Oxford Smith School for Enterprise and the Environment

THE GREENHOUSE GAS REMOVAL HUB

Policy brief

Deployment support for geological Greenhouse Gas Removals (GGR) in the UK

Summary

- **GGR plays a strategic role in counterbalancing residual emissions** from hard-to-abate sectors in the UK's pathway to net zero, and in limiting global warming.
- Under the Climate Change Committee's Balanced Net Zero scenario, **the UK will need 5 $MtCO_2$/year of geological GGR by 2030**, scaling to 58 $MtCO_2$/year by 2050.
- **Current UK GGR deployment is negligible, and there is a strong need for multiple policy interventions** to provide certainty to developers (supply) and buyers (demand) to grow a market at the speed and scale required for net zero.
- **We present a typology of barriers to geological GGR deployment** based on literature and evidence. Key barriers to deployment are the lack of inherent demand for removals, access to finance, and lack of regulatory support frameworks (e.g. for accounting, and Monitoring, Reporting and Verification - MRV).
- **We identify three categories of policy interventions to address these barriers**: demand-based (creating a demand for GGR), supply-based (facilitating the production of GGR), and business environment-related interventions (creating institutional and regulatory frameworks).
- **We set out three Policy Bundles to enable the scaling up of geological GGR:** a government-sponsored approach to boost early demand for GGR, a market-based approach with complementary supply-side policies, and a hybrid approach which combines a voluntary GGR market with government guarantees of trading volumes or prices.
- **Our analysis suggests that government intervention will be essential to kick-start a market for GGR**. A government-sponsored approach with procurement auctions could help boost early GGR demand; the 2030 GGR ambition of 5 $MtCO_2$/year could cost £500 million/year, which could be recouped through general taxation or from estimated carbon tax/ETS revenues of nearly £5 billion/year. Market commitments from the private sector are growing but still currently are insufficient to achieve this scale.
- **Over time, this could evolve into a hybrid approach**, with the future endpoint being a self-sustaining market for GGR, potentially integrating with the UK Emissions Trading Scheme (ETS). All approaches would need government-set and enforced regulatory standards around accounting, MRV and Environment, Health, and Safety (EHS) standards.

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1. GGR deployment at scale is urgently needed in the 2020s to achieve net zero emissions by 2050

The UK government has set out its strategy to achieve the legally-binding target to reach net zero emissions of greenhouse gases (GHGs) by 2050 (HMG, 2021). This requires deep, economy-wide emissions reductions, but some residual emissions from hard-to-abate sectors will likely remain. Technologies for Carbon Dioxide (CO_2) Removal (CDR, or more broadly, Greenhouse Gas Removal (GGR)) therefore play a crucial role in counterbalancing residual emissions to achieve net zero, as well as enabling net negative emissions beyond, if required.

GGR is present in all key illustrative Intergovernmental Panel on Climate Change (IPCC) scenarios shown to likely limit warming to 2°C or lower by 2100 (IPCC, 2022). Across the range of scenarios considered by the IPCC to limit warming to 1.5°C with limited overshoot, GGR deployment during the 21st century totals 20 - 666 Gigatonne of CO_2 (GtCO2).

There are several different GGR approaches, all of which capture CO_2 from the atmosphere and store it durably, using different methods (Figure 1). Methods used for capture range across geological, biological, and product-based (e.g. growth of trees and crops, chemical solvents) methods, and differ by storage location (e.g. in soil, in rocks, or in geological formations and minerals) (Royal Society, 2018). As CO_2 remains in the atmosphere for millennia after being emitted, a durable state of net zero emissions will only be achieved if residual emissions can be stored for millennia (Fankhauser et al., 2022).

Therefore, achieving net zero will require (near) permanent carbon storage. GGR methods using storage in geological formations or minerals (referred to here as "geological GGR"), are considered to be the most permanent methods. Principally these include Biomass Energy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS). Research suggests CO_2 leakage in well-regulated carbon stores is below 0.5% over 10,000 years, or 0.00005% per year - well below the 0.01% leakage per year that is considered the acceptable limit by many stakeholders, making it an environmentally highly valuable GGR option (Alcade et al., 2018).

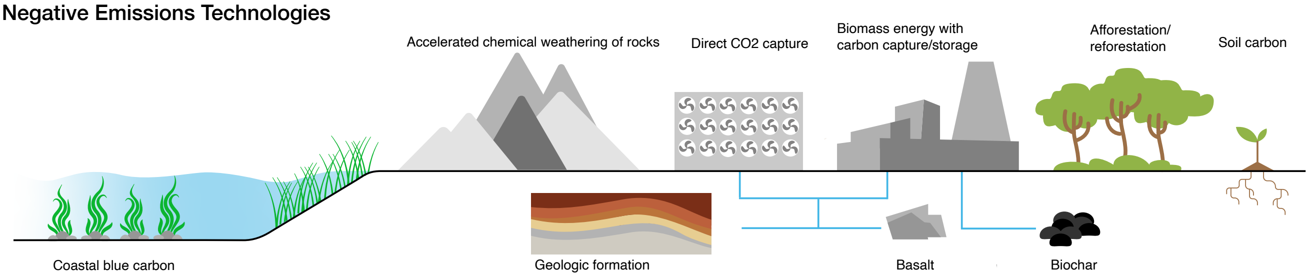
The Climate Change Committee (CCC) estimates in its 'Balanced Net Zero Scenario' that the UK will need at least 5 Million tonnes of CO_2 ($MtCO_2$)/year of geological[1] GGR by 2030, 23 MtCO2/year by 2035 and 58 $MtCO_2$/year by 2050 (CCC, 2020). The government's Net Zero Strategy targets a similar 23 $MtCO_2$/year by 2035 for engineered (essentially geological) GGR, but then a higher 75-81 $MtCO_2$/year by 2050 (HMG, 2021).

There exists plenty of geological CO_2 storage potential in the UK. Verified potential in the North Sea currently stands at 1 $GtCO_2$, three times larger than total UK CO_2 emissions in 2020, while total potential is possibly of the order of 20 $GtCO_2$ (Royal Society, 2018; BEIS, 2020). Given the size of geological storage capacity and ambition of climate policy, the UK has a technical and economic opportunity for GGR innovation and deployment. The government is funding a £100 million GGR innovation programme to spur this (BEIS, 2021).

Yet, there is essentially no deployment of geological GGR at present, and policies are required to create incentives for effective GGR deployment, and address key barriers. Support policies could either be self-standing or temporary; that is, they may eventually be wound down in a smooth transition to a self-sustaining market in the longer-term, in alignment with the wider carbon policy framework (e.g. the UK Emissions Trading Scheme - ETS).

Further interventions are also needed to ensure, from the outset, that a market for GGR has credible frameworks for Monitoring, Reporting and Verification (MRV) and alignment to other regulatory guiderails.

Figure 1: Negative Emissions Technologies



Source: Adapted from the National Academies of Science, Engineering and Medicine (2019)

With the government actively consulting on GGR inclusion in the ETS, and also committed to consulting on business models to incentivise early investment (BEIS, 2021), this Policy Brief sets out potential solutions to support the early deployment of geological GGR.

1 Geological GGR here mainly includes Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS).

2. Typology of barriers and policy interventions for geological GGR deployment

The design of a support framework for GGR must start with an understanding of key barriers (including market failures), and the support policies needed to address them. As there has been little experience with geological GGR, we draw from a wider literature on the deployment of other decarbonisation technologies globally to construct a general typology.

The key barriers to deployment of geological GGR can be broadly categorised into demand-side barriers, supply-side barriers, and the lack of an enabling business environment. These are not mutually exclusive categories (e.g., a lack of supply could also constitute a barrier to demand). We summarise each category in the tables that follow.

2.1 Demand-side barriers

This category includes barriers that impede the emergence of demand and a market for removal services. Two key issues include (Vivid Economics, 2019; Bellamy, 2018; BEIS, 2021):

- **Lack of inherent demand for removals:** GGR is not demanded (e.g. by the market) in the absence of regulation, policy incentives or government-led purchase programmes.
- **Lack of profitability of co-benefits:** While some GGRs deliver saleable co-products (e.g. energy in the case of BECCS) these are currently not enough in themselves to make GGR profitable at scale.

Interventions to address these barriers are fundamentally aimed at carbon emitters who need removals to reach net zero. Table 1 provides a portfolio of policy interventions that can help create demand for GGRs.

Table 1: Policy Interventions on Creation of Demand for GGR

Intervention Type	Policy Measure	Examples
Market-led	**Producer Responsibility or Portfolio Standards:** creating a market by mandating removals demand. Polluting industries would be required to remove a growing share of their emissions, either in-house or through third parties, leading to a market for removal credits.	Extended producer responsibility is often used in the product waste industry (e.g. take-back or recycling programmes). Portfolio standards are commonly used in the US to support renewable energy deployment. The UK Renewable Transport Fuels Obligation (RTFO) sets standards for the lifecycle emissions involved in generating fuels.
	Linking to ETS: recognition of GGR “offsets” as a compliance tool within ETS could enable the growth of the removals market, and thus demand.	Some experience with removals in ETS, e.g. inclusion of forest project offsets in California’s Cap-and Trade Program or DACCs in its Low Carbon Fuel Standard.
	Voluntary Carbon Market: creating a forum for the trading of carbon removal credits voluntarily between producers and buyers.	‘Puro Earth’ is a business-to-business voluntary market for carbon removals from biochar and wooden building elements (biological GGR) and mineralised building elements (geological GGR).
Government-led	**Public Procurement Schemes:** government auctions to procure GGR to incentivise early demand, potentially evolving into a private sector obligation in the long run.	Renewable energy is procured on contracts through auction schemes, in most countries. The UK Woodland Carbon Guarantee (WCG) ensures a minimum amount of demand in the market for Woodland Carbon Credits.
	Contracts for Differences (CfDs): contract between a goods or service generator and a purchasing entity (usually government-owned company) which provides a guaranteed fixed price for the good or service.	The UK renewable energy support scheme CfDs, instrumental in scaling up offshore wind generation. It has not to date attracted BECCS bidders, but is proposed as a potential GGR-CfD opportunity.
	Advanced Market Commitments (AMCs): a price or quantity guarantee by government (potentially complemented by private sector commitments) to assure GGR developers of a viable market.	Most prominently used in public health, for example to incentivise the production of medicines for developing countries (e.g. the UK-supported Med Access scheme). More recently, a private sector consortium (Frontier) committed $925 million to advanced GGR purchasing.
Fiscal Incentives	**Tax breaks:** results in a tax credit (or a capital allowance) to parties removing GHGs or preventing their emission via capture and storage.	45Q tax credit in the US for three categories of CCS projects: non-enhanced oil recovery carbon utilisation (projects used in production of beneficial products i.e. fuels, chemicals, concrete), industrial or direct air capture facilities, and power generation.
	Demand subsidies: financial interventions, typically in the form of a grant, that subsidise the cost of purchasing a good or service.	UK capital subsidies for electric vehicles. Also used in housing markets in Latin America, where high-per unit costs result in reduced utilisation of available housing.

Source: Vivid Economics (2019); BEIS (2021); Coggins (2001); Wagner (2009); Jenkins et al. (2021); Zetterberg et al. (2021); Ferguson et al. (1996); Global CCS Institute (2021).

2.2 Supply-side barriers

These are barriers that impede the delivery and scaling of GGR. In the long term, increased volumes would catalyse economies of scale, learning, and lower costs (BEIS, 2021; Fuss et al., 2018; Vivid Economics, 2019; IEAGHG, 2012). Key barriers include:

- Access to finance: This pertains to the lack, or high cost, of capital for new projects, exacerbated by high capital needs, technology risks (e.g. around performance) and uncertainty around demand (see demand-side barriers). Private finance, which has been low, is now beginning to flow into carbon removal technologies. 12

1 A shared feature of geological GGR with renewable technologies, is the high start-up costs or CAPEX: estimated at £55-100/tCO_2 for BECCS for power and BECCS for fuels, respectively, and £100-135/tCO_2 for DACCS (CNE, 2021).

2 Examples include $350 million from Lower Carbon Capital and $650 million equity raised by Climeworks.

- Scale and learning effects: These relate to factors that impede technology spill overs, including the inability to catalyse and benefit from scale and learning effects.
- Resource limitations: These include insufficient skills and knowledge-sharing, which may reduce the scope for cost reductions, and limit GGR delivery at scale. Other resource limitations (e.g. storage, land, infrastructure) may further delay deployment.

Policy interventions to address these barriers fundamentally target the providers of GGR solutions. Table 2 details the interventions.

Table 2: Policy Interventions on Incentivising Supply of GGR

Intervention Type	Policy Measure	Examples
Access to Finance	**Public Funding:** class of interventions (e.g. capital or operational subsidies to producers) whereby the government provides access to public funding to reduce the cost of capital or operations for contractors or suppliers.	Many examples of subsidies in biological GGR, including UK Woodland Carbon Fund; grants from 'Ireland Growing for the Future Forestry Development Strategy' and NZ One Billion Trees Fund.
	Green Investment/Infrastructure Bank: entities which use transaction-enabling techniques and structures to de-risk projects, with a more even risk allocation between developers and capital, and facilitate private investment into domestic low-carbon, climate-resilient (LCR) infrastructure.	Green investment banks are currently mobilising investments into retrofits, energy-efficient lighting, and renewable generation. A UK example is the Green Investment Group.
Skills Support	**Knowledge and technology transfer:** facilitating the transfer and dissemination of new knowledge and technology to develop emergent industries.	For geological GGR, these include promotion of international data exchange, improved information flows in public-domain and mature technologies, collaborative multi-actor public or private R&D programmes, and partnerships. (e.g. EU Climate Knowledge & Innovation Community (KIC) supports large-scale deep demonstration projects; Carbon Trust's Offshore Wind Accelerator aims to accelerate offshore wind as a viable commercial source.)
	Training and reskilling schemes: supporting labour and skills required to deploy GGR at large scales.	Examples include expanded access and programmes in relevant disciplines; incentives for education abroad; training-related movement to develop skills; and reskilling and retraining programmes for workers in adjacent industries.
Infrastructure Support	**Industry clusters:** partnerships between groups of geographically related business, supplier, and institutional actors in a similar industry to accelerate early stage development and shared infrastructure, and resource sites.	Proposed UK Carbon Capture, Use and Storage (CCUS) track clusters to demonstrate CCUS at scale, build industry and investor confidence, and accelerate project pipelines.
	Publicly provided infrastructure: shared CO_2 transport and storage networks to facilitate end-to-end GHG removals and storage at large scale.	Gas and electricity infrastructure are publicly owned in most countries (e.g. the National Grid in the UK).

Source: Hoekman et al. (2005); IEAGHG (2012) ; Madsen (2014); Vom Hofe and Chen (2006); BEIS (2021; 2021); Schenuit et al. (2021); Vivid Economics (2019); Green Investment Banks: Policy Perspectives (2015).

2.3 Lack of enabling business environment

These are barriers relating to the overall framework of processes and regulations within which businesses operate (BEIS, 2021; Bellamy, 2018; IEAGHG, 2012; Royal Society, 2018; Vivid Economics, 2019).

- Regulatory risk: This is a fundamental barrier to unlocking GGR. It includes a lack of universally-recognised reporting and accounting standards to ensure net removal across the lifecycle of GGR activity; inadequate legal frameworks around issues such as transboundary transport of carbon, and clarity over liability for leakages; and a lack of wider environmental guiderails on sustainable deployment of GGR.

- Public acceptability: Barriers include the moral hazard of postponing emissions reductions in the presence of GGR options; perceived environmental risks (e.g. seismic activity from carbon stores; adverse impacts on food security from biomass use); lack of transparency around planning for large-scale projects and resulting mistrust; perceived lack of effectiveness due to slowness of deployment; and issues around equity and distributional impacts.

- Policy risk: This includes the lack of long-term policy certainty (policy reversals or unexpected adjustments), a lack of coordination across the GGR support portfolio (risking a misallocation of resources), and a lack of integration of GGR policy into broader climate, environmental, and economic policy frameworks.

Table 3: Policy Interventions on Enabling Business Environments

Intervention Type	Policy Measure	Examples
Regulatory Support Frameworks	**Accounting and MRV Methods (Monitoring, Reporting, Verification):** Formalised and widely-applied approaches to robust quantification of GHGs removed by a particular project, and reporting these results to a larger emissions accounting framework.	Some GGR and carbon storage approaches have MRV requirements to reliably quantify the amount of carbon removed. E.g. the UK Woodland Carbon Code (see Box 1); US 45Q Tax credit for carbon capture, which requires an MRV plan approved by the government to claim credits and the measurement of CO_2 leakage throughout the project's duration.
	Planning Rules: Rules to govern location of GGR facilities, rights of local stakeholders and mitigation of local impacts.	Extensive planning rules and regulation exist for infrastructure investments. E.g. UK planning rules for onshore wind, which are currently under review.
	Liability Rules: Industry-wide insurance schemes, liability caps, and clear liability guidance for leakages or re-release of stored CO_2. Interventions provide security of liability for stored carbon and coverage to GGR providers, given the long timelines of geologic CO_2 storage.	Examples of liability coverage exist for oil and gas pollution. E.g. US Oil Pollution Act, and International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage - both of which outline liability frameworks and financial mechanisms for remediating spills.
ESG Regulation	**Regulatory Standards:** Clear regulatory standards on the additionality, permanence, and environmental integrity of GGR.	The UK Transition Plan Taskforce will set out standards for the decarbonisation plans of financial institutions and listed companies, which could include standards for use of GGR. The UK RTFO is another example. The EU imposes strict sustainability rules on biomass, for subsidies under the renewable energy directive.
	Environmental, health and safety (EHS) standards: Policy linkages to other environmental, health, safety, and development priorities to ensure deployment of GGR is synergistic with other social priorities.	It is a legal requirement for new industrial developments in the UK to gain an environmental permit, ensuring that they fall below thresholds of pollution to air, water or land. These will likely apply to large new BECCS and DACCS facilities.
Public Engagement	**Public engagement interventions:** Include policies to inform the public about GGR and include them in decision-making, to generate consensus, build trust and increase transparency.	Examples include public information campaigns, citizens' assemblies, and inclusion of GGR and climate change topics in public education curricula. Examples are found in wind farm planning, where combinations of information campaigns and engagement via local decision-making gatherings increase acceptance of novel technologies.

Source: Vivid Economics (2019); Royal Society (2018); Grigalunas et al. (1998); Bellamy (2018); Whitmarsh et al. (2011); DfT (2021).

BOX 1: UK Woodland Incentives

The UK has policies in place to stimulate tree planting, a biological form of carbon removal. Many of these are analogous to what may be implemented to stimulate geological removal. They therefore provide useful elements to inform future GGR policies.

The Woodland Carbon Code (WCC) was set up in 2011. It acts as a quality assurance standard for forestry, as well as a voluntary carbon credit market regulated by the government. Landowners can convert their land into woodland, generating CO_2 storage units. These credits can then be bought and sold on a transparent registry (the UK Land Carbon Registry). To ensure quality and permanence, there are several conditions of entry to the market, including a commitment to permanent land conversion and a robust project design plan with environmental and social criteria. Furthermore, independent evaluation of projects takes place at 5-to-10-year intervals, and credits issued are initially 'non-permanent' (Pending Issuance Units), before being converted to Woodland Carbon Units after a 5-year evaluation period.

This 'one-stop-shop' market with entry requirements and MRV procedures helps create an incentive framework with robust standards, generating long-term certainty for policymakers and investors. This in turn helps raise public acceptability through transparency and management of environmental risks. In combination with the WCC, the government also offers the Woodland Carbon Guarantee.

As the cost of planting trees can be higher than the carbon price paid on the (WCC) market, this policy enables landowners to sell their carbon credits to the government at a guaranteed price. This happens through a reverse auction process, whereby landowners pitch the carbon price they would need to be paid to make their project viable. If the project is accepted, landowners can then sell carbon credits to the government up to 2055. This helps tackle barriers relating to finance (both in the start-up phase and long term), low demand (through creating inherent demand) and lack of certainty (through a long-term commitment).

Finally, there is a range of grants and tax incentives available to landowners, providing supply support. Grants on offer include the Countryside Stewardship Scheme, the Woodland Creation Planning Grant, the England Woodland Creation Offer, and the HS2 Woodland Creation Fund. These grants provide funding for making a forestry plan, managing woodland health, creation of new woodland, and annual maintenance payments. Profits from commercial woodlands are also not subject to income or corporation tax, tree value is exempt from capital gains tax, and the sale of carbon credits is not subject to VAT. These policies can help tackle the high cost of (long-term) capital.

The House of Commons Environment, Food and Rural Affairs Committee's Tree Planting Enquiry (March 2022) concluded that the new higher subsidies available for woodland are seen as favourable compared to previous options, but still offer lower payments - and less financial certainty - than farmland. Furthermore, the Committee for Climate Change highlights that much of England's woodlands are under-managed and in poor condition. These findings highlight the need for the government to provide security of funding over a longer time horizon, and the need for capital support for both maintenance and start-up costs for GGR.

Source: WCC (2021; 2022); WCG (2022); FC (2022)

Table 4 below presents a framework to assess the effectiveness of different policy interventions in addressing the barriers for geological GGR deployment – the latter summarised from the evidence provided in Tables 1 to 3.

The first column lists the key barriers, colour coded in different shades of blue (see legend) based on the importance accorded to each barrier in a survey of stakeholder responses to a consultation on GGR published in BEIS (2021). Dark blue represents barriers which a majority of interviewed stakeholders identified as most important, with lighter blues representing reduced consensus on importance, and white representing barriers not explicitly identified in the summary.

Similarly, in assessing the effectiveness of interventions, black 'full moons' denote barriers which are addressed directly by the suggested policy interventions, while black 'half moons' denote policy interventions that could indirectly address the barrier, dependent on the specific design and implementation of the policy (for example, ESG regulations would directly address environmental risk concerns, and could indirectly address policy integration if the regulations were intentionally designed to integrate with existing environmental protection policy).

Table 4: Matrix of Barriers and Policy Interventions

	Demand creation			Supply support			Business environment		
	Market-led	Govt-led	Fiscal	Finance	Skills	Infrast	Regulation	ESG	Public
Category: Low Demand									
Lack of inherent demand for removals	●	●	●						◑
Lack of profitability of co-benefits (other externalities)		◑					◑	●	
Category: Access to Finance									
High cost of capital	◑	●	◑	●			◑		
Lack of long-term capital	◑	●	◑	●					
Category: Technology barriers									
Technology risk			◑	●	◑		◑		
Scale effects and learning externalities	●	●	●	●	◑	◑			
Category: Resource Limitations									
Knowledge and skills					●				
Other resource limitations				●		●	◑		◑
Category: Public Acceptability									
Moral hazard of postponing emissions reductions									●
Environmental Risks (seismic, food)								●	●
Lack of transparency and resulting mistrust							●		●
Perceived lack of effectiveness							●		●
Category: Regulatory risks									
Lack of robust standards						◑	●		
Inadequate legal frameworks							●		
Lack of environmental guiderails							◑	●	
Category: Policy risk									
Lack of long-term policy certainty	◑	●	◑				◑	◑	
Lack of coordination across GGR support portfolio		◑					◑		
Lack of policy integration		◑					●	◑	

Legend: Colour coding of barriers based on importance accorded to each by stakeholders, recorded in BEIS (2021). Most important Important Mentioned, not emphasized Not mentioned.
● Intervention directly addresses barrier ◑ Intervention Indirectly addresses barrier, contingent on specific policy design and implementation. Blank/ white space- Intervention does not address barrier. Source: Compiled by authors.

3. Policy Bundles to catalyse early GGR deployment at scale

The presence of multiple deployment barriers (summarised in Table 4) implies that no single policy intervention will unlock geological GGR deployment at the speed and scale required by the UK's decarbonisation pathway.

A bundle of policy interventions is needed, which must provide a clear, predictable and investable market environment that allows GGR providers to make long-term decisions. At the same time, it must be adaptable and respond flexibly as technologies mature and novel approaches emerge, ensuring that there are points for learning and adjusting, maximizing the effectiveness of policies in enabling technology-agnostic deployment. The government's role in this may also change over time (BEIS, 2021; IEAGHG, 2012.).

The government is faced with a number of options, but also some are trade-offs, in devising a suitable bundle of GGR interventions. Drawing from Table 4, we sketch out three potential bundles, based on a set of objectives, namely, to:

- Create market confidence for suppliers and consumers of geological GGRs;
- Ensure economic, social and environmental integrity, including clear reporting, accounting, and standards;
- Link short-term objectives with a longer-term framework for net zero and beyond; and,
- Use public funds efficiently, allowing the UK to meet its net zero target at least-cost.

Policy Bundle 1: Government-sponsored approach

The main components of a government-sponsored approach in creating early market demand for geological GGR are as follows:

- The main source of GGR demand would be **regular government auctions**, ramped up to reach 5 $MtCO_2$ by 2030. The auction price would provide important market information and prescribed standards for MRV and EHS would set a quality benchmark for wider GGR procurement.

- The government could draw from experience in renewable energy auctions, which provide a blueprint for a **technology-agnostic** process, maintaining a level playing field between technologies at different stages of development. Price and technology information is also available from global CCS and DACCS pilots.

- The government would likely offer **long-term contracts** to purchase removals at a set price over several years, providing certainty, encouraging investment, and facilitating access to capital, all of which would underpin the longer-term growth of a market for GGR.

- A **voluntary market** for GGR would exist in parallel, perhaps governed by standards developed of the current voluntary market bodies (e.g. VERRA, Gold Standard). The government may put its weight behind efforts to improve these standards.

- The award of long-term government contracts would substantially reduce market and policy risks, and the need for **supply-side interventions**. First-of-a-kind support would be wrapped into the government purchase price. Access to finance should be easier, but some support from the UK Infrastructure Bank, for example, may still be warranted. Other supply-side measures, such as the creation of industry clusters, would be valuable.

- The option exists to gradually **complement government demand for GGR with compliance demand**, either from the UK-ETS, or a new extended producer responsibility.

- A core objective of this bundle is to provide a **policy mechanism with the longevity** to allow buyers of GGR (demand) from hard-to-abate sectors with long planning horizons (e.g. steel) to make investment decisions in the present.

The advantage of active government participation in creating early market demand is that it provides certainty to GGR suppliers, encouraging investment across the supply chain, and facilitating access to finance.[1] This bundle also affords the government direct control over GGR volumes and over rules for MRV and EHS. A potential drawback is the transfer of risk from the private to the public sector, as well as the fact that market growth might be constrained by government demand for GGR, as it risks excluding the already-growing demand from the private sector. The transition into a long-term framework for GGR is also less clear.

A key issue in this bundle relates to funding for **GGR procurement**. The government's 2030 GGR ambition of 5 $MtCO_2$/year, based on the lower end of an estimated range of £100-£400/ tCO_2 (NIC, 2021) could cost £500 million/year.[2] These costs should not be recouped through energy bills, given their regressive impact and currently high energy costs. They could, alternatively, come from **general taxation**, or from the **hypothecation of carbon tax or ETS auction revenues**, which yield revenues of nearly 5 billion/year.[3]

1 For example, early government contracts for UK offshore wind kickstarted a market and brought down costs (Jansen et al., 2020; Higgins and Foley, 2014).

2 Or £2 billion/year, taking the upper end of the range (NIC, 2021).

3 Based on an allowance volume of 80 $mtCO_2$ for 2022 (see ICE) and an average clearing price of £60/tCO_2 for the 12 months preceding May 2022 from ICE.

Policy Bundle 2: Market-based approach with complementary supply-side policies

A market-based approach puts the 'polluter pays' principle at its core. This approach necessitates independent regulation to ensure the economic, social, and environmental integrity of GGR. The main components of this approach are as follows:

- A **market for geological GGR**, subject to government-set and enforced regulatory standards around accounting, MRV and EHS, which set a strong, widely adopted regulatory benchmark.

- To create depth, the market should combine **both voluntary and compliance demand.** Although there is pent-up demand, a voluntary market alone is unlikely to reach sufficient scale. Current private sector demand is estimated to be in the low millions of dollars (Joppa et al, 2021), though boosted recently by a $925 million commitment by the Frontier consortium.[1]

- The compliance element could be small initially, but would grow over time. It could take the form of an **extended producer responsibility** (carbon take-back obligation) or portfolio standard. Major emitters would be required to remove a small but growing share of their emissions. Removed emissions would not be subject to other forms of carbon pricing (e.g. the UK ETS), thus reducing the net cost of the obligation.

- To boost voluntary demand, voluntary GGR purchases might be supported through **fiscal incentives** such as tax breaks.

- There would initially be no **integration with the UK ETS**. However, over time the two markets may be linked by allowing ETS participants to use removal credits for compliance purposes. For such a link to be meaningful, the differential between GGR and ETS prices[2] would have to be substantially reduced, and GGR would have to have a track record of safe carbon storage.

- A market-based approach could be subject to significant (perceived and real) market and policy risks. These could be alleviated through supply-side measures, such as **finance support and de-risking** from the UK Infrastructure Bank. **First-of-a-kind (FOAK) subsidies** could reduce early deployment costs, and proposed zero-carbon industry clusters could create infrastructure and knowledge pools, catalysing economies of scale.

The advantage of focusing on major emitters is that it crowds in private buyers from the outset. This creates a baseline level of demand, allows for rapid market growth, and forces those carbon emitters designated by government to share in the cost of removal. The drawback is reduced certainty about prices and demand, which may discourage investment and potentially increase the cost of capital. The costs of complementary supply-side support (e.g. through FOAK subsidies) could be harder to predict and quantify than the government's contractual commitments in Policy Bundle 1.

1 See https://frontierclimate.com/

2 For GGR prices see Table 6, IPCC (2022), 12-61. For ETS prices, see ICAP and ICE.

Policy Bundle 3: Hybrid approach based on combined demand for GGRs from government and the voluntary market

The choice between government-sponsored and market-based approaches is not absolute. Various intermediate solutions exist. A potential hybrid solution, which features substantial government demand without crowding out private demand could entail the following:

- The establishment of a **government-regulated market** for geological GGR. Similar to Policy Bundle 2, this market would be at the core of GGR demand and create a regulatory benchmark.
- Unlike in Policy Bundle 2, there would be no compliance element to the market. Demand would come from **government purchases** and the **voluntary market**. Carbon emitters would face the full ETS price on all their emissions.
- The government would play a central role to ensure a minimum level of demand. This could happen in several different ways. For example, the government could enter the market directly through regular GGR purchases. This would be akin to an **Advanced Market Commitment (AMC) volume guarantee,** perhaps within an indicative price band. Alternatively, the government could guarantee price levels through Contracts-for-Differences (CfDs) benchmarked to the voluntary market price. This would be akin to an AMC price guarantee
- As under Bundle 2, voluntary demand for GGR could be boosted through **fiscal incentives**.
- In the absence of firm government contracts, market and policy risks would be similar to Policy Bundle 2. They would have to be alleviated through the same set of **supply-side measures**, including support from the UK Infrastructure Bank, possibly some capital (first-of-a-kind) subsidies and the creation of zero carbon industry clusters.
- The gradual **integration with the UK ETS** would be possible as in Bundle 2; but the GGR market would be opened to ETS compliance demand only once the price differential between the two markets has narrowed and there is a track record of safe carbon storage.[1]

Each of the above approaches has appeal. A market-based, emitter-led approach is consistent with the 'polluter pays' principle, requiring industry to shoulder most of the costs. A government-sponsored approach is more likely to attract early investment, but would require a significant fiscal commitment. All approaches can draw on existing experience with related interventions (e.g. offshore wind support in the case of Bundle 1, the Woodland Carbon Code in the case of Bundle 3).

The choice of policy bundle may evolve over time. Our analysis suggests that government intervention will be essential to kick-start a UK market for geological GGR, as set out in Table 4. The table also suggests that government-sponsored approaches would address a number of barriers relatively swiftly. A government-sponsored approach with procurement auctions could therefore be an effective way to boost early GGR demand. However, the long-term endpoint should be to create self-sustaining supply and demand for removals, for instance through the existence of a tradeable market. This suggests that sequencing from a government-sponsored approach to a hybrid and eventually market-led approach could be a potential policy path forward.

1 Premature linkages should be avoided to prevent substitution and downward pressure on the carbon price (Burke and Gambhir, 2022).

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