



# **Carbon capture utilisation and storage technologies: Decarbonising hard-to-abate industries and strengthening strategic autonomy**

## **Case study**

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The primary aim of this project is to support, through the analysis of climate relevant activities of Horizon Europe, the development and implementation of EU policies. Policy briefs, along with case study reports and communication materials, are produced to support the development and implementation of EU policies based on the results of the EU Framework Programme for Research and Innovation and other relevant scientific sources.

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# Contents

<b>Introduction</b>	<b>5</b>
<b>Eastern Lights: Validating onshore CO<sub>2</sub> storage in saline aquifers</b>	<b>6</b>
<b>AURORA: Deployment of integrated CCUS chains based on solvent capture technology</b>	<b>7</b>
<b>Carbon4Minerals: Transforming CO<sub>2</sub> into added-value construction products</b>	<b>8</b>
<b>CaLby2030: Decarbonising industrial processes through Calcium Looping</b>	<b>9</b>

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# Introduction

Horizon Europe funds industrial carbon management (ICM) to **enable decarbonisation of energy-intensive industries** towards climate neutrality by 2050. These technologies are set processes aimed at mitigating CO<sub>2</sub> emissions from industrial processes and preventing them from entering the atmosphere. This includes the capture of CO<sub>2</sub> emissions, amongst other from sources like power plants and heavy industry, utilising captured CO<sub>2</sub> for products such as fuels or materials, and/or storing it geologically, e.g. in depleted reservoirs. This case study analyses key Horizon Europe ICM projects, focusing on their technological advancements and contributions to EU-wide deployment targets as well as social acceptance challenges.

This case study report highlights four Horizon Europe projects delivering technology solutions across the ICM value chain:



**Eastern Lights:** Addresses critical downstream infrastructure by developing transport and storage solutions, specifically investigating the suitability of saline aquifers in North-West Bulgaria for large-scale onshore CO<sub>2</sub> sequestration.



**AURORA:** Focuses on solvent-based capture technology, aiming to position the CESAR1 solvent as a highly efficient and competitive alternative to conventional chemical absorption methods across multiple industrial sectors.



**Carbon4Minerals:** Explores the simultaneous utilisation of captured CO<sub>2</sub> and industrial waste streams to produce innovative low-carbon construction materials, aiming to reduce emissions by 80–135% compared to standard references.



**CaLby2030:** Aims to achieve commercial deployment of Calcium Looping (CaL) technology by 2030, using three pilot plants in Germany, Sweden, and Spain to demonstrate >99% CO<sub>2</sub> capture rates in cement, steel, and waste-to-energy sectors.

The implementation of these projects is integrated with the landscape of the EU climate policy initiatives, including the Net-Zero Industry Act<sup>1</sup>, which sets a target of 50 million tonnes of annual CO<sub>2</sub> storage capacity by 2030, and the Industrial Carbon Management Strategy<sup>2</sup>. The Strategy provides a comprehensive blueprint for scaling up carbon management technologies by focusing on three main pathways: **Carbon Capture and Storage** for permanent sequestration, **Carbon Capture and Utilisation** to replace fossil carbon in products, and **Industrial Carbon Removals** to address residual emissions. To support these goals, the EU aims to develop a cross-border CO<sub>2</sub> transport infrastructure, estimated to require up to €12.2 billion in investment by 2030, and increase annual capture capacity to approximately 280 million tonnes by 2040<sup>3</sup>. These frameworks emphasise the need for interoperable infrastructure and public-private collaboration to de-risk investments in ICM.

While ICM technologies are essential for climate neutrality, their deployment faces significant social acceptance challenges linked to perceived safety risks, such as potential CO<sub>2</sub> leaks and environmental impacts. Historical mistrust of industrial projects and concerns over local infrastructure often lead to community resistance. Addressing these complexities requires transparent, evidence-based engagement and the demonstration of safe, local storage solutions to foster trust. Proactive communication is vital to securing the public support necessary to achieve the EU's targets of 50 million tonnes of annual CO<sub>2</sub> storage capacity by 2030 and significant industrial decarbonisation.

# Eastern Lights:

## Validating onshore CO<sub>2</sub> storage in saline aquifers

### Fact sheet

Duration	1 September 2024 until 31 August 2028
EU contribution	€ 19 122 237,28
Type of action	Innovation Action
Coordinating organisation	Holcim Bulgaria AD
Consortium size	19 partners

### Main objective of the project

The primary goal of the Eastern Lights project is to research and prove the potential for onshore CO<sub>2</sub> storage in selected deep geological formations, specifically saline aquifers, in Northwestern Bulgaria. The project is establishing a technically validated, safe, and scalable storage solution that serves as a foundational step toward a large-scale onshore CCUS cluster in Eastern Europe. The technical scope includes testing cross-border logistics by transporting liquid CO<sub>2</sub> via trailers and standardised shipping containers from emitters in Turkey to Bulgaria to navigate non-EU to EU legal frameworks. Additionally, the project is constructing a 1-kilometer test pipeline to analyse material specifications and the behaviour of CO<sub>2</sub> based on varying impurities and injection timescales. Innovation is further driven by the development of a smart well—an optimised trajectory well designed to reach fractured carbonate rocks—which functions simultaneously as a high-efficiency injector and a real-time monitoring point. Finally, the project incorporates CO<sub>2</sub> utilisation by advancing a closed-loop geothermal concept where stored CO<sub>2</sub> acts as a working fluid to generate renewable electricity.

Project coordinator Veronika Georgieva (Holcim Bulgaria AD) emphasised the project's ambition to create an operational regional network:

*"Our project is a crucial first step towards a large-scale onshore CCUS cluster in Eastern Europe. We aim to lay the foundation for CO<sub>2</sub> reduction across Eastern Europe by delivering a real, technically viable solution that supports not only local Bulgarian industry but other regional emitters as well."*

### Impact

The Eastern Lights project is expected to have a transformative impact on the decarbonisation of hard-to-abate sectors, particularly the cement and chemical industries, by providing a real storage alternative that preserves the regional industrial base. By de-risking geological storage technically, regulatorily, and socially, the project lays the groundwork for regional CCUS hub development. A unique synergy is explored through the CO<sub>2</sub>-geothermal system, which strengthens the business case for storage infrastructure by generating renewable

power that could support industrial sites or local communities. The project's physical output will be a validated storage reservoir with a successful pilot injection of 10,000 tonnes of liquid CO<sub>2</sub>. Beyond technical delivery, Eastern Lights aims to build institutional know-how and public trust through a Knowledge Transfer Academy and a "regulatory sandbox" approach that helps the Bulgarian government identify legislative loopholes and refine permitting pathways.

### Connections to relevant EU policy

The project's implementation is fundamentally linked to the Net-Zero Industry Act (NZIA)<sup>4</sup>, supporting the EU's goal of achieving an annual injection capacity of 50 million tonnes of CO<sub>2</sub> by 2030. It supports the overall Clean Industrial Deal<sup>5</sup> objectives of ensuring industrial competitiveness while meeting mandatory climate neutrality goals via addressing the significant storage gap in Eastern Europe. The project also navigates the alignment of non-EU and EU legislation under the Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) Act<sup>6</sup> regarding the safe cross-border transportation of liquid CO<sub>2</sub>.

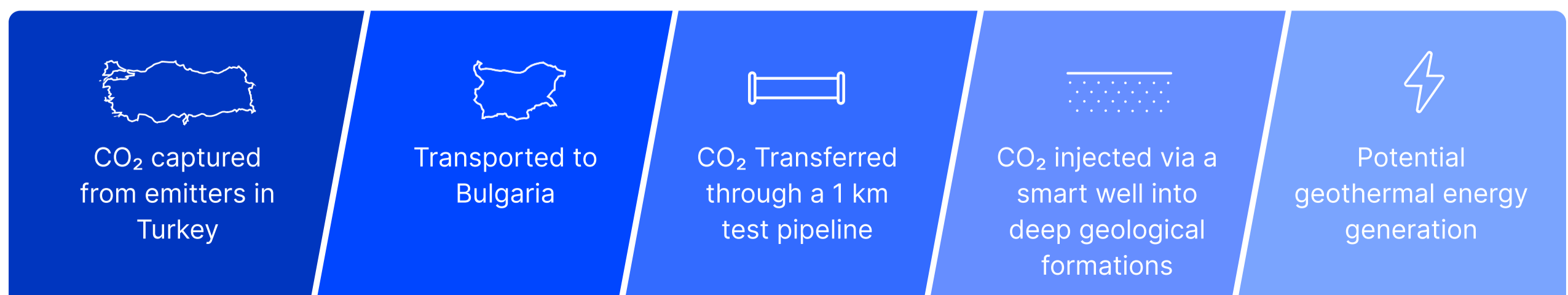
### Status of implementation

As of February 2026, Eastern Lights is in its 18th month of a 48-month timeline and has successfully transitioned from data screening to advanced reservoir modelling. The consortium has digitised and analysed extensive historical deep borehole and modern 2D seismic data covering roughly 2,000 square kilometres. Laboratory analyses of rock samples are currently simulating subsurface conditions to test CO<sub>2</sub> injection under different pressure regimes, confirming the suitability of 700m thick cap rock and 300-500m thick reservoir rock. Concurrently, the project has submitted applications for exploration permits.

### Next steps

Looking toward final outputs, following the receipt of the exploration permit, the project will move from the research phase to on-site fieldwork, including exploratory drilling and the construction of the storage reservoir and smart injection well. This phase will trigger an intensive public awareness campaign and the full launch of the Knowledge Transfer Academy. The partners are also developing detailed business model scenarios to evaluate the economic feasibility of intermodal transportation and full-scale infrastructure deployment.

### CO<sub>2</sub> transport and storage process



# AURORA:

## Deployment of integrated CCUS chains based on solvent capture technology

### Fact sheet

Duration	1 January 2023 until 30 June 2026
EU contribution	€ 12 196 763,33
Type of action	Innovation Action
Coordinating organisation	SINTEF AS (Norway)
Consortium size	12 partners

### Main objective of the project

The primary objective of the AURORA project is to qualify the **CESAR1** solvent technology for commercial deployment across diverse industrial sectors to capture CO<sub>2</sub> emissions from various industrial stacks.

**CESAR1** is a non-proprietary, amine-based aqueous solution consisting of 2-amino-2-methyl-1-propanol and piperazine and is being used for the chemical absorption of carbon dioxide, where it acts as a liquid scrubbing agent that selectively binds with CO<sub>2</sub> in an absorber column before being heated in a stripper to release the gas for storage or utilisation.

The project aims to establish a validated system for first-of-a-kind capture plants in carbon-intensive industries, specifically **refining, cement production, and materials recycling**, where alternatives for achieving climate neutrality are limited. Technically, the research focuses on closing existing knowledge gaps regarding solvent degradation, enhancing process operability, and mitigating heat dependency through advanced integration solutions like heat pumps. AURORA's methodology includes a full-chain CCUS assessment, evaluating the technical and economic viability of transport and storage clusters in the North Sea and the Mediterranean.

### Impact

AURORA is projected to facilitate a 47% reduction in carbon capture costs relative to the current industry benchmark. This significant cost reduction is achieved through the use of the CESAR1 solvent, which outperforms the standard single-solvent solution based on monoethanolamine (MEA). Unlike the MEA benchmark, the multi-component nature of CESAR1 allows for higher CO<sub>2</sub> loading capacity and lower energy requirements for solvent regeneration, enabling a target capture rate of 98%. Furthermore, it addresses critical societal and political barriers by conducting research on public acceptance to increase awareness and readiness for large-scale CO<sub>2</sub> infrastructure.

Project coordinator Hanne Marie Kvamsdal (SINTEF) highlighted the project's progress and its significance for the deployment of CCUS technologies:

*"We have developed very accurate models and achieved significant results. While this is vital for research institutions and universities, it is equally important for technology vendors and end users, providing them with the essential tools to establish full-scale deployment of this solvent and the process."*

### Status of implementation

As of February 2026, AURORA has achieved several major technical milestones:

**Pilot demonstrations:** Feasibility has been successfully demonstrated at TRL 8 in two major pilots in Norway: the **Tiller pilot (SINTEF)**<sup>7</sup> and the **Technology Centre Mongstad (TCM)**<sup>8</sup>, the world's largest test facility for this technology. These tests confirmed high-purity CO<sub>2</sub> products ready for transport.

**Digital tools:** Improved open-source models for the CESAR1 solvent have been implemented in commercial simulators (Aspen Plus).

**Advanced control:** An advanced process control system has been validated via the pilots in Norway to maintain energy efficiency even during highly fluctuating industrial operations.

**Strategic mapping:** The consortium studied **310 CCUS projects in 59 European hubs**, concluding that industrial clustering significantly enhances economies of scale.

### Connections to relevant EU policy

AURORA is closely aligned with the Clean Industry Deal<sup>9</sup> and the EU Climate Law<sup>10</sup>, which mandate a 55% reduction in greenhouse gas emissions by 2030 and is in alignment with the goal of achieving EU climate neutrality by 2050. The project provides a direct technical contribution to these targets by qualifying a non-proprietary, open-access technology that prevents technology lock-in and supports a competitive European CCUS market with no licensing fees or IP restrictions.

By targeting hard-to-abate sectors like cement and refining, the project addresses the specific industrial segments identified by the Clean Industrial Deal<sup>11</sup> as requiring urgent decarbonisation to maintain European competitiveness. Furthermore, AURORA provides validated data, full-chain assessment methodologies, and clustering strategies that

serve as a technical foundation for Member States to implement national CCUS strategies and regulatory frameworks.

### Next steps

Following the conclusion of the research activities, technology vendors within the consortium, such as SLB-Capturi, and within the Stakeholder Forum - Carbon Circle, are positioned as early adopters to integrate the qualified CESAR1 solvent into their commercial portfolios. The project's data and models is planned to be used for large-scale deployment at industrial sites, serving as a global benchmark for future CO<sub>2</sub> capture plants. Future commercial uptake is expected to be supported by the project's process control software, which the developing partners plan to refine and market jointly with capture technology vendors as an integrated package for cost-efficient operation.

# Carbon4 Minerals:

## Transforming CO<sub>2</sub> into added-value construction products

### Fact sheet

Duration	1 January 2023 until 30 June 2027
EU contribution	€ 14 846 811,00
Type of action	Innovation Action
Coordinating organisation	Vlaamse Instelling voor Technologisch Onderzoek (Belgium)
Consortium size	14 partners

### Main objective of the project

The primary goal of Carbon4Minerals is to simultaneously use CO<sub>2</sub> from industrial flue gases and industrial waste streams (such as steel slags and construction/demolition waste) to produce innovative low-carbon binders and construction materials. This integrated approach is critical because it addresses three major environmental challenges at once, it reduces industrial CO<sub>2</sub> emissions; significantly reduces the carbon footprint of the building industry; and diverts large volumes of industrial waste from landfills. The project focuses on mineral carbonation, a process where CO<sub>2</sub> reacts with minerals to form carbonates and amorphous

silica. While the stable carbonates harden into high-value building products like bricks, pavers, and facade panels, the silica increases the reactivity of the materials for use as cement replacements.

A central pillar of the project is the deployment of eight industrial pilots across the entire CCU value chain. These pilots range from advancing CO<sub>2</sub> capture technologies using liquid and solid sorbents to producing low-carbon cement replacements (SCMs) and end-products that store CO<sub>2</sub> permanently within their structure.

### Impact

The project is designed to deliver a transformative environmental impact on the construction sector:

**Negative carbon footprint:** The resulting materials aim for CO<sub>2</sub> emissions that are **80% to 135% lower** than traditional reference materials. In some instances, this results in a net uptake, where the product stores more CO<sub>2</sub> than was emitted during its production.

**Industrial scalability:** By capturing CO<sub>2</sub> directly from point sources (bricks, steel, and cement plants) and utilising it on-site, the project reduces the need for expensive purification and transport infrastructure required for traditional underground storage.

**Resource efficiency:** It unlocks a vast stock of currently underutilised waste resources, such as steel slags and fine particles from demolished buildings, to replace virgin raw materials.

**End-product benefits compared to the industry standard:** beyond having to meet rigorous safety and durability standards, these innovative construction materials offer enhanced aesthetic versatility through a wider range of colours and shades, alongside greater design flexibility and the unique benefit of permanent carbon storage within the mineral structure.

### Connections to relevant EU policy

Carbon4Minerals is developing a practical and high-potential solution to simultaneously address several industrial challenges: the mitigation of process-inherent CO<sub>2</sub> emissions and the sustainable management of industrial waste streams, while ensuring the technology is both scalable and commercially viable. This approach serves as a technical enabler for the Clean Industrial Deal<sup>12</sup> and the Circular Economy Action Plan<sup>13</sup>. By converting industrial waste and captured CO<sub>2</sub> into valuable resources, it directly addresses the EU's mandate to decarbonise hard-to-abate sectors such as steel and cement, whilst supporting their competitiveness. These industries face process-inherent emissions that cannot be eliminated through electrification alone, making Carbon4Minerals' approach to mineralised storage a key component in reaching Europe's 2050 climate neutrality targets.

### Status of implementation

As of February 2026, the project has successfully transitioned from design to active piloting and site testing. In the field of CO<sub>2</sub> capture, a mobile pilot using solid adsorption technology is being tested at VITO (Vlaamse Instelling voor Technologisch Onderzoek) using flue gases from its natural gas boiler, with plans to relocate to an

ArcelorMittal steel site by the end of 2026 to evaluate performance under industrial conditions. The pilots for low-carbon cements are also well-advanced; a carbonation clinker demonstration has already produced one tonne of material, while a Recycled Concrete Paste pilot led by Heidelberg Materials has been operational since mid-2025. In the final step of the CCU value chain, the pilot plant at Vandersanden is operational and producing bricks. Current efforts are focused on expanding the scope of input materials and testing new shapes for high-end products like facade and roof panels.

### Next steps

The final phase of Carbon4Minerals will prioritise the rigorous validation of the new materials to ensure they meet the same longevity and safety standards as traditional construction products. Partners will conduct deep-dive durability assessments and update life cycle analyses with real-world data from the pilots to prove economic and environmental sustainability at an industrial scale.

Strategic planning for future deployment is already underway, including a geographic assessment to identify the best European sites for integrating these circular value chains.

# CaLby2030:

## Decarbonising industrial processes through Calcium Looping

### Fact sheet

Duration	1 October 2022 until 31 March 2026 (+22 months extension granted)
EU contribution	€ 15 026 220,75
Type of action	Research and Innovation Action
Coordinating organisation	Agencia Estatal Consejo Superior de Investigaciones Científicas (Spain)
Consortium size	18 partners

### Main objective of the project

The primary goal of **CaLby2030** is to serve as a technical enabling tool to establish the operational and design evidence required for the industrial readiness of **Calcium Looping (CaL)** technology by 2030. The project seeks to demonstrate that this technology can provide a high-efficiency CO<sub>2</sub> capture solution for three **hard-to-abate** industrial sectors for three pilot plants reaching TRL 6 by the end of the project: (i) cement **MAGNUS pilot plant**, located in Germany, (ii) iron and steel, located in **Swerim, Sweden**, and (iii) Residual-biomass-fired **La Pereda** power plant, located in Spain. This includes adapting the capture loop to the fine particle sizes required by the cement industry, managing the highly discontinuous flue gas flows typical of steel-making electric arc furnaces, and targeting >99% CO<sub>2</sub> capture rates and acid gases removal when firing waste.

Project coordinator Carlos Abanades (CSIC) highlighted the technology's readiness:

*"We don't need to reinvent the wheel... every element in that direction has been already invented and demonstrated in commercial fluidised bed combustors. If we succeed at TRL 6, the scale-up can be very fast"*

To manage this cross-sectoral scope, the project utilises a diverse consortium of 18 partners. This large group is necessary to balance high-level academic research with the practical expertise of industrial technology providers, such as those leading the world in circulating fluidised bed technology, to ensure the solution is tailored to the unique technical constraints of each different industrial application.

### Impact

CaLby2030 is expected to significantly lower the economic and environmental costs of industrial decarbonisation by utilising natural limestone as sorbent precursor. A major advantage of this technology is its ability to produce heat at ~650°C during the carbonation step, which can be recovered to co-generate power or preheat industrial materials—offsetting a significant share of the process energy demand and enabling substantial internal heat-and-power recycling. This energy integration makes the technology particularly competitive for industries operating at high temperatures.

Furthermore, the project supports a circular economy by fostering material synergies; for instance, the calcium-rich purge from the capture loop can ideally be reintegrated into cement kilns as a renewable feedstock, reducing the need for virgin limestone. The process also produces a renewable and highly concentrated CO<sub>2</sub> stream when burning residual biomass in the calciner. This can be a critical benefit as it transforms the CO<sub>2</sub> into a sustainable commodity ready for industrial use or transport. When the source of carbon is biogenic and the CO<sub>2</sub> is purified, this CO<sub>2</sub> stream provides a high-value platform for producing synthetic fuels or chemicals, such as renewable methanol.

### Connections to relevant EU policy

The project is fundamentally linked to the Net-Zero Industry Act<sup>14</sup>, which mandates the rapid scaling of CO<sub>2</sub> capture to meet 2050 climate goals. By providing technical evidence for verifiable negative emissions when firing biogenic fuels, CaLby2030 feeds into the Carbon Removal Certification Framework<sup>15</sup> and supports the development of renewable commodity markets.

### Status of implementation

As of early 2026, the project has achieved significant milestones despite the delays faced in full industrial retrofitting to biomass-firing of one of the facilities:

**The La Pereda Pilot** in Spain has accumulated over 2,000 hours of operation, successfully demonstrating biomass-fueled oxy-calcination, achieving capture efficiencies >99% (when polishing with small flows Ca(OH)<sub>2</sub>), and removal (to <1ppmv) of SO<sub>2</sub>, HCl and HF present in Waste to Energy flue gases.

In Germany, the **MAGNUS Pilot** has conducted cam-

paigns with fine particle raw meals relevant for the cement sector, identifying new strategies to exploit natural tendencies of limestone to attrit in the oxy-fired calciner.

A brand-new pilot in **Swerim, Sweden** is currently being completed to handle the complex and variable flue gases of the steel industry.

The project is supported by IP, including a patent for a super-flexible calcium loop held by a partner of the project - Sumitomo SHI FW Energia. This patent details an apparatus and method for capturing CO<sub>2</sub> from gas, specifically designed to handle the variable and discontinuous flue gas flows typical of industrial processes like steel manufacturing.

### Next steps

The experimental data gathered across the pilots is being used to validate dynamic modelling tools—covering particle kinetics, fluid dynamics, and process integration—to bridge the gap to industrial application readiness. The next major phase involves completing Front End Engineering Design studies for at least four First-of-a-Kind commercial

demonstration projects. Several industrial partners are preparing to the possibility to move toward large-scale deployment via the Innovation Fund, particularly for Waste-to-Energy applications where the technology's robustness against fuel impurities and gaseous contaminants (like SO<sub>2</sub> and chlorine) provides a unique competitive edge.

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