



Industrial Energy-related Technologies and Systems (IETS)
&
Energy Technology Systems Analysis Programme (ETSAP)
Workshop

CCS and Bioenergy Pathways for Industrial Decarbonisation: Insights from IEAGHG Steel and Cement Studies

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Technology Collaboration Programme

by **iea**

Who are we?

Our internationally recognised name is the IEA Greenhouse Gas R&D Programme (IEAGHG). We are a Technology Collaboration Programme (TCP) and are a part of the International Energy Agency's (IEA's) Energy Technology Network.

Disclaimer

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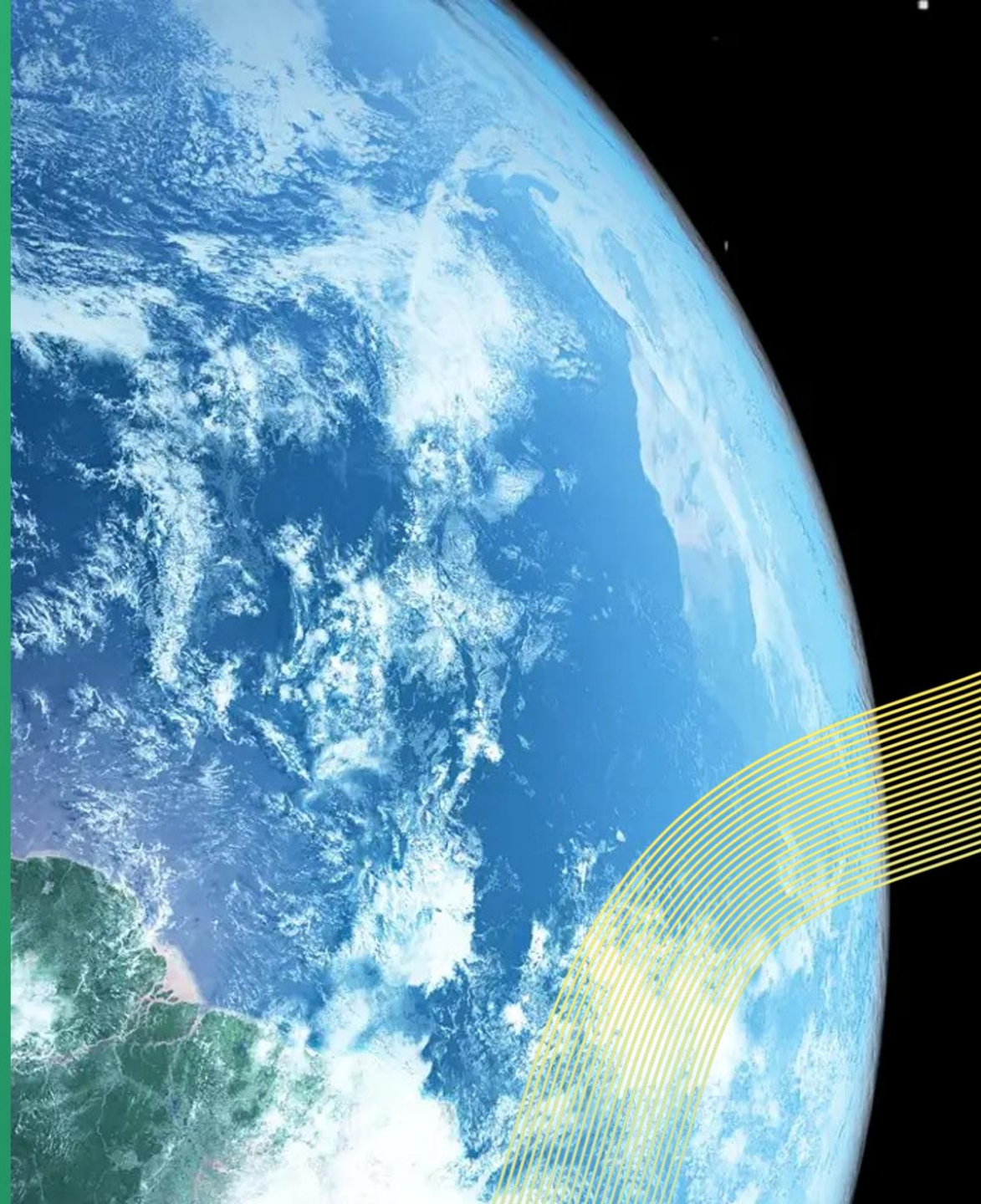




IEAGHG

About the IEAGHG

The IEAGHG are at the forefront of carbon capture, utilisation and storage (CCUS) research. We advance technology that reduces carbon emissions and accelerates the deployment of CCUS and carbon dioxide removals projects worldwide.



IEAGHG Executive Committee Members



Context: What Assumptions Shape Technology Attractiveness?

- Steel and cement present different process and emissions constraints, so the attractiveness of decarbonisation options is inherently sector- and site-specific.
- The relative cost and emissions performance of pathways can change materially with modelling assumptions - particularly electricity carbon intensity and price, fuel/feedstock choices, capture performance, utilisation, infrastructure and system boundaries.
- IEAGHG's 'Clean Steel' and 'Clean Cement' studies provide sector-specific TEA/LCA evidence of these trade-offs, showing how the relative cost and emissions performance of CCS, bioenergy, hydrogen and electrification pathways changes under different assumptions and conditions.

Technology attractiveness is not fixed; it shifts with the technical, economic and system assumptions under which the pathway is assessed.

IEAGHG's 'Clean Steel: an Environmental and Technoeconomic Outlook of a Disruptive Technology' Study

(Baseline) BF-BOF

Integrated BF-BOF with BAT technologies such as coke dry quenching, top pressure recovery turbine, and low flaring rates for off-gases.

BF-BOF + H₂

Hydrogen is injected to the blast furnace as an auxiliary reducing agent, partially replacing pulverised coal injection.

NG-DRI + ESF + BOF

Natural gas-based direct reduction using BF-grade pellets. Direct reduced iron (DRI) is charged to an electric smelting furnace (ESF) which melts the DRI in a reducing atmosphere producing hot metal. The hot metal is fed to a BOF.

BF-BOF + CCS

The blast furnace is retrofitted to an oxy-blast furnace with top gas recycling and CO₂ capture.

NG-DRI + EAF

Natural gas-based direct reduction, with DRI charged directly to an EAF together with scrap.

BF-BOF + Bioenergy with CCS (BECCS)

The BF is retrofitted to an oxy-blast furnace with top gas recycling and CO₂ capture. Charcoal is injected to the BF, fully replacing pulverised coal injection.

H-DRI + EAF

100% renewable H-DRI with electric preheating of the reducing gas. Hot DRI is charged to an EAF together with scrap.

NG-DRI + EAF + CCS

CO₂ is captured from the flue gas stream from the gas reformer in a post-combustion capture plant.

H-DRI + EAF + Bio

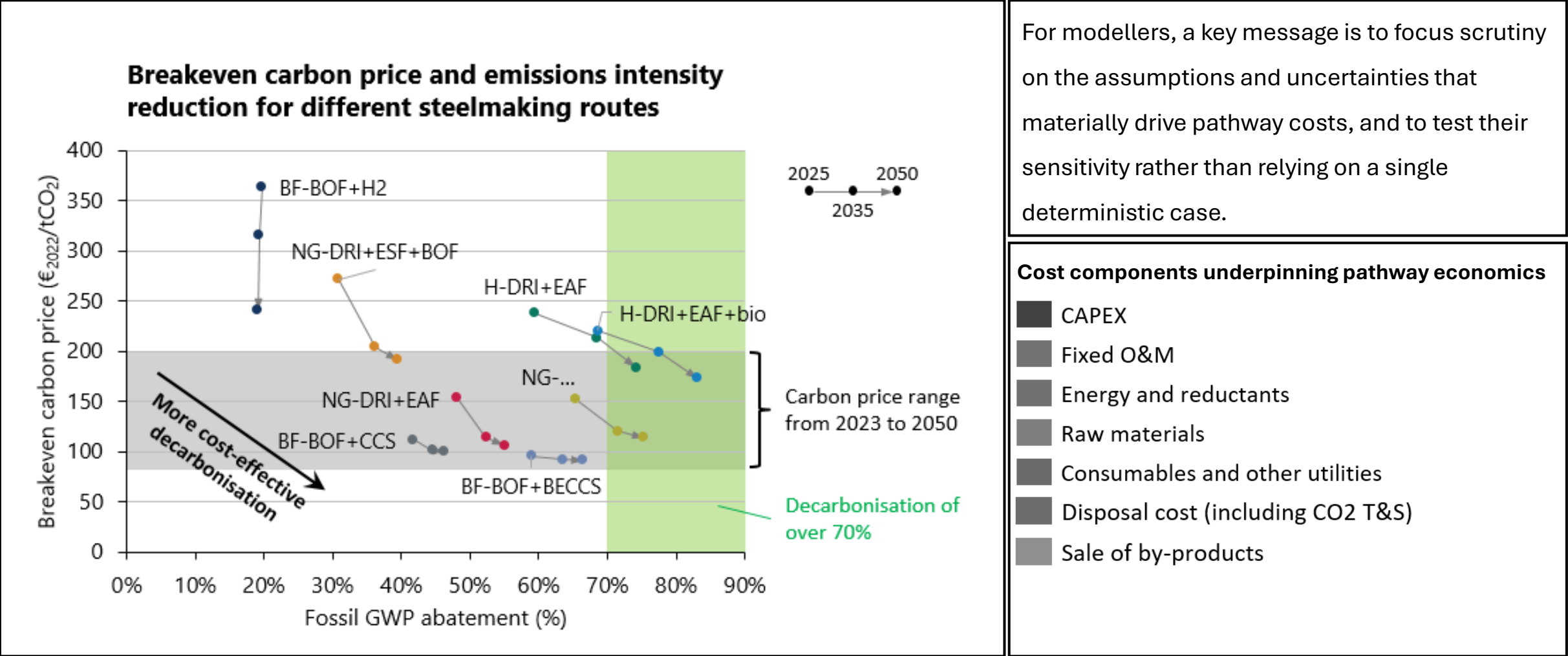
100% renewable H-DRI with electric preheating of the reducing gas. Charcoal is used to replace solid fossil carbon inputs to the EAF.

IEAGHG's '**Clean Steel**: an Environmental and Technoeconomic Outlook of a Disruptive Technology' Study

Key Modelling Assumptions

- Location & infrastructure: Coastal Northwestern Europe; access to natural gas, hydrogen, power, port and CO₂ transport & storage.
- Plant scale: 4 Mt crude steel/yr for BF–BOF; 2 Mt/yr for DRI-based pathways.
- Utilisation: 85% capacity factor.
- Scrap share: 20% metallic input across all pathways.
- Financial assumptions: 25-year economic life; 7% discount rate; costs in €2022 (real terms).
- Carbon policy: EU ETS carbon price; CBAM phase-out of free allowances from 2026–2034.
- CO₂ transport & storage: €53.6/tCO₂.

How Modelling Assumptions Shape Steel Production Costs



IEAGHG's 'Clean Cement: Environmental & Techno-economic Outlook of Transformative Decarbonisation Pathways' study

Pathway 1:

Electric pre-calcliner, solid biomass, and calcined clay. This pathway explores a non-CCS route to deep decarbonisation

Pathway 2:

Amine-based capture and calcined clay. This pathway introduces carbon capture using a mature amine-based technology.

- steam supplied by a natural gas boiler (boiler CO₂ is not captured)
- steam supplied via a high temperature heat pump with waste heat recovery

Pathway 3:

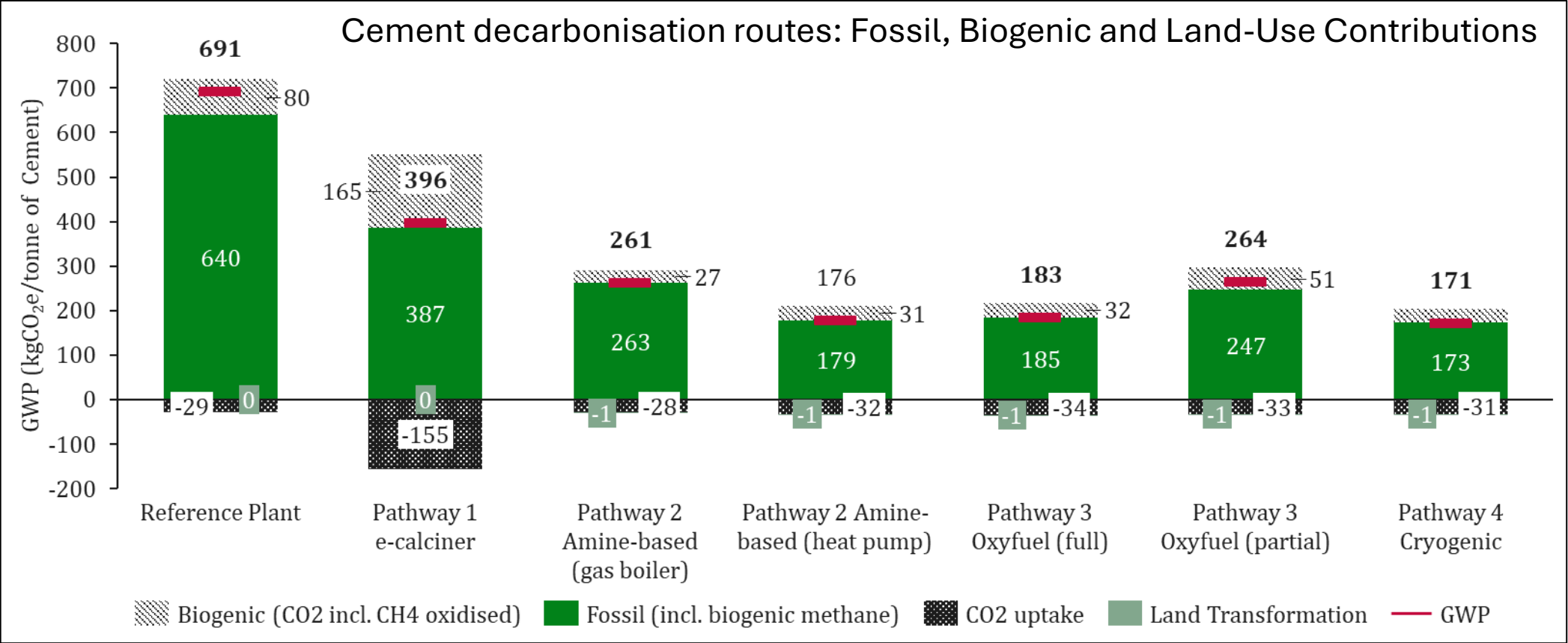
Oxyfuel CCS (with 94% CO₂ capture) + calcined clay

- Full oxyfuel configuration
- Partial oxyfuel configuration

Pathway 4:

Cryogenic CCS (PSA + cryogenic with 95% CO₂ capture) + calcined clay

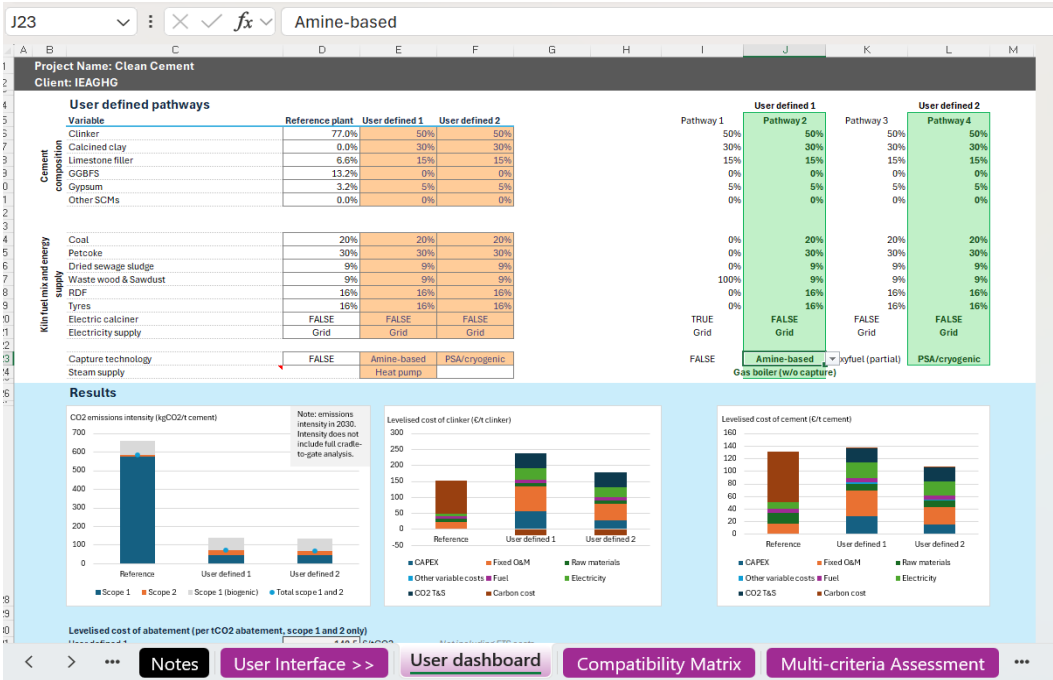
IEAGHG’s ‘Clean Cement: Environmental & Techno-economic Outlook of Transformative Decarbonisation Pathways’ Study



Modelling Cement Decarbonisation Pathways



Spreadsheet summary											
Project	IEAGHG -Clean Cement- Technology Screening Tool										
Produced for	IEAGHG										
Description of spreadsheet	This spreadsheet allows users to define variations on cement production pathways to understand the impact of decisions such as material or fuel mix ratios, decarbonisation levers and techno-economic variables. This accompanies the detailed word report on Clean Cement.										
Date issued	4th March 2026										
Status	FOR USE										
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Disclaimer

This model was developed by ERM for IEAGHG as part of the Clean Cement project. The conclusions and recommendations do not necessarily represent the view of IEAGHG. Whilst every effort has been made to ensure the accuracy of this model, neither ERM or IEAGHG warrant its accuracy or will, regardless of its or their negligence, assume liability for any foreseeable or unforeseeable use made of this model which liability is hereby excluded.

Conclusions: Implications for Modelling Industrial Decarbonisation

- Technology attractiveness is conditional, not intrinsic:
Cost and emissions performance shift with assumptions on energy, infrastructure, utilisation and system boundaries.
- Bioenergy assumptions need particular scrutiny:
Biomass availability, cost, sustainability and upstream emissions can materially change outcomes.
- BECCS should be modelled as a complete system, not simply as ‘biomass + capture’.
Include biomass supply, capture performance, CO₂ transport and storage, and biogenic carbon accounting.
- Steel and cement require different representations:
Their process emissions, fuel use and integration constraints are fundamentally different.
- Focus model refinement on high-impact assumptions and data gaps.
Prioritise the parameters that most strongly affect cost, emissions and technology competitiveness.

Technology assessment & modelling require transparent assumptions, consistent boundaries and like-for-like comparison across decarbonisation routes.

Thank you

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