UNLOCKING THE FIRST WAVE OF BREAKTHROUGH STEEL INVESTMENTS

in Southern Europe

INSIGHT REPORT / MARCH 2023

Prepared by

Energy Transitions Commission

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PREFACE

Energy Transitions Commission

In *Making Net-Zero Steel Possible*, published September 2022, the **Mission Possible Partnership** (MPP) found that approximately 70 'near-zero-emissions' primary (iron ore-based) steel mills need to be operational by 2030 for the global steel industry to be on a 1.5°C-aligned pathway to net zero. As of 2022, no such plant is yet in operation at commercial scale, and even among projects that have been announced, few have secured final investment decisions (FIDs) to proceed. Growing the project pipeline and accelerating commercial-scale proposals to FIDs is the critical task to decarbonise steel globally.

As a core partner of the MPP, the **Energy Transitions Commission** (ETC) has sought to build upon *Making Net-Zero Steel Possible* by assessing what it will take to achieve FIDs on near-zero-emissions primary steel projects in the next five years. To drive this assessment, Breakthrough Energy has supported the ETC to conduct a series of regionally focused forums to determine what is needed to make these projects investable under a given set of local conditions.

This insight report outlines the findings of the forum centred on Southern Europe, with a focus on Spain. It outlines the advantages for breakthrough iron- and steelmaking in the region, the financial gap this type of investment faces under prevailing conditions, and potential pathways to make the business case investable in the immediate future. Favourable conditions in Spain mean the opportunity the country offers for breakthrough iron and steel technology is already being seized by first mover businesses. However, those conditions, particularly Spain's excellent renewable energy resources, mean the opportunity could be taken much further. Projects centred on retrofitting existing scrap-based steelmaking assets with breakthrough ironmaking technology are within reach of a viable investment case, requiring only an effective carbon price that is applied to steel imports into the EU as well as production within the bloc. Targeted government support for upfront capital expenditures and forward offtake agreements at a premium could go one step further and establish a case for brand new greenfield iron and steel production. The Spanish case has positive implications for Southern Europe more widely and highlights how the region is well-placed to pioneer and drive the scale-up of breakthrough steelmaking globally.

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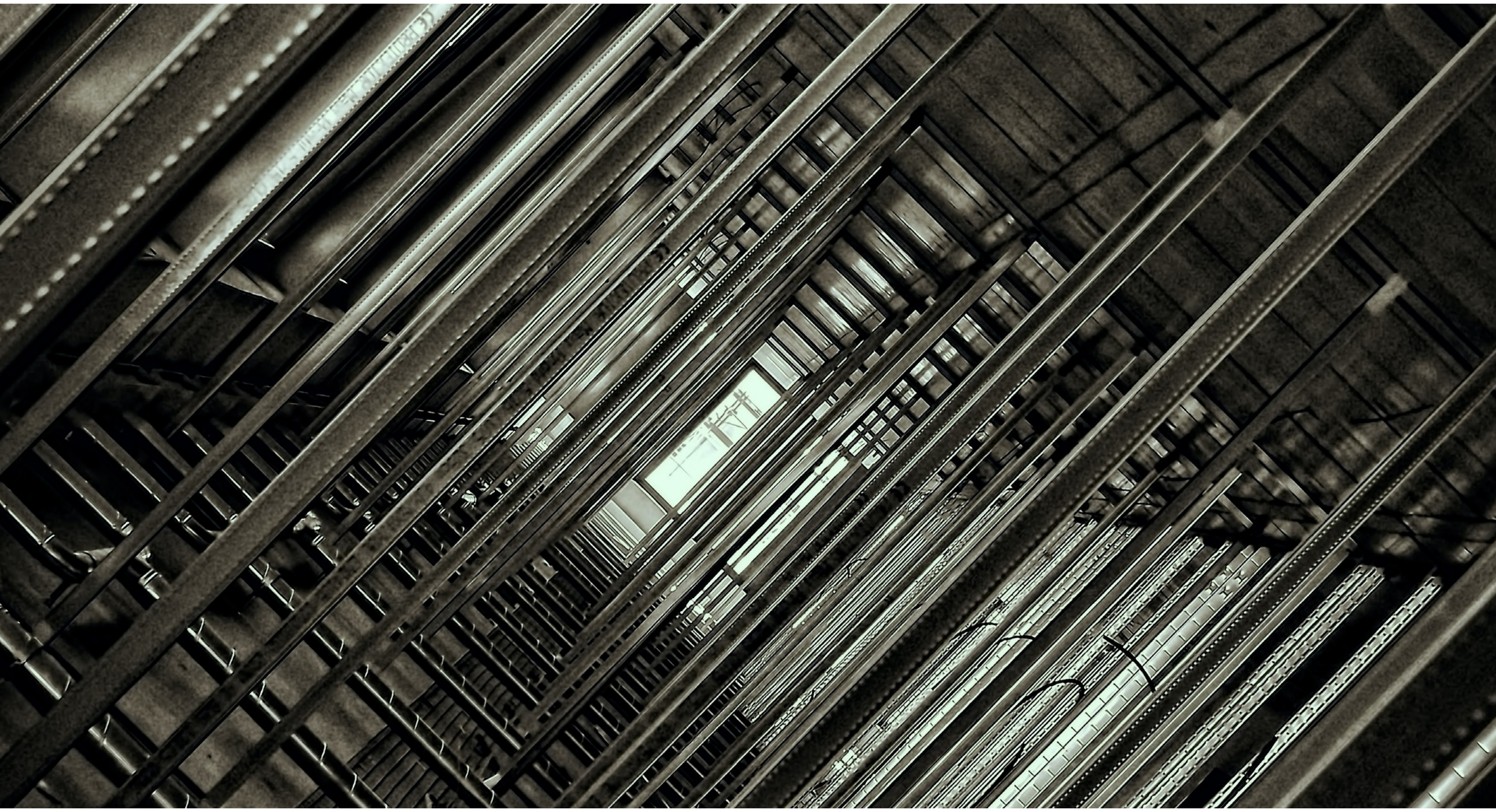
PART I

THE CASE FOR BREAKTHROUGH STEEL IN SOUTHERN EUROPE



Steel constitutes a fundamental component of most elements of everyday life. From buildings to cars, from chemicals to food, steel underpins a range of industries and processes. At the same time, the global steel industry is the largest emitter of greenhouse gases (GHG) of all heavy industries, accounting for 7% of annual global GHG emissions.[i] Achieving a sustainable, net-zero economy is only possible by decarbonising steel production.

Southern Europe, spanning Portugal, Spain, and Italy, already benefits from a comparatively low-emissions steel industry. The majority (81%) of crude steel manufactured across the three countries is made via secondary steelmaking processes fed with high proportions of scrap steel (Exhibit 1, next page). Recycling scrap in this way avoids the need to produce new iron from iron ore, a process that has conventionally relied on coal and constituted the most emissions-intensive part of steelmaking. As a result, the GHG emissions intensity of steelmaking in the region already falls well below the global average (0.6 tonnes of carbon dioxide equivalent [t CO_2e] vs 2 t CO_2e).[ii]

Southern Europe is also well-positioned to decarbonise its steel industry further. Given that the emissions generated by secondary steelmaking are largely driven by electricity usage,

i *Making Net-Zero Steel Possible*, Mission Possible Partnership, September 2022, p. 27.

ii Global emissions intensity is from *Making Net-Zero Steel Possible*, Mission Possible Partnership, September 2022, p. 28.

EXHIBIT 1

Overview of the Southern European steel industry, 2020

Primary (ore-based) steelmaking

Definition: Also referred to as "integrated steelmaking," as it combines both ironmaking and steelmaking processes. Most common production route today involves blast furnace-basic oxygen furnace (BF-BOF) technology. In this route, coke and coal are used in the BF to convert iron ore into iron with a small percentage of carbon content (also known as "pig iron"). The iron is then processed into steel in the BOF using oxygen, which reacts with carbon content and impurities.

Product type: Capable of producing a wide range of steel products. Main type of steelmaking used to produce higher grade "flat" products. BF-BOF production can also accommodate a degree of scrap input (up to 25%-30% per tonne of crude steel).

Secondary (scrap-based) steelmaking

Definition: Refers to the process of making steel primarily from recycled scrap. Production route involves electric arc furnace (EAF) technology. In this route, large amounts of electricity are used to melt scrap and process it into new crude steel.

Product type: Generally used to produce lower-grade "long" products. However, secondary steelmakers can also buy iron separately and add it to their production mix to allow them to produce higher grades of steel.

	Primary (ore-based) steelmaking		Secondary (scrap-based) steelmaking	
	Crude Steel Production, *Mt*	**GHG Emissions,** *Mt CO_2e*	**Crude Steel Production,** *Mt*	**GHG Emissions,** *Mt CO_2e*
	0	0	2.2	0.5
	3.0	3.9	8.0	3.7
	3.1	4.8	17.3	8.1

Notes: All figures refer to 2020. GHG emissions figures refer to Scope 1 and Scope 2 emissions.

Source: ETC analysis based on steel production data from World Steel in Figures 2021, worldsteel, April 2021; steel energy consumption data from Eurostat; power grid emissions data from the European Environment Agency (EEA); steel direct emissions data from the United Nations Framework Convention on Climate Change (UN FCCC)

the emissions intensity of most steelmaking in the region will continue to decrease as countries decarbonise their power systems. Complete decarbonisation of this electricity would mitigate around 5.8 million tonnes (Mt) of annual indirect (Scope 2) emissions associated with secondary steelmaking in Southern Europe.

At the same time, 8.7 Mt CO_2e (over 40%) of Southern Europe's annual steelmaking emissions come from the region's only two primary steelmaking sites, one in Spain (Gijón) and the other in Italy (Taranto), a reflection of their more emissions-intensive BF-BOF technology.[iii] However, the foundations are being laid to renovate both sites with breakthrough technology, whereby processes to produce direct reduced iron (DRI) with green hydrogen are combined with EAF steelmaking to enable near-zero emissions primary production. Plans for Gijón include government support and aim to have these new technologies in place by 2025, contingent on the availability of sufficient green hydrogen. Plans for Taranto are less advanced, where the ambition is to add an EAF by 2025 and integrate DRI production further out in time.[iv]

Alongside decarbonising the energy supply for secondary steelmaking, breakthrough iron and steel technology will help Southern Europe bring its steel sector emissions down in line with the EU's 'Fit for 55' target to reduce emissions by 55% by 2030 (compared to 1990 levels), while preserving primary steelmaking capacity. However, the opportunity to deploy this technology could be greater than simply renovating existing BF-BOF sites.

Decarbonising the EU (and the global economy more widely) will increasingly require breakthrough primary steel to meet the grades and volumes of low-emissions steel needed.[v] This demand is already materialising, with major primary steel buyers in the region, such as Stellantis, ACCIONA, and Enel, setting stringent supply chain decarbonisation targets. H2 Green Steel, a new entrant steel project developer with projects planned in Iberia and Sweden, has secured forward purchase agreements for the production of near-zero emission steel equivalent to 1.5 million tonnes per annum (Mtpa) of planned production starting from 2025.[vi]

iii Referring to Scope 1 emissions from the two sites in 2020.

iv Corporate press releases.

v ***Making Net-Zero Steel Possible***, Mission Possible Partnership, September 2022, p. 49.

vi ***H2 Green Steel has pre-sold over 1.5 million tonnes of green steel to customers***, H2 Green Steel, May 2022..

The cost of breakthrough steel production (particularly ironmaking) is driven above all by the cost of clean energy feedstocks. As a result, locations with high renewable energy potential could offer a strong competitive advantage for breakthrough primary steel production. Southern Europe possesses some of the best renewable energy resources in Europe that, combined with a skilled workforce, have allowed countries like Spain and Portugal to achieve a levelised cost of electricity for solar and wind ranking among the cheapest in the world.[vii]

Leveraging their renewable resources has also allowed these countries to increase the resilience and affordability of their energy supplies, as evidenced by the stability of the Iberian market for power purchase agreements (PPAs) (based on renewables) during the ongoing energy crisis in Europe. While average PPA prices in Europe doubled between March 2021 and November 2022, sometimes breaching €100 per megawatt-hour (MWh), prices in Spain and Portugal rose by less than €20/MWh on average across the same period.[viii] Current targets set by Southern European governments in their National Energy and Climate Plans (NECPs) to expand the share of electricity supplied by renewables by 2030 (to 55% in Italy, 74% in Spain, and 80% in Portugal) should help further increase the availability of low-carbon electricity and lower wholesale power costs, particularly following updates to their NECPs due in 2023.[ix]

Investment in breakthrough iron and steel capacity could offer Southern Europe a number of benefits, chiefly:

1. **Extracting the greatest value from Southern Europe's renewable resources.** While it is possible to transport and export energy vectors such as renewable electricity or green hydrogen directly, technical and economic factors can create challenges to doing so (such as how the efficiency of electricity transmission lines declines with distance or how exporting hydrogen would require financing and developing pipelines or other transport infrastructure). Breakthrough iron and steel, being energy-intensive goods, offer an additional opportunity for Southern Europe to capture value from its solar and wind resources in physical products that can be stored and exported through existing logistical infrastructure. Capitalising on the region's renewable energy resources in this way would also create high-quality industrial jobs, both directly within the steel industry but also indirectly along the wider value chain, particularly in the energy sector upstream.

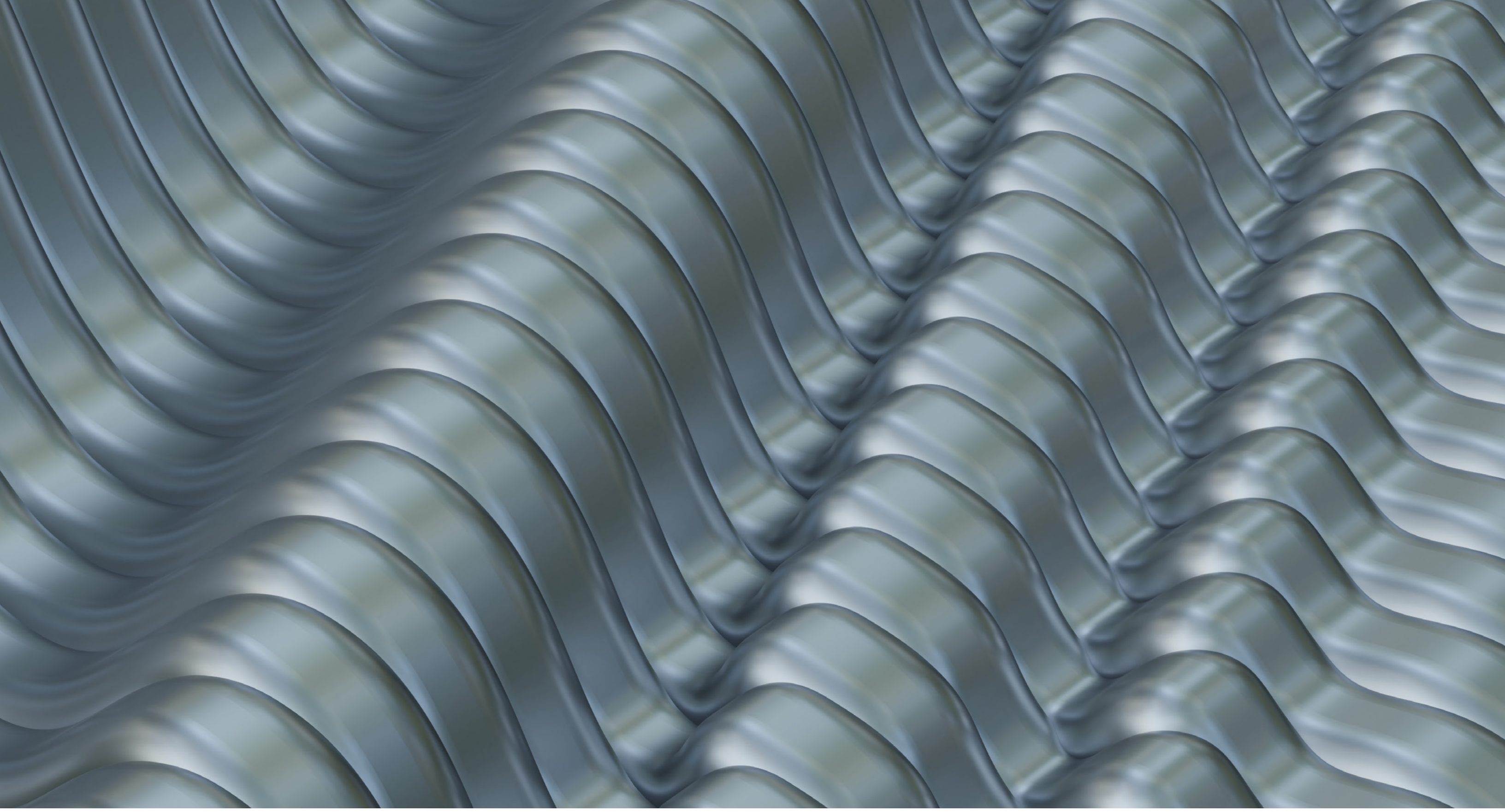
2. **Greater supply-chain resilience for regional steelmakers.** Given the lower emissions associated with making steel from scrap versus from iron ore, secondary steelmaking could grow its share of global steel production from 25% today to 40% by 2050 as countries around the world leverage scrap as a straightforward way to decarbonise their steel industries. However, inherent limits to the availability of scrap mean demand could outstrip supply and increase the cost of using a material whose market prices already face significant volatility.[x] As a net importer of scrap, the Southern European steel industry already faces the brunt

vii **Renewable Power Generation Costs in 2019**, International Renewable Energy Agency, June 2020.

viii Based on data from PPA Times monthly reports, published by Pexapark, for its 10-year, pay-as-produced PPA price index. European average prices rose from €42/MWh to €87/MWh, while the price average for Spain and Portugal rose from €31/MWh to €48/MWh across the period in question.

ix **National energy and climate plans (NECPs)**, European Commission, 2022.

x ***Making Net-Zero Steel Possible***, Mission Possible Partnership, September 2022, p. 33.



of this volatility.[xi] Scrap prices in Spain, for example, have been 8% higher on average and experienced greater volatility over the past decade than those in neighbouring France, which is a net exporter of the material.[xii] Investing in breakthrough ironmaking capacity would allow regional steelmakers to better hedge against future scrap market uncertainty by enabling them to produce their ferrous input when scrap prices are too high.

3. **Enhancing the ability of regional steelmakers to manufacture higher-grade and higher-value flat steel products.** Secondary steelmaking is typically orientated towards lower-grade long steel products. EAF steelmakers can produce higher grades but must add imported emissions-intensive iron products to their production to meet the necessary quality and product requirements. Building domestic breakthrough ironmaking capacity would enable local steelmakers to leverage local energy resources to produce steel that is both higher-grade and low-emissions, reducing dependence on imported iron. While most EAF steelmakers in the region are understandably likely to continue serving their traditional long product markets, those that invest in breakthrough ironmaking would also be able to access new markets. These markets would be built upon new demand for differentiated low-emissions flat steels, demand that is likely to come from elsewhere in Europe as much as from regional buyers. Even if flat product markets prove challenging, EAF steelmakers could produce low-emissions iron directly for export in the form of hot briquetted iron (HBI).

First movers around the world are already seizing the market for and benefits of breakthrough iron and steel investments. Projects have been approved in Sweden, Canada, and Germany, some of which have already struck forward offtake agreements with buyers and where the first FIDs globally have begun to emerge. Given its favourable energy conditions, Southern Europe is well-positioned to enter the race for breakthrough iron and steel and should do so before the first offtake volumes are locked up by projects elsewhere. In doing this, the region could become a driving force to deliver industrial decarbonisation for the EU and contribute significantly to kick-starting a supply of near-zero-emissions primary steel globally.

xi Based on data from **World Steel in Figures 2022**, worldsteel, April 2022.

xii Based on scrap price data between 2012-2021 from UN Comtrade.

PART 2

THE ECONOMICS OF BREAKTHROUGH STEEL INVESTMENTS

Steelmaking is highly capital-intensive, requiring significant investment into assets with long life spans. The cost of developing a conventional BF-BOF facility with best available technology for a production capacity of 1 Mtpa of crude steel would stand at almost €1.1 billion.[xiii] While investors typically expect steel assets to pay back their upfront investment in 10 years or fewer, facilities such as these can operate for decades, with a major reinvestment every 20 years on average to reline their blast furnaces.[xiv]

An integrated breakthrough steel mill would be similarly capital-intensive, with a 1 Mtpa greenfield H_2-DRI-EAF plant incurring capital expenditures of over €700 million for its iron and steel production equipment alone. While these upfront costs may be lower than those of a BF-BOF, the breakthrough mill would incur comparatively higher operational expenditures. Like other types of capital-intensive investments, the scale and complexity of steelmaking investments mean that proposed projects are subject to comprehensive techno-economic assessments, with crucial steps such as feasibility studies and front-end engineering design (FEED) studies. The nature of these investments also means they must often be delivered through complex financial structures, combining different funding sources and parties. In view of this, the final investment decision (FID) represents a critical point in the investment process, signalling a firm financial commitment upon which contractors can proceed with procurement, construction, design, and engineering works.

xiii All monetary values are denoted in real 2020 euros. The underlying modelling and analysis of this report were conducted in real 2020 USD (due to the international nature of steel investment and lending portfolios, where finances are assessed in USD terms) with final figures converted into euros at a rate of 0.877.

xiv ***Making Net-Zero Steel Possible***, Mission Possible Partnership, 2022, pp. 29, 59. The precise investment cycle length of a blast furnace depends on its "campaign" (operational) life and operational characteristics.

2.1 Progressing Breakthrough Steel Investments

While high-level decarbonisation roadmaps point to breakthrough technologies for primary steelmaking as essential for achieving net-zero, detailed insight into what is needed to achieve FIDs on breakthrough projects has been limited. Therefore, the ETC launched a forum, bringing together stakeholders from across the Southern European steel value chain in a series of roundtables, with the aim of resolving what it will take to reach FIDs on a first wave of commercial-scale breakthrough steel projects in the region within the next three to five years. Spain was selected as a reference case to provide a tangible basis for discussion.

To underpin forum discussions, the ETC developed an open-source tool that models the financials of different breakthrough iron and steel investments.[xv] The architecture and input assumptions of the tool were stress tested and validated with experts and forum participants, allowing the tool to reflect the realistic economics of an investment in Spain.

Analysis and discussion for the forum revolved around a set of breakthrough steel project 'archetypes' that assume 2 Mtpa as a reference plant capacity to enable direct comparison between the options (Exhibit 2). These archetypes were developed to provide a foundation for open discussion on the investment prerequisites whilst avoiding debate on particular assets. All the archetypes were centred on green hydrogen–based direct reduced iron–electric arc furnace (H_2-DRI-EAF) steelmaking as a reference for breakthrough steelmaking technology. This technology route was selected because of (a) its technology readiness level[xvi] and (b) its international project pipeline, which is the strongest of all 'near-zero emissions' primary steelmaking technologies with approximately 60 Mtpa of planned capacity globally as of mid-2022. H_2-DRI-EAF technology is, consequently, considered a credible contender for commercial-scale investment in the near term, particularly compared with alternatives such as carbon capture with sufficiently high (+90%) effective capture rates or nascent electrolysis-based production processes.

The three archetypes selected for Spain were chosen based on their relevance to the country's steelmaking context and validated by forum participants and other expert stakeholders.

EXHIBIT 2

Select breakthrough iron and steel project archetypes for Spain

	Brownfield EAF conversion to H_2-DRI-EAF	Greenfield H_2-DRI-EAF	Merchant HBI
Existing technology	EAF	N/A – Greenfield	N/A – Greenfield
Target site technology	DRI and EAF	DRI and EAF	DRI
DRI feedstock	100% green H_2	100% green H_2	100% green H_2
Potential emissions reductions	0%/97%	97%	97%
Known developments	• N/A	• SSAB HYBRIT, Sweden	• H2 Green Steel, Iberia and Sweden • GravitHy, France

Notes: Potential emissions reduction compared with an average BF-BOF using best available technology and assuming an average scrap intake of 30%. Proposed archetypes assume 0% scrap intake. Assumes power supply from a baseload PPAs based primarily on renewable electricity. Adding H_2-DRI production to an existing EAF would not lower the emissions of the existing site but would displace emissions from BF-BOF primary steelmaking elsewhere operating under the assumptions above (hence the "0%/97%" notation).

Source: ETC analysis

xv The tool is publicly available and allows users to modify inputs and explore the impact of changing assumptions on the financials of breakthrough steel projects.

xvi TRL refers to a method of assessing where a given technology stands in its journey to widespread adoption, commonly reflected by a score between 1 (initial idea) and 9 (commercially available). In the International Energy Agency's ***ETP Clean Energy Technology Guide***, last updated September 2022, H_2-DRI was given a TRL score of 6 (full prototype at scale) and the technology has seen further development since then.

1. **Brownfield EAF conversion:** Retrofitting an existing EAF site by adding DRI production capacity, fed with 100% green hydrogen. Relevant given the prevalence of EAFs in Spain (Exhibit 1, page 6) and the opportunity the archetype would offer to enable higher-grade steel production and diversify their ferrous input supply.

2. **Greenfield H_2:** Building a new DRI-EAF facility fed with 100% green hydrogen. Included for analysis because developing new capacity in the most favourable locations for low-emissions steelmaking is an archetype being pursued in other countries.

3. **Merchant HBI:** Building a new standalone DRI production site to manufacture hot briquetted iron (HBI) for sale to steelmakers domestically or internationally. An option to leverage potentially favourable conditions for low-emissions ironmaking in Spain without building new steel capacity and adding to already excess steel capacity globally.

Archetypes involving BF-BOF technology were considered, but they were not selected as there is only one existing BF-BOF site in Spain, and there are already plans in place to convert it to breakthrough technology.[xvii]

2.2 Investment under Prevailing Policy and Market Conditions

Before committing to an FID, investors consider a wide range of factors in evaluating a prospective investment. One metric that is commonly used to comprehensively assess the attractiveness of an investment is net present value (NPV).[xviii] Based on an assessment of the NPV of the three archetypes in Spain today, the investment case for breakthrough steel under prevailing market conditions is not attractive (Exhibit 3, next page). Although Spain has carbon pricing set by the European Union Emissions Trading System (EU ETS), this has not been included in the baseline analysis. This is because factors such as the free allocation of carbon allowances for steelmakers, or how the EU ETS does not currently affect steel imported from outside the EU, mean that carbon pricing does not yet fully affect steel market prices (and therefore archetype financial performance) (see Exhibit 5, page 14). The impact of carbon pricing, when applied effectively, is isolated and detailed in subsequent sections of this report.

High levels of upfront capital expenditures in iron and steel plant equipment (€647 million for Archetype 1, €1,167 million for Archetype 2, and €687 million for Archetype 3) heavily impact the NPV values as they result in strongly negative cash flows in initial years. Adding to this high levels of operational expenditure results in a levelised cost of production (LCOP) that is higher than projected market prices (up to 19% higher for steel, depending on the archetype, and 28% for HBI).[xix] If these archetypes cannot produce iron and steel at a cost that is competitive under prevailing policy and market conditions, a positive investment case for breakthrough steel will remain out of reach unless action is taken to either (a) lower the supply-side cost of production or (b) create conditions under which low-emissions iron and steel can achieve higher margins when sold.

xvii The DRI technology archetypes analysed in this report are not exhaustive. Variants include the use of submerged arc furnace (SAF) technology and electric melters in combination with a BOF. Several projects and feasibility studies using such technologies were announced over the course of the forum. It is possible to explore such variants in the accompanying financial model, provided the techno-economic input assumptions can be sourced.

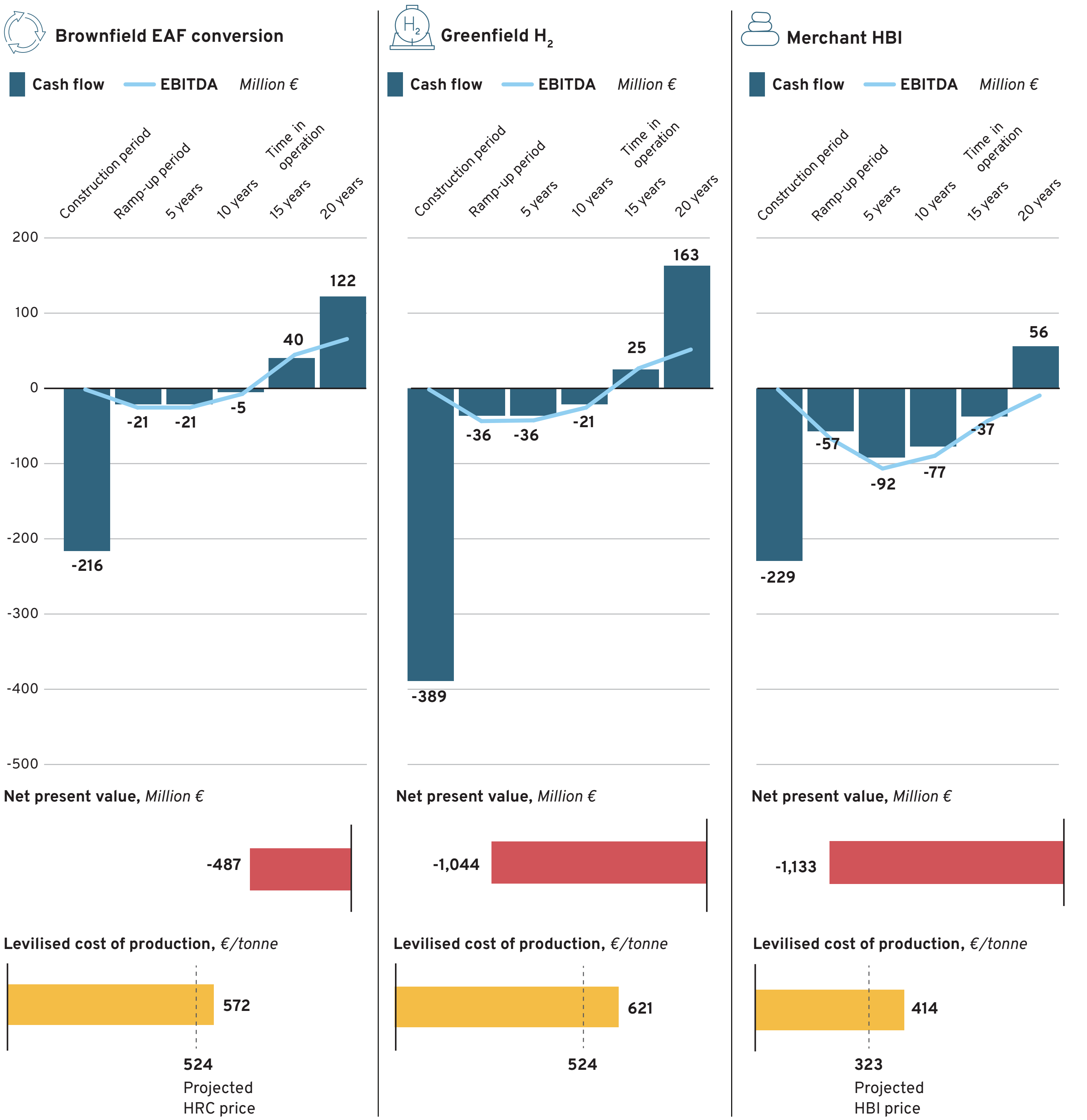
xviii Net present value (NPV) is the unlevered difference between the present value of cash inflows and the present value of cash outflows over a period of time.

xix LCOP is a form of discounted cash flow analysis that expresses the present value of non-revenue cash flows per unit of production. In this report all LCOP values are reported on a post-interest pre-tax basis. Unlevered NPV values, on the other hand, include include tax but do not include interest expenses. For more information on financial methodologies, please see the Technical Appendix to this report.

EXHIBIT 3

The breakthrough iron and steel business case in Spain under baseline conditions

Plant size:	Plant lifetime:	Utilisation rate:	Scrap intake:	Debt-to-equity:	Equity IRR:	Average interest rate:	FID date:
2 Mtpa	20 years	90%	0%	1.5	8%	6%	2024



Note: Financials assume three years for construction and one year to ramp up production, 15 years for debt repayment with a one-year grace period, electricity supply from baseload PPAs based primarily on renewables, 25% tax on earnings, and straight-line depreciation in 18 years following Spanish government instructions on methods to calculate depreciation for industrial equipment assets for tax purposes. IRR refers to internal rate of return assumed for the equity part of financing. Steelmaking archetypes produce hot-rolled coil (HRC), whose price projections are based on historical global HRC price behaviour as reported by UN Comtrade. Merchant HBI archetype produce hot briquetted iron (HBI), whose price projections are based on historical global price behavior as reported by Steel on the Net.

Source: ETC analysis

2.3 Cost Drivers of Breakthrough Steelmaking

Today's steel markets are highly globalised and competitive, meaning the business case for steelmaking is driven to a large extent by the cost of production. Breaking down the cost of goods sold (COGS) for the three archetypes offers insight into the key cost drivers of breakthrough iron and steel (Exhibit 4).

Under baseline conditions in Spain, the biggest cost drivers are:

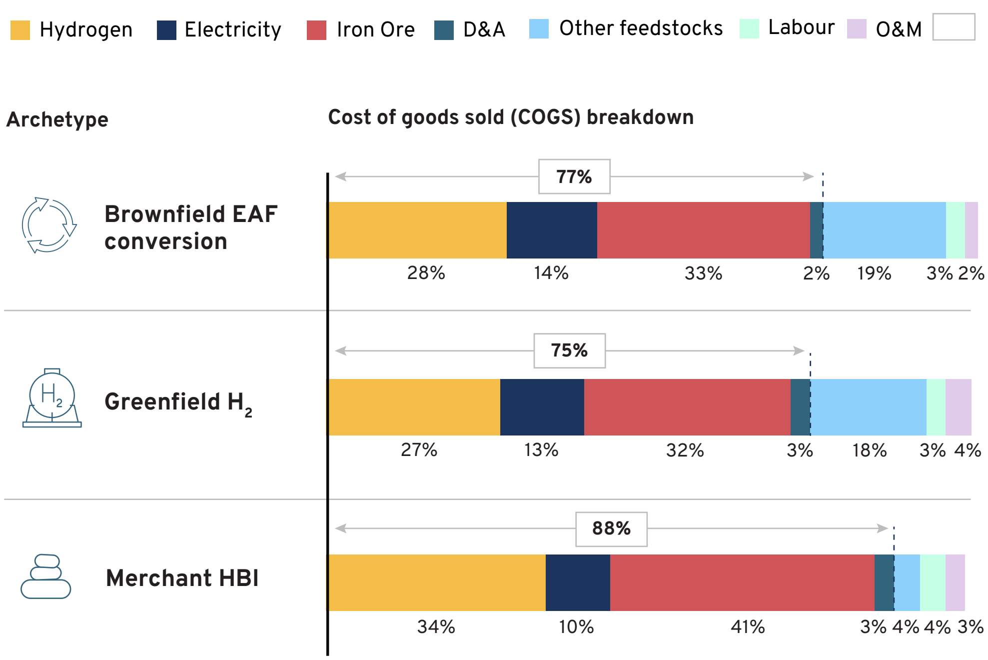
- **(Green) hydrogen (27%-34%):** The main feedstock utilised by all three archetypes to process iron ore into DRI, which can then be transformed into steel. Hydrogen has an even greater direct impact on the costs of Archetype 3 because there is less downstream processing, requiring less consumption of other feedstocks. Hydrogen cost is driven mainly by the price of power delivered to electrolysers.
- **Electricity (10%-14%):** The main power source for plant equipment, notably for running the EAFs that melt steel via electrical heating and constitute the essential piece of steelmaking equipment in Archetypes 1 and 2.
- **Iron ore (32%-41%):** Key ferrous base material for integrated steelmaking. Archetype 3 faces a proportionally higher cost in this category because it involves less downstream processing and less consumption of other feedstocks required for steelmaking specifically.
- **Depreciation and amortisation (D&A) (2%-3%):** A reflection of the cost of the capital expenditure in plant equipment over the lifetime of the plant. Although capital expenditure is significant in all three archetypes, it is highest in Archetype 2 because it requires significant new equipment (a DRI furnace, an EAF, pelletiser, and downstream equipment to process crude steel into HRC). In contrast, the capital expenditures of Archetypes 1 and 3 are centred primarily on new DRI furnaces.

Taken together, these categories amount to between 75%-88% of the cost of producing breakthrough iron and steel in Spain, with the rest comprising some remaining operational expenditures (chiefly labour and other feedstocks like ferroalloys or lime). Tackling the highest cost categories is crucial to improving the business case of corresponding projects.

EXHIBIT 4

Key cost drivers for breakthrough steel

Plant size:	Plant lifetime:	Utilisation rate:	Scrap intake:	Debt-to-equity:	Equity IRR:	Average interest rate:	FID date:
2 Mtpa	20 years	90%	0%	1.5	8%	6%	2024



	Price CAGR, *2024-2050*	2024 reference price
Scrap	1%	€371/t
Electricity	-1%	€47/MWh
Green hydrogen	-1%	€3/kg
HRC	0%	€524/t
HBI	0%	€323/t

Note: CAGR refers to compound annual growth rate. O&M refers to operations and maintenance. See Exhibit 3 note for underlying assumptions and the accompanying financial tool for details and sources of commodity prices.

Source: ETC analysis

2.4 Critical Levers

Given the baseline financial performance of the archetypes, interventions are needed to make the business case for breakthrough iron and steel in Spain investable and unlock FIDs. Discussions among stakeholders within the Southern European forum highlighted a variety of levers that could be applied to improve the business case.

Analysing the sensitivity of the three archetypes to a variety of levers (Exhibit 6, next page) reveals that the following four measures have the greatest relative impact on the attractiveness of the business case by reducing key cost drivers or offsetting them by increasing revenues (Exhibit 5).

EXHIBIT 5

Most impactful levers on the financials of breakthrough steel

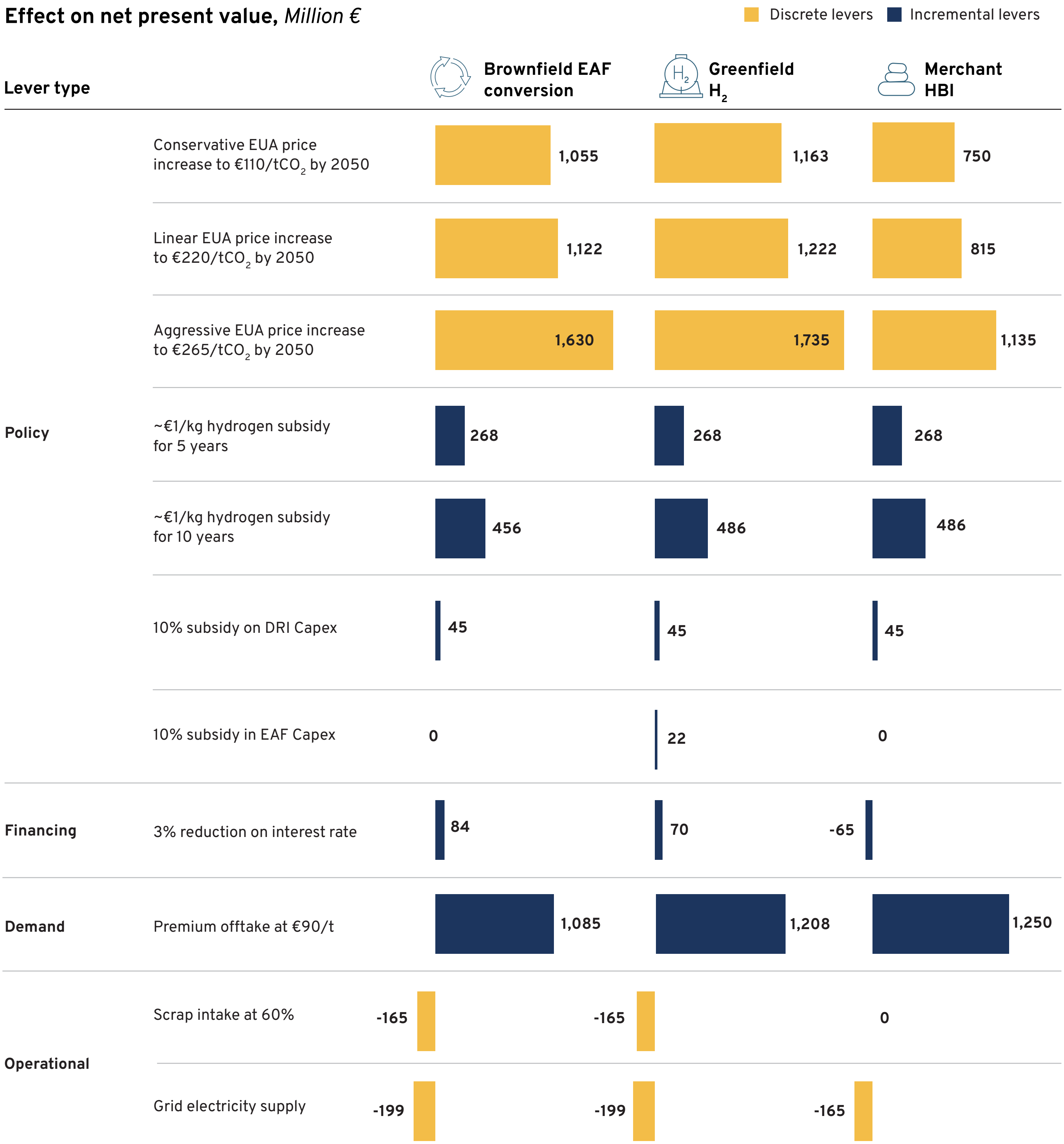
Lever	Description
Effective carbon pricing	Raises the production cost of conventional, emissions-intensive iron- and steelmaking, thereby raising the overall market price of these products. This improves the margins of a breakthrough mill by allowing it to sell its products at market price while avoiding the carbon costs of emissions-intensive competition. Carbon prices are projected to rise over time in a visible and predicable way. This lever assumes free allocations of carbon allowances for steelmakers that are phased out over time, in line with the latest European Commission proposals. Crucially, this lever assumes the markets in which a breakthrough project operates are all subject to the same projected carbon price. To ensure this is the case, at least in the breakthrough project's domestic/regional market, the lever assumes a carbon border adjustment mechanism (CBAM) or equivalent measure that guarantees imported iron and steel face the same carbon price as domestic producers. These assumptions are crucial because otherwise the effect of carbon pricing on iron and steel market prices cannot be ensured.
Green hydrogen subsidies	Applies a direct subsidy to reduce the production cost of green hydrogen, passed on as lower green hydrogen market prices, which lower the production cost of DRI.
Capital expenditure subsidies	Applies a direct subsidy to cover part of the upfront cost of new iron and steelmaking equipment. The subsidy also effectively reduces the amount of debt financing required by a breakthrough project, thereby lowering the interest paid over its lifetime.
Premium offtake	Guarantees a given price for some or all of the product manufactured and sold by a breakthrough mill. Additionally, raises the sale price for the chosen share of production by applying a premium above market prices (including the effect of carbon pricing). Offtake at a premium price reflects the added value ascribed by buyers to breakthrough iron or steel as a near-zero-emissions material, allowing the breakthrough mill to achieve higher margins on that offtake.

Source: ETC analysis

Sensitivity of breakthrough iron and steel archetypes to different levers

Plant size:	Plant lifetime:	Utilisation rate:	Scrap intake:	Debt-to-equity:	Equity IRR:	Average interest rate:	FID date:
2 Mtpa	20 years	90%	40%	1.5	8%	6%	2024

Effect on net present value, *Million €*



Note: Assumptions remain the same as in Exhibit 3 unless otherwise stated.

Source: ETC analysis

A WAY FORWARD

While Spain's renewable energy resources offer a potentially powerful advantage for breakthrough iron and steelmaking, action is needed to improve the investment case for these technologies. In this section, we set out two perspectives that are differentiated by the extent to which government and buyers are willing to support the development of breakthrough iron and steelmaking, particularly of new greenfield assets.

3.1 Two Perspectives to Progress to FIDs

Based on the analysis of the effectiveness of individual levers, the two scenarios outline different blueprints for what an investable business case for breakthrough iron and steel could look like in Spain (Exhibit 7, next page). Both scenarios were designed with the aim of exploring what would be needed to establish a positive NPV for the archetypes, with a payback period of 10 years or less on the initial investment. As such, they should not be treated as prescriptive roadmaps to FIDs, but rather as an indication of the scale and form of intervention required to strengthen the investment case for breakthrough iron and steel in Spain.

- **Scenario 1 – Augmenting existing production:** Effective carbon pricing on all iron and steel sold in the EU (via an effective EU CBAM) creates a potentially investable case for the **brownfield EAF conversion archetype**.

- **Scenario 2 – Capturing new markets:** In addition to the carbon pricing in Scenario 1, government support for capital expenditure and offtake at a 'green premium' above current market prices (via forward purchase agreements) further covers the costs of breakthrough iron and steelmaking. These levers create a potentially investable case for **the remaining greenfield archetypes**.

EXHIBIT 7

Overview of scenario results across different archetypes

Metric	Scenario 1		Scenario 2		
Archetype	**Brownfield EAF conversion**	**Greenfield H_2**	**Brownfield EAF conversion**	**Greenfield H_2**	**Merchant HBI**
Production capacity Million tonnes per year	2	2	2	2	2
Capital expenditure outlay Million €	647	1,167	647	1,167	687
Payback period Years	9	16	5	10	10
Net present value Million €	567	118	1,311	852	555
Levelised cost of production € per tonne of end-product	577	626	569	617	410
Profit before tax € per tonne of end-product	84	64	134	114	67
Average premium (over the market price) for premium offtake over project lifetime € per tonne of end-product	0	0	50	50	60
Direct government subsidy Million €	0	0	100	100	100

Source: ETC analysis

To illustrate pathways to investable business cases for the archetypes, a combination of levers was applied (Exhibit 8, next page). The choice and size of the levers aimed to strike a balance among three criteria: (1) efficiency (pulling as few levers as possible), (2) effect (selecting levers that had the greatest impact), and (3) feasibility (selecting levers and applying them as far as was deemed plausible by forum experts and value chain stakeholders).

3.1.1 Scenario 1 — Augmenting existing production

This scenario assumes a more limited appetite on the part of government to directly fund breakthrough projects, and on the part of buyers to pay a premium above market prices for iron and steel. However, it envisages that local steelmakers see strategic benefit in capitalising on the country's renewable energy resources through investing in breakthrough iron production capacity. Additionally, developing domestic ironmaking capacity is seen by EAF steelmakers as a valuable way to reduce their reliance on existing ferrous supply chains, particularly to produce higher grades of steel.

The key lever underpinning Scenario 1 is an effective carbon price regime that creates a level playing field between breakthrough iron and steel and their emissions-intensive counterparts by gradually raising the market price of the latter. The modelled carbon pricing regime is broadly aligned with current EU plans to phase out free allowances for steelmakers by the end of 2034 and projects a rise in the price of EU carbon allowances (EUAs) to €90/t CO_2 by 2030 and to €110/t CO_2 by 2050.

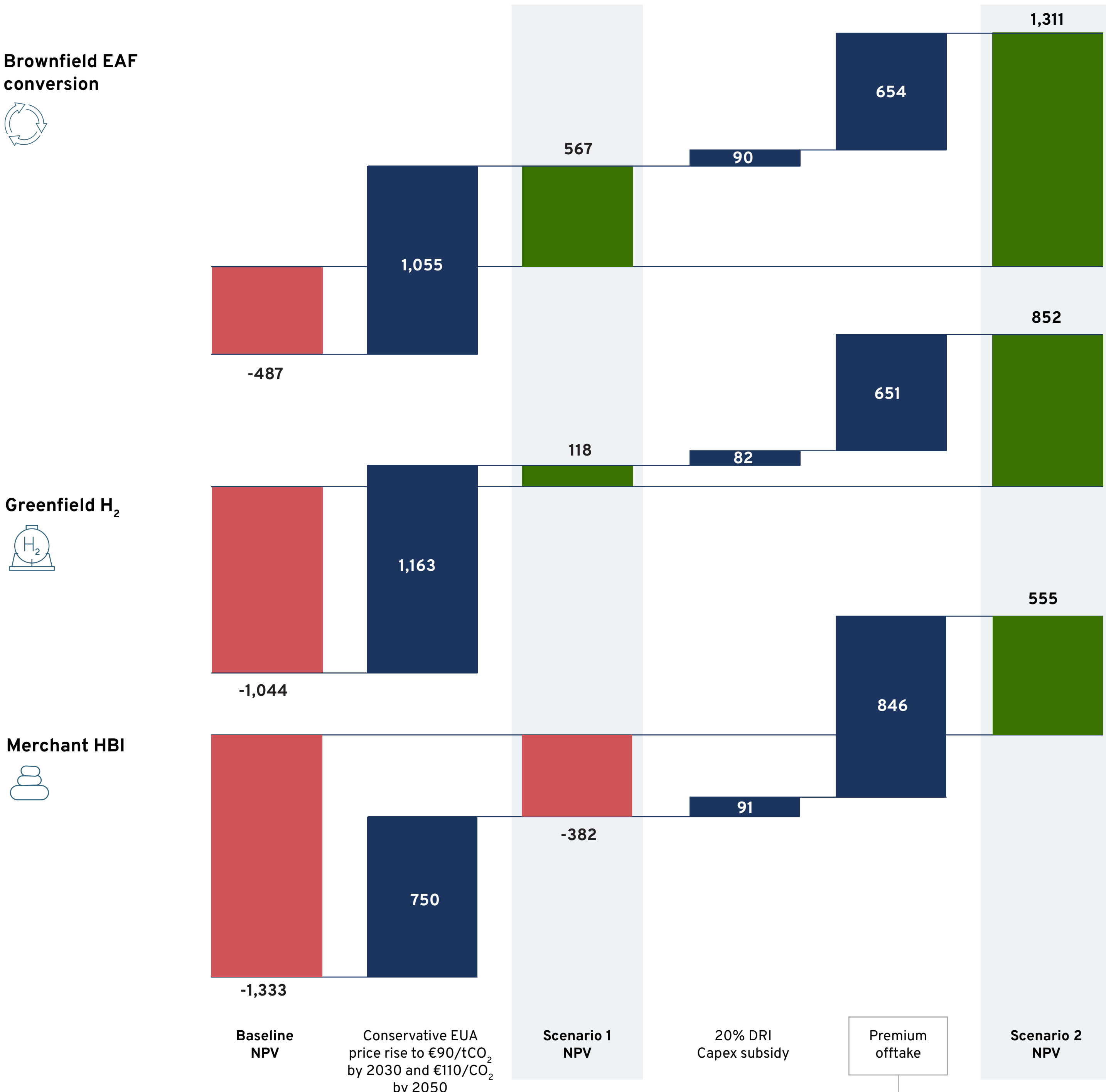
Effectively applied, the impact of even this modest carbon price rise is significant, triggering a €750 million–€1,163 million improvement in NPV, depending on the archetype (Exhibit 8, next page). While the assumed price trajectory is conservative relative to recent EUA prices, it was applied in this way given feedback from forum participants around the degree of uncertainty inherent to actual future prices. The crucial point would be that prices do not rise too quickly (and place an undue burden on incumbent steelmakers), but rise progressively and are applied effectively to iron and steel imports. The practical implication of the scenario is that breakthrough iron and steel products would be sold almost entirely within Spain and the EU. Given that annual steel consumption across the EU totaled almost 150 Mt in 2021, it is not unreasonable to assume that the EU market would be large enough to absorb the output of a first wave of breakthrough projects in Spain.

Carbon pricing — applied effectively via a CBAM — is sufficient to tip the brownfield EAF conversion into a positive NPV

EXHIBIT 8

Impact of scenario levers on the NPV of breakthrough steel archetypes

Plant size:	Plant lifetime:	Utilisation rate:	Scrap intake:	Debt-to-equity:	Equity IRR:	Average interest rate:	FID date:
2 Mtpa	20 years	90%	0%	1.5	8%	6%	2024



Premium offtake assumptions for Scenario 2: Premium applied to 100% of offtake | Price premium declines over time, starting at:
- €101/t for HRC
- €123/t for HBI

Note: Assumptions remain the same as in Exhibit 3 unless otherwise stated.

Source: ETC analysis

and a payback period below 10 years without any additional levers. It has to be recognised, however, that the secondary steelmaking sector in Spain is relatively fragmented, which might make it challenging for a single player to secure the financing required to make upfront investments on the scale required for DRI production. Enabling FIDs on brownfield EAF conversions would likely require additional solutions beyond carbon pricing. Examples of such solutions could be joint ventures between multiple EAF operators to enable collective investment (while managing all the potential anti-trust issues) or direct government support on upfront capital expenditures — a feature of the next scenario.

3.1.2 Scenario 2 — Capturing new markets

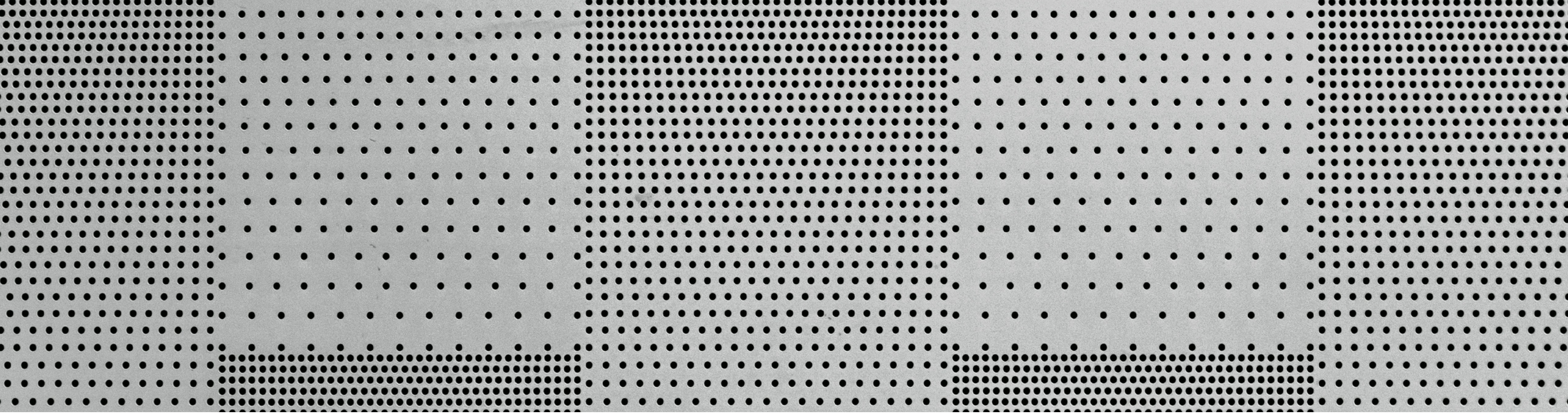
Scenario 2 assumes that government and buyers ascribe greater strategic value to breakthrough iron and steel, making them more willing to bear the costs of developing it. Consequently, the scenario builds on the carbon pricing applied in Scenario 1 by adding a green premium to offtake of low-emissions iron and steel. This would require clear and substantial demand for breakthrough iron and steel and a willingness among buyers to pay a commensurate premium. Additionally, a government subsidy is applied, equal to 20% of the capital expenditure of a new DRI unit.

A capital expenditure lever was applied because of the one-off nature of the support, which forum experts deemed more feasible than subsidising operational expenditures (such as electricity or green hydrogen) in a way that might require ongoing support over a long period of time. Moreover, there are already real-world examples of governments committing large amounts of funding to breakthrough steel projects in this way, such as the €1 billion of German state aid approved by the European Commission for the Salzgitter SALCOS project. Breakthrough iron and steel projects in Spain could similarly leverage EU or national government funding.

The scenario assumes the greenfield H_2 archetype being able to sell its steel initially at a premium of +€101/t (+19% above a market price of €524/t in 2024) and the merchant HBI archetype selling its iron initially at a premium of +€123/t (+38% above a market price of €323/t in 2024). The level of premium offtake applied to the greenfield H_2 archetype is also applied to the brownfield EAF conversion archetype to assess the resulting attractiveness of its business case. In principle, the latter would require no premium offtake to be viable, having already achieved a positive NPV in Scenario 1. Moreover, if the premium on breakthrough steel implied by Scenario 2 became achievable in practice, the brownfield EAF conversion could become increasingly attractive in its own right, meaning that the government would likely be unwilling to offer direct public subsidies for such projects.

Experts in the forum signalled a potential appetite in Spain and elsewhere in Europe to pay a premium for near-zero-emissions steel products, resulting from environmental, social, and governance (ESG) commitments and other pressures to decarbonise supply chains. The premium offtake in this scenario could materialise in the form of voluntary private sector demand but could equally be driven by green public procurement requirements on the part of government, as both types of buyers face growing pressure to reduce their upstream Scope 3 emissions.

While the competitive nature of wholesale iron and steel markets might make any price premium seem ambitious, it is crucial to note that the premium figures mentioned above represent a peak that would only apply to the first volumes of iron and steel produced by these projects, with the premium declining to zero over their lifetime. If the total premium paid by offtakers in Scenario 2 were averaged out across the lifetime production of the archetypes, it would amount to +€50/t of steel (+10% above market prices in 2024) and +€60/t of HBI (+19% above market prices in 2024) (see Exhibit 7, previous page). This declining premium aims to reflect how production costs for breakthrough projects will likely fall over time (particularly as key technologies, such as hydrogen electrolysers, continue to mature), thereby reducing the need for premium offtake to achieve viable margins. Moreover, the declining premium also represents that the market for breakthrough iron and steel products may see competition emerging in places with renewable energy resources equal to (or even superior to) Spain's, driving down the potential premium these products can achieve.



Moreover, the steelmaking archetypes are assumed to produce hot-rolled coil (HRC), meaning the price premiums applied in Scenario 2 relate to the market price for this steel product. Given the integrated nature of these archetypes, they would also have the potential to produce higher-grade steel products. Such products have historically enjoyed higher market prices, with higher-grade coated sheets securing prices 30%–60% above lower-grade hot-rolled products over the past ten years in Spain as an example.[xx] Although additional equipment investments and new customer relationships would be needed to allow breakthrough steelmakers to produce and sell these types of products, expanding offerings with higher-grade steel manufacturing could help cover the additional costs initially imposed by breakthrough technologies and reduce the need to secure offtake at a 'green' premium explicitly above market prices.

3.1.3 Scenario sensitivity and comparison

The levers applied in Scenarios 1 and 2 should not be presumed to *guarantee* an investable business case for breakthrough steel. The economics of steelmaking are sensitive to a variety of operational and market conditions, changes to any one of which could markedly affect the business case for a breakthrough iron or steel project (Exhibit 9, next page). For example, all scenarios assume investment in 2 Mtpa of production capacity for any given archetype, based on feedback from forum experts that a capacity of this size is both reasonable and offers good economies of scale. However, the majority of existing EAFs in Spain have capacities of less than 2 Mtpa, meaning that, in practice, an investment in the brownfield EAF conversion archetype may need to be sized accordingly or would require joint investment by multiple EAF operators. The possible reduction in economies of scale would need to be offset by other interventions to preserve a worthwhile investment case.

A few factors merit special mention, not only because of their potential impact on archetype finances but also their importance to the technical feasibility of potential projects. First, all scenarios (including the baseline case) assume the electricity needed by the archetypes (for process power as well as hydrogen electrolysis) would be supplied via baseload PPAs in which a significant majority of the power comes from renewables. A slowdown in the build-out of clean electricity infrastructure or rising costs to firm intermittent supply from renewables in Spain might cause the market for these PPAs to become constrained. This could force a switch to grid power that could cost these archetypes their 'breakthrough' status (by incurring greater indirect carbon emissions that would come with this alternative supply) and reduce their eligibility for government support.

Similarly, all scenarios assume co-located DRI production and hydrogen electrolysers, with the required infrastructure to supply the water and renewable electricity needed for onsite green hydrogen production. This assumption avoids the need to develop hydrogen transport and storage infrastructure, which could add to or constrain steel plant development timelines. While this might be a fair assumption for the two greenfield archetypes, as their location could be optimised accordingly, it may be more challenging for the brownfield archetype. If green hydrogen cannot be produced onsite, development of hydrogen networks based on pipelines and storage systems could provide an alternative means of firm supply in the medium to long term. The required infrastructure could impose additional costs (see Exhibit 9, next page), but those costs could be mitigated if there infrastructure were developed as part of a hub and designed to serve additional industrial users.

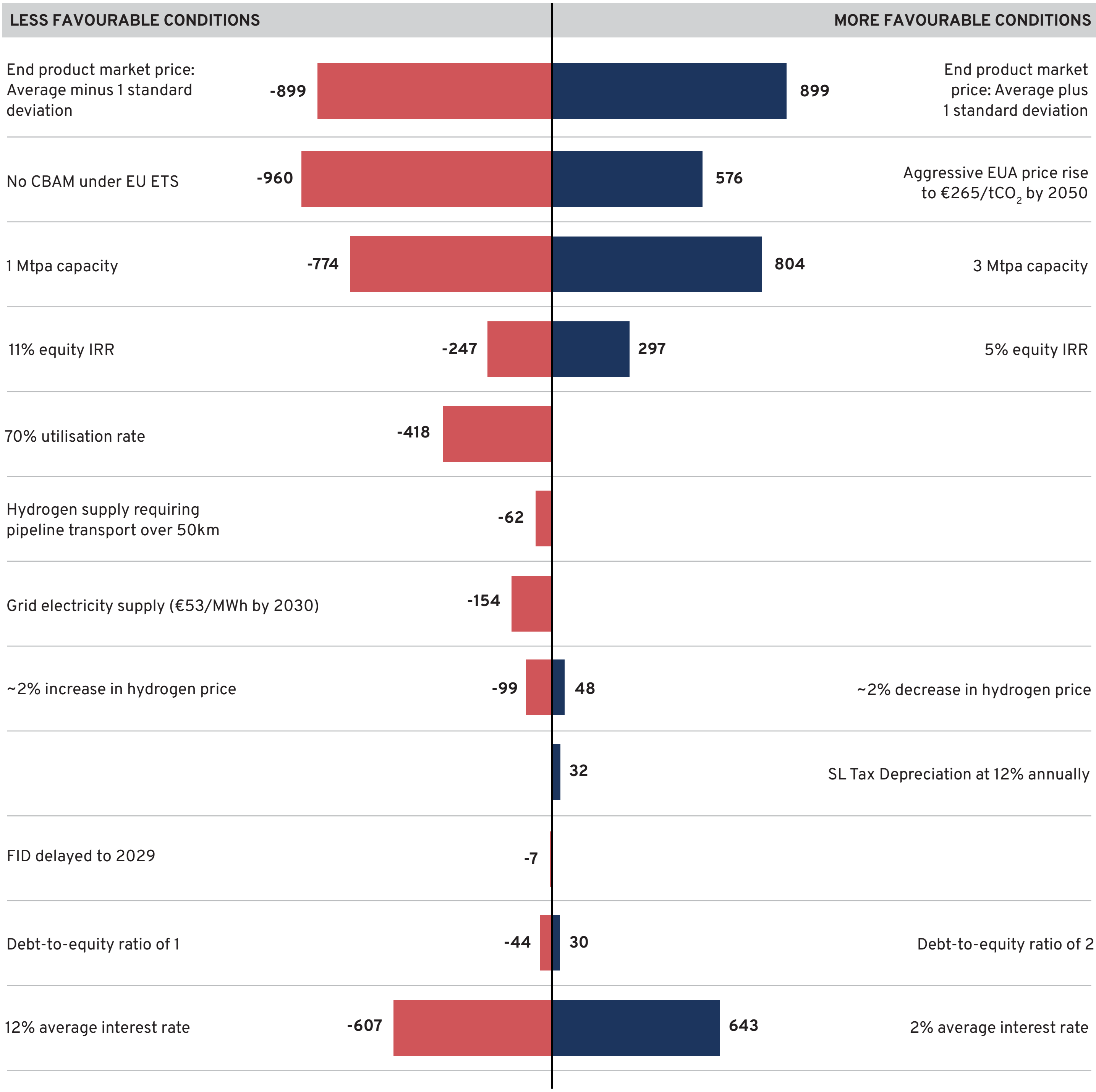
Lastly, the technology assumptions for all archetypes presume the use of high-grade iron ore, specifically iron ore fines with a 65% Fe content. The choice of a higher-grade iron ore product such as this helps to reduce the energy costs and slag (a waste byproduct) generated by the operation of the archetypes. While shifts in the price of this type of ore would affect the financial performance of the archetypes, securing a supply of it is essential in the first place. Given the prevalence of scrap-based steelmaking, Spain has not historically constituted a significant market for iron ore of any grade, meaning prospective breakthrough projects would need to go beyond existing ferrous supply chains in the country to secure the materials they need. Plans to mitigate the negative impact of potentially unfavourable future conditions, such as high prices for the inputs above, would be expected by any financier before committing capital.

xx Based on steel product price data from UN Comtrade and the World Bank.

Sensitivity of breakthrough steel archetype NPV to operational and commercial factors

Brownfield EAF conversion

Change in net present value under less and more favourable conditions, € millions



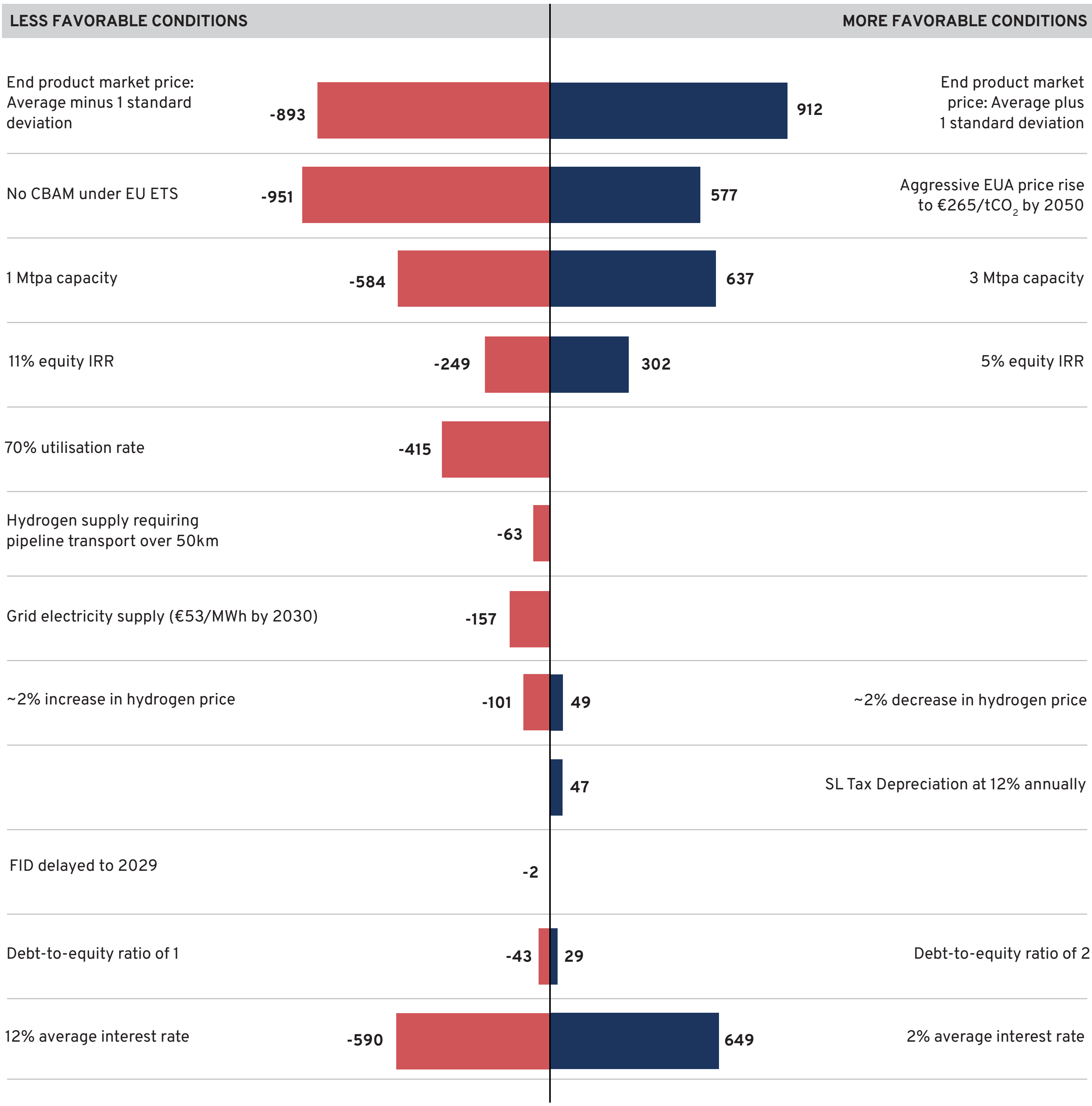
Note: For end product market prices, unfavourable and favourable conditions are represented by prices -1 or +1 standard deviation from historical prices (over the past 20 years), respectively. For the brownfield EAF conversion and greenfield H2 archetypes, the end product is HRC (€446/t vs. €603/t). For the merchant HBI archetype, the end product is HBI (€276/t vs. €369/t). Postponing the FID date benefits from lower future prices of electricity and hydrogen but misses peak premium offtake opportunities, as these are assumed to be greater in the immediate future, where the supply of breakthrough iron and steel would be scarce. For hydrogen prices, unfavourable and favourable conditions are created by increasing or decreasing electrolyser capital expenditure assumptions, respectively. All other assumptions remain the same as in Scenario 2 unless stated otherwise.

Source: ETC analysis

Continued: Sensitivity of breakthrough steel archetype NPV to operational and commercial factors

Greenfield H_2

Change in net present value under less and more favourable conditions, € millions



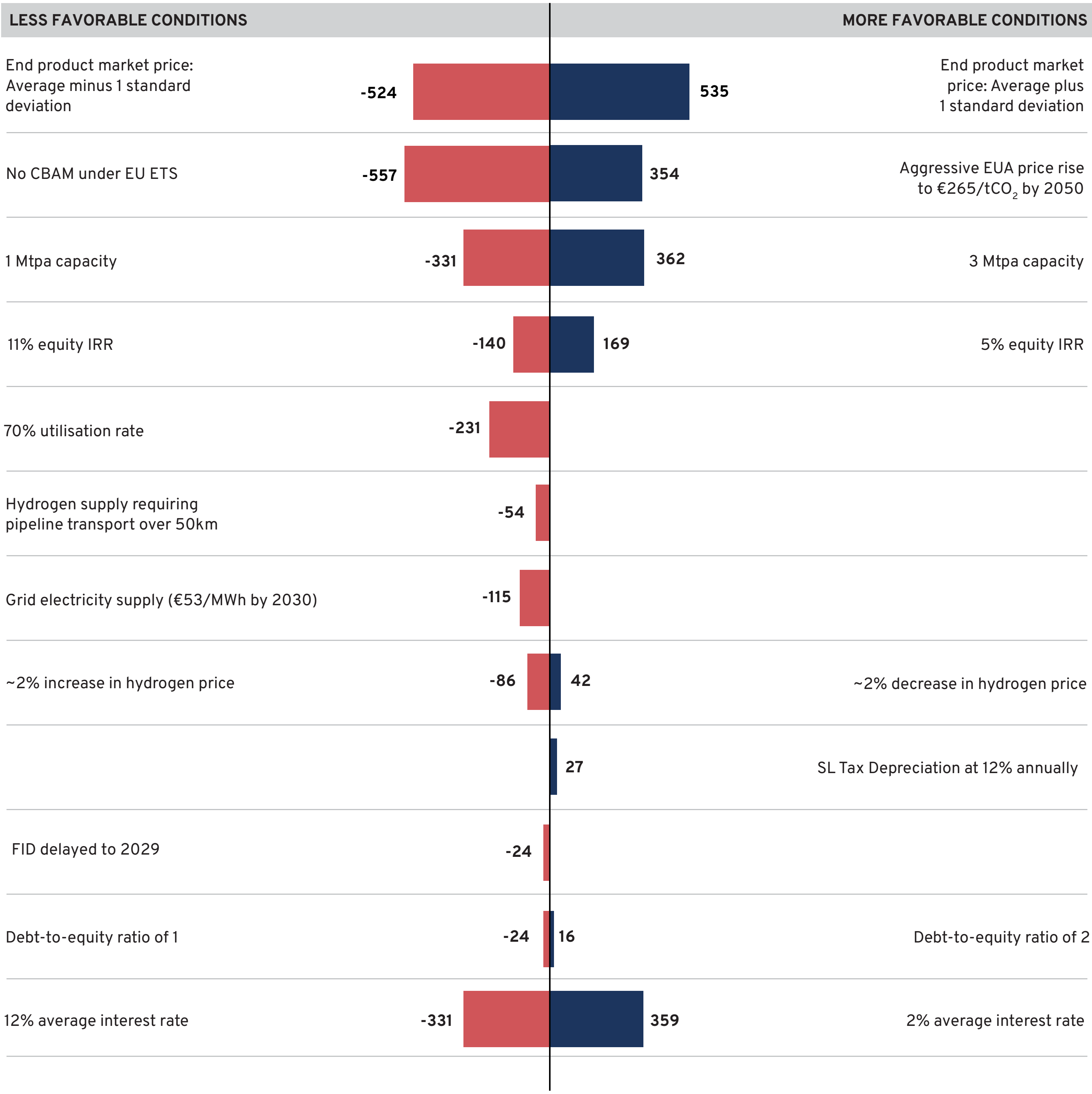
Note: For end product market prices, unfavourable and favourable conditions are represented by prices -1 or +1 standard deviation from historical prices (over the past 20 years), respectively. For the brownfield EAF conversion and greenfield H2 archetypes, the end product is HRC (€446/t vs. €603/t). For the merchant HBI archetype, the end product is HBI (€276/t vs. €369/t). Postponing the FID date benefits from lower future prices of electricity and hydrogen but misses peak premium offtake opportunities, as these are assumed to be greater in the immediate future, where the supply of breakthrough iron and steel would be scarce. For hydrogen prices, unfavourable and favourable conditions are created by increasing or decreasing electrolyser capital expenditure assumptions, respectively. All other assumptions remain the same as in Scenario 2 unless stated otherwise.

Source: ETC analysis

EXHIBIT 9

Continued: Sensitivity of breakthrough steel archetype NPV to operational and commercial factors

Merchant HBI *Change in net present value under less and more favourable conditions, € millions*

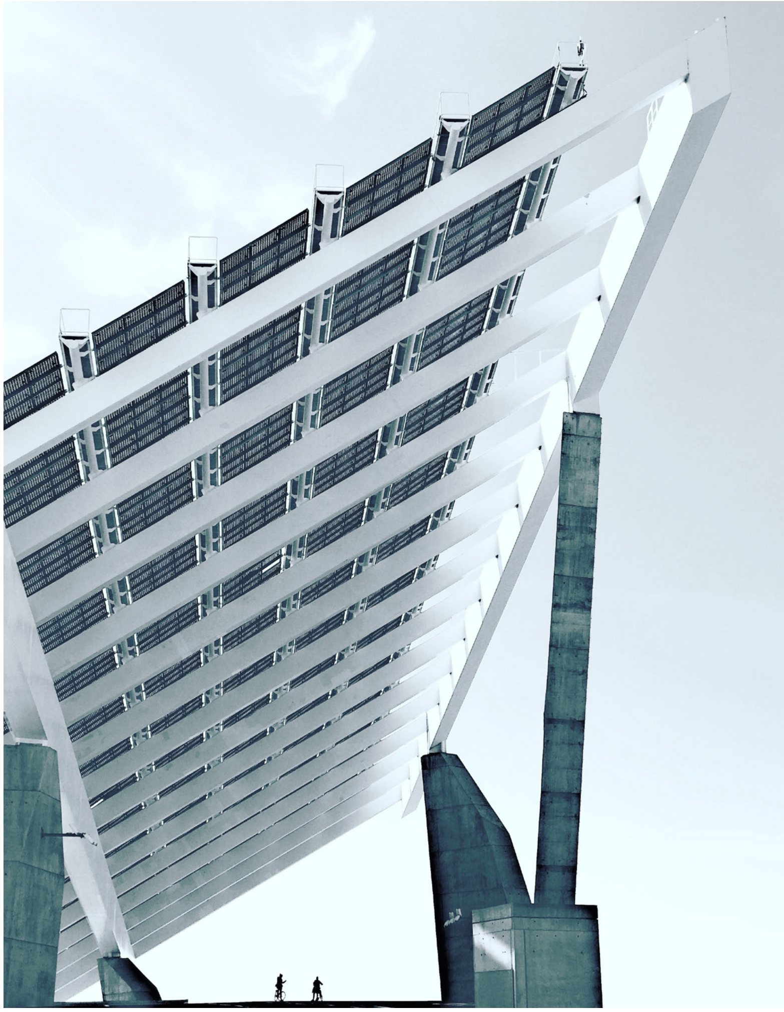


Note: For end product market prices, unfavourable and favourable conditions are represented by prices -1 or +1 standard deviation from historical prices (over the past 20 years), respectively. For the brownfield EAF conversion and greenfield H2 archetypes, the end product is HRC (€446/t vs. €603/t). For the merchant HBI archetype, the end product is HBI (€276/t vs. €369/t). Postponing the FID date benefits from lower future prices of electricity and hydrogen but misses peak premium offtake opportunities, as these are assumed to be greater in the immediate future, where the supply of breakthrough iron and steel would be scarce. For hydrogen prices, unfavourable and favourable conditions are created by increasing or decreasing electrolyser capital expenditure assumptions, respectively. All other assumptions remain the same as in Scenario 2 unless stated otherwise.

Source: ETC analysis

3.2 Additional Considerations for Achieving FID Status

Even if the discussed levers are applied to close the financial gap for breakthrough steelmaking, a positive *business case* does not guarantee a bankable *investment case*. To establish the latter and create the foundations for an FID, additional considerations must be taken into account, particularly around technology and project-specific risks.

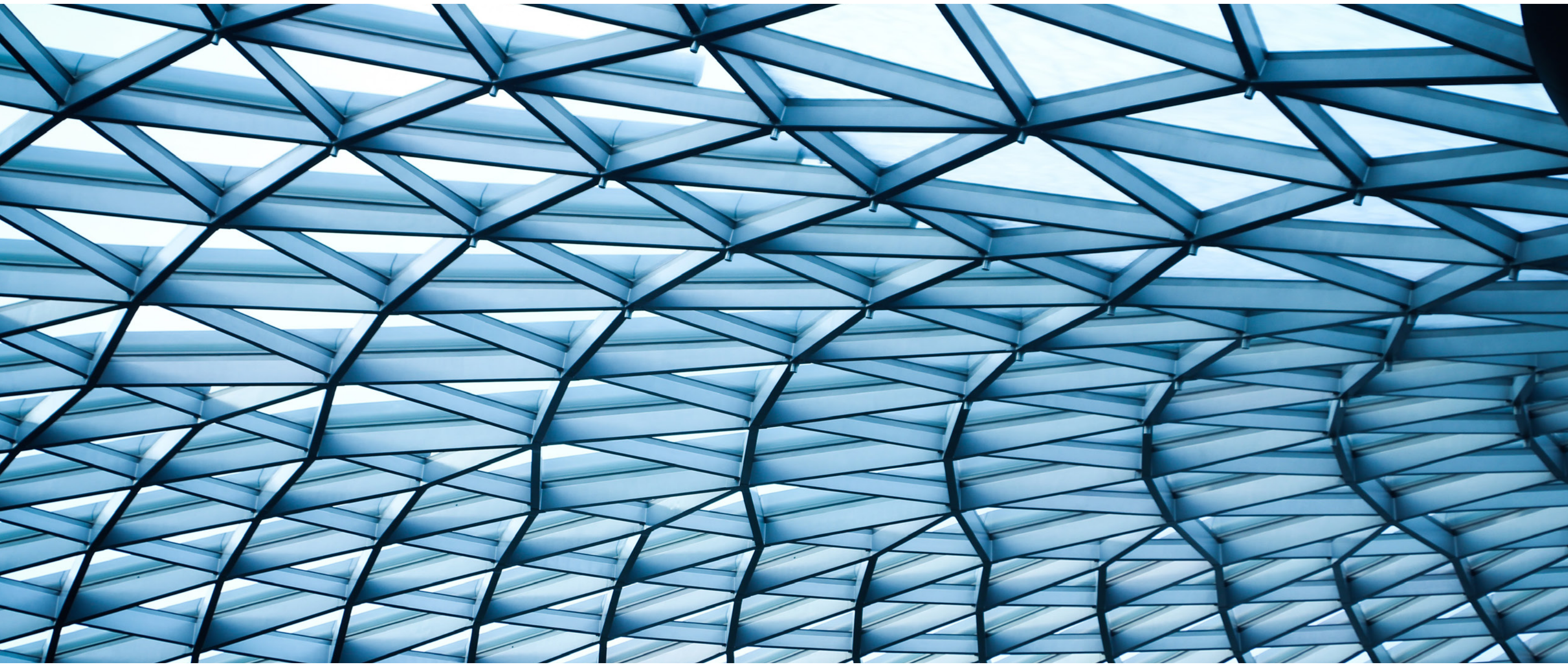


Given the relative novelty of the breakthrough steelmaking technologies considered in this report, a project proposal in Spain centred on such technologies would likely be treated as a first-of-a-kind (FoaK) investment. Given higher levels of uncertainty commonly associated with new technologies, financiers normally expect additional guarantees to mitigate technology risks before making FIDs on FoaK investments or else apply higher costs to the capital they provide to balance those risks. These guarantees or risk-management measures could take a variety of forms, including loan repayment guarantees offered by governments or the participation of public banks and development finance institutions in financing investments.

Lastly, an FID will be contingent on project-specific conditions that cannot be captured in an archetype-based assessment of an investment case. Factors such as the physical conditions of a target site or the financial health of its expected operator may present risks that can only be fully understood when project-specific assessments (such as feasibility studies) are carried out.

PART 4

CONCLUSIONS AND RECOMMENDATIONS



Assessing the investment case for breakthrough iron and steel in Spain offers insight for Southern Europe more widely. Alongside greening the energy supply for secondary steelmaking, breakthrough iron and steel technology is already being taken forward as the solution for decarbonising existing primary steelmaking in the region. However, the case for expanding breakthrough iron and steel capacity goes beyond industry decarbonisation. It offers benefits to the wider steel value chain in the region that it might not otherwise capture if breakthrough technologies are limited only to existing primary sites.

With strategic action, Southern Europe can leverage its excellent renewable energy resources to capture the new market for low-emissions and high-grade iron and steel emerging in Europe and elsewhere. Investing in breakthrough iron and steel technology would provide an additional means for Southern Europe to extract value from its local energy resources, grow regional industry to create high-value jobs, future-proof the ferrous supply chains of those steelmakers, and improve their ability to enter and compete in higher-value markets both at home and abroad.

Two scenarios demonstrate what would be needed to strengthen the investment case and accelerate FIDs on breakthrough steel projects in Spain, the implications of which offer insight for Southern Europe more broadly. The levers and additional considerations indicate there are prerequisites that would likely be essential under any scenario:

1. Investment in clean energy production and transportation infrastructure for both renewable electricity and green hydrogen
2. A progressive and effective carbon price regime applied to both domestic steel production and imports from abroad
3. Targeted government funding for first-of-a-kind (FoaK) projects
4. Mechanisms (for example, guarantees) to manage the technology risk associated with a FoaK project, which the government is likely best placed to offer

Given the significance of clean energy feedstocks to the cost of breakthrough iron and steel production, continued efforts to build out generation, transmission, and distribution infrastructure would be critical for ensuring breakthrough investments in Southern Europe have affordable access to these feedstocks. In addition to supporting the development of clean energy generally, industry and government should also look at targeted measures for breakthrough projects, such as exempting FoaK projects from power grid charges if captive renewable generation or baseload green PPAs are not possible. Going beyond electricity, if the technical feasibility of co-locating green hydrogen production with iron and steel mills proves limited, particular attention will also need to be given to scaling hydrogen transport and storage infrastructure.

On top of supporting clean energy development, governments will have additional crucial roles in realising breakthrough iron and steel projects in Southern Europe. Beyond effective carbon pricing on domestic production and imports (via the EU ETS and the CBAM), a degree of targeted support for breakthrough projects would likely be needed, particularly for greenfield projects. Given public sector preferences for one-off support mechanisms, governments should leverage existing funds or create new ones to support projects with the high upfront costs of breakthrough iron and steelmaking equipment. For example, the Spanish government could explore opportunities to offer capital expenditure subsidies for DRI equipment through the *proyecto estratégico para la recuperación y transformación económica* (PERTE) on industrial decarbonisation it recently approved in December 2022.

The choice of subsidy applied in the scenarios does not preclude other options. Indirect or ongoing forms of support could be at least as impactful. For example, if breakthrough iron or steel projects are coordinated with hydrogen projects that secure public funding support for clean hydrogen (for example, from the EU Hy2Use Important Project of Common European Interest [IPCEI] or the Spanish government PERTE on *energías renovables, hidrógeno renovable y almacenamiento* [ERHA] on renewable energy, green hydrogen, and storage), that support could be translated into hydrogen cost reductions that would improve the business case for breakthrough iron or steelmaking. In light of the sensitivity of steel investments to a variety of market and operational conditions (see Exhibit 9, pages 21-23), innovative mechanisms that help to manage the associated risks could be particularly effective. Contracts for difference (CfDs), whereby governments guarantee the price of breakthrough iron or steel, or carbon contracts for difference (CCfDs) that reward projects for avoiding emissions, could help firm up revenue streams for breakthrough investments and help them manage key market risks.

The opportunity offered by a growing need for low-emissions primary steel is already being seized, with the first breakthrough iron and steel projects emerging in Europe and North America. In response to this window of opportunity, Southern Europe is already seeing its first movers. Notable developments include the €460 million of Spanish state aid approved by the European Commission to support ArcelorMittal in converting its facility in Gijón to breakthrough technology, the agreement between Iberdrola and H2 Green Steel to develop a €2.3 billion green hydrogen facility in Iberia for greenfield DRI production, the announcement by Hydnum Steel of its plan to develop a brand new green steelmaking site in Puertollano, and the creation of DRI d'Italia S.p.A, a company established by the Italian national development agency to build the country's first DRI plant.[xxi] Although formal announcements of FIDs on their iron and steel components remain to be made, these projects highlight the region's potential for breakthrough investment.

One untapped opportunity is presented by the brownfield EAF conversion, particularly given that it does not appear far from an investable business case. An immediate next step would be for government and industry (particularly existing EAF steelmakers in the region) to come together to explore the opportunity. Private steel buyers around the world looking for low-emissions and high-grade products could offer a strong spur to action in this regard, particularly if their existing suppliers were based in locations that do not offer favourable conditions for breakthrough steelmaking. Such buyers would seek to purchase breakthrough steel from locations where it could be made competitively, such as Southern Europe, and so could send powerful signals to regional steelmakers of their willingness to act as offtakers for potential investments. These signals could be achieved through an alliance of steel buyers, not unlike the First Movers Coalition or SteelZero efforts globally but underpinned by firm volume-based commitments.

Looking beyond the relative economic and technical advantages and disadvantages of different archetypes, it is clear that Southern Europe offers a compelling opportunity for breakthrough iron and steel and vice versa. The recommendations made in this report would improve conditions for FIDs, both for projects already underway as well as any new ones yet to emerge, thereby creating a strong foundation to launch breakthrough steel in Southern Europe and, with it, a new green industrial revolution.

xxi Corporate announcements and press releases.

Energy Transitions Commission

The Energy Transitions Commission is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century.