UNLOCKING THE FIRST WAVE OF BREAKTHROUGH STEEL INVESTMENTS

in France

Prepared by

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PREFACE

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 on *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 supported the ETC to conduct a series of regionally focused forums to determine what is needed to make these projects investable under given local conditions.

This insight report outlines the findings of the forum centred on France. 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.

France's low-emissions electricity grid, existing orientation towards high-value steel manufacturing for export, and increasingly supportive policy environment offer a robust foundation for breakthrough, hydrogen-based iron- and steelmaking technologies. A few key additional measures, requiring the collaboration of the entire steel value chain, including both public and private actors, would strengthen the investment case for these technologies and create conditions for FIDs. These measures include: effective carbon pricing on steel imports into the EU (as well as domestic production), a stable and affordable low-carbon electricity supply (potentially via a more developed market for power purchase agreements), forward offtake agreements (at an initial, proportional price premium), guarantees to de-risk new technology, and direct government funding for high upfront equipment costs. Alternatively, ambitious government support for breakthrough iron and steel, targeted at key operational expenditures such as hydrogen costs, would be enough to secure the investment case.

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PART I

THE CASE FOR BREAKTHROUGH STEEL IN FRANCE

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 (GHGs) 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.

Through the Ultra-Low CO_2 Steelmaking (ULCOS) project, France has been actively pursuing solutions to steel sector decarbonisation since the early 2000s,[ii] yet progress remains limited. In 2020, France adopted a revised National Low Carbon Strategy (*Stratégie Nationale Bas-Carbone* or SNBC) that aims to reduce the country's industrial carbon emissions by 35% by 2030 (compared to 2015).[iii] The composition of steelmaking in France presents a challenge to achieving that goal. Between 2019 and 2022, France produced an average of 13 million tonnes per annum (Mtpa) of crude steel,[iv] of which the majority (68%) was produced from primary (ore-based) steelmaking at integrated blast furnace–basic oxygen furnaces (BF-BOF) sites (Exhibit 1, next page).[v] This primary production yielded, on average, 1.7 tonnes of CO_2 per tonne of steel.

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

ii ULCOS was a consortium of 48 European companies and organisations from 15 European countries, formed to oversee research and development initiatives that would enable significant CO_2 emissions reductions from steel production.

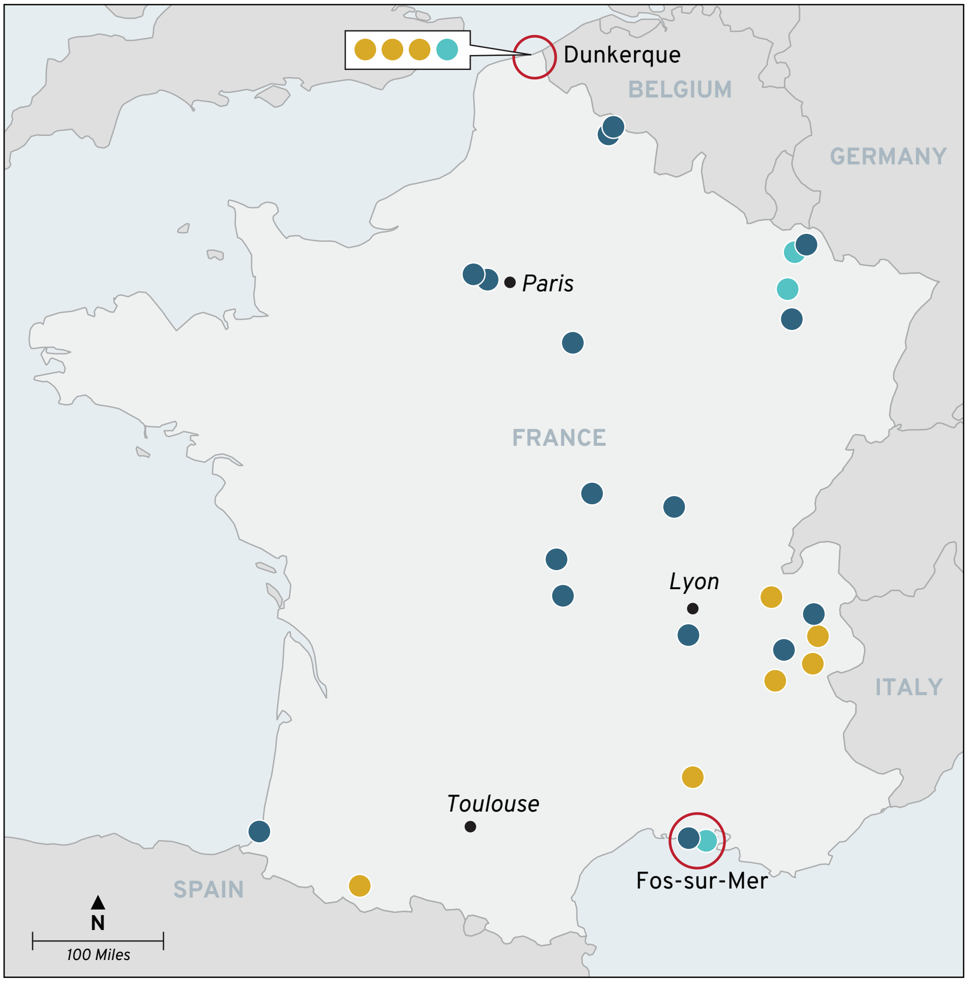
iii *Stratégie Nationale Bas-Carbone*, Ministère de la Transition écologique, July 2022.

iv *World Steel in Figures 2022*, World Steel Association.

v *Global Steel Plant Tracker*, Global Energy Monitor, March 2022.

Locations of France's steel mills

EXHIBIT 1



Plant type

- BF-BOF
- EAF
- Ferroalloys/downstream processing
- Zones Industrielles Bas Carbone (ZIBaC)

Crude Steel Production Capacity
Million tonnes per year

Total BF-BOF Capacity	**~11.9**
BF-BOF Average Capacity	**~4.0**
Total EAF Capacity	**~5.5**
EAF Average Capacity	**~0.8**

Notes: The map includes all sites in France, including some that have been idled within the past decade. The French steel production figures cited previously do not reach the total capacity figures in the exhibit because some sites have been idled and because even those that are active do not normally operate at full capacity. ZIBaCs are low-carbon industrial hubs, designated by the French government as part of its industrial decarbonisation strategy. The ZIBaCs in Dunkerque and Fos-sur-Mer are the first two to be established.

Source: Global Steel Plant Tracker, Global Energy Monitor, March 2022; Sectoral Transition Plan of the French Steel Industry, ADEME (to be published in 2023)

The French Agency for Ecological Transition (ADEME) notes the importance of scrap steel in reducing emissions in the sector.[vi] The potential to increase the share of secondary (recycled scrap-based) steelmaking via electric arc furnace (EAF) production is possible given that France currently exports around 5.5 Mtpa of scrap steel. Yet the need to reach France's climate targets and supply its domestic energy, automotive and defence industries with high-grade steels, principally sourced from integrated, ore-based production processes, will require a profound transformation of France's primary steelmaking assets by 2030 even if the balance of primary and secondary steelmaking shifts.

Decarbonising the steel sector presents both a challenge and an opportunity for France. European steel consumption is skewed towards higher-grade 'flat' steels (produced via primary production routes) to meet European manufacturing requirements, particularly for the automotive sector, where most sector experts believe the lead market for green steel will originate. France's international steel trade balance is strongly oriented towards flat products, with 70% of exports and 52% of imports in 2021 falling into this category.[vii] The French steel industry possesses significant downstream steel processing capabilities (such as hot rolling, cold rolling, and coating), processes that could be integrated into decarbonised iron and steel production.

The decarbonisation of steel will be driven, above all, by energy feedstocks, particularly clean electricity (as Part 2 of this report illustrates). France's nuclear-dominated low-emissions power system, which provides comparatively competitive industrial power pricing with EU peers, creates conditions for France to be an early mover in steel decarbonisation.

Maintaining an affordable supply of low-carbon electricity, will no doubt necessitate an expansion of low-carbon electricity generation capacity. As France undergoes its energy transition,

vi *'Les Plans de Transition Sectoriels,'* ADEME, December 2021.

vii Based on International Trade Organization data.

total final energy consumption in the form of electricity could rise to as much as 762 TWh per year by 2050 (60% growth from 2021), as the country becomes increasingly electrified.[viii] Supply will need to keep pace with demand to avoid rising prices for electricity consumers, including steelmakers. The inclusion of nuclear technology in the EU taxonomy of environmentally sustainable economic activity, including the production of electrolytic (green) hydrogen,[ix] will help France leverage its nuclear capabilities in addressing growing demand for low-carbon power. The production of green hydrogen could become a significant driver for an expansion of low-carbon power generation, particularly in light of recent EU regulation defining renewable hydrogen (namely the requirement that it be produced using 'additional' low-carbon electricity capacity, as opposed to existing capacity).[x]

The overall policy environment is also becoming increasingly favourable for breakthrough iron and steel development in France. The European Commission's recently announced Green Deal Industrial Plan intends to support industrial decarbonisation in the bloc, particularly via changes to state-aid rules for projects.[xi] At the national level, the *France 2030* plan, announced by the government in 2022, allocates €5.6 billion of funding to tackle industry decarbonisation.[xii] The details of how this budget will be deployed are currently being devised (potentially involving direct subsidies, grants, and/or more complex mechanisms, such as carbon contracts for difference).[xiii] In parallel, the government has announced it intends to focus on the country's top 50 highest-emitting industrial sites, directing a possible additional €5 billion to this end and requiring the operators of those sites to present decarbonisation plans.[xiv] Moreover, the government will also prioritise developing at least 10 low-carbon industrial hubs (*Zones Industrielles Bas Carbone* or ZIBaCs), with calls for projects open until May 2023.

These conditions mean breakthrough iron and steel technology, involving the production of direct reduced iron (DRI) using low-carbon hydrogen, is already progressing in France. In late 2022, ArcelorMittal announced a €1.7 billion investment plan to decarbonise its French BF-BOF assets in Dunkerque and Fos-sur-Mer, which include the development of an integrated H_2-DRI-EAF facility at their Dunkerque site.[xv] These plans have already secured support from the government, including up to

€13.6 million of funding for engineering and feasibility studies to develop the Dunkerque ZIBaC.[xvi] Separately, a consortium-backed merchant green iron company, GravitHy, announced plans to build a 2 Mtpa facility in Fos-sur-Mer to be operational by 2027.[xvii]

Formal announcements of FIDs have yet to be attained for these projects in France. Meanwhile, FIDs for such projects have been reached in Sweden, Canada, and Germany. The combination of increasingly favourable supply-side policies, existing competitive low-emissions power, and auspicious domestic and export markets means France is well positioned to join this list in the near term.

viii *Transition(s) 2050 Synthèse*, ADEME, March 22, p. 16.

ix *Taxonomy: MEPs do not object to inclusion of gas and nuclear activities*, European Parliament, July 2022.

x *Delegated regulation on Union methodology for RNFBOs*, European Commission, February 2023.

xi *A Green Deal Industrial Plan for the Net-Zero Age*, European Commission, February 2023.

xii *La décarbonation de l'industrie se poursuit avec France 2030*, ADEME, March 2022.

xiii *Comment profiter des 5,6 milliards de France 2030*, L'Usine Nouvelle, February 2022.

xiv *Macron unveils decarbonisation strategy for France's industrial sector*, Euractiv, November 2022.

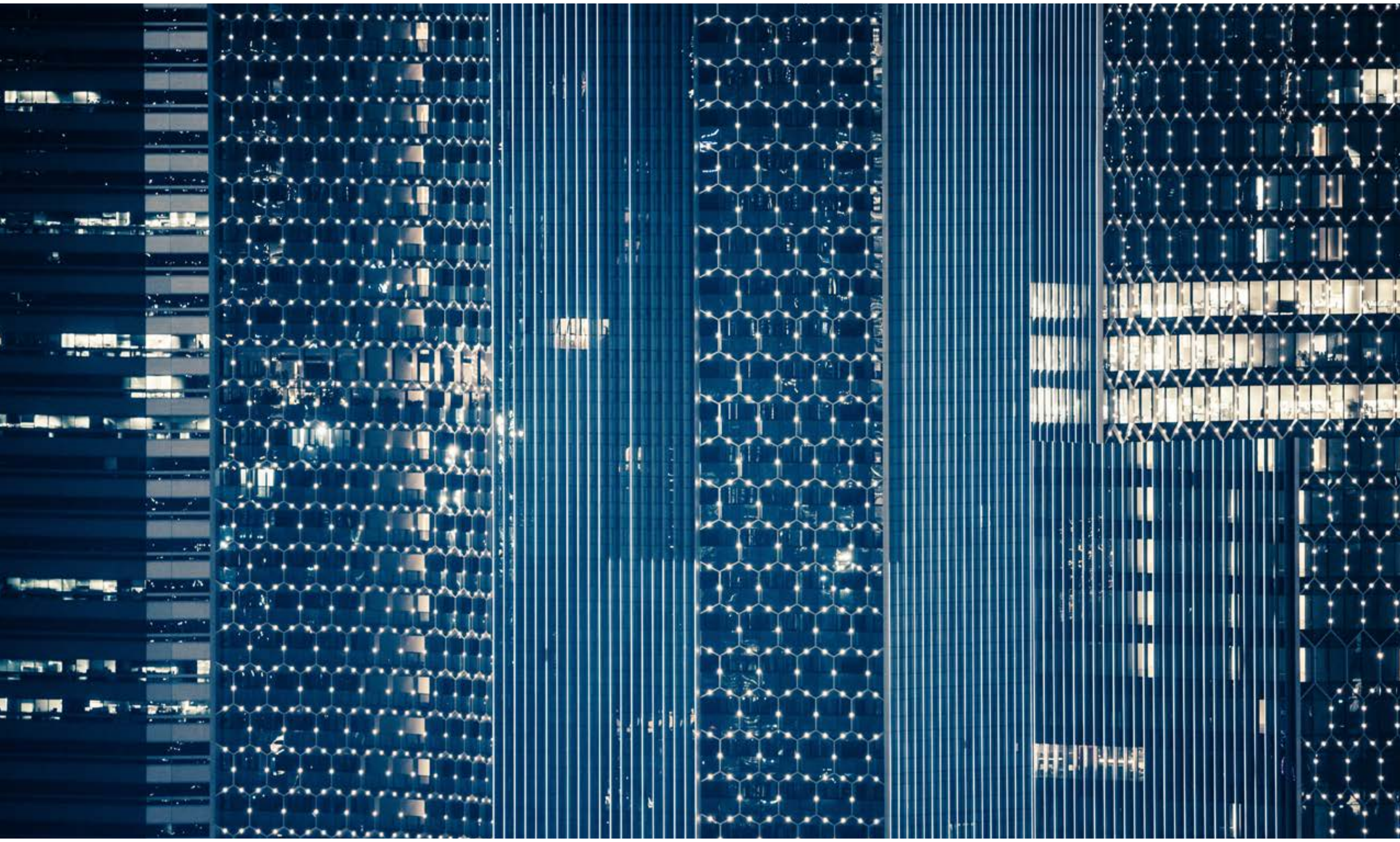
xv *1,7 milliard d'investissements pour accélérer la décarbonation*, ArcelorMittal, February 2022.

xvi *France 2030 | Annonce des zones industrialo-portuaires de Dunkerque et de Fos sur Mer, lauréates de l'AAP « zones industrielles bas carbone » (ZIBAC)*, Secrétariat général pour l'investissement (SGPI), January 2023.

xvii *GravitHy, imminent market leader in green iron and steel, is launched today by world-class industrial consortium*, GravitHy, June 2022.

PART 2

THE ECONOMICS OF BREAKTHROUGH STEEL INVESTMENTS



Steelmaking is highly capital-intensive, requiring significant investment into assets with long life spans.[xviii] While investors typically expect steel assets to pay back their up-front investment in 10 years or fewer, steel facilities can operate for decades. 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 studies. The nature of these investments also means they must often be delivered through complex financial structures, combining different funding sources and parties. An 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. FID status, therefore, represents a vital stage gate in realising a steel project in the real world.

xviii All monetary values in this report 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.

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 France's 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.

To underpin forum discussions, the ETC developed an open-source tool that models the financials of different breakthrough iron and steel investments.[xix] 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 France.

Analysis and discussion within the forums revolved around a set of breakthrough iron and 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 while avoiding debate on particular assets.

All the archetypes were centred on green hydrogen–based direct reduced iron (H_2-DRI) as a reference for breakthrough ironmaking technology, paired either with an EAF or a melter in combination with a BOF for steel production. EAFs and BOFs are already well-established steelmaking technologies, and H_2-DRI was selected because (a) its technology readiness level (TRL)[xx] and (b) its international project pipeline are the highest of all near-zero-emissions ironmaking technologies,

EXHIBIT 2

Select breakthrough steel project archetypes for France

	Brownfield total conversion	Brownfield EAF conversion	Brownfield melter conversion	Merchant HBI
Existing technology	BF-BOF	EAF	BF-BOF	N/A – Greenfield
Target site technology	DRI and EAF	DRI and EAF	DRI, Melter, and BOF	DRI (for export as HBI)
DRI feedstock	100% green H_2	100% green H_2	100% green H_2	100% green H_2
Capital expenditure	€766 million	€647 million	€774 million	€687 million
Potential emissions reductions	97%	0%/97%	97%	97%
Known developments	• ArcelorMittal, France • ArcelorMittal, Spain • Tata Steel, Netherlands • Salzgitter, Germany	• N/A	• Thyssenkrupp, Germany	• GravitHy, France • H2 Green Steel, Iberia

Notes: Capital expenditure assumes investment in 2 Mtpa of production capacity. 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 based on grid electricity. Adding H_2-DRI production to an existing EAF would not lower the emissions of the existing site but could displace emissions from BF-BOF primary steelmaking elsewhere operating under the assumptions above (hence the '0%/97%' notation).

Source: ETC analysis

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

xx 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 although the technology has seen further development since then.

with 60 Mtpa of planned capacity globally as of mid-2022.[xxi] Consequently, H_2-DRI ironmaking combined with commercially mature technologies for steel production were considered the most credible contender for commercial-scale near-zero-emissions 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 four archetypes selected for France were chosen based on their relevance to the country's steelmaking context and were validated by forum participants and other expert stakeholders.[xxii] Importantly, the selected archetypes specifically avoid adding new *greenfield steelmaking* capacity, given problems stemming from excess steelmaking capacity globally and the preference of forum participants to focus on archetypes that would not add to these problems.

1. **Brownfield total conversion**
   - Retrofitting an existing BF-BOF site and switching it to H_2-DRI-EAF technology. Relevant given France's existing BF-BOF sites and the country's decarbonisation ambitions.

2. **Brownfield EAF conversion**
   - Retrofitting an existing EAF site by adding H_2-DRI production capacity. Relevant given the prevalence of EAFs in France and the opportunity the archetype would offer to enable higher-grade steel production through existing assets.

3. **Brownfield melter conversion**
   - Retrofitting an existing BF-BOF site by adding H_2-DRI production capacity and a melter to prepare the DRI for steelmaking in the BOF. Also relevant given France's existing BF-BOF sites and the country's decarbonisation ambitions, plus the opportunity to preserve existing BOFs, which may be able to accept DRI made from lower qualities of iron ore.

4. **Merchant HBI**
   - Building a greenfield, stand-alone H_2-DRI production facility to manufacture hot briquetted iron (HBI) for sale to steelmakers domestically or internationally. An option to leverage potentially favourable conditions for low-carbon ironmaking in France that could help decarbonise other assets in the country and elsewhere without building new steel capacity or managing the complexities of retrofitting existing assets.

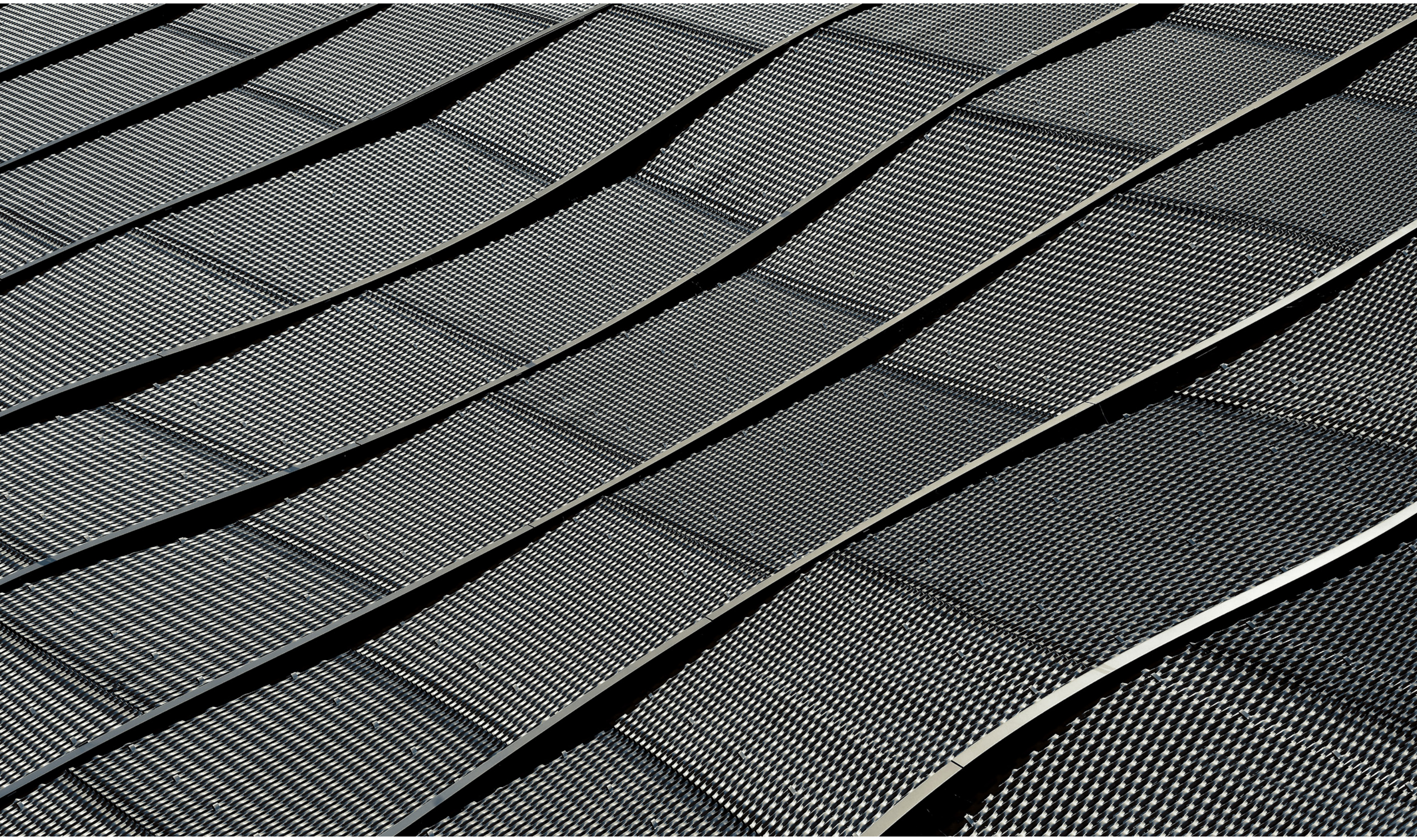
xxi ETC analysis based on company announcements, press releases, and discussions with industry.

xxii The DRI technology archetypes analysed in this report are not exhaustive, with variants including the use of submerged arc furnace (SAF) technology for steelmaking. Several projects and feasibility studies employing alternative technologies were announced over the course of the forum. It is possible to explore additional variants in the accompanying financial model, provided the techno-economic input assumptions can be sourced.

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).[xxiii] Considering the NPV of the four archetypes in France today, alongside a comparison of production costs versus prevailing market prices, it is hard to make a case for breakthrough steel investment under current conditions (Exhibit 3, next page). Although France has carbon pricing in the form of the European Union Emissions Trading System (EU ETS), this has not been included in the baseline analysis. This is because factors such as EU ETS free allowances for steelmakers and the lack of comparable carbon pricing levied on imports from outside the EU mean that carbon pricing is not fully reflected in steel market prices (and therefore archetype financial performance) (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 up-front capital expenditure in iron and steel plant equipment (see Exhibit 2, page 9) heavily impact the NPV values as they result in strongly negative cash flows in the initial years for all four archetypes. In addition, high levels of operational expenditure result in a levelised cost of production (LCOP) that is higher than projected market prices (up to 16% higher for steel, depending on the archetype, and 35% for merchant HBI).[xxiv] 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.

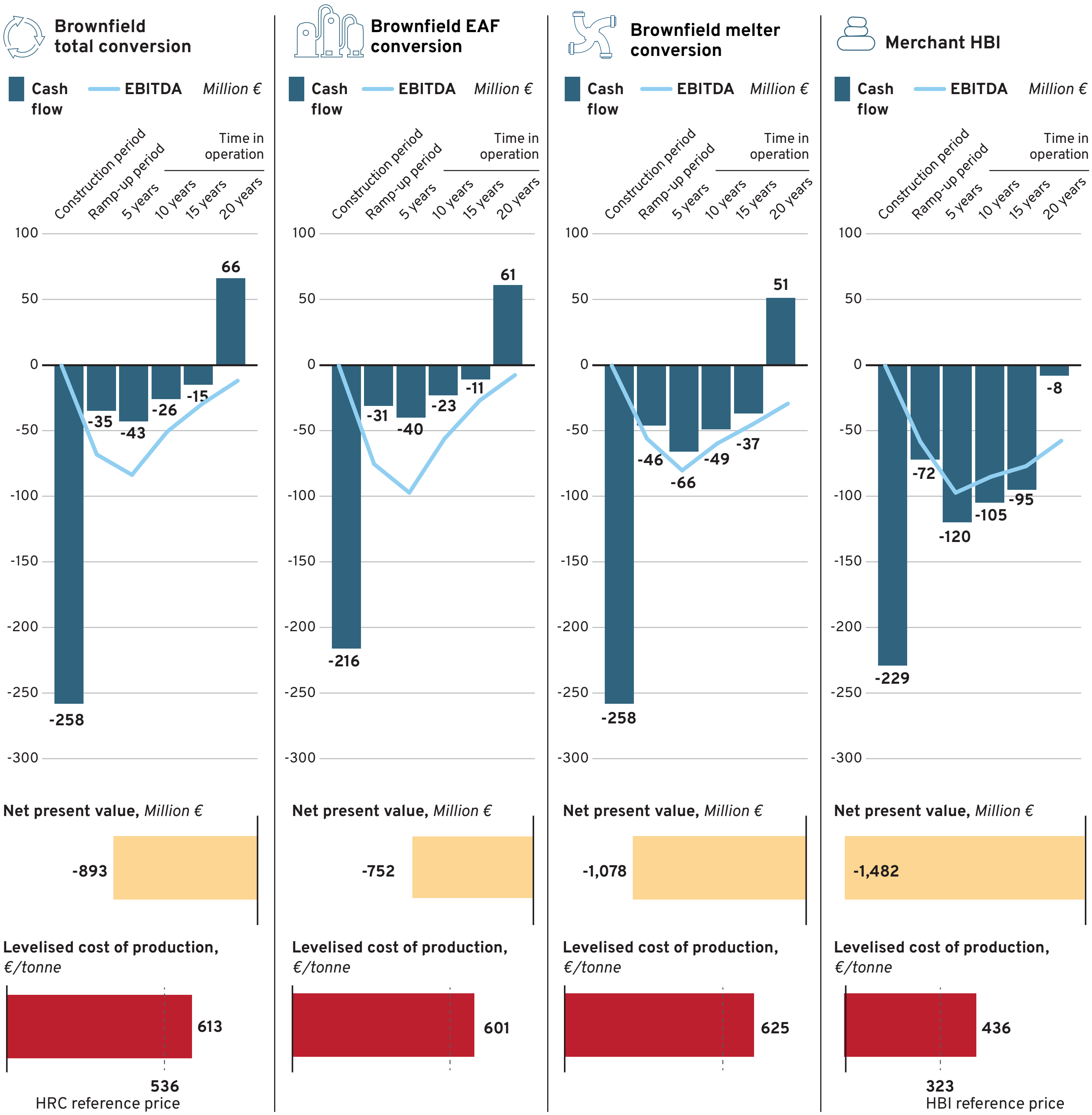


xxiii NPV is the unlevered difference between the present value of cash inflows and the present value of cash outflows over a period of time.

xxiv 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 but pre-tax basis. Unlevered NPV values, on the other hand, include tax but do not include interest expenses. For more information on financial methodologies, please see the Technical Appendix to this report.

The breakthrough steel business case in France under baseline conditions

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



Note: EBITDA refers to earnings before interest, taxes, depreciation, and amortization. Financials assume three years for construction and one year to ramp up production, 15 years for debt repayment with a one-year grace period, 25% tax on earnings, and the Inland Revenue Service's (IRS) General Depreciation System (GDS) Straight Line method to account for depreciation over seven years. IRR refers to the internal rate of return assumed for equity 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 produces hot briquetted iron (HBI), whose price projections are based on historical global price behavior as reported by Steel on the Net. NPV figures do not take into account any residual or non-amortised value of existing assets for brownfield archetypes.

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 for the four archetypes offers insight into the key cost drivers of breakthrough iron and steel (Exhibit 4).

Under baseline conditions in France, the most impactful and actionable cost drivers are:

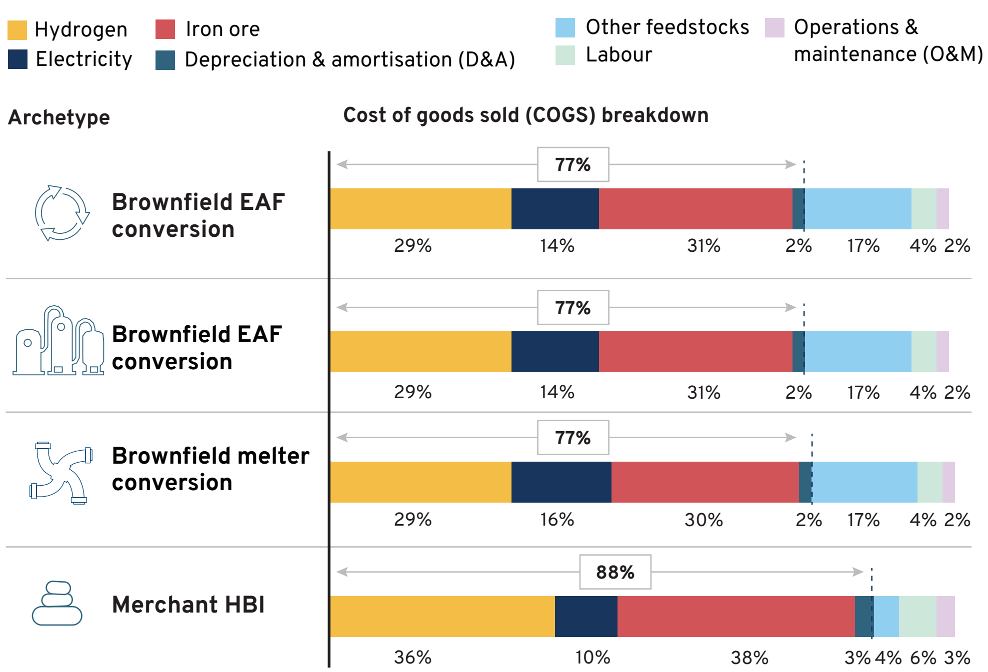
- **(Green) hydrogen (29%–36%):** The main feedstock utilised by all four archetypes to process iron ore into DRI, for transformation into steel. The merchant HBI archetype is particularly sensitive to hydrogen costs because there are fewer downstream processing costs to dilute its impact. Hydrogen cost is driven mainly by the price of power delivered to electrolysers.
- **Electricity (10%–16%):** The main power source for various pieces of plant equipment, particularly the electrical heating equipment integral to the steelmaking archetypes (either an EAF or melter).
- **Iron ore (30%–38%):** Key ferrous base material for integrated steelmaking. Merchant HBI archetype faces a proportionally higher sensitivity in this category because it involves less downstream processing.
- **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. The capital expenditure of all archetypes is relatively consistent owing to the common DRI furnace cost.

Taken together, these categories amount to between 77% and 88% of the cost of producing breakthrough iron and steel in France, 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 iron and steel

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



% of energy, ferrous input, and capex on COGS

	Price CAGR, *2024-2050*	2024 reference price
Scrap	1%	€310/t
Electricity	0%	€51/MWh
Hydrogen	-1%	€3/kg H_2
HRC	0%	€536/t
HBI	1%	€323/t

Note: CAGR refers to compound annual growth rate. See Exhibit 3 note for underlying assumptions.

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 France investable and unlock FIDs. Discussions among stakeholders highlighted a variety of levers that could be applied to improve the business case.

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

EXHIBIT 5

Most impactful levers on the financials of breakthrough iron and steel

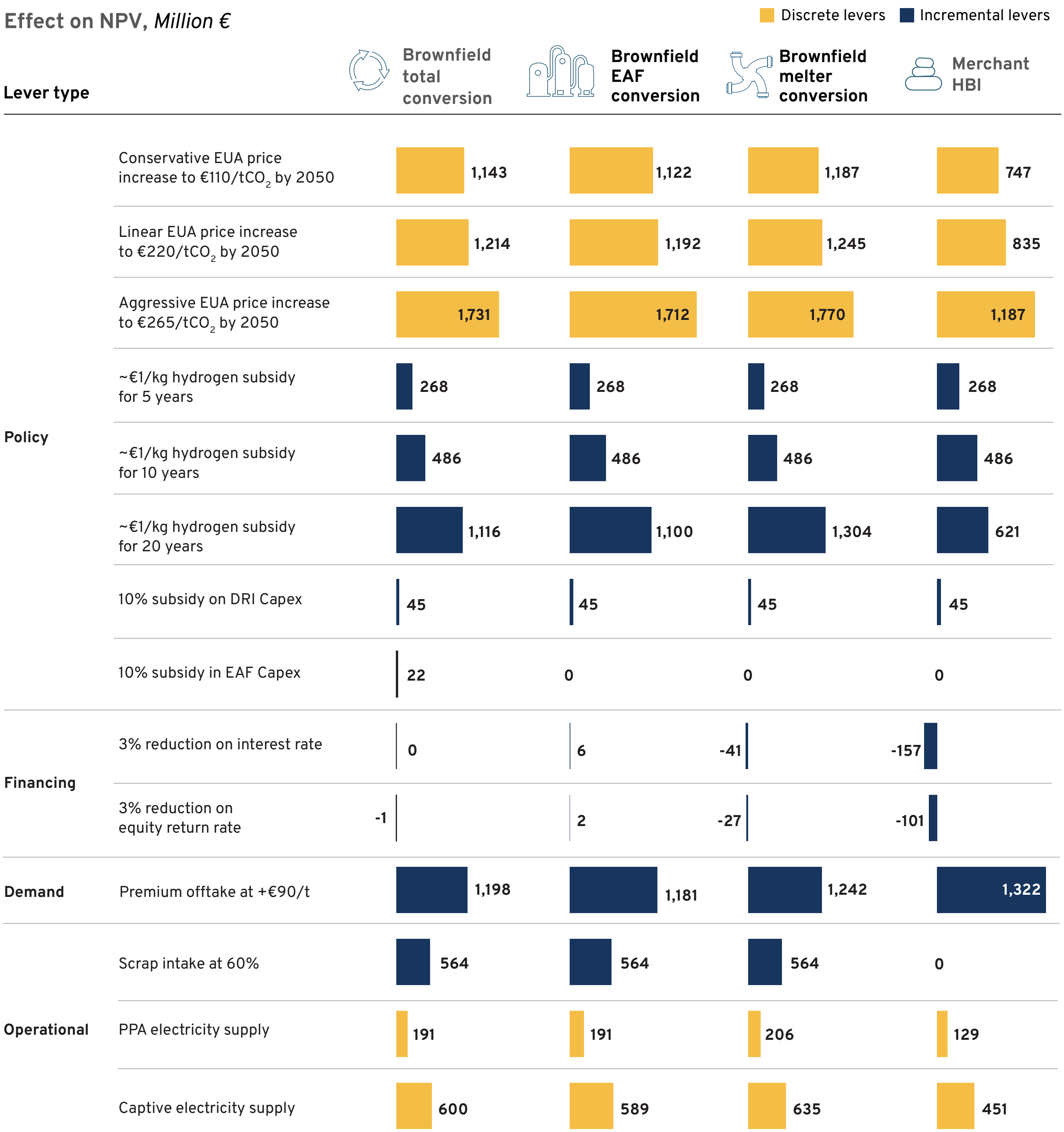
Lever	Description
Effective carbon pricing	Raises the production cost of conventional, emissions-intensive iron- and steelmaking, thereby raising the overall market price of these products. This improves the margins of a breakthrough mill by allowing it to sell its products at market price while avoiding the carbon costs of carbon-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.
Operational expenditure subsidies	Applies a direct subsidy to key operational inputs (such as electricity or green hydrogen), which manifest as lower market prices for these inputs, thereby lowering production costs.
Capital expenditure subsidies	Applies a direct subsidy to cover part of the up-front cost of new iron and steelmaking equipment. Such subsidies also effectively reduce the debt financing required by a breakthrough project, lowering the interest paid over its lifetime.
Premium offtake	Guarantees a given price for some or all of the production from a breakthrough iron or steel mill. Additionally, premium offtake 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.
Higher scrap intake	Optimises ferrous input, increasing scrap consumption if it is cheaper than producing DRI and reducing scrap intake if the opposite is true.

Source: ETC analysis

EXHIBIT 6

Sensitivity of breakthrough iron and steel archetypes to different levers

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



Note: Assumptions remain the same as in Exhibit 3 unless otherwise stated. EUA refers to EU emissions allowance, a representation of the price of carbon under the EU ETS. Smallimprovements in equity IRR and interest rate (represented by the financing levers) can result in a negative effect on project NPV given that a reduction in the value of capital can also lower its benefit as a tax 'shield, thereby decreasing overall NPV. Financing levers such as these should not be assumed to have a linear impact on archetype financial performance.

Source: ETC analysis

PART 3

A WAY FORWARD

While France's energy, domestic and export steel markets, and policy environment present a comparatively favourable enabling environment, additional action is needed to create the necessary conditions for investable breakthrough iron- and steelmaking business cases. In this section, we set out two perspectives that are differentiated by the extent to which the French government is willing to lead and support the development of breakthrough iron and steelmaking.

3.1 Two Perspectives to Progress to FIDs

To understand the combined effect of levers needed for an investable case for breakthrough steel in France, two scenarios set out plausible pathways to FIDs (Exhibit 7).

Both scenarios explore what would be needed to establish a compelling investment case for the archetypes, defined as a positive NPV and a payback period of approximately 10 years. They should not be treated as prescriptive roadmaps to FIDs, but rather an indication of the scale and form of intervention required to strengthen the investment case for breakthrough iron and steel in France.

- **Scenario 1 – Whole-value-chain cooperation:** A combination of government, industry, and buyer action (in the form of effective carbon pricing, including an EU CBAM, targeted government support for up-front capital expenditures, scrap intake, and forward offtake agreements at an initial price premium) creates a viable investment case for the archetypes.
- **Scenario 2 – Enhanced government support:** Robust operational subsidies are applied alongside effective carbon pricing to create a viable investment case for the archetypes.

To achieve attractive business cases for the archetypes in question, a combination of levers were applied (Exhibit 8, pages 18-19). The choice and size of the levers aimed to strike a balance between 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).

EXHIBIT 7

Overview of scenario assumptions across different archetypes

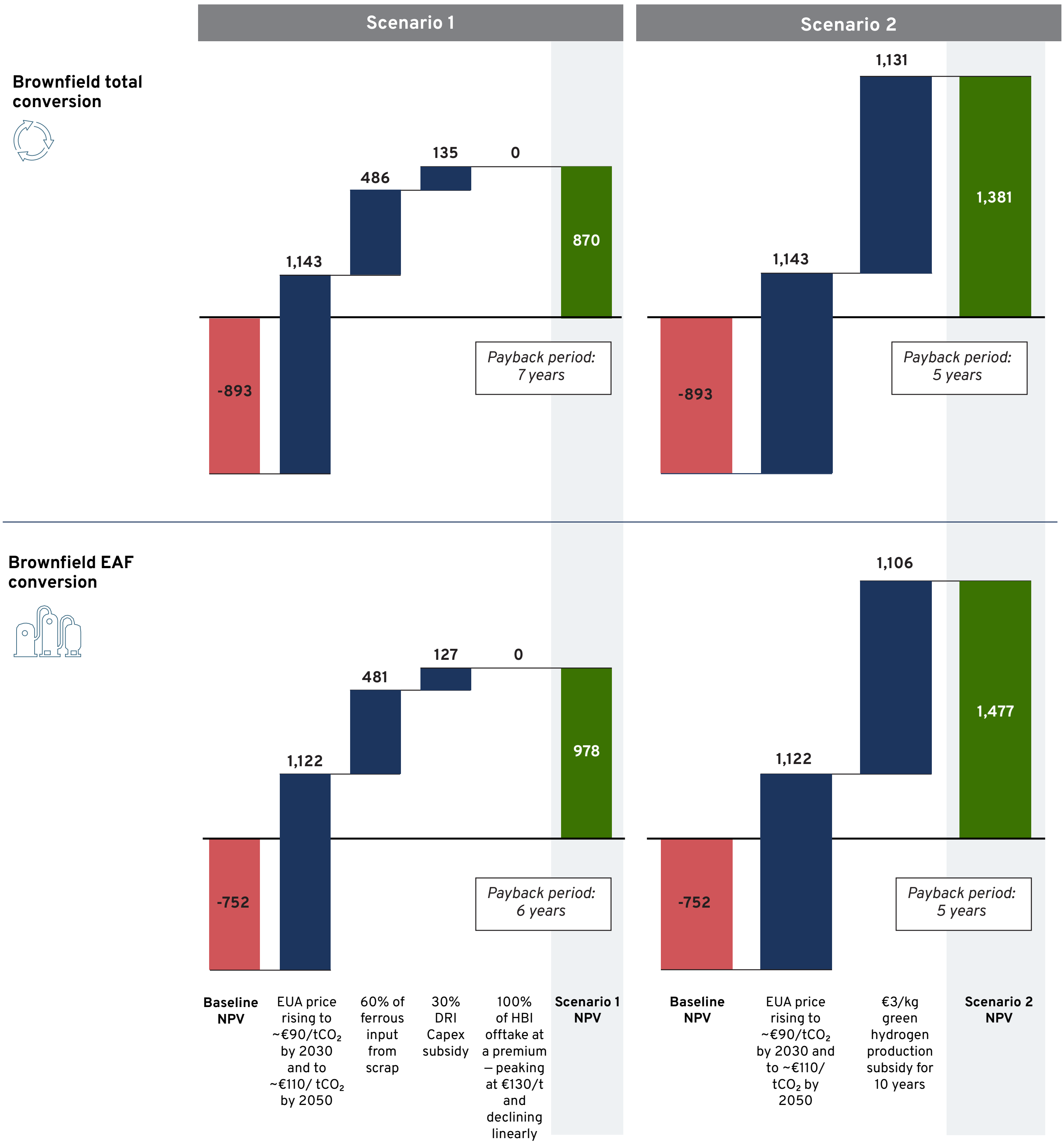
Metric		Scenario 1		Scenario 2	
Archetype		**Brownfield conversions**	**Merchant HBI**	**Brownfield conversions**	**Merchant HBI**
Production capacity	Million tonnes per year	2	2	2	2
Capital expenditure outlay	Million €	647-775	687	647-775	687
Payback period	Years	6-10	10	5-6	8
Net present value	Million €	729-979	423	1,239-1,477	531
Levelised cost of production	€ per tonne of end-product	553-578	428	507-531	341
Average profit before taxes	€ per tonne of end-product	84-102	46	117-135	53
Average premium (over the market price) for premium offtake over project lifetime	€ per tonne of end-product	0	65	0	0
Direct government subsidy	Million €	149 (Capex)	149 (Capex)	2,551 (Opex)	2,551 (Opex)

Source: ETC analysis

EXHIBIT 8

Impact of scenario levers on the NPV and payback period of breakthrough iron and steel archetypes

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



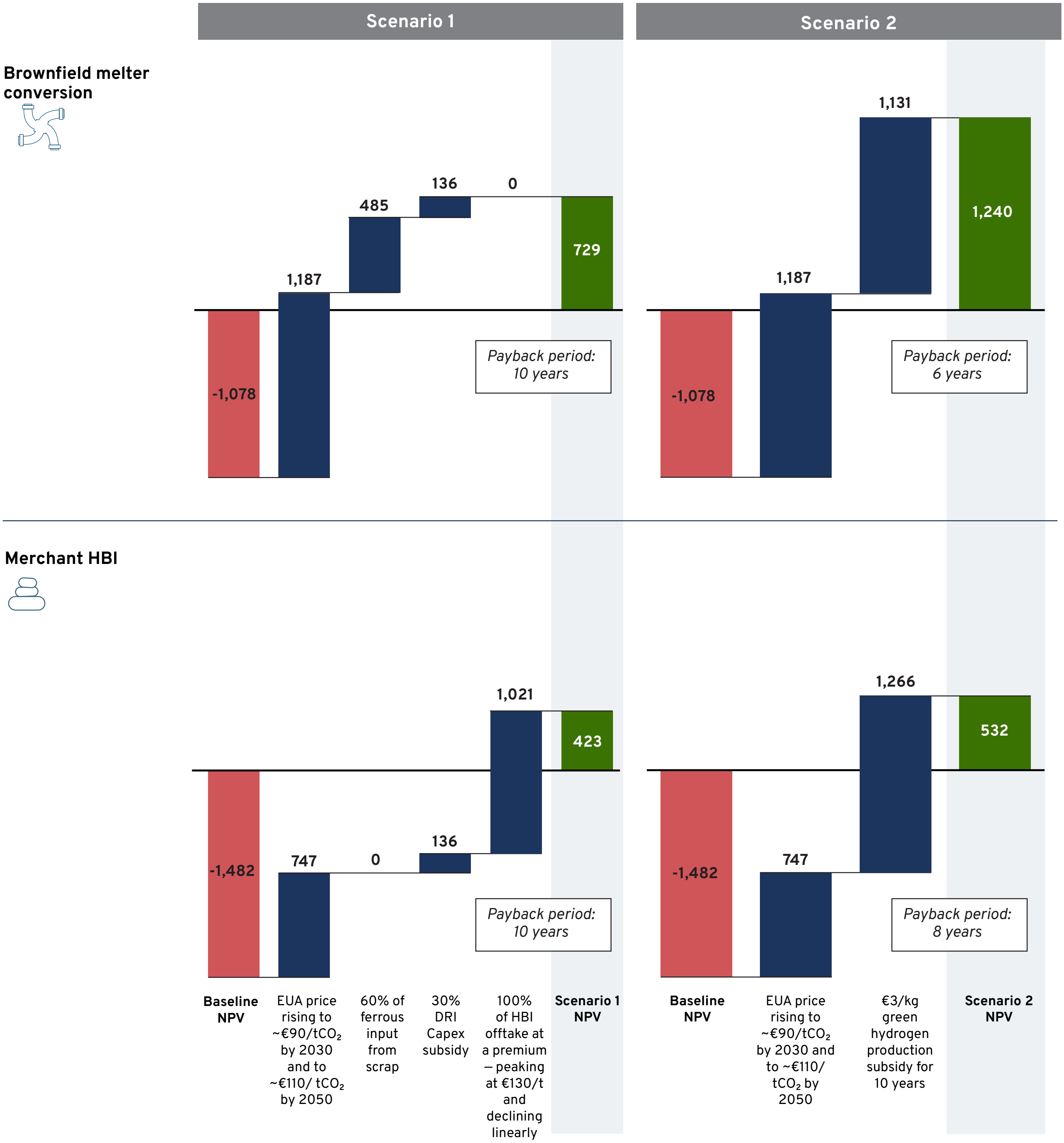
Note: Assumptions remain the same as in Exhibit 3 unless otherwise stated. Carbon pricing assumes gradual phaseout of free allocations for steel by the end of 2034 and the implementation of an effective EU CBAM.

Source: ETC analysis

EXHIBIT 8

Impact of scenario levers on the NPV and payback period of breakthrough iron and steel archetypes (continued)

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



Note: Assumptions remain the same as in Exhibit 3 unless otherwise stated. Carbon pricing assumes gradual phaseout of free allocations for steel by the end of 2034 and the implementation of an effective EU CBAM.

Source: ETC analysis

3.1.1 Scenario 1 — Whole-value-chain cooperation

Scenario 1 envisages the strategic value of breakthrough iron and steel is recognised across the French steel value chain, and additional costs involved in making projects investable are borne more equally by the government, industry, and buyers.

A key lever underpinning Scenario 1 is an effective carbon price regime that creates a level playing field between breakthrough iron and steel products 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. While the 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.

Carbon pricing is assumed to apply to all markets where French breakthrough iron and steel would be sold (see Exhibit 5, page 14), and an effective CBAM is assumed to be in place by 2026. The practical implication of the scenario would be that breakthrough iron and steel products would be sold in France and the EU. This assumes a continuation of existing French domestic and export market trends in which less than 2% of French flat steel production is exported to markets outside the EU.[xxv] It also assumes the first FID projects are able to secure offtake within domestic and EU markets.

Effectively applied, the impact of even a modest carbon price rise (to €90/t CO_2 by 2030 and to €110/t CO_2 by 2050) is significant, already achieving a positive NPV for all three brownfield archetypes. However, payback periods for these archetypes remain in excess of 10 years, meaning additional levers are required to strengthen the investment case. One of these is to increase the proportion of scrap in the ferrous input to production (from 0% to 60%). Assuming 2 Mtpa of capacity and a 90% utilisation rate, this would imply over 1.1 Mtpa of scrap consumption for a breakthrough steel plant. While this a significant amount, diverting even a portion of France's 5.5 Mtpa of scrap exports towards breakthrough steelmaking should be sufficient to meet the needs of a first wave of projects.

Given that the steelmaking archetypes use electrical heating in one form or another to process scrap, ensuring an affordable supply of power would be vital to enabling this lever in practice. Additionally, increasing scrap intake presents a trade-off at the facility level. Scrap can lower production costs when it is more affordable to buy than to produce DRI from hydrogen, but using end-of-life scrap adds impurities (so-called tramp elements) that can prevent the resulting steel from being utilised for higher-grade applications. For example, certain flat steel products must contain less than 0.1 weight percent (wt pct) copper to avoid metallurgical problems. Enhanced scrap sorting and upgrading are possible, but they impose additional costs, not least from additional energy consumption.

To ensure reasonable payback periods for the brownfield archetypes, Scenario 1 also applies a government subsidy equal to 30% of the capital expenditure of a new DRI unit. Forum experts considered such a subsidy preferable by the government compared to long-running operational expenditure supports (such as electricity or green hydrogen). Crucially, there are already real-world examples and precedents 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.[xxvi]

xxv Based on 2021 data for **flat product** exports (from Alliance des Minerais, Minéraux et Métaux) as a proportion of **domestic oxygen (primary) steel production** (from worldsteel).

xxvi ***State aid: Commission approves €1 billion German measure***, European Commission, October 2022.

Given that the merchant HBI archetype does not produce steel, and so does not benefit from the scrap intake lever, alternative action is needed to strengthen its investment case. This action takes the form of forward purchase agreements at a price premium. The scenario sees the archetype being able to secure offtake agreements for HBI at an initial premium of +€130/t (+40% above forecast 2024 market prices). Forum experts noted the market for conventional merchant HBI is relatively less commoditised, and there is currently no supply of near-zero-emissions HBI anywhere in the world. Consequently, the first volumes of breakthrough HBI are likely to be able to command a premium, driven directly by conventional steelmakers seeking to produce low-emissions flat products and indirectly by steel users looking to buy such products.

The price premium of 40% would represent a peak that would only apply to the first volumes of output produced by a merchant HBI project, with the premium declining to zero over the lifetime of the project as the market increasingly commodifies, breakthrough technologies mature, and the carbon costs of emissions-intensive production continue to rise. If the total premium achieved by the project were averaged over its total lifetime production, it would equal +€65/t (+20% above market prices in 2024; see Exhibit 7, page 17).

3.1.2 Enhanced government support

Scenario 2 assumes a greater appetite on the part of the government to bear the costs of supporting the development of breakthrough iron and steel value chains in France. It applies the same carbon pricing regime as Scenario 1 but, in place of subsidising capital expenditures, it applies substantial operational support in the form of a green hydrogen production subsidy, available for 10 years starting from the date at which the archetypes begin operations (in this case, 2027 given an FID date of 2024).

Scenario 2 explores how high levels of ongoing government support could affect the financial performance of the given archetypes in France. Although such support might be complex to implement, comparable approaches already exist today or are being planned. The ~€2.6/kg hydrogen subsidy applied in the scenario was purposefully designed to mirror the US$3/kg hydrogen production tax credit provision approved under the Inflation Reaction Act (IRA) in the United States. In response to this provision of the IRA, the European Commission has now also announced operational support for green hydrogen production. As part of its Green Deal Industrial Plan, the Commission communicated that it will auction fixed premiums for renewable hydrogen production, with the first auction due to be launched in the autumn of 2023 funded by €800 million from the EU Innovation Fund.[xxvii]

The ongoing nature of the hydrogen production subsidies in Scenario 2 results in a higher total cost to the government, up to €2.6 billion cumulatively (in contrast to the €0.2 billion of up-front DRI capital expenditure subsidies applied in Scenario 1). Given the comparatively higher cost implications, subsidies targeting operational expenditures would only be merited where long-term costs would fall as a result. In Scenario 2, French hydrogen production costs are assumed to fall by 15% by 2035 (driven by global technology cost curves).

3.1.3 Scenario sensitivity

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, pages 22-25).

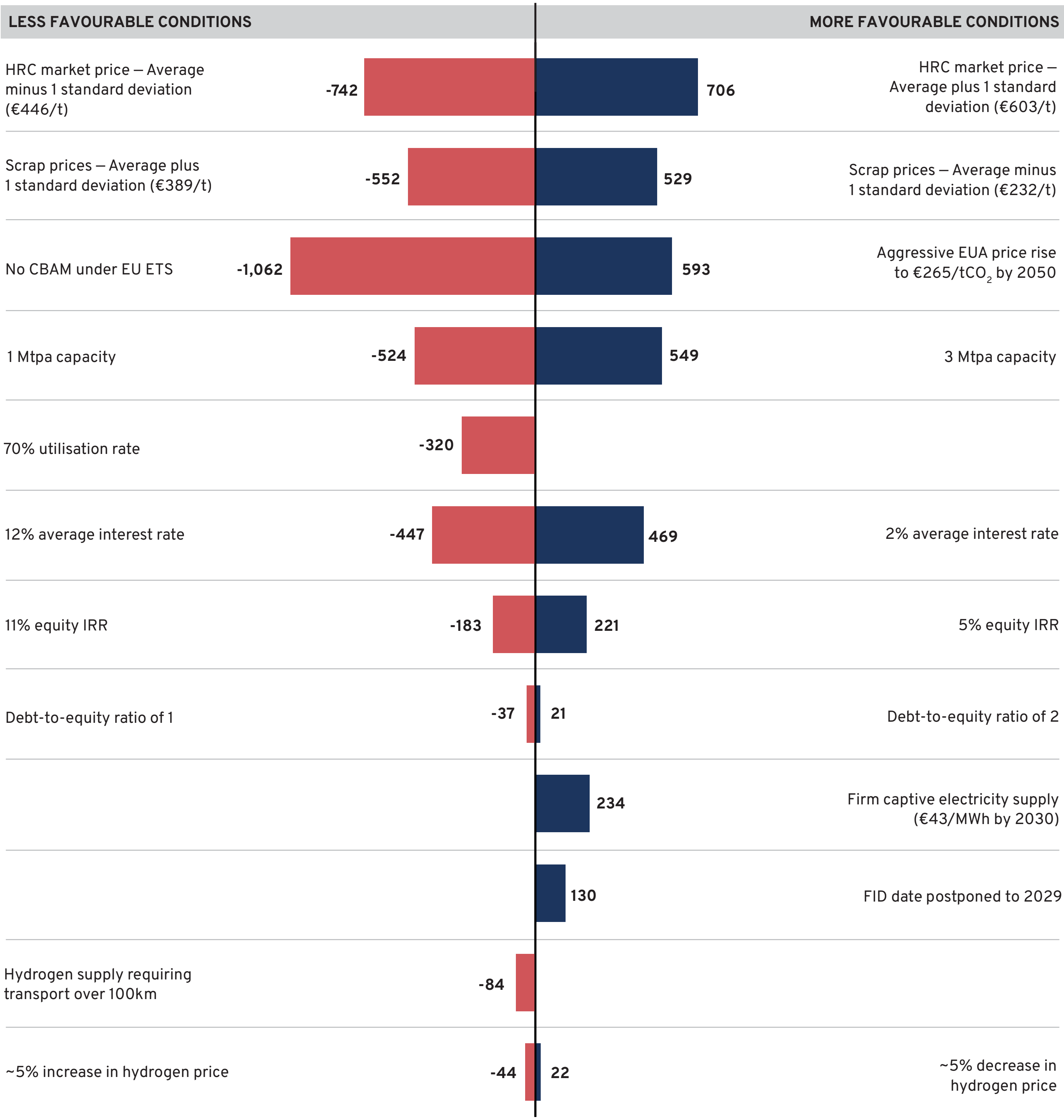
xxvii *A Green Deal Industrial Plan for the Net-Zero Age*, European Commission, February 2023, p. 12.

EXHIBIT 9

Sensitivity of breakthrough steel archetype NPV to operational and commercial factors

Brownfield total conversion

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

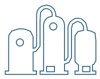


Note: For hydrogen prices, unfavourable and favourable conditions are created by increasing or decreasing electrolyser capital expenditure assumptions, respectively. All other assumptions remain the same as in Scenario 1 unless stated otherwise.

Source: ETC analysis

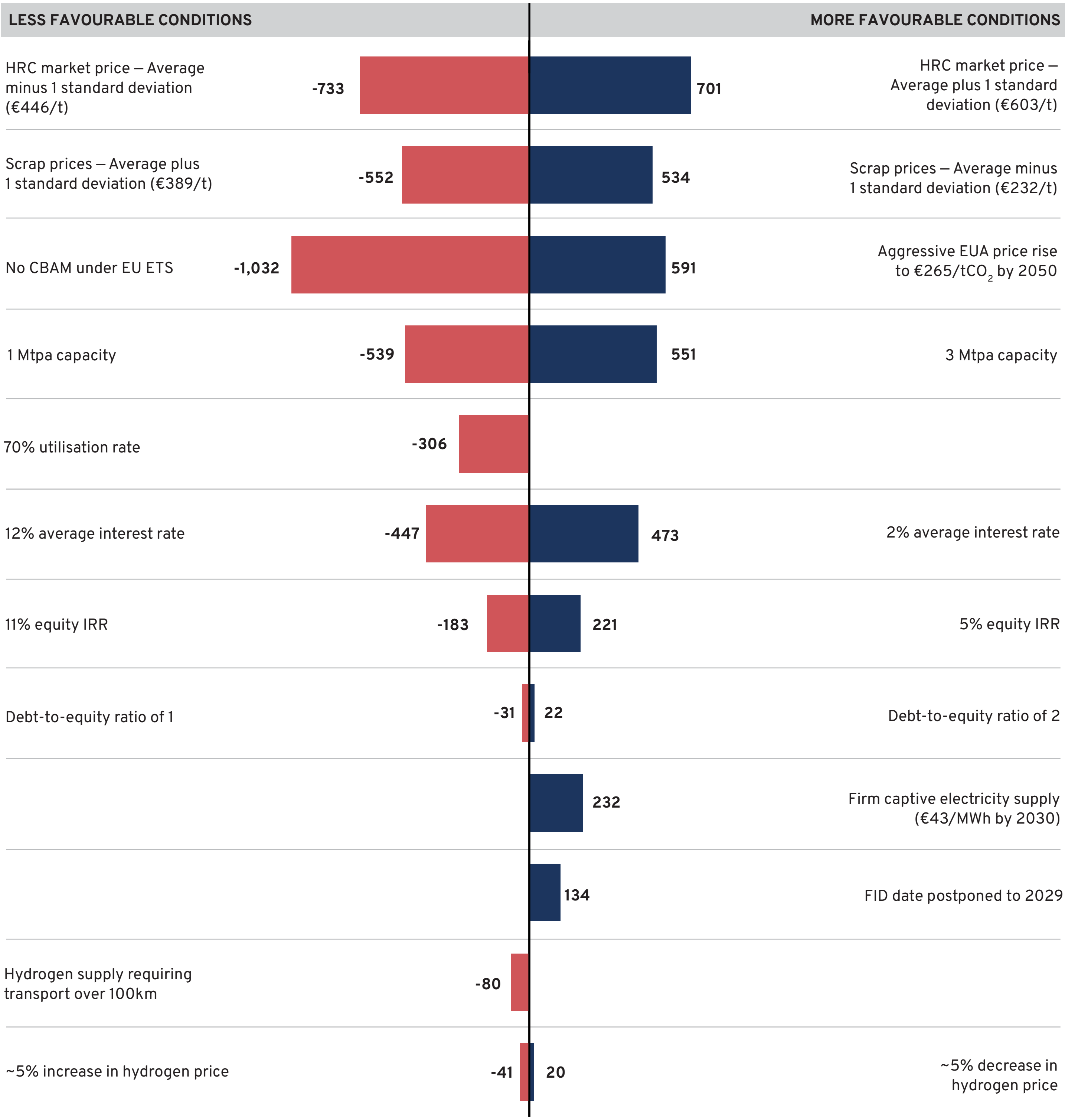
EXHIBIT 9

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



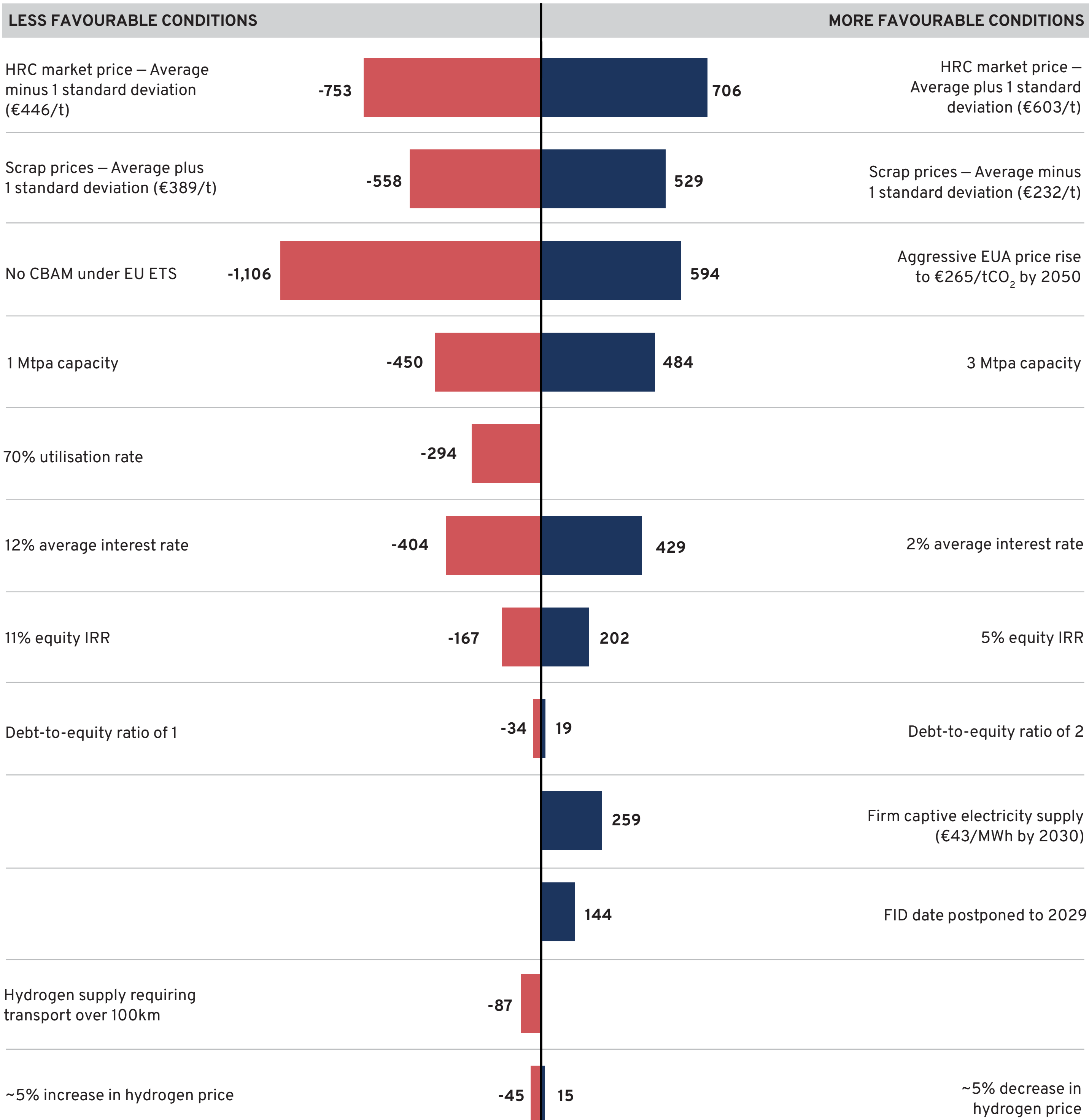
Note: For hydrogen prices, unfavourable and favourable conditions are created by increasing or decreasing electrolyser capital expenditure assumptions, respectively. All other assumptions remain the same as in Scenario 1 unless stated otherwise.

Source: ETC analysis

Sensitivity of breakthrough steel archetype NPV to operational and commercial factors

Brownfield melter conversion

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



Note: 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 1 unless stated otherwise.

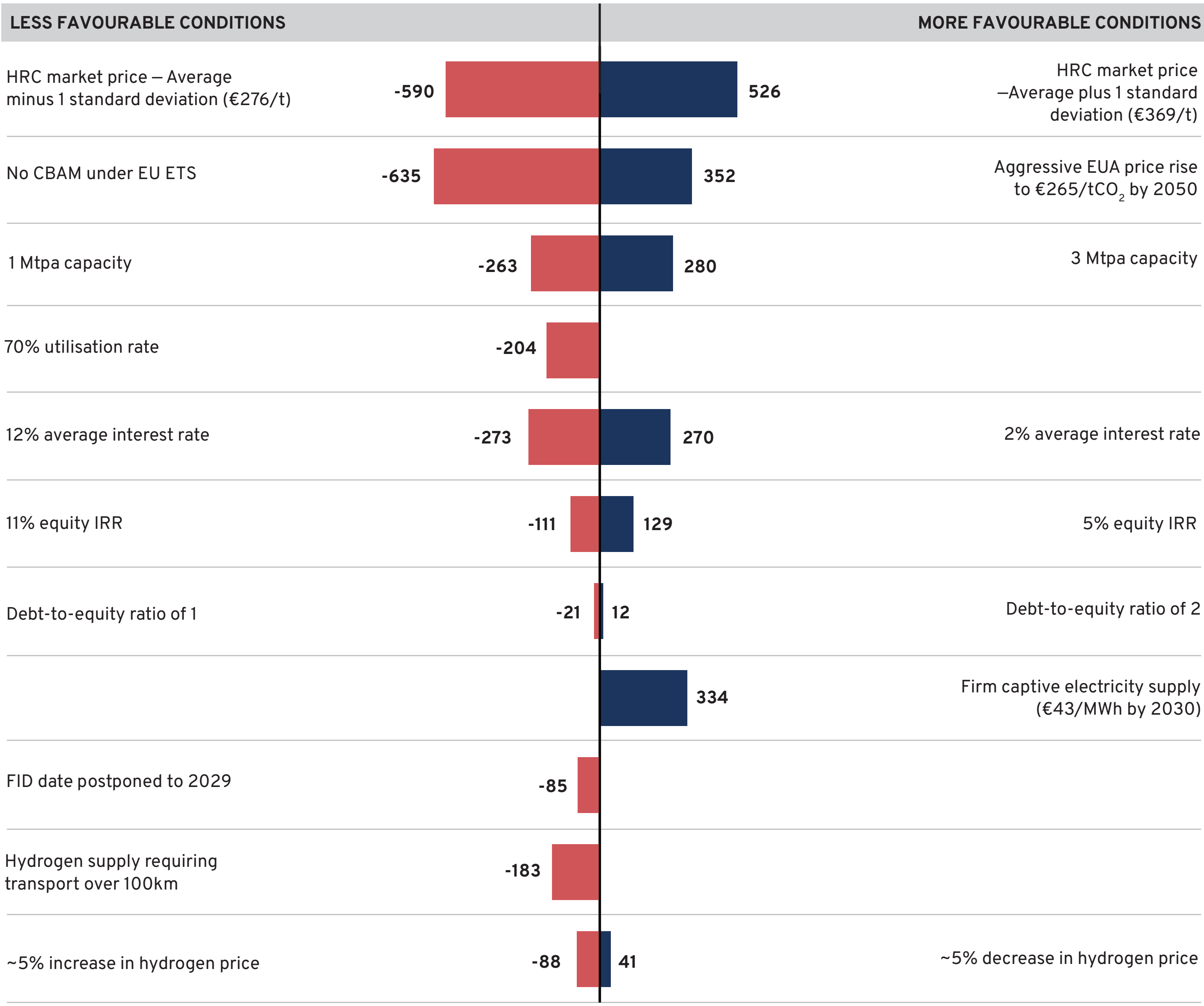
Source: ETC analysis

EXHIBIT 9

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: 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 1 unless stated otherwise.

Source: ETC analysis

These operational and market conditions present both risks and opportunities for breakthrough investments. In terms of risks, for example, the baseline analysis and both scenarios assume all archetypes (including their green hydrogen supply) would secure electricity from the French grid at an average price of €51/MWh for the foreseeable future. If greater electrification of the French economy causes power demand to rise and the build-out of low-carbon electricity infrastructure fails to keep pace, grid electricity could become both more expensive and carbon-intense, raising the production costs and indirect emissivity of breakthrough iron and steel production.

Similarly, all scenarios assume colocated DRI production and hydrogen electrolysers, with the required infrastructure to supply the water and low-carbon electricity needed for on-site green hydrogen production. This is a reasonable assumption for brownfield archetypes located in industrial hubs or for greenfield merchant HBI (as its location could be optimised accordingly). However, if green hydrogen cannot be produced on-site, the development of hydrogen networks based on pipelines and storage systems could provide an alternative means of firm supply in the medium to long term, albeit at the cost of higher hydrogen prices (Exhibit 9, pages 22-25).

At the same time, operational and market conditions present potential opportunities for breakthrough investments, exemplified by the topic of iron ore supply. 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 input is designed to minimise the energy costs of DRI production and slag (a waste by-product) generated by EAF steelmaking. However, the properties of the melter-BOF technology in the brownfield melter conversion could allow it to handle lower grades of iron ore, which have correspondingly lower market prices and could offer a way for the archetype to lower its ferrous input costs. Risks and opportunities such as the above would be a key concern of investors and financiers prior to making an FID, meaning they would require due consideration by prospective project proponents.

3.2 Additional Considerations for Achieving FID Status

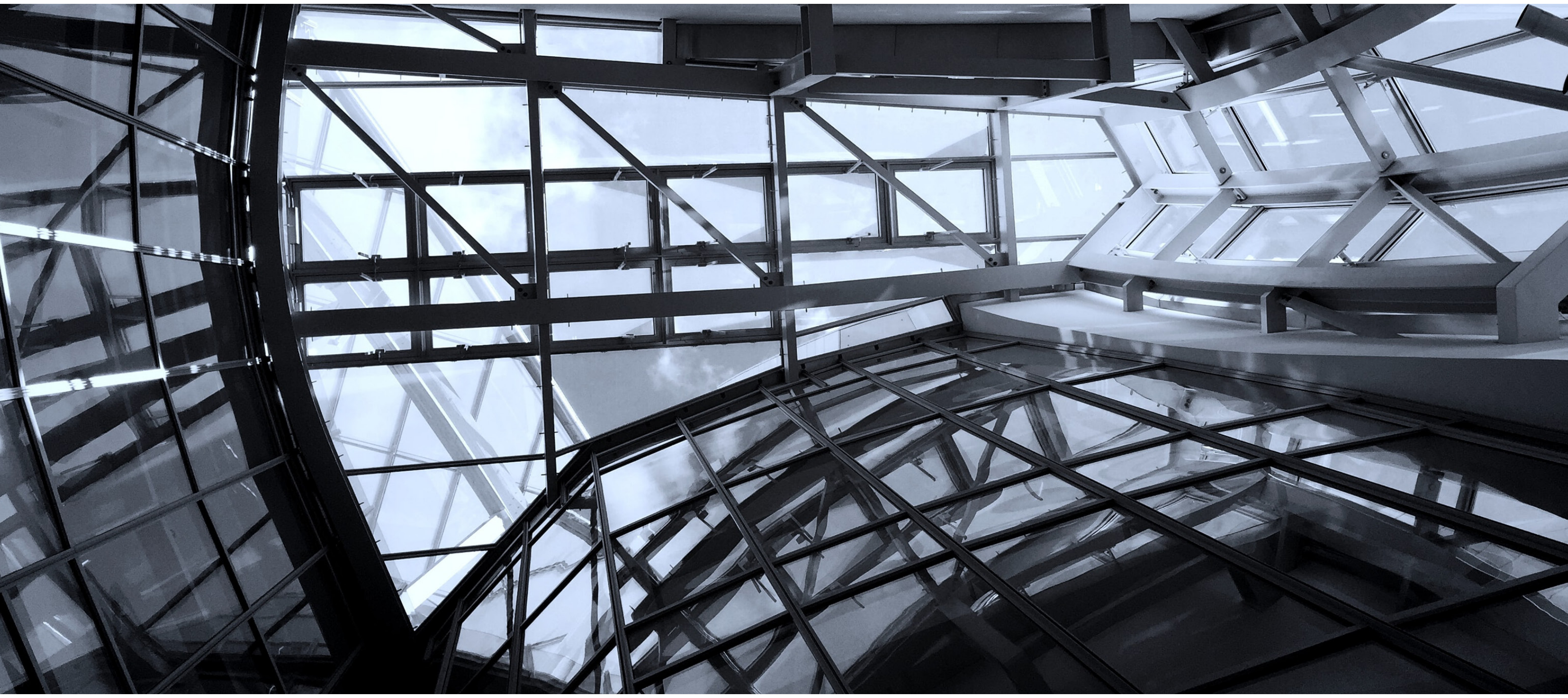
Even if the discussed levers are applied to close the financial gap for breakthrough steelmaking, a positive *business* case does not guarantee a bankable *investment* case. To establish the latter and create the foundations for an FID, additional considerations must be taken into account, particularly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

Given the relative novelty of the breakthrough steelmaking technologies considered in this report, a project proposal in France 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. Providing these guarantees could enable more favourable financing terms, such as lower interest rates or longer repayment periods on debt finance from banks, that could improve overall project finances (Exhibit 9, pages 22-25). Conversely, without such guarantees, financiers may well apply higher costs to the capital they provide to balance the aforementioned risks.

In practice, 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 undertaken.

CONCLUSIONS AND RECOMMENDATIONS



Favourable energy, market, and policy conditions in France have already enabled the first breakthrough iron and steel projects and plans to emerge in the country. However, to secure FIDs on those projects and seed additional ones, further action is needed to strengthen the investment case for breakthrough technology. Coordinated action from industry, government, buyers, and finance would maximise the potential of breakthrough technologies to decarbonise French steel, preserve domestic steelmaking capacity, and capitalise on a market for low-emissions iron and high-grade steel emerging in France and across the EU more widely.

Two scenarios demonstrate what would be needed to strengthen the investment case and accelerate FIDs on breakthrough iron and steel projects in France. Although the scenarios take different approaches, their levers and additional considerations indicate there are prerequisites that would likely be essential under any circumstance. In the absence of these prerequisites, the investment case for breakthrough iron and steel in France would remain challenging:

1. A stable and affordable supply of low-carbon energy (particularly electricity, via the grid or power purchase agreements), requiring investment in low-carbon energy production and transportation infrastructure outside of the steel sector
2. A progressive and effective carbon price regime applied to both domestic steel production and imports from abroad
3. Direct government funding, either in the form of up-front capital expenditure support or ongoing operational expenditure subsidies
4. Forward offtake agreements to firm revenues, potentially at a premium above market prices for a proportion of production
5. Mechanisms (for example, risk guarantees) to manage the technology risk associated with a FoaK project, which the government and related agencies are likely best placed to offer

The energy requirements of breakthrough iron- and steelmaking would be considerable. Assuming a plant size of 2 Mtpa, a 90% utilisation rate, and no scrap intake, a breakthrough project would require between 5.9-8.5 TWh per year of electricity (depending on the archetype) once operational.[xxviii] Part of this would be accounted for by the electro-intensive steelmaking processes of the archetypes, but the majority (between 60%-75%) would go towards making the hydrogen needed for DRI production. As an example, the electricity requirements of a single breakthrough project in France could amount to 1%-2% of total national electricity consumption in 2021 (474 TWh).[xxix]

Given the significance of clean energy feedstocks to breakthrough iron and steel production, both in terms of volume and cost, continued efforts by industry and government to build out the necessary generation, transmission, and distribution infrastructure would be critical. A stable and affordable low-carbon power supply would lower direct electricity and green hydrogen costs and enable other levers, such as scrap intake, by lowering the electricity costs associated with processing it.

The necessary low-carbon electricity supply could be delivered via the grid, but another option industry and government should explore would be developing the market for green power purchase agreements (PPAs). Making these types of agreements more accessible and affordable could offer multiple benefits to breakthrough projects. These include reducing electricity costs by avoiding grid fees (in the case of physical PPAs), greater electricity price stability (hedging against future market fluctuations), and contractually guaranteed supply of low-carbon power for green hydrogen production and steelmaking processes.

Increasing the power supply could come from increasing renewables generation but could also be supplied by expanding France's nuclear capacity, given the country's strengths in that sector. Going beyond electricity, if the technical feasibility of colocating green hydrogen production with iron and steel facilities proves limited, particular attention will also need to be given to scaling hydrogen transport and storage infrastructure.

In addition to supporting clean energy development, the government (both at the national and EU level) will have additional crucial roles in making breakthrough iron and steel projects happen in France. Effective carbon pricing on domestic production and imports (via the EU ETS and an effective CBAM) would level the playing field between breakthrough iron and steel and their conventional emissions-intensive counterparts, laying a solid foundation for breakthrough investments.

xxviii The 2027 date represents the year in which the breakthrough plant would be ramped up to full production assuming an FID date of 2024. Electricity requirements for hydrogen production would decline over time given assumptions around the increasing efficiency of electrolysers, but would remain with the same order of magnitude throughout the lifetime of the plant.

xxix Based on electricity consumption data from the IEA **Energy Statistics Data Browser**.

As well as establishing a supportive regulatory environment, government funding for breakthrough projects would also be needed, targeting either their capital or operational expenditures. Given public sector preferences for one-off support mechanisms, the French government could already leverage existing funds or create new ones to support projects with the up-front costs of breakthrough iron- and steelmaking equipment. For example, the French government could explore opportunities to offer capital expenditure subsidies for DRI equipment through the €5.6 billion allocation for industry under the *France 2030* programme, not only brownfield retrofits but also for greenfield ironmaking projects that could in turn supply those existing steelmaking sites.

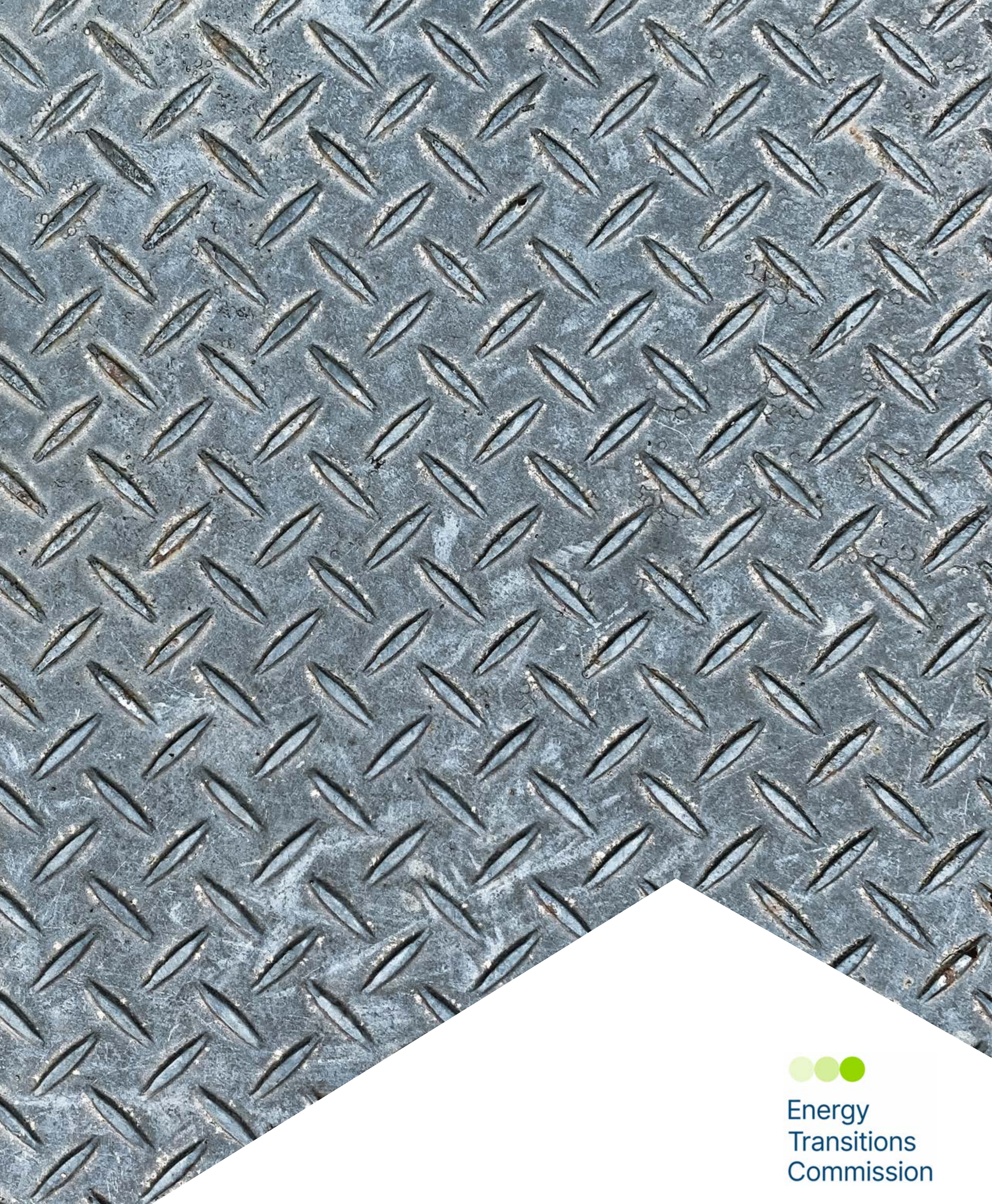
Operational expenditure subsidies would offer costlier but potentially more impactful government support for breakthrough iron and steel. Scenario 2 considers support for green hydrogen production, given its significance to the cost of producing breakthrough ironmaking and in light of similar support measures already in place in the United States. However, the choices of subsidy applied in the scenarios do not preclude other options, including other ongoing forms of support that could be equally, if not more, impactful. For example, providing direct government support on electricity prices for steelmakers and green hydrogen producers, reducing them by 35%–50% (to an average of €33–€25/MWh), would have the same effect on NPV (depending on the archetype) as the hydrogen production cost subsidy in Scenario 2. Alternatively, in light of the sensitivity of steel investments to a variety of market and operational conditions (see Exhibit 9, pages 22-25), innovative mechanisms that help to manage the associated risks could be particularly effective. Carbon contracts for difference (CCfDs), designed to reward projects for avoiding emissions relative to a baseline activity, could help firm up the revenue streams for breakthrough investments and help them address key market risks.

Although offtake at a price premium is only applied as a lever for one archetype in Scenario 1, the importance of the demand side and forward offtake agreements should not be underestimated. Even if a project proposal presented a viable business case by selling its products at wholesale spot market prices, securing forward offtake agreements at projected prices would help firm up revenue streams and manage the sensitivity of breakthrough projects to fluctuations in iron and steel market prices (see Exhibit 9, pages 22-25). This is particularly relevant for raising the debt required to finance breakthrough investments, as lenders typically expect guarantees around at least a portion of revenues before committing capital.

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, France is already seeing its first movers in Dunkerque and Fos-sur-Mer. Although formal announcements of FIDs have yet to be made, these projects highlight the country's potential for breakthrough investment.

One immediate next step could involve existing government plans around low-carbon industrial hubs. The government has already designated two ZIBaCs, for which breakthrough iron and steel projects have been proposed. The government could consider how these hubs could be further leveraged to support breakthrough iron and steel, as well as identify additional potential hub locations that could do the same. Channelling support through hubs would create clear signals around which industry, finance, and buyers could collaborate to advance breakthrough projects.

Regardless of whether low-carbon industrial hubs become the main vehicle for their implementation, the recommendations made in this report would put FIDs for proposed projects within touching distance and expand the pipeline of projects that will be needed to to meet France's climate targets. Establishing these conditions would allow French industry and government to take a leading role in building a net-zero steel industry in Europe and globally.



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.