**The Storage Bottleneck, CCS Limits are Redefining Global Net Zero Timelines Beyond 2070**

## Introduction

A global commitment to net-zero greenhouse gas emissions by 2050 rests, in large measure, on the anticipated contribution of carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies. Yet a convergence of evidence from European $CO_2$ storage trajectories, international policy assessments, and storage development data from China, North America, and Australia reveals a structural gap between ambition and delivery that cannot be closed within the current timeline. This abstract argues that the European Union's position – widely regarded as the world's most ambitious and legally codified decarbonisation framework – is itself symptomatic of a global storage supply crisis. When assessed against conservative geological carbon storage (GCS) reserve projections, the combined contribution of CCS and CDR to global decarbonisation is unlikely to exceed 5% or $2GtCO_2$ annually by 2050, leaving a residual gap of approximately 10% that cannot be addressed without new technical pathways and policy approaches. The implication is a revised global net-zero timeline of at least 2070.

## Method

The analytical framework applied here integrates three streams of evidence: (1) back-calculated storage requirements derived from IPCC AR6 and IEA net-zero scenario modelling (IPCC, 2021; 2023; IEA, 2021; 2025), matched against realistic supply-side GCS maturation rates; (2) comparative regional deployment data for CCS and CDR from the EU, UK, Norway, North America, China, and Australia; and (3) global assessments of coal power decommissioning feasibility and CCS retrofit potential across emerging economies. The analysis applies a conservative estimate of bankable GCS reserves as distinct from resources, prioritising justified reserves over theoretical geological capacity, consistent with the SPE $CO_2$ Storage Resources Management System (SRMS) classification (SPE, 2017). Where regional data permit, a low-range scenario is adopted throughout: the European Commission's 1.5LIFE pathway for the Europe (EC, 2018), and equivalently constrained scenarios for other regions.

The EU's legal framework – the European Climate Law (EU, 2021) mandating climate neutrality by 2050 – and its associated Net Zero Industry Act (NZIA) target of 50 Mtpa of $CO_2$ injection capacity by 2030 provide the primary policy anchor. Analysis by Cavanagh and Lockwood (2025) indicates that EU storage outcomes are likely to be closer to 25 Mtpa by 2030, and possibly as low as 18 Mtpa. Europe has stored just 30 million tonnes of $CO_2$ since 1996 – an injection rate of approximately 1 Mtpa over three decades that must increase by two orders of magnitude to support even the low-demand 1.5LIFE pathway requiring 80 Mtpa and 1.4 Gt of banked storage by 2050 (EC, 2018; IEA, 2021).

## Analysis

Europe's storage gap, while acute, is not an outlier. It is the clearest available diagnostic of a global problem. Currently, the EU accounts for approximately 7.5% of global fossil $CO_2$ emissions (Crippa et al., 2024); China has the largest share at 33.5% followed by North America, 13.3%. The three regions together represent 55% of global emissions (Table 1), yet none has demonstrated CCS deployment at a scale consistent with net-zero 2050 pathways. In North America, CCUS project attrition rates remain high: of the dozens of projects announced since 2010, fewer than fifteen operate at megatonne scale and most of these enhance oil recovery, with global and regional production reaching unprecedented levels; cumulative North American storage remains below 0.1 Gt. In China – the world's largest emitter, having increased fossil $CO_2$ output by an astonishing 550% since 1990 – CCS is constrained by storage site characterisation deficits, regulatory fragmentation, and the sheer scale of coal infrastructure, with over 1,270 GW of coal capacity – half the world's capacity – representing the largest single CCS retrofit challenge in the world. Australia's Gorgon project, intended as a flagship CCS demonstration, failed to meet its injection targets for five consecutive years following commissioning, highlighting the operational risks that are systematically underweighted in optimistic scenario modelling.

The Asian Development Bank's assessments of coal power decommissioning across South and Southeast Asia (ADB, 2022) reinforce the structural argument. The ADB's Energy Transition Mechanism identifies over 100 GW of coal capacity in the Philippines, Indonesia, and Vietnam – economies where early decommissioning is politically contested and where CCS retrofitting faces both geological storage access constraints and capital cost barriers estimated at USD 80–150 per tonne of $CO_2$. The absence of bankable storage reserves in the region means that CCS cannot function as a transitional technology to bridge coal phase-out, effectively eliminating the technology as a decarbonisation contributor across the region's highest-emitting assets. This compounds the global shortfall: if Asia-Pacific coal, at over 50% of global coal generation (Figure 1), proceeds to end-of-design-life without CCS, the emissions locked in exceed a carbon budget compatible with 1.5°C.

Applying conservative GCS reserve estimates globally, and assuming that North America and China require 1.5x and 3x Europe's storage development activity respectively to support equivalent net-zero pathways, the aggregate global storage development needed is around 14,000 injection wells by 2050 under P90 conditions (Ringrose and Meckel, 2019). This compares to the IEA's Net Zero Emissions (NZE) scenario of approximately 7.6 Gt per year by 2050, with 90% destined for geological storage (IEA, 2021). Even under the most optimistic interpretation, the CCS contribution by 2050 is constrained to the low-demand equivalent of the EC's 1.5LIFE pathway: approximately 2–5% of fossil $CO_2$ reductions (IEA, 2025). CDR technologies – including direct air carbon capture (DAC) and bioenergy with CCS (BECCS) – face compounding storage bottlenecks: both are dependent on the same geological storage infrastructure as industrial CCS, and neither can be deployed at scale without the bankable reserves that current trajectories cannot deliver.

***Table 1*** *$CO_2$ emissions 1990 to 2018. While Europe has achieved notable cuts, the three largest regions sum to 55% (54% in 1990) and 74% of GHG emissions (69% in 1990). Source: Crippa et al. (2024).*

| **EDGAR 2024 Emissions Database** | **1990 Emissions, Gt/yr Fossil $CO_2$ / GHG** | **2018 Emissions, Gt/yr Fossil $CO_2$ / GHG** | **2018 / 1990 Fossil $CO_2$** | **2018 share Fossil $CO_2$** |
|---|---|---|---|---|
| **Global** | **22.7 / 32.7** | **38.0 / 51.0** | **+ 67%** | **100%** |
| **China** | **2.41 / 3.88** | **11.6 / 14.0** | **+ 480%** | **30%** |
| **North America** | **5.42 / 6.79** | **5.73 / 7.13** | **+ 6%** | **15%** |
| **EU28** | **4.39 / 5.64** | **3.42 / 4.29** | **- 22%** | **10%** |
| **UK** | **0.582 / 0.761** | **0.373 / 0.458** | **- 36%** | **1%** |
| **Norway** | **0.036 / 0.055** | **0.047 / 0.060** | **+ 29%** | **0.1%** |

### Implication: The 10% Gap

Most credible net-zero 2050 scenarios assign CCS a contribution of 15% of necessary emissions reduction and removal (IEA, 2021; IPCC, 2023). If actual delivery is constrained to below 5%, a gap of approximately 10% remains unaddressed – a deficit that cannot be bridged by incremental improvements at current deployment rates. This 10% gap is not simply a rounding error in emissions accounting; it represents roughly 4–5 Gt of $CO_2$ per year that must be removed or avoided through mechanisms not currently scaled or commercially proven. The gap is simultaneously technical, financial, and political. Technically, it demands accelerated innovation in DACCS, geothermal enhanced weathering, and marine CDR – none of which has passed commercial readiness levels consistent with gigatonne-scale deployment before 2050. Politically, it requires new multilateral governance architectures capable of coordinating storage site access across exclusive economic zones, mobilising concessional finance for GCS in emerging economies, and resolving the liability and monitoring frameworks that have stalled projects in Germany, France, and across the Global South.

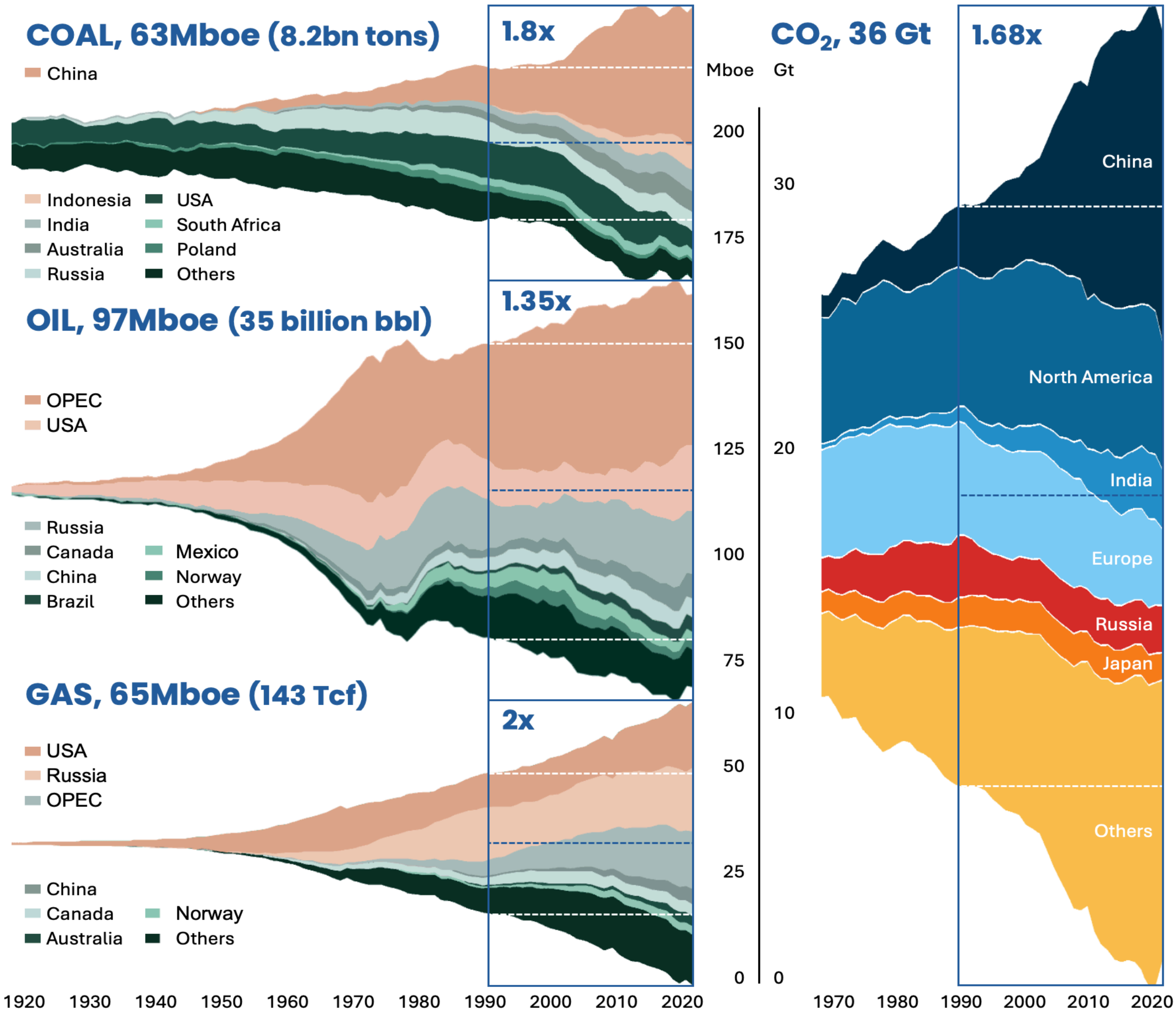


***Figure 1*** *Number goes up. Average daily fossil fuel production since 1920 (left panel) in millions of barrels of oil equivalent, Mboe (annual totals in brackets), and increase above 1990 levels by 2020 (blue box, white dashed line). Right, annual $CO_2$ emissions in gigatonnes (Gt) since 1970. A small number of jurisdictions account for more than half of all production and emissions which have further increased in the 2020s, approaching 40 Gt, with unprecedented levels of fossil fuel production. In 1990, $CO_2$ emissions (23 Gt) accounted for 69% of GHG emissions. In 2023, both absolute $CO_2$ emissions (39 Gt) and relative share (74%) are up. Sources: Our World in Data (2025), Energy Institute (2025).*

## Conclusions

Europe's trajectory – storing just 30 Mt since 1996 while targeting 50 Mtpa by 2030 and 450 Mtpa by 2050 (EC, 2024) – is not an outlier of institutional failure but an accurate reflection of the structural constraints that limit CCS globally. Under conservative geological storage reserve projections, global CCS and CDR deployment will fall below a 5% contribution by 2050, regardless of policy ambition. The resulting 10% gap in global decarbonisation is neither a planning anomaly nor a correctable shortfall under current trajectories: it is a structural feature of a transition architecture that has relied on an unlikely acceleration in CCS deployment and optimistic $CO_2$ storage assumptions for three decades without building the geological, regulatory, and financial infrastructure to support them.

We calculate from the data in this paper that "CCS will continue to be late". The global implication is a revised net-zero timeline of 2070. This is not a policy preference or a concession to inertia; it is an empirical consequence of storage maturation lead times (typically five to ten years per site from first application and reliant on a decade of prior regional resource analysis) compounded across the number of sites required globally, against a backdrop of delayed action in every major emitting region. Deferring net zero to 2070 has the same probability of limiting warming to 2°C as achieving it in 2050 has for 1.5°C, according to IPCC AR6 modelling (IPCC, 2021; 2023). The risks of intensified heat extremes, accelerated ice loss, and cascading resonant hazards including crop failure, are substantially greater at this threshold. Closing the 10% gap before 2070 will require a combination of: (1) emergency-scale investment in GCS appraisal drilling beginning no later than January 2027; (2) new multilateral instruments for storage access financing in the Indo-Pacific; (3) a reassessment of CDR technology portfolios toward GCS-independent pathways; and (4) political coalitions capable of sustaining CCS investment across electoral cycles in China, North America, India, and the EU simultaneously. In the absence of these interventions, the 2050 net-zero target remains arithmetically implausible.

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