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Uncertain storage prospects create a conundrum for carbon capture and storage ambitions

Joe Lane[1,2,3] ✉, Chris Greig[1,3] and Andrew Garnett[4]

Grand hopes exist that carbon capture and storage can have a major decarbonization role at global, regional and sectoral scales. Those hopes rest on the narrative that an abundance of geological storage opportunity is available to meet all needs. In this Perspective, we present the contrasting view that deep uncertainty over the sustainable injection rate at any given location will constrain the pace and scale of carbon capture and storage deployment. Although such constraints will probably have implications in most world regions, they may be particularly relevant in major developing Asian economies. To minimize the risk that these constraints pose to the decarbonization imperative, we discuss steps that are urgently needed to evaluate, plan for and reduce the uncertainty over CO_2 storage prospects.

Global modelling studies indicate that large-scale deployment of carbon capture and storage (CCS) is crucial to reduce the cost and increase the feasibility of constraining global temperature rise to less than 2 °C (refs. [1–6]). Furthermore, recent research has emphasized the urgency of accelerating all decarbonization efforts, including CCS, to meet these goals[5,7–14]. Consistent with this, most integrated assessment modelling (IAM) scenarios that are compliant with the 2 °C outcome involve a rapid scale-up of CCS infrastructure that increases to mid-century and beyond (Fig. 1a).

However, the motivations directing most of the research and policy push for CCS development are more granular. That includes governments and corporations hoping to maintain a role for fossil-fuelled energy supply in a decarbonizing world[15,16], along with materials production industries (MPIs; steel, cement, fertilizer and chemicals) that are heavily dependent on fossil-fuel use[17,18]. The other growing motivation, which is now critical in CCS storylines, is the hope that negative emission technologies (NETs) can be deployed at a large scale to compensate for decarbonization shortfalls over the coming decades[8,9,19–21]. That would probably require a major ramp-up of bioenergy production with CCS (BECCS) and/or direct air capture of CO_2 with geological storage (known as DACCS)[6,12,22,23], indicated in the IAM scenarios as a strong shift towards CCS for negative emissions around mid-century (Fig. 1b,c).

Despite the varied motivations, attempts to stimulate early CCS industry growth have fallen short of expectations; investment and activity on geological CO_2 storage make up only a tiny fraction of that envisioned a decade ago[15,24,25]. Furthermore, only 20% of the CO_2 being captured for CCS projects is used to build the crucial experience needed for injection into dedicated, permanent storage sites (Supplementary Fig. 6). These trends cannot continue if CCS is to deliver on expectations in most IAM scenarios, which would require decades of sustained deployment at a pace that far exceeds what has been achieved to date[26,27].

Although that failure of expectations may fuel new resolve to motivate a ramp-up of CCS projects, we think that progress will continue to languish unless a major shortcoming in the dialogue on CCS is addressed. Specifically, a deliberate focus is needed on the uncertainty surrounding how fast, where and to what extent the deployment of storage infrastructure could happen. Unfortunately, those concerns barely feature in the dominant themes of conventional CCS research[28–32].

Our goal in this Perspective is to help optimize the contribution that CCS makes to global decarbonization, outlining how that uncertainty over CO_2-storage prospects is relevant to those interested in regional and global CCS strategies. Our outlook is grounded in the principles and practice of CO_2-storage development, leading to a deep scepticism about the prospects of achieving the scale of CCS ambition (multiple gigatonnes of CO_2 per year by mid-century) that IAM scenarios imply is necessary. However, it is not our intention to side with arguments that the CCS enterprise should be abandoned because of the challenges involved[33–35]. CCS offers proven, tangible value for many situations, and ongoing project-level deployment is feasible. We even remain optimistic that CCS could make a major and effective contribution to decarbonization efforts, achieving deployment at the gigatonnes of CO_2 per year scale this century in some regions. However, this would be possible only with an urgent and strategic commitment to understanding how to plan for, and overcome, the deep uncertainties that are associated with regional CO_2-injection prospects.

To build our case, we consider CCS deployment through three different lenses—capacity, confidence and substitutes. Each highlights a different challenge associated with the inherent uncertainty in ascertaining CO_2-storage prospects, and each indicates a clear priority for steps to be taken if CCS is to fulfil its grand potential.

First, the notion of geological storage capacity must be reframed as a dynamic consideration, recognizing that, even at the macro scale, the limiting factor will be the determination of sustainable injection rate by the developers of each storage resource. Urgently needed is a global, regionally differentiated review of practicable storage opportunity that accounts for important determinants of injection dynamics, and that sheds light on how much the uncertainty in that assessment varies across regions. Second, the uncertainty that underlies forecast injection dynamics will affect the confidence of prospective storage developers and slow the pace of CCS deployment. Assessing future regional and global CCS

[1]Andlinger Center for Energy and Environment, Princeton University, Princeton, NJ, USA. [2]Princeton Institute for International and Regional Studies, Princeton University, Princeton, NJ, USA. [3]Dow Centre for Sustainable Engineering Innovation, The University of Queensland, Brisbane, Queensland, Australia. [4]Centre for Natural Gas, The University of Queensland, Brisbane, Queensland, Australia. ✉e-mail: joe.lane@uq.edu.au