NUS National University of Singapore | Sustainable and Green Finance Institute

THE NUS MASTER OF SCIENCE SUSTAINABLE AND GREEN FINANCE

Decarbonizing Hard-to-Abate Sectors: Championing Green Tech Solutions for the Iron & Steel Industry to Decarbonize by 2050

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MU Investments

Project Introduction

The iron and steel industry accounts for about 7% of global greenhouse gas emissions, making it one of the most carbon-intensive and challenging sectors to decarbonize. As international climate targets tighten and carbon pricing expands, the pressure is increasing for steel producers to shift toward low-carbon production pathways that align with global net-zero goals.

This project set out to identify practical and scalable solutions to support the decarbonization of steel industry.

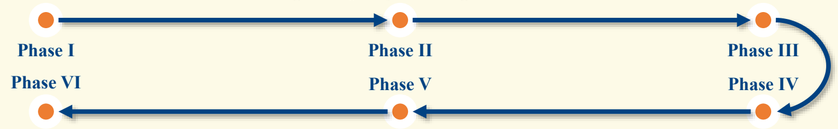
The **green steel** has been considered as a critical pathway for aligning the steel industry with the global net-zero targets. In our research, green steel refers to steel that is produced with lower carbon emissions compared to traditional steelmaking methods. Currently, it accounts for around USD 4.33 billion market share and located majorly in European countries. Most of the green steel project remained at pioneering stage, but demonstrated high potentials in decarbonization and profitability.

Research Methodology

Market Analysis
- Green steel is an **emerging** trend globally
- Buyer side demand growth driven by **sustainability pressures** and led by EU
- Supply trends reflect rising low-carbon **tech investments** and **policy-driven** transitions

Policy Landscape Analysis
- Strong **net-zero targets** and carbon policies exist in EU & CN, but face challenges like regulatory complexity, and shifting priorities
- ASEAN markets show **growth potential** but lack clear pricing, enforcement, and technological capacity to scale green steel.

Regional Analysis
- Case studies and SWOT analysis reflected various potentials across the regions
- EU with **stable external environment** and **advanced technology** -> quick entry
- Southeast Asia with **low cost** and **first mover advantage** -> alternative



Technology Analysis
- Consider available **green transition routes** from technology readiness level, reduction effectiveness, and costs
- Exploring **technology combos** of BF-BOF-MEA and Scrap & HBI-EAF-PSA

Financial Analysis
- Consider the **CAPEX, OPEX, lifetime, and green revenues** of both technology combos
- Established a **comprehensive financial model** for each combo to calculate the NPV, discounted payback period, and CO2e saving effectiveness.

Final Recommendation
- Simulated **sensitivity and scenario analysis** for each model's investment suggestions
- Conducted **SROI** analysis specifically for Tech Combo 2 to take additional social benefit into consideration

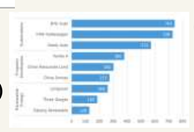
Market & Technology Research

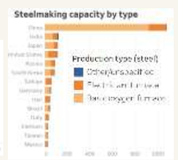
Market Overview

Buyers

EU & US (top importers)
China&India: High domestic demand

Key sectors:
- Construction
- Automotive (EVs)
- Renewables





Sellers

Tech transition: BF-BOF to EAF/DRI
Leading producers: China/US/India
Emerging players: Vietnam & Philippines

Policy Underline

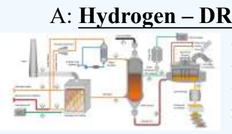
	Policy Strengths	Key Challenges
USA	• Net-zero by 2050 • State-level green action	• Policy shifts, IRA uncertainty • Oil & gas priority
EU	• Strong climate laws & subsidies • High carbon pricing	• Complex regulations • Burden on non-EU exporters
China	• Weak carbon price impact - Data transparency gaps	• Weak carbon price impact • Data transparency gaps
Vietnam	• Net-zero roadmap • Export-oriented growth	• Weak enforcement • Tariff risk (US/EU)
Philippines	• Green finance roadmap • Infra-driven demand	• No net-zero goal • Tech/regulatory gaps

Regional comparison

	EU	South-east Asia	China
Policy Support	**Very strong:** Legally binding regulations (ETS/CBAM).	**Developing:** Initiatives exist, but fragmented.	**Relatively strong:** National goals, uneven enforcement.
Tech Readiness	**Advanced:** H_2-DRI + EAF + CCUS	**Emerging:** EAF growth, green H_2/CCUS early-stage	**Developing to advanced:** Pilots active, scaling limited.
Market Maturity	**Mature:** Strong demand, ESG, investor base	**Developing:** Export-led, fragmented domestic markets	**Transitioning:** Large producer, price-sensitive buyers
ESG Pressure	**High:** Strong mandates from auto & real estate sectors	**Growing:** Certifications (e.g. ISO 14001), uneven integration	**Growing:** Emerging disclosure & green product standards
Financing Environment	**Mature:** VC, EU climate funds, blended finance	**Developing:** MDBs, PPPs, foreign partnerships	**Evolving:** State-owned banks & green bonds dominate
Carbon Reduction Potential	**Up to 95%:** HYBRIT: 100% fossil-free steel	**40%:** through scrap + circular economy	**40–80%:** in selected EAF/DRI pilot projects
Innovation	**High:** Global leadership in steel decarb tech	**Low:** Relies on foreign partners	**Growing:** State-led innovation leads, private sector catching up
Investment Risk & Return	**Low risk, steady return** in scaling	**High risk, high return** in early transition	**Moderate risk, attractive return** with scale potential

Tech Research

A: Hydrogen – DRI – EAF

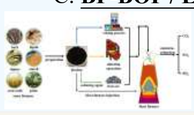


- Ultra-low CO_2
- High maturity
- High-grade iron ore & green H_2 supply

B: Scrap-based electric

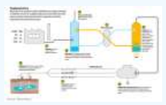
- Low-cost solution
- Effective emission cuts
- Highly mature & scalable
- scrap quality

C: BF-BOF / EAF + Biomass



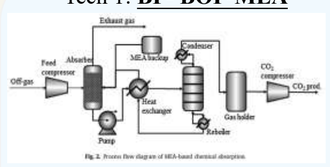
- Moderate emission
- Risk from land-use impact
- Still↓ development

D: CCUS



- Good for retrofitting
- High capture potential
- Limited deployment
- Complementary tech

Tech 1: BF- BOF-MEA



- Mature Technology
- Easy Retrofit to Existing Plant
- Suitable for Low CO_2 Concentration
- European context: CCUS first

Tech 2: Scrap&HBI-EAF-PSA

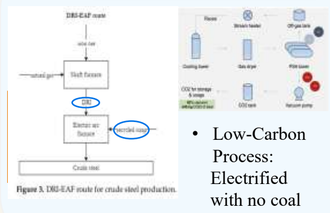
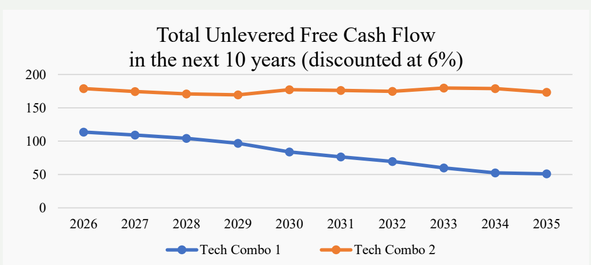
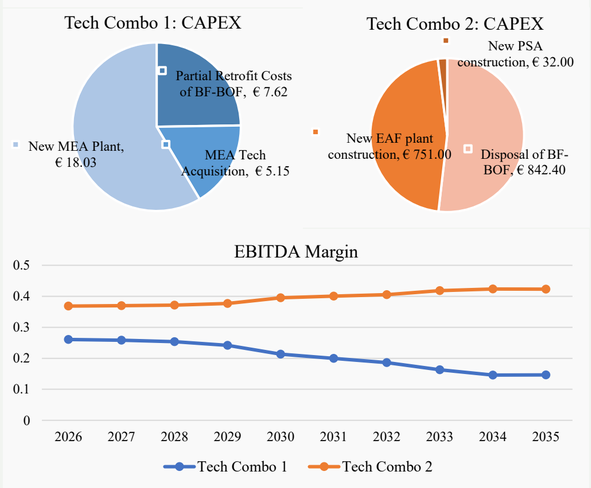


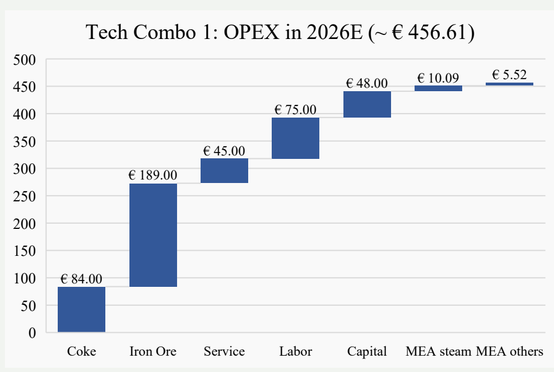
Figure 3. DRI-EAF route for crude steel production.

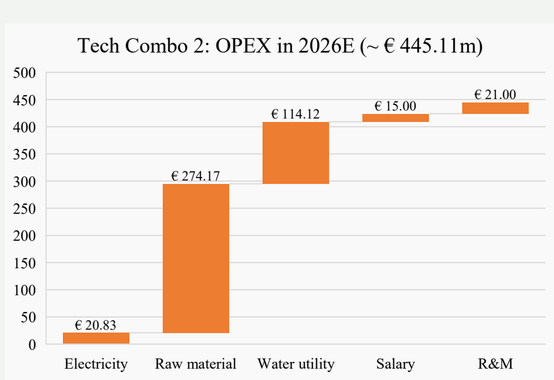
- Low-Carbon Process: Electrified with no coal use

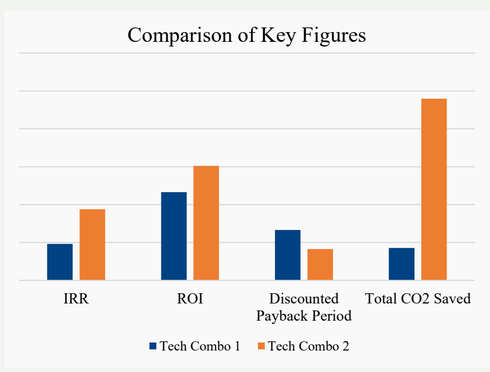
Sustainable & Financial Modeling

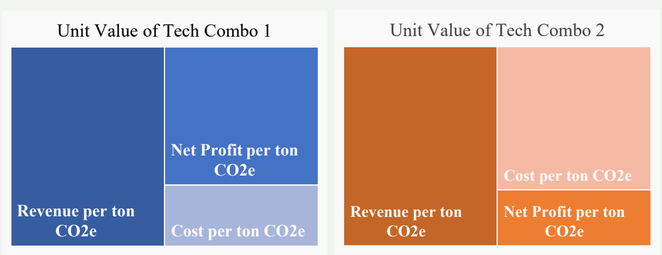












Tech Combo 2 preforms better in IRR and ROI, with shorter discounted payback period, larger CO2 saving potential, and higher net profit of saving a unit of CO2.

**Certain figures have been omitted in accordance with company confidentiality requirements.*

Scenario Analysis	Tech Combo 1			Tech Combo 2		
	Worst	Base	Best	Worst	Base	Best
ROI	-141.85%	100.00%	161.88%	-154.77%	100.00%	180.15%
IRR	-51.09%	100.00%	43.73%	-16.73%	100.00%	15.93%
Discounted Payback Period	68.74%	100.00%	-33.88%	23.12%	100.00%	-17.19%
Net Profit of CO2e saved	-16.59%	100.00%	18.88%	-30.22%	100.00%	35.22%

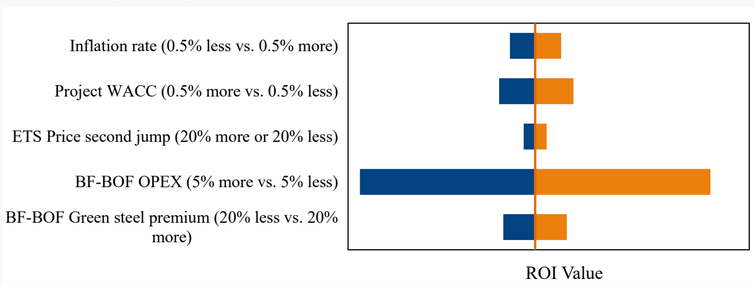
**Results shown as % change vs. base case due to company confidentiality requirements.*

Worst Case Resilience:
Key drivers: tighter monetary policy, commodity price shock, policy uncertainty / delay
- Both tech-combos yield negative NPVs.
- Tech Combo 1: more conservative option in highly adverse environments.

Best Case Upside:
Key drivers: stronger climate policy push, effective cost control, green finance conditions
- Tech Combo 2 > Tech Combo 1
- Tech Combo 2: strong scalability and return potential, esp. under favorable scenarios.

Sensitivity Analysis

Sensitivity Analysis for Combo 1

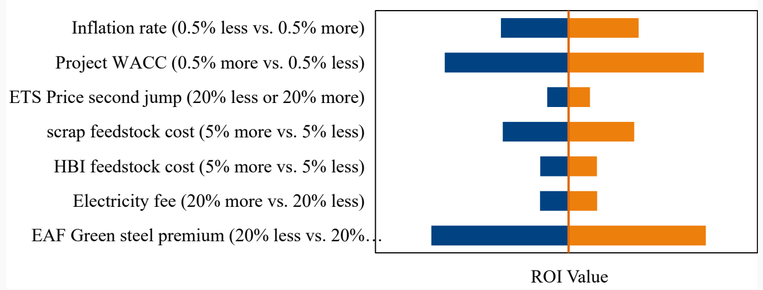


Transition Takeaway

1. Expedient Solution:
Bridge to low-carbon steelmaking with lower transition investment and predictable operational costs and revenue

2. Risk Management:
While the cost trajectories are stable, cost control on BF-BOF OPEX is critical

Sensitivity Analysis for Combo 2



Transition Takeaway

1. Choose as a main transition path:
Use combo 2 as a main transition option before market condition for hydrogen-based technology matures

2. Risk hedging:

Be cautious about future price volatility of raw materials and ETS price where hedging instruments are available

**Certain figures have been omitted in accordance with company confidentiality requirements.*

Conclusion & Recommendation

Main findings
- Iron & steel industry is crucial for global decarbonization process
- EU leads in green steel transition
- ETS–CBAM policy and rising green steel demand from automotive are the driving forces

Investment recommendations
- Traditional model of BF-BOF risks accelerating value decline
- A phased approach starting with CCS and followed by EAF adoption offers a balanced path toward sustainable returns
- Hydrogen-based steel mill might be too risky for the majority to consider within 3-5 years

Next steps

Explore financial instruments
- Explore green loan and green bond opportunities with financial institutions
- Explore innovation fund or other government subsidies
- Target various investors and buyers

Implementation level market research
- Surveying potential buyers for first-hand data on willingness to pay for green premium
- Interviewing stakeholders in green steel supply chain for transition intention and challenges