Strategic Energy Technology Plan

Implementation Working Group on
Industrial Carbon Management (ICM)

Thematic Vision on Industrial Carbon Management (CCS, CCU, CDR)

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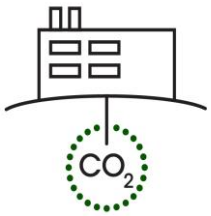

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Executive summary

Industrial carbon management (ICM) – encompassing carbon capture and storage (CCS), carbon capture and utilisation (CCU), and industrial carbon dioxide removals (CDR) – will play an important role in achieving climate neutrality in Europe, alongside electrification, energy efficiency, and renewable energy deployment. It contributes to emissions reductions in energy-intensive sectors, supports selected low-carbon industrial value chains (including low-carbon hydrogen production), and enables the management of residual emissions through permanent carbon removals. This Thematic Vision outlines a realistic and staged pathway for the development of ICM across Europe, reflecting Member States' perspectives, current market conditions, and infrastructure constraints.

Achieving large-scale deployment will require addressing a number of key bottlenecks, including cost reductions in capture technologies, storage characterisation, CO_2 transport system development, monitoring and verification, and viable business models. Substantial R&D programs are needed to meet these challenges.

By 2030, ICM should reach early commercial deployment, with initial CO_2 value chains in operation. This includes delivering geological storage capacity in line with EU policy objectives, notably the target set out in the Net-Zero Industry Act for a CO_2 injection capacity of at least 50 million tonnes per year in the EU by 2030, supported by a limited number of operational storage sites and predominantly regional transport systems centred on industrial clusters, including the first cross-border CO_2 transport routes. A first wave of CCS projects should reach final investment decision, supported by targeted de-risking mechanisms and clear allocation of responsibilities across the value chain. Deployment should focus on hard-to-abate industrial emissions from sectors such as cement, lime, waste incineration, and suitable biomass applications (taking into account sustainability considerations and local circumstances). Initial biogenic carbon capture and storage (BioCCS) projects should be operational, with early Carbon Removal and Carbon Farming (CRCF)-certified removals and continued development of direct air carbon capture and storage (DACCS). This phase is primarily characterised by infrastructure development and initial market formation.

By 2040, ICM should achieve broad scale-up across regions, with operational geological storage capacity reaching around 150-200 $MtCO_2$ per year[1] integrated with expanded transport systems – including pipelines, shipping, trains, and road transport. CCS should be deployed at scale in priority sectors and integrated into low-carbon industrial clusters. Project development should become more standardised, supported by more mature financing structures and emerging industrial supply chains, contributing to cost reductions. Carbon removals should increase, supported by clear targets and compliance and/or market-based demand. Certification frameworks under the CRCF should be fully operational and increasingly aligned with international approaches. This phase reflects system expansion, industrialisation, and growing market maturity.

[1] This figure is derived from official EU scenarios. It is intended to inform strategic planning and should not be interpreted as a legally binding target or obligation. The Impact Assessment report accompanying the 2040 climate target provides estimates ranging from 42 Mtpa (S1), to 147 Mtpa (S2), 197 Mtpa (LIFE), and 243 Mtpa (S3) at the level of the European Union by 2040. The EU Industrial Carbon Management Strategy sets out an indicative CO_2 storage objective of at least 250 Mtpa across the wider European Economic Area (EEA) by 2040. Should future EU legislation establish mandatory targets or revise these figures, this plan will follow them accordingly.

By 2050, ICM should be a mature component of a climate-neutral economy, with operational geological storage capacity close to 250 $MtCO_2$ per year[2] and established CO_2 transport systems supporting regional, cross-border, and potentially international CO_2 flows. Energy-intensive sectors should reach complete decarbonisation through a combination of emissions reductions (including decarbonised energy inputs) and the use of CDR to compensate for residual emissions. Carbon removals should be deployed at large scale (and on a path to help the EU achieve net negative emissions after 2050) and integrated both into EU and international frameworks, while CCU remains focused on targeted applications with clear climate benefits. Markets for CCS, CCU, and CDR should function with limited and targeted reliance on public support (if still needed), underpinned by stable regulatory frameworks and strong European industrial capabilities.

Large-scale deployment of industrial carbon management is fundamentally policy-driven, requiring predictable and long-term regulatory frameworks, targeted public support, and clear market incentives to enable investment decisions across the value chain. Given the long development timelines and capital-intensive nature of ICM projects, the pace and scale of this transition will therefore depend critically on the timely development of stable and credible policy frameworks.

Key drivers include strengthened EU climate targets, the need to maintain industrial competitiveness, and increasing recognition of the role of carbon removals. However, today, barriers remain, including both uneven distribution of CO_2 storage potential and insufficient availability of developed capacity – which is currently concentrated in North-West Europe – as well as long development timelines, investment uncertainty, cross-chain risks arising from value chain interdependencies, fragmented regulatory approaches, and public acceptance challenges. Addressing these barriers requires continued cross-border cooperation, coordinated infrastructure planning, improved availability of subsurface data, clearer regulatory frameworks, and stable policy signals. As deployment scales, maintaining public trust and ensuring that the benefits of industrial carbon management are both understood and shared across regions will also become increasingly important. Securing and maintaining a social license to operate will be critical for project development, permitting, financing, and long-term implementation.

IWG9 will support the scale-up of CCS, CCU and CDR by facilitating coordination between Member States, promoting knowledge sharing and capacity building, aligning R&I with deployment needs, and contributing to the development of harmonised standards and methodologies. Member States and industry emphasise the need for predictable policy frameworks to foster investment and scale-up, and for strengthened cross-border cooperation.

Priority areas for R&I under the next Multiannual Financial Framework (2028–2034) include: (i) CO_2 storage characterisation, to reduce uncertainty, lower costs, and accelerate storage development; (ii) CO2 transport system optimisation, including regional infrastructure and cross-border coordination; and (iii) carbon capture and carbon removal technologies, focusing on cost reduction and system integration. Delivering industrial carbon management at scale will require a sustained and coordinated European effort to ensure that these technologies contribute effectively to climate objectives while supporting a competitive and resilient industrial base.

[2]This figure is derived from official EU scenarios. It is intended to inform strategic planning and should not be interpreted as a legally binding target or obligation. The EU Industrial Carbon Management Strategy sets out a CO_2 storage objective of 250 Mtpa by 2050, and the Impact Assessment report accompanying the 2040 climate target provides a 247 Mtpa estimate (S3) by 2050.

1. Introduction

Role of IWG9 within the SET Plan and policy context

The SET-Plan aligns national research and innovation programmes with the EU's clean energy policy objectives, supporting strategic autonomy, competitiveness, and decarbonisation. By fostering cooperation among European countries, industry, and research organisations, it helps align R&I and market uptake activities across EU and associated countries, thereby accelerating the development, cost reduction, and deployment of low-carbon energy technologies. To facilitate this process, the SET Plan's Steering Group establishes Implementation Working Groups (IWGs) to guide cooperation on R&I priorities and funding programmes in specific clean energy technology areas.

In this context, the Implementation Working Group no. 9 (IWG9) focuses on industrial carbon management (ICM), which encompasses carbon capture and storage (CCS), carbon capture and utilisation (CCU), and industrial carbon dioxide removal (CDR) methods such as direct air carbon capture and storage (DACCS) and biogenic carbon capture and storage (BioCCS). These technologies are essential to decarbonising hard-to-abate emissions from industrial sectors, enabling negative emissions, and supporting the transition to a climate-neutral European economy.

IWG9 operates at the intersection of research, innovation, and industrial deployment. Its role within the SET Plan is to facilitate coordination between Member States, support the alignment of national and European R&I priorities, and help translate technological innovation into large-scale implementation. In doing so, IWG9 contributes to bridging the gap between early-stage research and commercial deployment across the full CO_2 value chain.

The importance of IWG9 has significantly increased in the evolving EU policy landscape. The Industrial Carbon Management Strategy (2024) and the Net-Zero Industry Act (2024) both recognise CO_2 infrastructure and carbon management as critical enablers of EU climate neutrality, industrial competitiveness, and strategic autonomy. These frameworks set clear ambitions for scaling up CO_2 storage capacity and establishing a European CO_2 transport network, positioning ICM as a core pillar of the Energy Union.

Within this context, IWG9 brings together representatives from interested EU and EEA countries and the European Commission. The group is co-chaired by the Netherlands and Norway and supported by a technical secretariat led by Carbon Management Europe, with support from The Foundation for Industrial and Technical Research (SINTEF), the Netherlands Organisation for Applied Scientific Research (TNO), and the British Geological Survey (BGS). IWG9 also engages with relevant industrial, research, and innovation actors, including the European Energy Research Alliance (EERA), the European Network of Excellence on the Geological Storage of CO2 (CO2GeoNet), the European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL-ERIC), and the broader research community, supporting coordination across research, innovation, and deployment activities.

Objective of the Thematic Vision

This Thematic Vision aims to define a coherent, long-term pathway for the development and deployment of industrial carbon management technologies in Europe up to 2050. It sets out strategic targets and milestones for 2030, 2040, and 2050, reflecting the ambitions of SET Plan countries and aligning with EU climate, energy, and industrial policy objectives.

The Vision is intended to:

- Provide a shared direction for Member States on the role of CCS, CCU, and CDR in achieving climate neutrality

- Identify gaps and priority areas for research, innovation, and deployment across the ICM value chain
- Support the alignment of national and EU-level efforts, reducing fragmentation and accelerating scale-up
- Contribute to the development of future Strategic Research and Innovation Agendas (SRIAs) and Common Implementation and Investment Plans (CIIPs)

A dedicated Vision is essential in this field due to the systemic nature of industrial carbon management. Unlike single technologies, ICM requires the coordinated development of infrastructure, markets, regulatory frameworks, and public acceptance. Without a clear and shared long-term vision, there is a risk of delayed investment, higher cost, fragmented development, and failure to meet climate targets.

Key developments, drivers and barriers

Recent years have seen a significant shift in the role and urgency of industrial carbon management in Europe. This evolution has been accompanied by important developments across the industrial carbon management landscape. The adoption of the Industrial Carbon Management Strategy, the Net-Zero Industry Act (NZIA) – including its legally binding target of developing at least 50 $MtCO_2$/year of annual CO_2 injection capacity in the European Union by 2030 – and the Carbon Removal and Carbon Farming (CRCF) Regulation has significantly strengthened the European framework for industrial carbon management. In parallel, progress in implementing the London Protocol has helped remove legal barriers to cross-border CO_2 transport and offshore storage. Europe has also moved beyond isolated pilot and demonstration projects towards the first commercial-scale CO_2 value chains, with large-scale projects progressing through construction and early operation across an increasing number of Member States.

Key drivers include:

- Strengthened EU climate ambition, including legally binding 90% emissions reduction by 2040 and climate neutrality by 2050
- Increasing role of the EU Emissions Trading System (EU ETS) and the Carbon Border Adjustment Mechanism (CBAM) in strengthening investment incentives for industrial decarbonisation through a more robust carbon price signal and the gradual phase-out of free allocation for certain sectors
- Increasing focus on industrial competitiveness, particularly for energy-intensive industries exposed to global competition
- Growing need for negative emissions technologies to address residual emissions and potential overshoot scenarios
- Rising geopolitical concerns around energy security and strategic autonomy, reinforcing the need for domestic decarbonisation solutions

At the same time, important barriers remain:

- Insufficient development of CO_2 transport and storage infrastructure
- Lack of investment certainty and viable business models, including unclear revenue streams and risk allocation
- Fragmentation of national approaches and R&I programmes across Member States, which results in duplication in some areas and gaps in others, reduces opportunities for joint learning, and limits the scope for coordination and efficient scale-up
- Limited public awareness and societal acceptance challenges, especially for onshore storage and infrastructure

- Skills and workforce gaps related to the scale-up of CCS, CCU, and CDR value chains
- Challenges related to accelerating innovation, demonstration, and market uptake across industrial carbon management technologies – including the optimisation of capture technologies for different industrial processes and the scale-up of industrial carbon removals

Addressing these barriers requires coordinated action across policy, industry, and research, as well as sustained public and private investment.

As deployment scales, public trust, community engagement, and the equitable distribution of costs and benefits may become increasingly important factors influencing project development, permitting, and long-term implementation. Beyond technical, regulatory, and financial challenges, the successful deployment of industrial carbon management will therefore also depend on public trust and societal acceptance. Large-scale infrastructure development may have implications for spatial planning, land use, and local communities. Ensuring transparent engagement, effective communication, and a fair distribution of benefits across regions will be important considerations throughout the transition.

Priority R&I focus areas (2028–2034)

To enable the transition from early deployment to scalable and credible industrial carbon management, targeted R&I efforts under the next Multiannual Financial Framework (2028–2034) should focus on addressing key technical, geological, system-level, and market-enabling gaps. The following priority areas were identified:

(a) **CO_2 storage characterisation, to reduce uncertainty, lower costs, and accelerate storage development**

- Improved geological characterisation of storage resources across Europe, particularly onshore storage and storage in saline aquifers
- Enhanced data availability and transparency, building on initiatives such as the EU CO_2 Storage Investment Atlas, and in line with Article 21 of the Net-Zero Industry Act
- Continued development and standardisation of monitoring, reporting and verification (MRV) technologies for storage integrity and long-term stewardship
- Streamlining of permitting and site development processes, based on operational experience

(b) **CO_2 transport system optimisation, including regional infrastructure and cross-border coordination**

- Design and optimisation of regional CO_2 transport systems, particularly those which use multiple transport methods
- Development of CO_2 corridor approaches to enable efficient cross-border flows
- Integration of CO_2 infrastructure into energy system planning, including interactions with hydrogen and electricity systems
- Improve understanding of the impact of impurities on common CO_2 pipeline infrastructure
- Research on possible standardisation of CO_2 specifications

(c) **Carbon capture and carbon removal technologies, focusing on performance, cost reduction, and system integration**

- Cost and energy efficiency improvements in capture technologies for priority sectors (e.g. cement, lime, waste-to-energy)
- Development and scale-up of carbon removal technologies, including BioCCS, DACCS (subject to low-carbon energy availability and cost), and other emerging industrial carbon removal approaches where relevant

- Integration of capture and removal technologies into industrial clusters
- Exploration of modular and flexible capture solutions for smaller or dispersed emitters
- As capture technologies mature and deployment increases, further research on operational performance, reliability, availability, maintainability, and asset lifetime – drawing on experience from other mature industrial sectors to support long-term cost reductions and knowledge sharing
- Improved understanding of the compatibility between industrial flue gas compositions and capture technologies, including optimisation of flue gas pre-treatment, identification of suitable capture technologies for different industrial sectors, and optimisation of trade-offs between flue gas cleaning requirements and lifecycle costs

(d) **Carbon accounting and sustainability reporting**

- Development and harmonisation of carbon accounting methodologies, including robust life-cycle assessment methodologies to evaluate the climate performance of CCU pathways, approaches for mixed CO_2 streams, and accounting for hybrid CCS/CCU/CDR configurations
- Continued refinement and expansion of CRCF methodologies, including alignment with international approaches
- Research on sustainability criteria and system impacts, ensuring that deployment delivers real climate benefits

(e) **Market design, risk reduction and business models**

- Development of standardised contractual frameworks across the value chain
- Improved understanding of cross-chain risk allocation and financing structures
- Evaluation of policy instruments and support mechanisms (e.g. CfDs, public procurement for CDR)
- Analysis of demand-side drivers, including the role of compliance markets and targets for carbon removals

(f) **Public engagement, social acceptance, and Just Transition**

- Research on public perceptions, risk communication, and social acceptance of ICM technologies and infrastructure
- Development and evaluation of approaches for stakeholder engagement and community participation
- Improved understanding of the social, economic, and regional impacts of industrial carbon management deployment
- Identification of good practices to support public trust, transparent decision-making, and a fair and inclusive transition

Across all priority R&I areas, digital tools – including data-driven and AI-enabled approaches where appropriate – should be considered to accelerate research, improve modelling and simulation, optimise the design and operation of CO_2 value chains, support monitoring and verification, enhance predictive maintenance and asset management, strengthen scenario analysis and decision-making, and facilitate knowledge sharing and collaboration across the European industrial carbon management community.

Reflection on SET Plan Task Force recommendations

The work of IWG9 is closely aligned with the SET Plan's cross-cutting Task Forces. Several recommendations are particularly relevant for industrial carbon management:

- **Access to market:** Critical for enabling investment in large-scale CCS/CCU/CDR projects – including through de-risking instruments, regulatory clarity, and the development of CO_2 markets and infrastructure
- **R&I for societal needs:** Essential to strengthen public understanding and acceptance of ICM technologies. This includes supporting transparent communication, sharing of operational experience, and ensuring that deployment contributes to a just, inclusive, and regionally balanced transition across Europe.
- **Skills:** The scale-up of industrial carbon management will require a skilled and adaptable workforce, spanning engineering, geology, regulatory expertise, and project development – with attention to regional capacity gaps across Member States.
- **Digitalisation:** Important to enable robust MRV systems, support the efficient operation of CO_2 transport networks, improve system optimisation, and facilitate data transparency.
- **Circularity and materials substitution:** Relevant for selected CCU pathways, where applications must demonstrate clear climate benefits, environmental integrity, and resource efficiency based on robust life-cycle assessments.

IWG9 will integrate these recommendations into its strategic planning and future SRIA development, ensuring that technological progress is accompanied by societal, economic, and systemic readiness.

2. Vision and targets

The Vision of IWG9 is to enable the progressive deployment and scale-up of industrial carbon management (ICM) across Europe, supporting climate neutrality while preserving industrial competitiveness and strengthening energy system resilience.

This Vision is based on three overarching objectives:

(a) **Decarbonisation**: Deliver substantial and verifiable greenhouse gas emissions reductions, including negative emissions, particularly in hard-to-abate sectors

(b) **Competitiveness**: Safeguard and strengthen European industrial value chains by enabling low-carbon production and preventing carbon leakage (i.e. the relocation of industrial production and associated emissions outside Europe)

(c) **Security of supply and strategic autonomy**: Develop a resilient European CO_2 management system, reducing dependence on external solutions and enabling domestic decarbonisation pathways

Achieving these objectives requires the coordinated development of the full CO_2 value chain – including CO_2 capture, transport, storage, utilisation, and removals – taking into account regional specificities, infrastructure constraints, and evolving policy and market conditions.

The targets and milestones outlined below reflect the transition from early deployment (by 2030) to scale-up across regions and sectors (by 2040) and ultimately system maturity and optimisation (by 2050).

Industrial carbon management also plays an important role in enabling low-carbon hydrogen production, thereby supporting the decarbonisation of key industrial value chains.

2.1 Short-term (2030)

By 2030, industrial carbon management in Europe will transition from demonstration projects to early commercial deployment, with initial CO_2 value chains in operation and a credible basis for further scale-up. This phase should involve: (i) de-risking projects and value chains, (ii) establishing infrastructure where most viable, (iii) building confidence among investors, industry, and regulators.

Key targets for 2030

1. CO_2 transport and storage infrastructure	• Delivery of CO_2 storage capacity in line with EU policy objectives, including the NZIA target of at least 50 $MtCO_2$/year of annual injection capacity in the EU by 2030, and potential further contributions in the wider EEA • Commissioning of at least several new operational storage sites, with a broader pipeline of storage sites in advanced permitting and development • Development of regional CO_2 transport solutions focused on key industrial clusters and storage basins • Progress in geological characterisation and data availability, including through the EU CO_2 Storage Investment Atlas, implementation of the NZIA provisions on transparency of CO_2 storage capacity data (Article 21), and strengthened national mapping efforts • Integration of CO_2 infrastructure planning into TEN-E / TYNDP and national network planning strategies
2. Deployment of CCS in industrial sectors	• Development of industrial cluster-based CCS projects, where shared infrastructure improves economics • Deployment of CCS solutions in priority hard-to-abate sectors, notably cement, lime, and waste-to-energy, as well as biomass-based industries, taking into account sustainability considerations and local conditions • Initial deployment of CCS in low-carbon hydrogen production – including blue hydrogen where relevant – particularly where it contributes to near-term decarbonisation and system flexibility • Exploration and case-specific deployment of CCS in additional sectors, including iron and steel (e.g. gas-based DRI with CCS) and chemicals and refining
3. CO_2 utilisation and carbon accounting frameworks	• Development of selected CCU pathways, prioritising applications with clear long-term relevance (e.g. chemicals) and demonstrable climate benefits, supported by robust life-cycle assessments (LCAs) • Improved and standardised carbon accounting methodologies for CCU pathways, mixed CO_2 streams, and hybrid CCS/CCU/CDR configurations
4. Scale-up of carbon removal technologies	• Operation of first commercial-scale BioCCS projects, with additional projects under development • Continued development of DACCS through pilot and demonstration projects (without assuming large-scale deployment by 2030) • Implementation of the EU CRCF framework, with first certified carbon removals issued and initial market uptake • Delivery of initial volumes of certified removals, with a clear trajectory for post-2030 scale-up • Continued R&I to improve cost, energy efficiency, and MRV methodologies across all CDR pathways • Further development of CRCF methodologies – including, for e.g., mineral carbonation, carbon storage in construction products, enhanced rock weathering (ERW), ocean alkalinity enhancement (OAE), and direct ocean carbon capture and storage (DOCCS)

5. Project development, markets, and risk allocation	• A portfolio of CCS projects reaching FID across several Member States, reflecting different national contexts and business models • Continued development of project pipelines (feasibility, permitting, commercial structuring) • Progress toward standardised contractual frameworks (e.g. transport and storage agreements, liability allocation) • Increased clarity on cross-chain risk allocation (capture–transport–storage interfaces) • Development of targeted de-risking mechanisms (e.g. CfDs, state aid, EU funding instruments) • Improved cross-border operability, including the development of common minimum CO_2 quality specifications, more consistent and streamlined EU ETS monitoring and reporting requirements, and clarified responsibilities along the value chain • Clearer national strategies and policy signals to build investor confidence

Key milestones to 2030

2026-2028	• A first wave of CCS projects reaching FID across multiple Member States, including key flagship clusters • First new European CO_2 storage sites entering operation outside Norway
2028-2029	• Initial CO_2 transport solutions operational, primarily in cluster-based configurations
By 2030	• CO_2 infrastructure integrated into European and national planning frameworks • A credible project pipeline established across capture, transport, storage, and removals

IWG9 supporting activities (to 2030)

To support the achievement of these targets, IWG9 will:

- Facilitate coordination between Member States on CO_2 infrastructure planning and cross-border cooperation
- Encourage national investment in storage characterisation and data collection
- Promote knowledge sharing and best practices from early projects and clusters
- Facilitate capacity building between experienced and less-experienced Member States
- Identify R&I gaps across the value chain and strengthen collaboration with ETIPs, EERA, and industrial stakeholders to align R&I with deployment needs
- Support the harmonisation of standards and methodologies (including MRV frameworks, sustainability criteria for CCU/CDR, and technical standards related to CO_2 specifications, transport, storage, and interoperability of multi-source CO_2 networks)
- Promote stable policy signals and no-regret measures to build market confidence

(Fiches to be provided in Annex / SRIA / CIIP as appropriate.)

Addressing Task Force priorities (2030 perspective)

- **Access to market**: enable FIDs through de-risking mechanisms and predictable frameworks
- **R&I for societal needs**: improve public awareness and acceptance
- **Skills**: develop workforce for project deployment and operation
- **Digitalisation**: support monitoring, reporting, and optimisation systems

- **Circularity and materials substitution**: promote targeted CCU applications that demonstrate net climate benefits

2.2 Medium-term (2040)

By 2040, industrial carbon management in Europe should transition from early deployment to scale-up, with multiple CO_2 value chains in operation and increasing industrial uptake. This phase is characterised by: (i) expansion of regional CO_2 networks and storage capacity, (ii) increasing industrial uptake, (iii) gradual emergence and stabilisation of carbon removal markets.

Key targets for 2040

1. CO_2 transport and storage infrastructure	• Expansion of operational CO_2 storage capacity to around 150-200 $MtCO_2$/year (as per current EU official scenarios and non-binding objectives for 2040) • Development of a diversified portfolio of storage sites across key regions (including onshore where feasible) • Continued improvements in subsurface knowledge and monitoring technologies • Expansion of regional CO_2 transport systems • Development of CO_2 corridors enabling cross-border flows and international cooperation, where economically justified and supported by compatible regulatory frameworks
2. Deployment of CCS in industrial sectors	• Integration of CCS into low-carbon industrial clusters, supporting near-zero emissions production in key value chains • CCS deployed at scale in cement, lime, waste incineration (including waste-to-energy), as well as in biomass-based industries where sustainable biomass resources and local conditions support deployment • Continued role of CCS in low-carbon hydrogen production, depending on system needs • More selective uptake in other sectors (e.g. steel, chemicals, refining), depending on economic and policy conditions
3. CO_2 utilisation and carbon accounting frameworks	• Deployment of selected CCU pathways in sectors where alternatives are limited and where the net climate benefits of captured CO_2 uses have been demonstrated through robust LCAs • Integration of captured CO_2 into specific industrial value chains, such as aviation and maritime fuels and certain chemical processes • Clear differentiation between short-lived carbon uses (limited climate value) and durable or system-relevant uses • Robust sustainability reporting and carbon accounting frameworks ensuring environmental integrity
4. Scale-up of carbon removal technologies	• Scale-up of BioCCS in sectors with sustainable biomass availability, alongside early deployment of mineral carbonation and carbon storage in products where climate benefits are demonstrated • Early commercial deployment of DACCS subject to cost reductions and availability of low-carbon energy • Emergence of compliance and/or market-based demand for certified removals • Clarification of CDR's role in addressing residual emissions, including interactions with EU ETS • Contribution of CDR to EU 2040 climate objectives – with defined targets or ranges (distinct from emissions reductions) rather than open-ended flexibility • Alignment of CRCF with international approaches, and cooperation under Article 6 of the Paris Agreement to support interoperability
5. Project development, markets, and risk allocation	• Transition from project-by-project development to more standardised approaches in project design, contracting structures, and risk allocation • Emergence of structured industrial supply chains • Broader availability of de-risking mechanisms and blended finance models

	• Improved cost visibility and reduction, driven by learning-by-doing, innovation, and standardisation • Increased experience and clarity in liability management across the value chain • Greater alignment of national frameworks and standards to support cross-border CO_2 value chains, including streamlined EU ETS accounting • Competitive European industrial value chains for carbon management technologies and services, with strong global positioning

Key milestones to 2040

2030-2035	• Expansion of existing clusters and emergence of new regional CO_2 hubs • Increasing number of projects reaching FID and entering operation
By 2035	• Consolidation of regional CO_2 transport systems • Initial evidence of cost reductions and standardisation effects
Late 2030s	• Progressive scale-up of CDR deployment, supported by maturing certification and demand frameworks • Improved integration of CO_2 management into industrial and energy system planning

IWG9 supporting activities (to 2040)

To enable scale-up at system level, IWG9 will focus on:

- Supporting coordination of cross-border CO_2 infrastructure development, particularly where regional systems begin to connect
- Encouraging standardisation of technical and contractual frameworks across the value chain
- Promoting knowledge sharing and exchange of best practices from early projects, including on onshore CO_2 storage and public engagement
- Facilitating capacity building between Member States
- Using common fora (e.g. ICM Forum) to enhance transparency and encourage open dialogue
- Contributing to the refinement of CDR methodologies and policy frameworks
- Strengthening links between R&I priorities and deployment needs, including through SRIA updates
- Promote knowledge sharing on public engagement, social acceptance, and community involvement, including lessons from storage and infrastructure projects

(Fiches to be provided in Annex / SRIA / CIIP as appropriate.)

Addressing Task Force priorities (2040 perspective)

- **Access to market**: shift from strong public support to targeted de-risking and market-based instruments
- **R&I for societal needs**: support equitable access and just transition outcomes, with continued attention to public acceptance, particularly in new regions deploying storage and infrastructure
- **Skills**: scaling and maintaining a specialised workforce across regions
- **Digitalisation**: wider use of monitoring, optimisation, and data-sharing systems
- **Circularity and materials substitution**: ensure CCU contributes only where resource-efficient and climate-relevant

2.3 Long-term (2050)

By 2050, industrial carbon management in Europe should be a mature and integral component of the climate-neutral economy, supporting the management of residual emissions and the delivery of durable carbon removals. Rather than a fully uniform system, the 2050 ICM landscape is expected to be: (i) heterogeneous across regions and sectors; (ii) shaped by evolving technologies, policies, and market conditions; (iii) integrated where relevant into broader energy and industrial systems.

Key targets for 2050

1. CO_2 transport and storage infrastructure	• CO_2 storage capacity developed in line with EU climate neutrality needs, on the order of ~250 $MtCO_2$/year (as per current EU official scenarios and non-binding objectives for 2050) • Portfolio of storage sites across Europe and multiple CO_2 corridors enabling cross-border flows • CO_2 transport systems enabling flexible and back-up routing options (cf. possibility to temporarily divert CO_2 streams in case a part of a network is down), interoperability, and operational resilience • Continued improvements in monitoring, safety, and long-term stewardship – including robust and increasingly harmonised post-closure management frameworks ensuring safe and permanent CO_2 storage across Europe
2. Deployment of CCS in industrial sectors	• Complete decarbonisation of hard-to-abate sectors, combining maximum direct emissions reductions and CDR to offset residual emissions • CCS widely deployed in cement, lime, waste-to-energy, and biomass-based industries where sustainable biomass resources and local conditions support deployment • More limited or case-specific deployment in other sectors – including steel, chemicals, and refining – depending on the availability of alternative decarbonisation pathways as well as cost and policy developments (e.g. gas-based DRI coupled with CCS in the steel industry where scrap and green hydrogen are constrained) • Contribution of CCS to maintaining industrial activity and competitiveness in Europe, particularly in sectors exposed to international competition
3. Scale-up of carbon removal technologies	• CDR deployed at large scale, supporting EU climate neutrality by balancing residual emissions and contributing to net negative emissions after 2050 • Integration of CDR into EU and international climate frameworks • Increasing role of Member States as potential buyers of certified removals, supported by compliance mechanisms and/or carbon markets • Portfolio approach combining: BioCCS (where sustainable biomass is available), DACCS (subject to cost and energy constraints), mineral carbonation pathways (using both captured biogenic and industrial CO_2), and potential contribution from other emerging industrial carbon removal solutions depending on technological maturity • Continued improvement of MRV and certification systems, including international alignment
4. CO_2 utilisation and carbon accounting frameworks	• CCU deployed in high-value and climate-relevant applications • Prioritisation of biogenic and atmospheric CO_2 as feedstock • Likely concentration in synthetic fuels for aviation and maritime sectors, and selected chemical value chains • Continued need to ensure strict carbon accounting, particularly for short-lived products and hybrid CCS/CCU/CDR pathways • Phase-out of CCU pathways that do not deliver clear and verifiable climate benefits

5. Project development, markets, and risk allocation	• Functioning markets for CCS, CCU and CDR, with reduced reliance on public support • Continued role for targeted funding mechanisms for carbon removals and CO_2 infrastructure development in less mature regions • Harmonised standards and stable regulatory frameworks across Europe, enabling long-term investment certainty • CO_2 management fully embedded into industrial strategy, energy system planning, and climate policy frameworks • Europe positioned as a major global player in industrial carbon management technologies and services

Key milestones to 2050

Early 2040s	• Expansion and optimisation of regional CO_2 systems, with interconnections where beneficial • Progressive cost reductions across the value chain, driven by scale, innovation, and standardisation • Progressive scale-up of CDR deployment, driven by policy demand and technology improvements
Late 2040s	• Full integration of carbon management into energy system operation, including sector coupling with hydrogen, renewables, and industry • Development of international CO_2 value chains and cooperation frameworks, where aligned with EU strategic interests
By 2050	• Industrial carbon management embedded in European decarbonisation pathways, with established infrastructure and broad sectoral uptake

IWG9 supporting activities (to 2050)

To support the long-term vision, IWG9 will:

- Support the continuous improvement of regulatory and technical frameworks
- Provide a platform for strategic coordination and policy alignment among Member States, particularly on long-term infrastructure and storage strategies
- Facilitate exchange of long-term operational experience and best practices to optimise performance and reduce costs, including on storage performance and risk management
- Update R&I priorities in line with technological and market evolution
- Support the exchange of best practices to maintain public trust and ensure that ICM deployment contributes to a fair and inclusive transition across regions
- Strengthen collaboration with international partners to support global deployment and standard-setting

Addressing Task Force priorities (2050 perspective)

- **Access to market**: stable, long-term frameworks combining market signals and targeted support
- **R&I for societal needs**: continued importance of public trust and acceptance, embedded in a just and inclusive transition
- **Skills**: skilled, experienced, and adaptable workforce
- **Digitalisation**: optimised CO_2 system management with advanced monitoring and data systems
- **Circularity and materials substitution**: selective and strategic use of CO_2 as a resource

3. Conclusions and next steps

This Thematic Vision sets out a clear and ambitious pathway for industrial carbon management (ICM) in Europe, positioning CCS, CCU, and industrial CDR as critical components of climate neutrality, industrial competitiveness, and energy system resilience.

By 2030, Europe should establish initial operational CO_2 value chains; by 2040, achieve broad scale-up across regions and sectors; and by 2050, deliver a mature and well-functioning system capable of supporting industrial decarbonisation and carbon removals.

The analysis confirms that while key technologies are available, the main challenge lies in scaling deployment under real-world constraints, requiring coordinated action across infrastructure, regulation, financing, and societal engagement. In particular, the development of CO_2 transport and storage infrastructure remains an indispensable enabler for achieving all targets.

The achievement of these objectives will continue to rely on a combination of national programmes and European instruments supporting research, innovation, demonstration, and deployment – including Horizon Europe, the Innovation Fund, and their successors.

Timely and coordinated action in the coming years will be decisive in ensuring that Europe achieves its climate objectives while maintaining a strong and competitive industrial base.

Priority actions

To deliver on this Vision, IWG9 highlights the following priorities:

- Strengthen geological characterisation and data availability, including national efforts and EU-level initiatives to improve understanding of storage potential
- Accelerate CO_2 infrastructure deployment through coordinated European and national planning, including cross-border cooperation and integration into TEN-E and TYNDP processes
- Develop and scale market frameworks, including de-risking mechanisms, standardised contractual approaches, and predictable policy signals
- Strengthen coordination of R&I efforts across Member States to reduce fragmentation and accelerate innovation-to-deployment pathways
- Scale up carbon dioxide removals through dedicated policy frameworks, clear targets, robust certification systems, and tailored support mechanisms
- Enhance public engagement and societal acceptance, ensuring transparent communication and alignment with just transition principles
- Develop skills and industrial capabilities to support the rapid expansion of the ICM value chain across Europe

R&I governance

Building on this Thematic Vision, the next step will be the development of a Strategic Research and Innovation Agenda (SRIA) for industrial carbon management.

IWG9 recommends that the SRIA be developed in close collaboration with:

- ETIP Carbon Management, as the primary stakeholder platform providing technical and industrial expertise
- EERA's Joint Programme on CCS, CO2GeoNet, ECCSEL-ERIC, and the research community, ensuring alignment with scientific priorities
- Industry stakeholders, to reflect deployment needs and investment realities

- SET Plan countries, to ensure consistency with national strategies and priorities

The SRIA should be prepared over the 2026–2027 period to inform the next Multiannual Financial Framework (2028–2034) and the development of Common Implementation and Investment Plans (CIIPs).

IWG9 stands ready to support the implementation of this Vision by continuing to act as a platform for coordination, knowledge exchange, and strategic alignment among Member States and stakeholders.

Synergies with other SET Plan working groups

Industrial carbon management is inherently cross-cutting and requires strong coordination with other SET Plan working groups. Key areas of synergy include:

- **Hydrogen**: integration of CCS in low-carbon hydrogen production and shared infrastructure development
- **Sustainable and efficient energy use in industry**: joint decarbonisation pathways for industrial sectors
- **Bioenergy**: alignment on bio-energy with carbon capture and storage (BECCS) deployment and sustainable biomass use
- **Energy systems**: integration of CO_2 infrastructure into broader energy system planning and sector coupling
- **Renewable fuels and CCU interfaces**: development of synthetic fuels and carbon-based value chains

Strengthening these synergies will be essential to ensure a coherent approach to the energy transition, avoiding duplication and maximising system efficiency.

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