge. [src T] Copper tolerance is the binding scrap-quality constraint examined in Section 6.1, so the process design confers a feedstock advantage as well as an energy one.

Arvedi is efficient by fundamental process design rather than by retrofit. The single largest combustion-abatement lever available at a conventional flat mill (decarbonising the reheating furnace) is largely absent here, because the emissions it would target were engineered out of the process decades ago. The residual Scope 1 footprint is correspondingly small, and what remains of it is technically hard and capital-intensive to remove.



2.3 Energy and emissions profile

The plant's headline carbon intensity is **138 kg CO_2 per tonne of steel**, which Arvedi contrasts with approximately **2,100 kg/t** for the European integrated (blast-furnace) flat route. [src A]

Two definitional points govern the baseline in Section 3:

- The 138 kg/t is presented as Scope 1 + Scope 2, but Scope 2 is accounted **market-based** and driven to zero by certified renewable supply from Enel. [src A][src D] The figure is therefore, in effect, the plant's **physical Scope 1** intensity.
- Arvedi states that this Scope 1 **"coincides with the ETS calculation."** [src A] That makes the EU ETS verified figure the authoritative source, and is why the baseline in Section 3 is anchored to the EUTL rather than to the company's headline number.

Energy and emissions profile — Cremona installation

Metric	Value	Provenance
Verified Scope 1 (absolute)	**434,844 tCO_2** (CY2023)	[EUTL]
Free allocation (CY2023)	352,308 allowances	[EUTL]
Net short position	**≈ 82,536 t** — Arvedi is an allowance buyer	DERIVED
Physical Scope 1 intensity	138 kg/t	[src A]
Crude / flat steel output	~3.15 Mt/yr (CY2023)	DERIVED
Natural gas consumption	~650 GWh/yr (~0.75 GJ/t)	DERIVED
Electricity consumption	~1,200 GWh/yr (~380 kWh/t)	ASSUMED
Scope 2 (market-based)	~0	[src A][src D]
Scope 2 (location-based)	~114 kg/t (~359 $ktCO_2$)	DERIVED
Scope 3	Excluded from the net-zero claim	[src A]

Location-based Scope 2 (~114 kg/t) is of the same order as physical Scope 1 (138 kg/t). Roughly 45% of the plant's true emissions footprint is set to zero by the electricity contract rather than by the process. Market-based accounting is permitted under the GHG Protocol but it is precisely the exposure that tightening standards address. [src L]

The verified total exceeds free allocation by roughly 82,500 t. For context, the CBAM benchmark for scrap-based EAF production is 0.072 tCO_2e/t where more than half the crude steel mass derives from scrap [src G] — approximately half Arvedi's 0.138 t/t. Even a world-leading scrap-EAF producer sits above the benchmark set for its own route.

The company identifies its Scope 1 reduction work as concentrated on two measures: **higher-quality selected and pretreated scrap**, and **substitution of the anthracite injected into the electric furnace.** [src B] Injected carbon is therefore among the largest single Scope 1 sources — corroborating both the process-carbon decomposition in Section 3.3 and the biocarbon measure in Section 5.5.

3. The Baseline – Interrogating “Net-Zero”

Arvedi's physical achievement is real and world-leading: 138 kg CO_2/t against approximately 2,100 kg/t for the integrated route [src A] is decades of genuine process engineering. This section does not allege greenwashing but abatement strategy can only be built on the what the company has already achieved and can be improved upon.

3.1 What Arvedi reports

On 1 July 2022, Acciaieria Arvedi obtained from RINA (an accredited third-party certifier) validation of its calculation model under the GHG Protocol, making it, the first steelmaker in the world certified **net-zero CO_2 emissions**, reaching the milestone 28 years ahead of the EU's 2050 target. [src A][src B]

- The direct intensity (Scope 1) was driven to 138 kg/t through process levers: the scrap–EAF–ESP route itself, a metallic charge concentrated on high-quality selected and pretreated scrap, and substitution of the anthracite injected into the electric furnace. [src A][src B].
- Indirect electricity emissions are zeroed using the **market-based** method: certified renewable supply from Enel. [src A][src D]
- The rest of the CO_2 "not yet avoided" is compensated with voluntary **VCS forestry credits**. [src A]
- Upstream raw materials, ferroalloys, transport and logistics (Scope 3) sit explicitly outside the net-zero calculation. [src A]

So the reported result is: *one real physical reduction, plus a market-based Scope 2 convention, plus retired forestry offsets, plus a Scope 3 exclusion.* Three of the four load-bearing elements are accounting choices.

The EU ETS record for the Cremona installation shows verified Scope 1 rising from 29,647 tCO_2 in 2005 to 434,844 tCO_2 in 2023 — an approximately fifteen-fold increase, and within 1% of the installation's all-time peak (437,890 t in 2021). [EUTL] Arvedi's decarbonisation is an intensity achievement layered over absolute emissions that have grown with output and now sit near record highs.

3.2 The baseline

A marginal abatement cost curve ranks measures by cost per tonne of CO_2 removed, measured against a baseline. After market-based Scope 2 and retired offsets, the reported figure is approximately zero. There are no tonnes to abate; every measure's cost-per-tonne divides by zero. But the reported zero is an accounting construct laid over a plant that still emits roughly 138 kg of CO_2 for every tonne of steel it produces. A decarbonisation strategy cannot be built against a number that a renewable electricity contract and a portfolio of forestry credits have already set to zero. This analysis therefore rejects the reported baseline and adopts the physical one.

The emissions are **third-party verified** under the EU ETS rather than self-reported. It is **boundary-explicit** for the Cremona installation only, excluding Trieste (Section 2.1). An intensity of 138 kg/t is presented by Arvedi as Scope 1 + Scope 2, but Scope 2 is accounted market-based and is zero [src A] [src D], so the 138 kg/t is the physical Scope 1 intensity.

The production determines what *intensity* the verified total implies, which is a test of the 138 kg/t claim.

CY2023 production (Cremona)	**Implied intensity**	**Reading**
2.50 Mt	173.9 kg/t	+26% — claim would not hold
3.00 Mt	144.9 kg/t	+5% — close
3.15 Mt ← adopted	138.0 kg/t	matches Arvedi's stated figure
3.50 Mt	124.2 kg/t	–10% — claim conservative
~4.0–4.25 Mt (nameplate)	102–109 kg/t	–21 to –26% — claim conservative

3.3 Decomposition of the verified baseline

Some known sources from engineering assumptions include carbon input, electrode consumption, and three natural-gas units which reached approximately 81 kg/t against a real 138 kg/t. The residual was 42% of the baseline. The emission sources of a working steelworks cannot be fully enumerated from outside the fence, and the named buckets are themselves uncertain.

By using the anchor top-down method, the analysis allocates that fixed number across buckets rather than accumulating toward it.

Scope 1 decomposition — allocation of the verified total

Bucket	Share	tCO_2/yr	kg/t
Process carbon (charge + injected C)	58%	252,210	80.0
Natural gas combustion (all units)	30%	130,453	41.4
Graphite electrode oxidation	6%	26,091	8.3
Flux calcination (limestone/dolomite)	4%	17,394	5.5
Other (mobile, fugitive, minor combustion)	2%	8,697	2.8
Total	100%	434,844	138.0

At 58% of the baseline, the carbon injected and charged into the furnace to foam slag and carburise the melt is the dominant source. It is oxidised in the melt, not burned as fuel, so no amount of electrification reduces it. Only substituting the carbon itself addresses this bucket. Arvedi's own stated abatement focus on replacing injected anthracite [src B] corroborates the allocation.

At 30% of the verified total, the gas bucket is 130,453 tCO_2, equivalent to approximately 652 GWh/yr at 0.20 tCO_2/MWh:

Gas sub-bucket	GWh/yr	tCO_2/yr
Tunnel furnace (equalising)	~280	~56,000
Finishing lines (pickling, galvanising, painting) + space heating	~214	~42,800
EAF burners / oxy-fuel	~88	~17,600
Ladle + tundish preheating	~70	~14,000
Total	~652	~130,453

Cremona is not a melt-and-roll site alone; it operates downstream pickling, galvanising and painting lines. Therefore, most of the former 42% gap was unenumerated natural gas together with flux calcination.

3.4 Offsets

The frequently quoted "48% by 2030" is the IPCC **economy-wide** absolute-contraction reference, not a steel-sector pathway [src U]. Steel-specific 2030 benchmarks bracket it as approximately **–37% (Mission Possible Partnership)** to **–50% (E3G/PNNL 1.5 °C structural pathway)** [src U].

The 2030 measures in Section 5 abate approximately **192,500 tCO_2 — around 44% of the verified baseline.** That clears the MPP pathway and falls short of the more demanding E3G/PNNL structural target. On the arithmetic alone, the technology is not the binding obstacle: a physically-real 2030 pathway broadly consistent with sector expectations does exist for this plant.

Approximately 59% of the entire package's abatement comes from a single measure: biocarbon substitution. That measure requires on the order of 36,000 tonnes per year of certified biochar, against a European market currently measured in tens of kilotonnes. Arvedi alone would be bidding for a material share of total European supply, in a market whose sustainability certification under RED III is itself a condition of the carbon claim (Section 5.5).

So the conclusion is: A physically-real 2030 pathway exists, but it rests on one measure and one immature supply chain. Its real job is to **shrink the residual the offsets must cover, and to reduce the concentration risk that currently sits in a single measure.** The offsets bridge execution risk and residual emissions, not a technological impossibility. The surrounding accounting (market-based Scope 2 at zero, Scope 3 excluded, absolute emissions at record highs) flatters an already-strong physical position into a claim that **will not survive tightening standards** such as SBTi V2.0 [src L].

4. Regulatory and Commercial Context — the Moat

4.1 The mechanism

CBAM entered its definitive phase on 1 January 2026, with the first declaration and certificate surrender due 30 September 2027 for 2026 imports. [src E] CBAM is coupled by design to the phase-out of free ETS allowances in the sectors it covers: as free allocation to EU producers falls, the levy on imports rises in step, so domestic and imported steel face an equivalent carbon cost at the margin. [src E][src F]

The phase-out follows a fixed, non-linear schedule — the **CBAM factor**, the share of embedded emissions exposed to the carbon price each year:

Year	2026	2027	2028	2029	2030	2031	2032	2033	2034
CBAM factor (%)	2.5	5	10	22.5	48.5	61	73.5	86	100

Free allocation falls from 97.5% intact in 2026 to zero in 2034. [src E][src F] The critical planning feature is the **cliff between 2029 and 2030**, where the factor more than doubles from 22.5% to 48.5%. [src F]

4.2 The moat

Effective carbon-cost exposure per tonne of steel is, to first order, ***emission intensity × ETS price × CBAM factor*.** Comparing Arvedi's 0.138 tCO_2/t against a representative integrated (BF-BOF) route at 2.0 tCO_2/t:

Effective carbon cost	2026 (2.5%)	2029 (22.5%)	2030 (48.5%)	2034 (100%)
Arvedi — 0.138 t/t	€0.26/t	€2.33/t	€5.02/t	€10.35/t
BF-BOF — 2.0 t/t	€3.75/t	€33.75/t	€72.75/t	€150.00/t
Arvedi cost advantage	€3.49/t	€31.42/t	€67.73/t	**€139.65/t**

By 2034 a blast-furnace competitor carries roughly €150 of carbon cost per tonne of steel — about 23% of a ~€650/t product price — while Arvedi carries approximately €10/t, around 1.6%. The estimate is conservative, since ETS prices are widely projected to rise toward 2034 [src F], which only widens the gap.

It is often assumed that a low-intensity EAF producer sits below its benchmark and earns surplus allowances. The EU ETS record shows the opposite for Cremona. In CY2023, verified emissions of 434,844 t exceeded free allocation of 352,308 t by approximately **82,536 allowances**, and the installation has been short in every year since roughly 2015. [EUTL]

Free allocation is set by product benchmark applied to historical activity levels, then adjusted by the linear reduction factor and correction factors. Arvedi's output has grown beyond the historical baseline underlying its allocation, and the cap declines annually — together these produce a persistent short position. Applying the phase-out to Arvedi's actual verified position:

Year	CBAM factor	Free allocation	Shortfall	Cost @ €75	Per tonne steel
2026	*2.5%*	*343,500*	*91,344 t*	*€6.9M*	*€2.17/t*
2029	*22.5%*	*273,039*	*161,805 t*	*€12.1M*	*€3.85/t*
2030	*48.5%*	*181,439*	*253,405 t*	*€19.0M*	*€6.03/t*
2034	*100%*	*0*	*434,844 t*	*€32.6M*	*€10.35/t*

Arvedi's carbon cost rises from roughly €6.9M/yr today to €32.6M/yr at full phase-out. For context, the €19.0M annual liability arriving in 2030 exceeds the entire near-term capital cost of the 2030 abatement package (Section 7).

One forward-looking marker is that the CBAM benchmark for scrap-based EAF production is **0.072 tCO_2e/t** where more than half the crude steel mass derives from scrap [src G] — roughly **half** Arvedi's 0.138 t/t. Even a world-leading scrap-EAF producer sits above the regulatory reference set for its own route.

4.3 Some points to consider

- From 2026, continued receipt of free allocation is conditional. An installation that fails to implement the recommendations of its mandatory energy audits — specifically those measures with a payback period of three years or less faces a **20% reduction** in free allowances, on top of the standard phase-out. [src G] Applied to Arvedi's CY2023 allocation, a 20% penalty is roughly 70,000 allowances, or about **€5.3M per year at €75/tCO_2**, an avoidable loss of the same order as the plant's entire current carbon liability.
- The moat protects Arvedi inside the EU and against imports. It does not protect exports. EU steel sold outside the EU carries full domestic carbon costs with no equivalent border adjustment in the destination market. [src F] The Commission has proposed a temporary decarbonisation fund to partly compensate EU exporters in 2026–2027 [src F], but it is transitional and partial. Export exposure is carried to the risk register in Section 8.
- The "ferrous scrap sliding scale" debate holds that crediting scrap-based producers with very low intensities can obscure a structural fact: global scrap supply is finite and already fully utilised, so one producer's clean scrap is unavailable to another, and scrap-based low-carbon claims do not scale to the sector as a whole.

5. The 2030 Package

5.1 Method

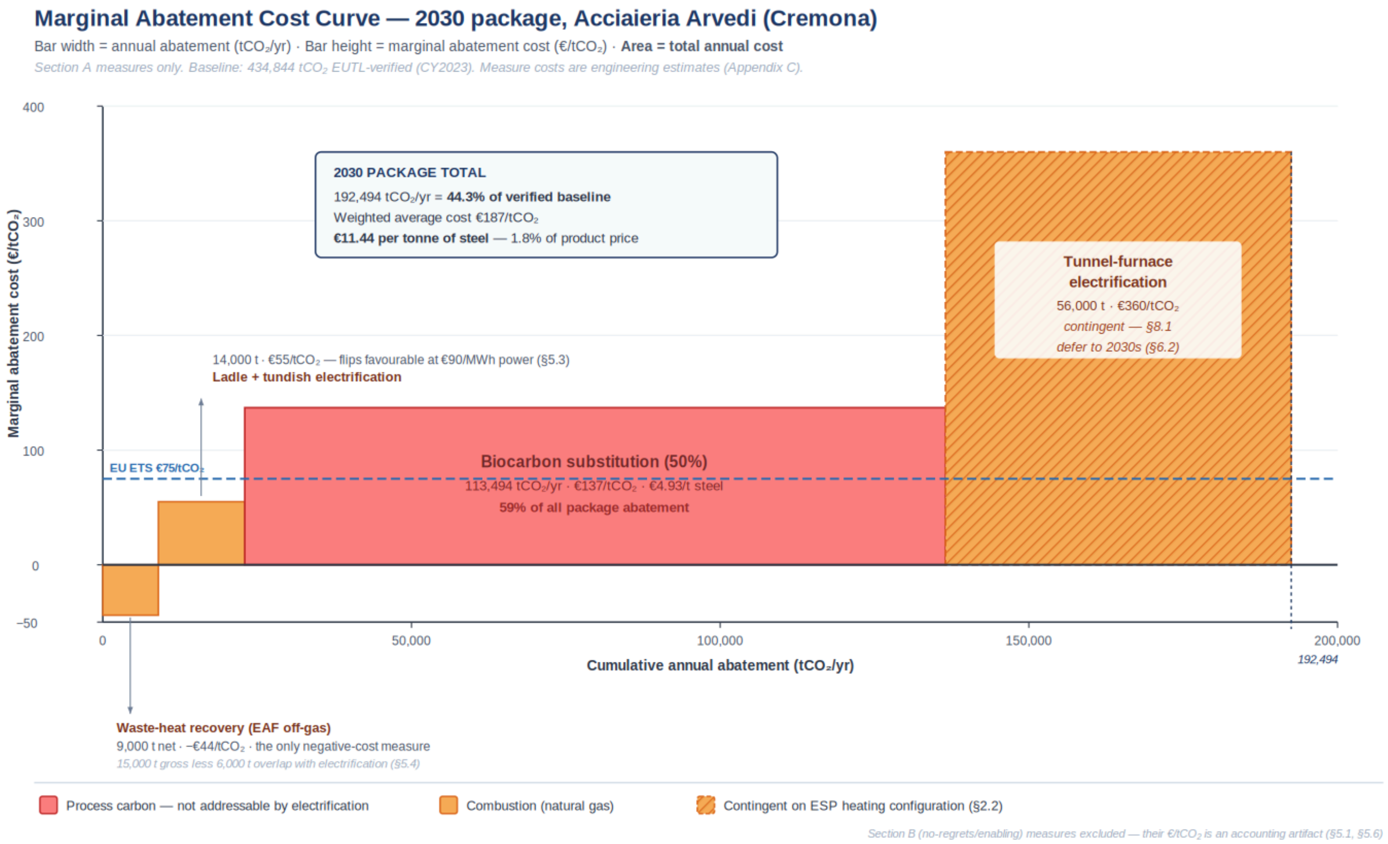
The curve is built against the verified physical Scope 1 baseline of **434,844 tCO_2** (Section 3.2). Capital cost is converted to an annual charge by capital recovery factor at 8% WACC, amortised over each measure's own economic life (instrumentation and mechanical plant are not amortised on the same schedule). Net annual cost is annualised capex plus the change in annual operating cost. Marginal abatement cost is net annual cost divided by annual tonnes abated. A parallel column expresses the same net annual cost per **tonne of steel**, which is the metric relevant to a commercial decision.

A MACC's vertical axis is cost per tonne of CO_2. Measures whose business case is driven by **non-carbon** economics like energy cost, scrap procurement etc divide a large non-carbon saving by a small carbon denominator and produce figures with no analytical meaning. An instrumentation upgrade can read as –€600/tCO_2, a yield project as –€1,000/tCO_2, purely because the CO_2 they happen to touch is small. A single such bar renders every genuine abatement measure invisible on the same chart. The measures are therefore split:

- **Section A** — measures that physically reduce Scope 1. These form the curve (5.2).
- **Section B** — no-regrets and enabling measures whose case is non-carbon. Excluded from the curve, retained in the strategy, with the reason recorded per measure (5.6).

5.2 The curve — Section A

Measure	Net abatement (tCO_2/yr)	Capex	€/tCO_2	€/t steel
Waste-heat recovery (EAF off-gas)	9,000	€18.0M	**−44**	−0.13
Electrify ladle + tundish preheat	14,000	€6.0M	**55**	0.25
Biocarbon substitution (50% fossil C)	113,494	€4.0M	**137**	4.93
Tunnel-furnace electrification	56,000	€30.0M	**360**	6.39
Total 2030 package	**192,494**	**€58.0M**	**187** (wtd)	**11.44**



Exactly one Section A measure (waste-heat recovery) is negative, marginally, and its business case leans on district-heat revenue rather than raw payback (5.4). Every other measure that physically reduces Scope 1 costs money, rising to a €360/tCO_2 tail.

The package abates **192,494 tCO_2/yr, or 44.3% of the verified baseline.** It does so at **€11.44 per tonne of steel — approximately 1.8% of a ~€650/t product price.** The second figure is the hinge of the financing argument in Section 7.

5.3 The electrification rule

Electrifying heat is opex-favourable only when:

(power price ÷ gas price) < (electric efficiency ÷ incumbent gas efficiency)

The left side is the price penalty for switching fuel; the right side is the efficiency dividend for switching technology. Electrification wins on operating cost only when the dividend exceeds the penalty.

- **Ladle and tundish preheat.** Open-flame gas preheating delivers perhaps 25% of its heat into the refractory; electric induction reaches around 80%. That is a **3.20× efficiency dividend**, against a price ratio of 3.43× at €120/MWh power and €35/MWh gas. The measure narrowly misses, at €55/tCO_2 therefore cost-neutral.
- **Tunnel furnace.** A recuperative furnace already operates near 60% efficiency; electric through-heating reaches perhaps 75%. Only a **1.25× dividend** against the same 3.43× price ratio. There is no efficiency headroom to harvest, and the measure lands at €360/tCO_2.

Sensitivity — power price. Holding gas at €35/MWh:

Power price	**Price ratio**	**Ladle €/tCO_2 *(dividend 3.20×)***	**Tunnel €/tCO_2 *(dividend 1.25×)***
€90/MWh	2.57×	~€9/t — **favourable**	€240/t — unfavourable
€120/MWh	3.43×	€55/t — marginally unfavourable	€360/t — unfavourable
€150/MWh	4.29×	€102/t — unfavourable	€480/t — unfavourable

At €90/MWh, the ladle measure's operating cost turns to a net saving and the measure becomes near cost-free. Because Arvedi purchases power under a renewable PPA, the PPA strike price determines whether this is a 2030 project or a deferral.

In the case of the tunnel furnace, no power price in a realistic range rescues it; the price ratio would have to fall below 1.25×, implying power at roughly €44/MWh against €35/MWh gas. The correct conclusion is deferral (Section 6.2), with what eventually closes the gap being a rising carbon price on the residual gas rather than a falling power price.

5.4 Interaction effects

Three of the four Section A measures address the same natural-gas bucket (130,453 tCO_2, Section 3.3), and summing them naively double-counts.

Measure	Gross gas abatement (tCO_2/yr)
Waste-heat recovery	15,000
Electrify ladle + tundish	14,000
Tunnel-furnace electrification	56,000
Naive sum	**85,000 — 65% of the entire gas bucket**

Waste-heat recovery *displaces* gas, while the electrification measures *remove* the gas load entirely. Recovered heat can only displace gas that still exists. If ladle and tundish preheating are electrified, that gas demand is gone, and heat earmarked to displace it has nothing left to displace.

Of waste-heat recovery's 15,000 t gross, approximately 6,000 t targets preheating loads that electrification also removes. Net contribution is therefore **9,000 t**, which is the figure carried in Section 5.2. Ladle and tunnel electrification do not overlap each other, addressing physically separate loads, and carry their full abatement.

Deploying waste-heat recovery first and electrifying later strands part of the recovery asset, since the gas it was built to displace is subsequently removed. Electrifying first allows the recovery system to be sized correctly against the residual load from the outset. The staging recommendation in Section 6.2 follows from this: electrify the low-efficiency loads first, then size heat recovery against the gas demand that remains.

5.5 Biocarbon Substitution

Biocarbon is the largest single measure in the package: **113,494 tCO_2/yr, approximately 59% of total package abatement.** It addresses process carbon, the injected and charge carbon that foams slag and carburises the melt, which at 252,210 tCO_2 is 58% of the verified baseline (Section 3.3). Arvedi has itself identified substitution of injected anthracite as a principal Scope 1 lever. [src B]

At €137/tCO_2 the measure appears expensive against the ETS price. Measured against product rather than carbon, the picture changes: **€4.93 per tonne of steel, or approximately 0.76% of a ~€650/t product price.** For under one percent of product value, biocarbon delivers nearly three-fifths of the package's physical abatement.

The funding mechanism already exists. Arvedi sells low-carbon steel under the Arvzero line at a premium [src A]; a premium of €10–20 per tonne of steel on the low-carbon volume covers this measure several times over.

Three constraints bound the claim:

- **Supply:** 50% substitution requires approximately **36,400 tonnes per year of certified biochar** against a European market measured in tens of kilotonnes. Arvedi alone would be bidding for a material share of total European supply. The realistic response is staged substitution (20% by 2028, 50% by 2032) backed by long-term offtake or vertical integration.
- **Metallurgy:** Biochar has a higher volatile content and different reactivity which can alter slag-foaming and melt behaviour. The achievable rate of substitution is an outcome of plant trials rather than an input to them.
- **Accounting:** Biogenic CO_2 is zero-rated under the EU ETS, conditional on the feedstock meeting RED III sustainability criteria. Uncertified feedstock voids the carbon claim. Demonstrating that conditionality is the function of ISO 14064-2 project-level quantification, which is what makes the measure bankable.

5.6 Section B

Per the two-bucket rule, three measures are held off the curve. They remain in the strategy.

Measure	Reason for exclusion	Retained value
EAF and oxy-fuel optimisation	Saving is almost entirely electricity; with market-based Scope 2 at zero, the genuine Scope 1 slice is small and the €/tCO_2 is an artifact	Self-funding, payback in months, material energy-cost resilience
Closed-loop scrap / yield improvement	Saving is scrap procurement, not carbon	Strategic hedge against the scrap-quality ceiling — the dominant long-run risk (Section 6.1)
On-site PV (~30 MWp)	Abates zero physical Scope 1; under market-based accounting abates approximately zero Scope 2	Converts an unbundled-certificate zero into a physically additional, hourly-matched zero — the difference between a Scope 2 claim that survives tightening standards and one that does not [src L]

These measures have real value that lies outside the carbon axis. Forcing them onto the MACC would generate bars between –€600 and –€1,000/tCO_2 and render the genuine abatement measures unreadable.

5.7 The result

The 2030 package abates 192,494 tCO_2/yr (44.3% of the verified Scope 1 baseline) at €58.0M capital cost and €11.44 per tonne of steel. Steel-specific 2030 pathways run from approximately –37% (Mission Possible Partnership) to –50% (E3G/PNNL 1.5 °C structural pathway) [src U]. The package clears the former and falls short of the latter, positioning mid-range. *(The frequently quoted 48% figure is the IPCC economy-wide reference, not a steel-sector pathway, and is not used here.)*

The pathway is arithmetically reachable, but 59% of it rests on a single measure dependent on a supply chain that does not yet exist at the required scale. Remove biocarbon and the package falls to 79,000 tCO_2 (18% of baseline) at which point no combination of remaining commercial measures approaches the sector range.

If Cremona's ESP lines already use induction rather than gas-fired heating (Section 2.2), the tunnel-furnace measure is void. The package then abates 136,494 tCO_2 (31.4% of baseline) at €28.0M capex and approximately €5.05 per tonne of steel. Cheaper and more concentrated, but well below the sector range. Resolving that configuration question is the highest-value verification item in the study.

The conclusion is that a physically-real pathway to roughly 44% exists, at a cost well within the plant's commercial reach. What does not yet exist is the certified biochar supply chain to deliver the measure that carries it.

6. The 2050 Pathway

The two constraints that genuinely bind Arvedi's mid-century position are **feedstock quality** (6.1) and **firm clean power** (6.3).

6.1 The scrap-quality ceiling

Unlike carbon, silicon or phosphorus, copper and tin cannot be removed by oxidation during steelmaking, being less reactive than iron, and therefore accumulate in the melt. Copper in particular causes hot shortness (surface cracking during hot rolling) which is disqualifying for the surface-critical flat products Arvedi sells.

Low-residual prime scrap derives largely from new-production offcuts such as automotive stamping returns. Obsolete and shredded scrap carries copper from motors, wiring and electronics. The global industry is now decarbonising precisely by shifting *toward* the scrap–EAF route, so demand for clean scrap is rising faster than the end-of-life stock that supplies it.

Because the endless route holds the strand in the heating stage for roughly one minute rather than the prolonged residence of a conventional tunnel furnace, it tolerates close to **double the copper content** in the charge compared with conventional processing. [src T] This means that, as the scrap pool degrades, Arvedi can use feedstock that competitors cannot.

To maintain product quality against a structurally degrading scrap pool, dilution with direct-reduced iron (DRI) or hot-briquetted iron (HBI) which are essentially residual-free becomes the remaining lever. Conventional DRI is gas-based and carbon-intensive; the clean variant is hydrogen-based. A plant that avoided ironmaking entirely, and whose low Scope 1 is a direct consequence of that avoidance, may by 2050 need to re-enter the primary-route transition to protect product quality reintroducing an ironmaking emissions question it does not have today.

The EU 1.5 °C pathway anticipates approximately 64% EAF-from-scrap, 15% hydrogen-based DRI, and a limited CCUS role by 2050 [src U]. That hydrogen-DRI share is the diluent the scrap route requires to continue making high-grade product as the scrap pool degrades. Arvedi's 2050 feedstock will plausibly include a share of it. This is why closed-loop scrap belongs in the strategy despite being excluded from the MACC. Securing clean, known-chemistry prime scrap through closed loops with industrial customers locks in low-residual feedstock that the open market will increasingly ration.

6.2 Staging

Each phase of the pathway is gated on an external enabler maturing — biochar supply, PPA pricing, grid capacity, hydrogen cost. Committing capital ahead of the enabler is not recommended.

2026–2030 - The priority follows directly from Section 5.7: the package is 59% dependent on one measure, so the first task is **de-risking the biocarbon supply chain**, through staged substitution (20% by 2028, 50% by 2032) backed by long-term offtake or vertical integration. In parallel: electrify ladle and tundish preheating if the PPA strike price supports it (5.3); deploy waste-heat recovery sized against the *residual* gas load rather than the original (5.4); build on-site PV for claim quality (5.6); and begin closed-loop scrap procurement as the feedstock hedge (6.1).

2030–2040 - Convert the ESP heating stage only when power price and grid capacity permit; at €360/tCO_2 today (5.3) it is deferred rather than presented as a near-term measure. The fuel-free induction configuration is **commercially proven and available from Arvedi's own technology partner.**[src T] Address the finishing-line gas load (~214 GWh, Section 3.3), pilot CCU and slag carbonation on residual process carbon and contract firm CO_2-free power ahead of any electrification commitment.

2040–2050 - Blend green HBI/DRI for residual control (6.1); apply CCU to the irreducible process carbon that biocarbon substitution cannot displace; eliminate offsets entirely as physical Scope 1 approaches genuine near-zero.

The sequence runs from high-TRL and supply-constrained, through electrification as enablers arrive, to green iron and carbon capture last. What eventually makes the expensive tail viable is that the **rising carbon price on residual gas** as free allocation disappears toward 2034 (Section 4.2). The regulation will eventually pay for the hard measures.

6.3 The binding constraint: firm clean power

Every electrification and hydrogen step above depends on firm, additional, CO_2-free electricity at scale.

Zero-emission EU steel is estimated to require on the order of 400 TWh of CO_2-free electricity, roughly a sevenfold increase over current sector consumption [src U]. Electric arc furnaces stresses transmission networks and causes voltage flicker, making grid capacity a feasibility question. Converting the ESP heating stage alone would add roughly 220 GWh/yr on top of Cremona's approximately 1,200 GWh site consumption (Section 2.3) which would amount to an 18% load increase before any hydrogen electrolysis is contemplated.

For Arvedi's 2050, the methods for electrifying process heat and operating hydrogen-based DRI also requires additional zero-carbon electricity to run them without relocating the emissions to the grid. This is why the PV and PPA work is important. Capital should not be committed to electrification until the power to feed it is contracted.

7. Financing and Incentives

7.1 The incentive position in 2026

The **Transizione 5.0 tax credit closed on 31 December 2025.** For investments in 2026–2028 the successor instrument is the **iperammortamento** (enhanced super-depreciation) under Budget Law 2026, which is materially less generous: a tiered super-deduction of 180% up to €2.5M, 100% between €2.5M and €10M, and 50% between €10M and €20M, with **no relief above €20M**. The 40% "green" premium that made the predecessor attractive for energy-efficiency investment was removed in the final text. [src Q]

At the 24% IRES rate, effective relief by measure:

Measure	Capex	Effective deduction	Tax relief	As % of capex
Biocarbon (handling plant)	€4.0M	150%	€1.44M	36.0%
Ladle + tundish electrification	€6.0M	133%	€1.92M	32.0%
Waste-heat recovery	€18.0M	89%	€3.84M	21.3%
On-site PV	€21.0M	81%	€4.08M	19.4%
Tunnel-furnace conversion	€30.0M	57%	€4.08M	13.6%

The €20M ceiling means the largest measures receive the least proportional support. Biocarbon's €4.0M of handling plant attracts the highest proportional relief in the table, but its actual burden is the €15.1M annual feedstock premium (Section 5.5), which has no capital incentive.

Other instruments apply at the margins: **TEE / Certificati Bianchi** reward measured energy savings and suit the waste-heat recovery and electrification measures; **Conto Termico** is limited in industrial applicability; the **EU Innovation Fund** and IPCEI are the appropriate routes for the large 2030s measures (tunnel-furnace conversion, CCU and hydrogen pilots) because national capital relief runs out above €20M. *(Current parameters for TEE and Conto Termico were not verified for this study.)*

The full package carries €58.0M of capital cost and a net annual cost of approximately €36.0M, or €11.44 per tonne of steel (around 1.8% of a ~€650/t product price) (Section 5.2). Most of the capital is deferred: excluding the tunnel-furnace conversion, which Section 5.3 defers to the 2030s, the near-term 2026–2030 capital requirement is approximately €28.0M.

Against this, Arvedi already sells the output. The Arvzero line is marketed as low-carbon steel at a premium [src A]. A premium of €12–15 per tonne on low-carbon volume covers the entire package cost; €20/t would fund it with margin to spare.

Biocarbon is the one measure that has a large operating cost and must be funded incentives because it has a larger operating cost rather than capex.

7.2 The internal carbon line

Because Cremona is already short of allowances (82,536 t in CY2023) every tonne abated is a tonne of allowance the company does not have to purchase.

Applying the package's 192,494 t of abatement against the actual shortfall trajectory (Section 4.2), at €75/tCO_2:

Year	CBAM factor	Shortfall without abatement	Tonnes offset by package	Avoided cost	vs package annual cost
2026	2.5%	91,344 t	91,344 t	€6.9M/yr	19%
2030	48.5%	253,405 t	192,494 t	€14.4M/yr	**40%**
2034	100%	434,844 t	192,494 t	€14.4M/yr	**40%**

First, **in 2026 the package would eliminate the shortfall entirely** because abatement capacity exceeds the current deficit, so the measures would take the plant from short to balanced. Second, from 2030 the avoided cost stabilises at approximately €14.4M/yr, offsetting roughly **40% of the package's annual cost**, and rises further with any increase in the ETS price above €75/tCO_2.

The value inflects on the 2029–2030 cliff, when free allocation falls sharply. The measures that appear uneconomic on a pure abatement-cost basis biocarbon at €137/tCO_2, electrification at €55 and €360 move toward viability precisely as the carbon price they avoid becomes material.

8. Risks, Sensitivities and Limitations

8.1 The two risks that could invalidate the analysis

1. ESP heating configuration
2. Biocarbon concentration

Both of these risks are discussed in detail in section 5.7

8.2 Sensitivities

Power price (gas held at €35/MWh): (Power-price sensitivity is tabulated in Section 5.3)

The ladle measure's verdict is set by Arvedi's PPA strike price. The tunnel furnace is unfavourable at any realistic power price.

Discount rate (6% / 8% / 12% WACC):

Measure	6%	8%	12%	Behaviour
Waste-heat recovery	–€72/t	–€44/t	+€16/t	**Flips sign** — capex-heavy, low-opex
Ladle electrification	~€49/t	€55/t	~€67/t	Moderate
Biocarbon	~€136/t	€137/t	~€138/t	Negligible — opex-dominated
Tunnel furnace	~€353/t	€360/t	~€376/t	Low — opex-dominated

Two results. WACC matters only for capex-heavy, low-opex measures: waste-heat recovery moves by roughly €90/t across the range and **turns positive-cost at 12%**, at which point the package contains no negative-cost measure at all — which strengthens rather than weakens the exhausted-curve finding.

Production volume. The verified baseline (434,844 t) is fixed and independent of the production assumption. Only intensity, and the €/t-steel costs in Sections 5 and 7 carry that uncertainty. At 2.5 Mt the package cost would be approximately €14.42/t of steel rather than €11.44/t; the abatement percentage against the verified baseline would fall as the measures scale with output.

8.3 Risk register

Risk	Impact	Response
ESP configuration assumption	Voids the largest measure; package falls to 31.4%	Verify against plant documentation or AIA permit — **highest priority**
Biocarbon supply concentration	59% of abatement on an immature supply chain	Staged substitution (20% 2028 → 50% 2032); long-term offtake or vertical integration
Bucket share assumptions	58/30/6/4/2 split is literature-derived, not plant data	EMAS declaration or AIA permit would replace with measured values
Scrap residuals (Cu, Sn)	Long-run product-quality constraint	Partially buffered by endless-route copper tolerance [src T]; closed-loop scrap; DRI dilution
Grid capacity (Cremona)	Gates all electrification and hydrogen steps	Early TSO engagement
Export exposure	No CBAM protection outside the EU	Monitor the temporary exporter compensation mechanism
Claim durability under SBTi V2.0	Market-based Scope 2 and offsets may cease to qualify	Physically additional PPAs; retire offsets as abatement lands
Incentive regime change	Transizione 5.0 closed; successor is weaker and capped	Programme is premium-funded, not subsidy-dependent — de-risked by design
Unaddressed finishing-line gas	~214 GWh with no measure assigned	Add to a later iteration

8.4 Stated limitations

1. No vendor quotations, plant cost data or Arvedi-specific operating figures were obtained. All measure-level capex, operating deltas and lifetimes are engineering estimates.

2. Allocating the verified total across buckets eliminated a visible 42% bottom-up residual, but **moved the uncertainty into the five assumed shares rather than removing it.** The EMAS environmental declaration and the AIA/IPPC permit, neither obtained, would replace assumption with measurement.
3. The ~3.15 Mt figure is inferred from Arvedi's stated intensity and is consistent with, not independent evidence for, the 138 kg/t claim. The company's sustainability report was requested and not received.
4. The MACC model fails to account how abatement costs evolve with energy prices, carbon prices and technology maturity. The 2030 curve is not the 2040 curve; Section 6 handles the dynamics separately.
5. Carbon price is excluded from NPV**,** deliberately, so that underlying abatement economics remain visible. It is quantified separately in Section 7.2.
6. Measures are treated as independent except for the explicitly netted waste-heat-recovery and electrification overlap (Section 5.4). Second-order interactions, for example biocarbon's effect on off-gas heat available for recovery are not modelled.
7. The copper-tolerance and induction-heating figures central to Sections 2.2 and 6.1 derive from a manufacturer publication [src T] and are manufacturer-reported.

9. Appendices

Appendix A — Provenance grading

Every quantitative input in this study carries one of four grades. The grade appears with the figure in the main text and in the assumption register (Appendix C).

Grade	Definition	Examples in this study
VERIFIED	Third-party verified primary source	EU ETS verified emissions [EUTL]; EMAS registration status
SOURCED	Company statement or documented public source, not independently verified	138 kg CO_2/t intensity [src A]; regulatory schedules [src F] [src G]
DERIVED	Computed from a VERIFIED or SOURCED figure; formula stated	Production tonnage; natural-gas energy; location-based Scope 2
ASSUMED	Literature benchmark or engineering estimate; no Arvedi-specific source obtained	All measure capex and operating deltas; bucket shares; energy prices

One figure in this study is VERIFIED (the Scope 1 baseline and its allocation record), a small number are SOURCED, and majority of measure-level economics are ASSUMED. The analysis is built on a verified foundation with a modelled superstructure, and should be read accordingly.

Appendix B — Source register

The full reference list is maintained separately in "Appendix — References" (Parts 1 and 2), which contains complete citations, URLs, access dates and source-specific notes. Summary index below.

Tag	Short form	Domain	Principal use
[src A]	Arvedi, *Arvzero*, 2026	Company	Intensity claim; Scope 1 ≡ ETS; market-based Scope 2; VCS offsets; Scope 3 exclusion
[src B]	Regione Lombardia, 2022	Company	Scope 1 levers (scrap quality, anthracite substitution); Trieste reconversion
[src C]	Innovation Hero, 2022	Company	Group structure; AST acquisition; Trieste pig-iron reference
[src D]	Symbola, 2022	Certification	RINA net-zero attestation, 1 July 2022; Enel renewable supply
[src E]	EC DG TAXUD, 2026	Regulation	CBAM definitive phase; surrender dates; certificate pricing
[src F]	CBAM Guide / iFactory / ICAP, 2026	Regulation	Free-allocation phase-out schedule; BF-BOF cost trajectory; ETS price; exporter fund
[src G]	Reg. (EU) 2023/956; Dir. 2003/87/EC; Impl. Reg. 2025/2621	Regulation	CBAM legal basis; scrap-EAF benchmark 0.072 tCO_2e/t; **20%** audit conditionality
[src H]	GSCC, 2024; SteelWatch, 2024	Sector debate	Scrap sliding-scale critique and counter-position

[src I]	McKinsey, 2009; Kesicki & Ekins, 2012	Methodology	MACC construction and its documented limitations
[src J]	Impl. Reg. 2018/2066 arts. 38–39; RED III	Accounting	Biogenic CO_2 zero-rating, conditional on sustainability criteria
[src K]	ISO 14064-2:2019	Methodology	Project-level GHG quantification
[src L]	SBTi, 2026	Standards	Corporate Net-Zero Standard V2.0; Scope 2 matching; credit ineligibility
[src M]	MPP/ETC, 2022; Climate Bonds, 2024	Benchmark	Steel sector –37% by 2030; scrap-weighted intensity trajectory
[src N]	E3G & PNNL, 2022	Benchmark	1.5 °C steel pathway; –50% by 2030; 2050 route shares
[src O]	EUROFER, 2019	Constraint	~400 TWh CO_2-free electricity requirement; EAF grid stress
[src P]	Daehn et al., 2017	Metallurgy	Copper hot shortness; tramp-element accumulation
[src Q]	L. 199/2025; MIMIT, 2026	Incentives	Iperammortamento structure; Transizione 5.0 closure
[src R]	DM MASE 2025; GSE, 2026	Incentives	Certificati Bianchi; Conto Termico 3.0; cumulation rules
[src S]	Dir. 2003/87/EC art.	Incentives	EU Innovation Fund;

	10a(8); IPCEI		IPCEI framework
[src T]	Scholler et al., Primetals, 2026	Technology	ESP/eHRC configuration; induction heating; copper tolerance
[src U]	IPCC AR6, 2023; NewClimate, 2024	Benchmark context	Economy-wide 48% reference — **not** a steel pathway
[EUTL]	Union Registry / EU Transaction Log	Database	**The verified baseline anchor**
[EMAS]	EMAS registration IT-002004	Database	Registration status only; declaration **not obtained**
[SR]	Arvedi *Sustainability Report 2025*	Company	**Not obtained** — requested, not received

Citation discipline applied. The EUTL is cited as the data origin; euets.info is recorded as the access route, not the source. Derived quantities (net short position; production tonnage; sub-bucket energy) are attributed to this study, not to the EUTL, which publishes neither. Vendor-sourced technical claims [src T] are identified as manufacturer-reported wherever relied upon.

Appendix C — Assumption register

Every non-verified input used in the analysis, with its basis and the document that would replace it.

C.1 Baseline and boundary

Input	Value	Grade	Basis	Replaced by
Physical Scope 1 baseline	434,844 tCO_2 (CY2023)	VERIFIED	EU ETS verified emissions, Cremona installation [EUTL]	—
Free allocation	352,308 (CY2023)	VERIFIED	[EUTL]	—
Net short position	82,536 t	DERIVED	Verified emissions – allocation	—
Scope 1 intensity	138 kg/t	SOURCED	[src A]	Independent LCA or EPD
Crude steel production	~3.15 Mt (CY2023)	DERIVED	434,844 ÷ 0.138 — **circular**	[SR] or company accounts
Reporting year	CY2023	VERIFIED	Latest year with verified emissions at time of access	CY2024/25 when published

C.2 Scope 1 decomposition

Input	Value	Grade	Basis	Replaced by
Process carbon share	58%	ASSUMED	Literature scrap-EAF composition	[EMAS] / AIA permit
Natural gas share	30%	ASSUMED	Literature	[EMAS] / AIA permit
Electrode share	6%	ASSUMED	Literature (1–2 kg/t consumption)	[EMAS] / AIA permit
Flux calcination share	4%	ASSUMED	Literature (lime 30–50 kg/t)	[EMAS] / AIA permit
Other / fugitive share	2%	ASSUMED	Residual allocation	[EMAS] / AIA permit
Gas — tunnel furnace	~280 GWh	ASSUMED	**Contingent on §2.2 configuration**	Plant documentation
Gas — finishing lines	~214 GWh	DERIVED	Residual of gas bucket after named units	[EMAS] / AIA permit
Gas — EAF burners	~88 GWh	ASSUMED	Engineering estimate	[EMAS] / AIA permit
Gas — ladle/tundish	~70 GWh	ASSUMED	Engineering estimate	[EMAS] / AIA permit
Electricity intensity	380 kWh/t	ASSUMED	Literature EAF + rolling + finishing	[EMAS] / AIA permit

C.3 Prices and financial parameters

Input	Value	Grade	Basis
Discount rate (WACC)	8%	ASSUMED	Sensitivity tested 6/8/12% (§8.2)
Natural gas	€35/MWh	ASSUMED	Indicative European industrial price
Electricity	€120/MWh	ASSUMED	Indicative Italian industrial/PPA price; **decisive for §5.3**
Steel price	€650/t	ASSUMED	Indicative flat-product price
ETS carbon price	€75/tCO_2	SOURCED	Q1 2026 official reference €75.36 [src F]
Certified biochar	€650/t	ASSUMED	**The study's most volatile input**
Anthracite	€250/t	ASSUMED	Indicative injection-carbon price
Natural gas emission factor	0.20 tCO_2/MWh	ASSUMED	Standard factor
Italian grid emission factor	0.30 tCO_2/MWh	ASSUMED	Indicative national average
IRES rate	24%	SOURCED	Italian corporate tax rate

C.4 Measure parameters

Measure	Capex	Life	Abatement	Grade
Waste-heat recovery	€18.0M	15 yr	15,000 t gross / 9,000 t net	ASSUMED
Ladle + tundish electrification	€6.0M	15 yr	14,000 t	ASSUMED
Biocarbon substitution	€4.0M	15 yr	113,494 t	ASSUMED (linked to C.2 share)
Tunnel-furnace electrification	€30.0M	20 yr	56,000 t	ASSUMED (**contingent**)
WHR overlap adjustment	−6,000 t	—	Engineering judgement (§5.4)	ASSUMED

No vendor quotations, plant cost data or Arvedi operating figures were obtained for any measure.

Appendix D — Model disclosure

Standard disclosure lines for use wherever model outputs are cited.

Baseline and decomposition: measure-level figures derive from the study MACC workbook (Section A/B split; electrification and biocarbon calculation blocks), normalised to the CY2023 verified Scope 1 baseline of 434,844 tCO_2 [EUTL]. Bucket allocation uses assumed literature shares (Appendix C.2), not plant data.

Energy figures: natural gas ~652 GWh/yr is DERIVED from the assumed 30% share of the verified total at 0.20 tCO_2/MWh. Site electricity ~1,200 GWh/yr and the tunnel-furnace draw of ~220 GWh/yr are ASSUMED, pending production and consumption confirmation [SR] / [EMAS].

Avoided-cost line (§7.3): derived from the CBAM-factor schedule [src F][src G] at €75/tCO_2, applied to CY2023 free allocation of 352,308 allowances [EUTL]. Static illustration holding emissions, allocation and carbon price constant; benchmark update rates of 2.5%/yr for 2026–2030 [src F] are not applied.

Comparative exposure (§4.2): the BF-BOF comparator uses ~2.0 tCO_2/t gross intensity. Using the official 1.370 tCO_2e/t benchmark [src G], the 2026 net cost is approximately €2.57/t rather than €3.75/t; the emission-factor assumption is disclosed wherever the higher figure is quoted.

Appendix E — Open verification items

Consolidated from all sections, in priority order. Items 1 and 2 are capable of changing the study's conclusions.

#	Item	Section	Impact if resolved differently	Source required
1	**ESP heating configuration** — gas tunnel furnace or induction?	2.2, 8.1	Voids the largest measure; package falls to 31.4% of baseline	Plant documentation; AIA permit
2	**Certified biochar supply, price, metallurgical limit**	5.5, 8.1	59% of package abatement depends on it	Market data; plant trials
3	Bucket shares (58/30/6/4/2)	3.4	Redistributes abatement between measures	[EMAS] declaration; AIA permit
4	CY2023 crude steel production	2.3, 3.3	Removes circularity; converts the intensity table into a test	[SR]; company accounts
5	Site electricity and gas consumption	2.3	Replaces derived and assumed energy figures	[EMAS]; AIA permit
6	CY2024–25 verified emissions	3.3	CY2023 is a two-year lag for a 2026 study	[EUTL]
7	PPA strike price	5.3	Determines the ladle electrification verdict	Company disclosure
8	Arvzero premium level	7.2	Tests the funding	Company disclosure

	and volume		argument; €12–15/t is a derived break-even	
9	EU regional 2050 route shares	6.1	Currently cited from global figures	[src N], specific table
10	Conventional cold-charge reheating (1.2–1.5 GJ/t)	2.2	Comparator for the "efficient by design" claim	DOE/AMO or IEA literature
11	Annual VCS offset volume retired	3.1	Would size the residual the offsets cover	Company disclosure
12	Forward free allocation 2026+	4.2	EUTL nil values are unrecorded data, **not** policy zeros — do not cite	[EUTL], when published

Appendix F — Supporting materials

Item	Description
MACC workbook	Scope 1 decomposition, price block, electrification and biocarbon calculation blocks, Section A/B measure split, KPI panel. All inputs colour-graded by provenance.
Process flow diagram	Scrap yard → EAF → ladle furnace → thin-slab caster → heating stage → hot rolling → coil, annotated with process CO_2, combustion CO_2 and Scope 2 sources.
Reference list	"Appendix — References," Parts 1 and 2: full citations, URLs, access dates, source-specific notes.