ERM

PUBLIC REPORT

EfW with CCS: a key pillar for net zero in the UK

AN ERM REPORT COMMISSIONED BY VIRIDOR

NOVEMBER 2024

Sustainability is our business

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About this document…

An exploration of the opportunities and potential staged deployment of CCS on Energy from Waste (EfW) assets in the UK.

ABOUT ERM

Sustainability is our business. As the largest global pure play sustainability consultancy, ERM partners with the world's leading organizations, creating innovative solutions to sustainability challenges and unlocking commercial opportunities that meet the needs of today while preserving opportunity for future generations.

ERM's diverse team of 8,000+ world-class experts in over 150 offices in 40 countries and territories combine strategic transformation and technical delivery to help clients operationalize sustainability at pace and scale. ERM calls this capability its "boots to boardroom" approach - a comprehensive service model that helps organizations to accelerate the integration of sustainability into their strategy and operations.

ERM acquired Element Energy and E4tech in 2021, which are now fully integrated in ERM's Sustainable Energy Solutions (SES) team. The team consists of over 150 specialists bringing deep expertise in the development, commercialisation, and implementation of emerging low-carbon technologies across a wide range of sectors, including industrial decarbonisation (hydrogen, carbon capture utilisation and storage, electrification), low carbon fuels and chemicals, the built environment, smart energy systems, electricity and gas networks, low carbon transport and funded project management.

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ABOUT THIS DOCUMENT

This document summarises analysis conducted by ERM into the opportunities for CCS on EfW in the UK, including:

- assessing the **cost of carbon capture** for different assets
- assessing the **cost-optimal mode of transporting CO_2** to UK storage sites on an asset-by-asset basis
- defining **how deployment could be staged over time** as infrastructure and incentives develop using a multicriteria assessment and red-amber-green screening approach
- identifying **how CCS on EfW fits with UK net zero strategy and targets** (as developed by the UK government and its independent Climate Change Committee)

The project was commissioned and funded by Viridor.

We would like to acknowledge the Viridor team for their input, guidance and technical review throughout this work, with particular thanks to Tim Rotheray and James Eyton.

A staged deployment of CCS on EfW in the UK presents an opportunity aligned with a net zero transition

Summary of key outcomes from this analysis:

- **Energy from Waste (EfW) facilities will play a long-term role in UK waste management**, offering critical local services and energy generation.
- Uptake of carbon capture on EfW in the UK could capture up to **20 $MtCO_2$/y** and help **underpin the development of CO_2 transport and storage infrastructure.**
- Carbon capture and permanent storage (CCS) of CO_2 from EfW provides valuable greenhouse gas removals (GGRs) that could contribute **27% of the UK's 2035 GGR target** and enable a carbon neutral electricity grid.
- CCS on EfW has a cascading impact of **reducing Scope 3 emissions across UK value chains**, and lowering household carbon footprints.
- Deployment of CCS on EfW is anticipated in stages with an **estimated £19bn to be invested**, supporting the UK economy with potential to generate over **14,000 green jobs** and unlock nearly **£40bn in GVA.**

The **EfW sector is already progressing on this journey**

Six of the UK's EfW assets located near prioritised hubs for CO_2 storage have already announced CCS plans and applied to the government's CCUS Cluster Sequencing competition[1].

The government is currently in **negotiations with two EfW assets, Protos ERF and Viridor Runcorn**, to receive funding for CCS deployment and be operational by 2027[2].

A total of **30 EfW assets are well-placed to deploy CCS by 2035,** laying foundations for the development of more CO_2 hubs and rapid decarbonisation of the waste sector.

Next steps require the **connection of other suitable EfW assets** to Teesside and Merseyside hubs, the further **development of CO_2 hubs** (e.g., Grangemouth, Humber), and the development of hubs for **CO_2 shipping** (e.g., Medway, Avonmouth).

1- ERM analysis for this study – see full report for details.
2 - DESNZ 2023, Cluster sequencing Phase-2: Track-1 project negotiation list

Executive Summary

EfW facilities will play a long-term role in UK waste management, offering critical local services and energy generation

In 2020-21 local authorities in England collected 26 Mt of waste[1], covering household, commercial and industrial sources. Solutions for handling this waste include recycling or composting, incineration, landfill, and Energy from Waste (EfW) plants.

The **use of EfW facilities by local authorities has increased significantly** over the last two decades as measures were introduced to limit the amount of residual waste sent to landfills. In 2020-21, an estimated 47% of local authority waste in England was processed by EfW facilities[1].

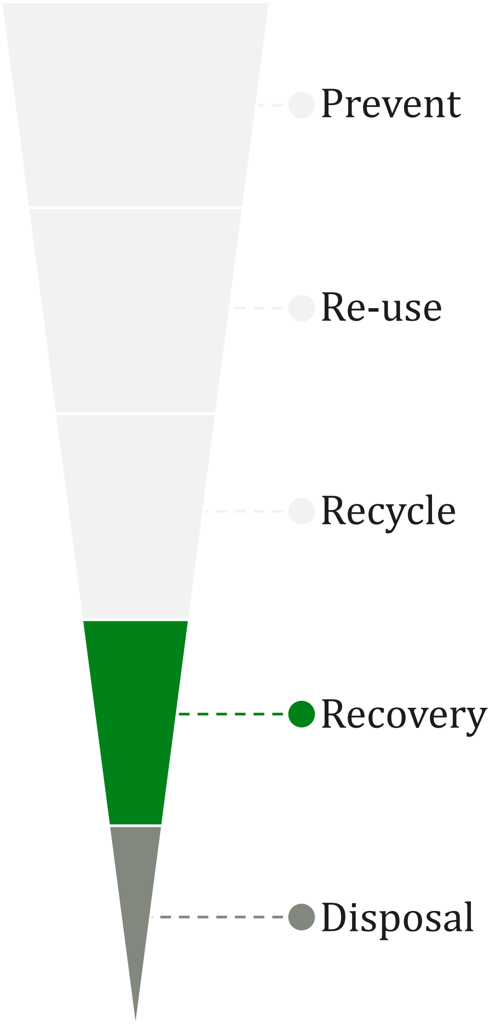
EfW facilities are a **critical technology for processing residual waste** as they offer emission reductions compared to landfill and provide additional benefits[3]:

- ✓ Providing effective waste management services to local communities
- ✓ Avoiding landfill environmental impacts (incl. methane emissions and leachate)
- ✓ Generating electricity (and sometimes useful heat)
- ✓ Allowing recovery of valuable metals from waste

In 2023, the UK had **60 operational EfW facilities and 18 in development**[2], in total operational assets:

- ✓ Processed 16 Mt waste per year[2]
- ✓ Generated 3.1% of the UKs power in 2023[2]
- ✓ Supported local jobs

Waste Hierarchy



Prevention, re-use and recycling are crucial steps in the waste hierarchy, however, **even with ambitious uptake** of these measures, the UK is still forecasted to produce a **significant amount of residual waste** in **2050** – equivalent to 300kg per person per year[3,4].

Residual waste is a mixed waste that cannot be usefully reused or recycled and would therefore otherwise go to landfill – it may contain recyclable elements however these are often too contaminated to be practically or economically recovered.

Analysis by the UK's Climate Change Committee shows a **long-term role for UK EfW facilities** in waste management, critically **diverting waste away from landfill**[3].

1- DEFRA 2023, Local authority collected waste management - 2021/22
2 – Tolvik 2024, UK Energy from Waste Statistics - 2023
3 – CCC 2020, Sixth Carbon Budget: Waste
4 – CCC 2020, Sixth Carbon Budget: Local Authorities and the Sixth Carbon Budget

CCS is the only technology available to minimise EfW Scope 1 emissions, and generates valuable GGRs from biogenic CO_2 storage

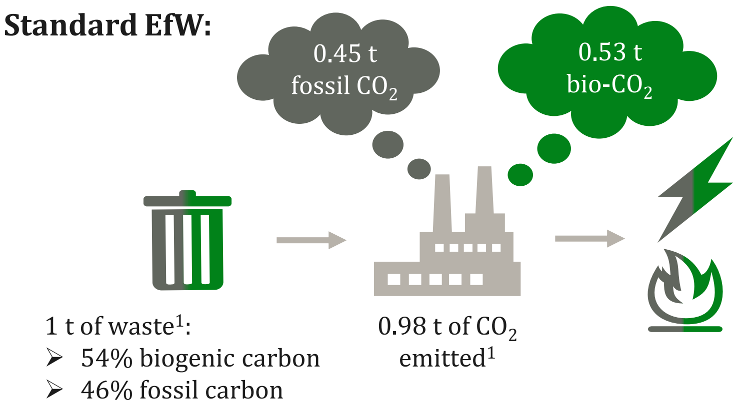
Carbon capture and storage (CCS) refers to the **capture of CO_2 followed by its processing, transport, and permanent storage**, typically in geological formations. The global development of CCS projects has increased dramatically in the past 5 years as a way of capturing industrial and power emissions. **In 2023, there were 41 operational CCS facilities**, 26 in construction, and 121 in advanced development[1].

Deployment of **CCS is the only available technology for abating Scope 1 emissions from EfW** assets. Analysis for the CCC shows that in all net zero scenarios, CCS is deployed on all EfW assets operational in 2050 with deployments commencing between 2025-2040[2].

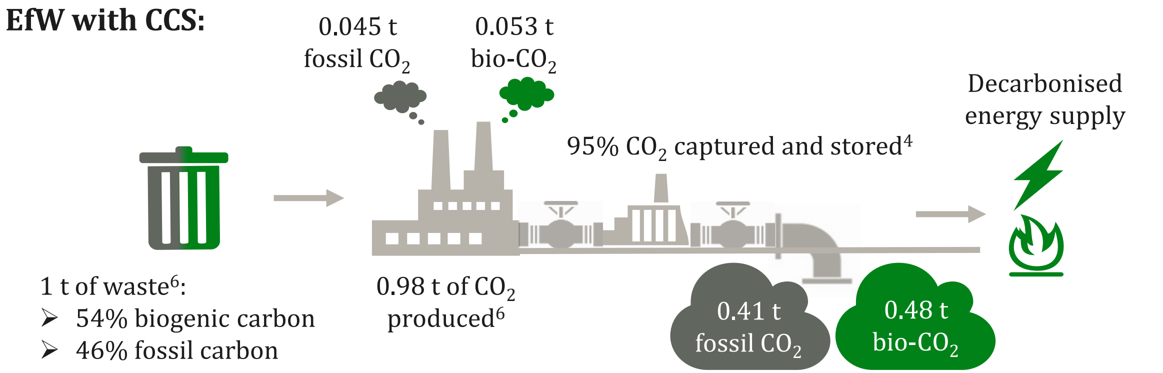
Several **EfW companies in Europe have already announced plans to adopt CCS** with a total of 38 EfW with CCS projects in Europe identified[3].

It is anticipated that EfW assets in the UK would use advanced amines for post-combustion carbon capture. This technology is anticipated to achieve a 95% capture rate[4] which, if operational for 95% of the time of EfW operations, would **result in 90% of emissions being captured** from the flue gas.

Deploying **CCS on EfW is recognised as a form of greenhouse gas removal**[5] **(GGR)**, meaning that it works to remove and permanently store CO_2 that was recently atmospheric. This is due to over half of residual waste combusted being of biogenic origin (e.g., agricultural & food waste)[6]. This GGR route has advantages over many nature-based GGRs due to the **permanence of geological storage and relative ease of MRV** (monitoring, verification and reporting).



Analysis of UK waste statistics indicates **54% of residual waste sent to EfWs is of biogenic origin**[6].



Permanent storage of CO_2 of sustainable biogenic origin is considered a **robust form of greenhouse gas removal**[5].

1- GCCSI 2024, Global Status of CCS 2023
2 – CCC 2020, Sixth Carbon Budget: Waste
3 – ERM analysis of UK and European BECCS projects (July 2024)
4 – AECOM 2022, Next Generation Carbon Capture Technology (WP6)
5 – CCC 2020, The Sixth Carbon Budget: Greenhouse gas removals
6 - Tolvik 2024, UK Energy from Waste Statistics - 2023

Deployment of CCS on EfW is anticipated in four stages with an estimated £19bn to be invested, supporting the UK economy

In this study, ERM conducted a multicriteria assessment to evaluate each EfW asset in the UK for its CCS suitability, considering the location and scale of assets as well as the costs of CO_2 capture, transport and storage. From this, we identified a staged approach to deployment of CCS on EfW facilities across the UK:

Prioritized clusters | **CO_2 hubs & shipping** | **Expanded networks** | **Truly dispersed**

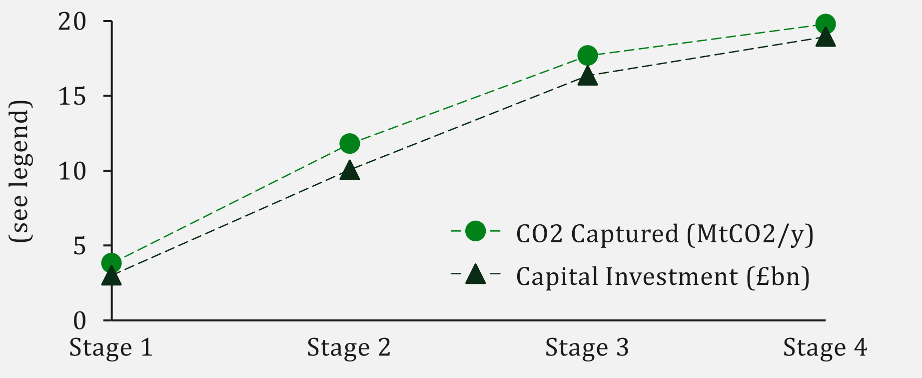
Stage 1
Eight large capacity facilities in strategic locations to directly connect to prioritized Track 1 cluster's CO_2 T&S infrastructure. This infrastructure is expected to be operational before 2030.

Stage 2
22 medium-large assets located <50km from CO_2 storage clusters or large ports that could become CO_2 shipping hubs - such as Medway, South Wales, or Avonmouth - that could be operational by the mid-2030s.

Stage 3
30 small-medium assets further from transport hubs. These sites may depend on CO_2 transport network expansion, potentially via rail, concurrent through the 2030s with the establishment of a multi-sectoral UK CCUS economy.

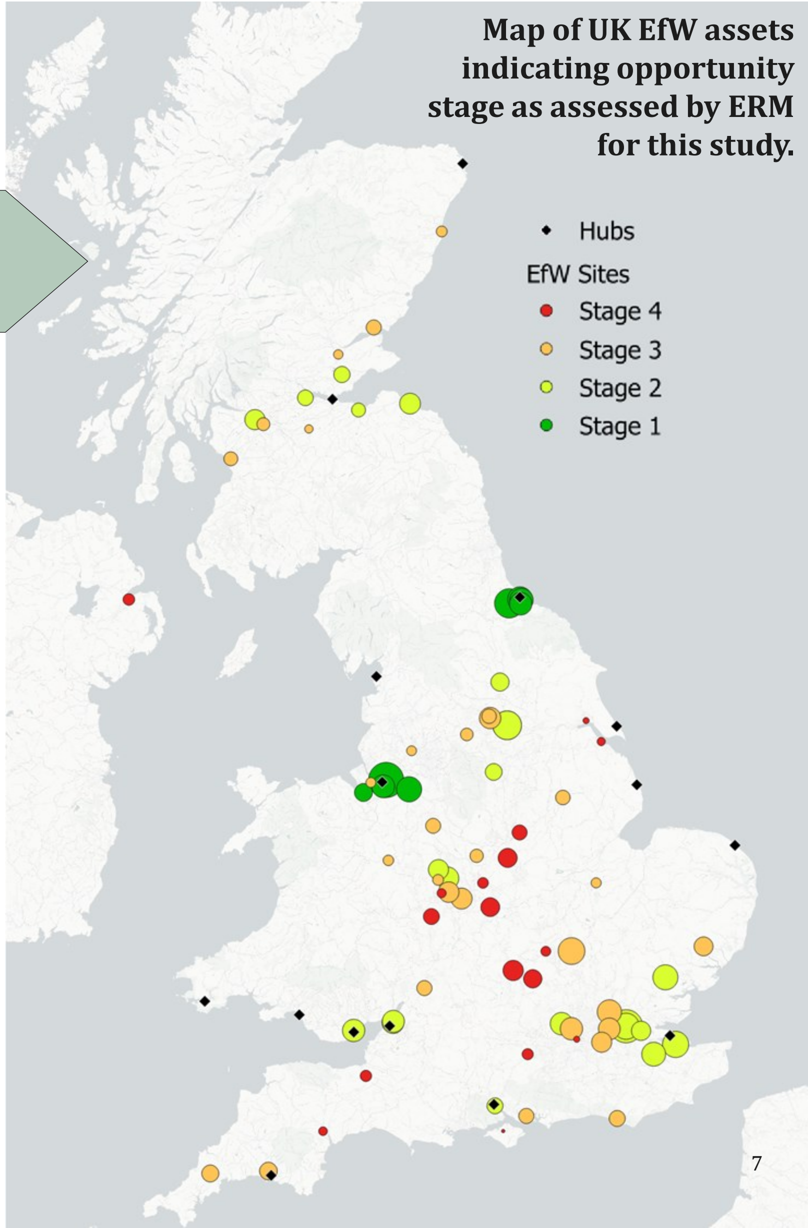
Stage 4
18 small and dispersed facilities, predominantly more than 100km from a CO_2 transport hub. Likely to be confined to asset relocation, aggregation, rely on inland CO_2 transport cluster formation, or investigate local CCU opportunities.

Cumulative impact of deploying CCS on EfW in the UK



Eight large-capacity EfWs are within 25km of Track 1 CCUS clusters, Merseyside and Teesside, which have a target operational date by 2027. Six of these EfWs applied for government CCUS funding.

Map of UK EfW assets indicating opportunity stage as assessed by ERM for this study.



Source: ERM analysis for this study – see full report for details.

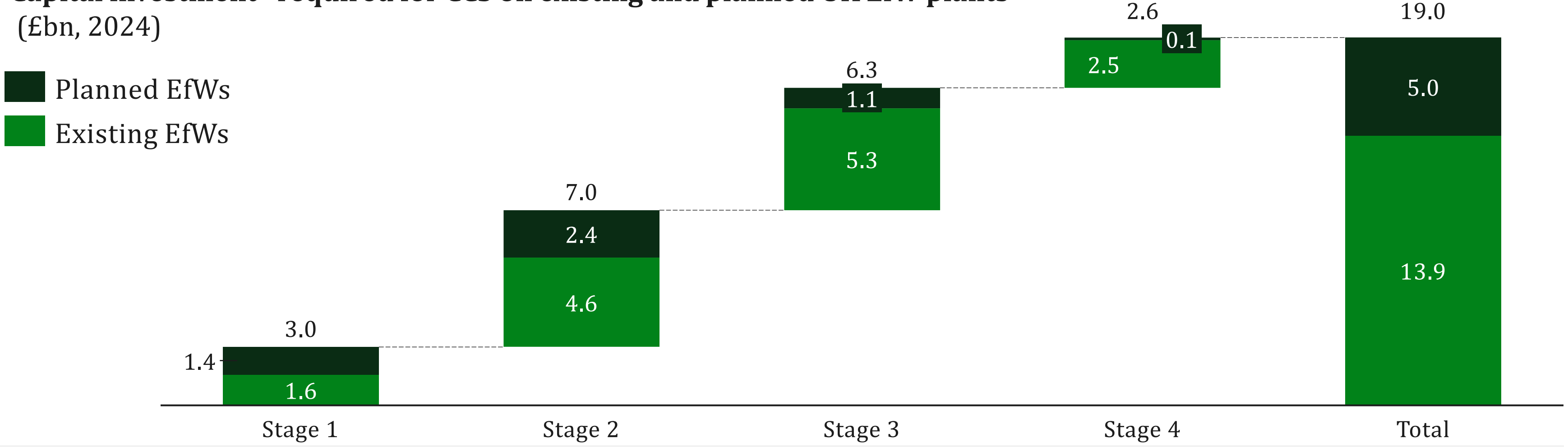
Investment in CCS on EfW in the UK could generate over 14,000 green jobs and unlock nearly £40bn in GVA

The total estimated **capital investment opportunity for carbon capture on EfW assets in the UK is £19bn**[1]**,** with the large majority associated with decarbonising existing, operational EfW facilities. This investment can unlock **nearly £40bn in GVA**[1] **primarily for the UK economy and over 14,000 jobs**[1] in project development, construction, operation, and supporting industries.

The location of EfW plants, especially early Stage 1 opportunities in Merseyside and Teesside, provides the **opportunity for investment, growth, and green jobs in historic industrial areas**. The expected staged nature of deployment, gives the EfW sector the opportunity to develop and upskill a workforce to deliver EfW-CCS projects.

Ongoing sectoral learnings, reduced financing costs, standardisation, and technology improvements are likely to allow later stage plants to benefit from the deployed pipeline of EfW-CCS assets in the future.

Capital investment* required for CCS on existing and planned UK EfW plants[1]
(£bn, 2024)



	Stage 1	Stage 2	Stage 3	Stage 4	Total
Average CCS Cost (£/tCO$_2$)**	**201**	**237**	**275**	**335**	**242**

ERM used capital and operational costs to estimate UK economic impacts (total, all stages)[1]*:*

£19.0bn
capital investment opportunity

£38.8bn
GVA delivered

4,800
construction jobs on average until 2040

9,350
permanent green jobs

* Capital investment is shown for the carbon capture facility only. Costs of CO_2 transport and storage are considered as operational expenses.
Average CCS costs are **inclusive of CO_2 capture, transport and storage costs.
1 - ERM analysis for this study – see full report for details. Jobs and GVA figures are estimated based on high-level breakdown of project costs into Standard Industry Classification (SIC) codes and using ONS input-output tables and import ratios for economic impact.

Uptake of CCS across the UK's EfW facilities is aligned with the UK Net Zero strategy and supports key Government targets

Following the assessment, ERM conducted an analysis of UK policy and UK energy data to identify how CCS on EfW supports government targets focusing on the five key topics below. The outcomes are presented in more detail on the following slides.

Waste Management

EfW facilities are a critical technology for treating residual waste which cannot be recycled. They have a long-term role in UK waste management[1].

Carbon Capture Targets

Uptake of CCS on EfW contributes to the governments target to capture 20-30 $MtCO_2$/y by 2030[2]. CCS across all EfW facilities could achieve 19.7 Mt of CO_2 capture per year[6].

Greenhouse Gas Removals

As over half of residual waste is of biogenic origin[3], CCS on EfW captures biogenic CO_2 and acts as a GGR technology. The UK government has a target to deploy 23 Mt GGRs by 2035[4].

Net Zero Industry

CCS is a key technology for decarbonising UK industry. Uptake of CCS in the EfW sector supports shared CO_2 transport and storage infrastructure development[6].

Carbon Neutral Electricity

The UK government aims to deliver 'clean power' by 2030[5]. EfW with CCS can offer GGRs alongside electricity generation, offsetting residual power emissions.

Scope 3 Emission Reductions

Waste management is a component of most upstream and downstream value chains. CCS on EfW therefore contributes to Scope 3 reductions across the economy[6].

1- CCC 2020, Sixth Carbon Budget: Waste
2 – DESNZ 2023, CCUS: a vision to establish a competitive market
3 – Tolvik 2024, UK Energy from Waste Statistics - 2023
4 – HM Government Oct 2021, Net Zero Strategy
5 – DESNZ 2024, Mission Control to deliver clean power by 2030
6 – ERM analysis for this study – see full report.

CCS on EfW in the UK could capture up to 20 $MtCO_2$/y and help underpin the development of CCS infrastructure

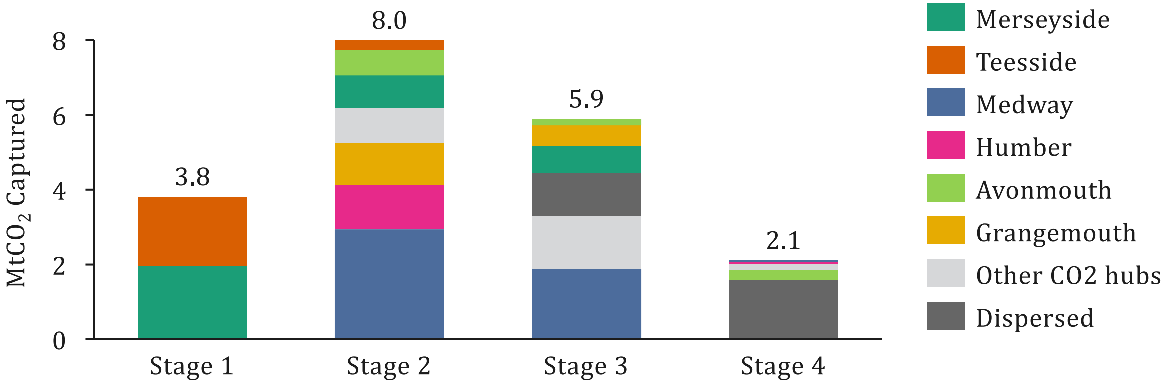
Carbon Capture Targets

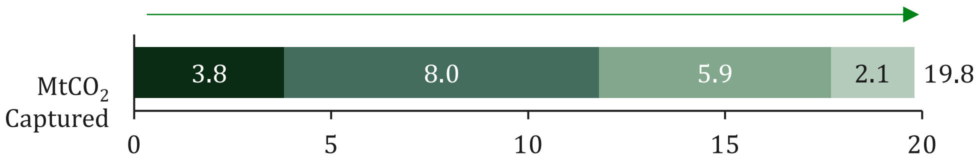
- The UK government has an **ambition to capture and store 20-30 $MtCO_2$/y by 2030** through the creation of four CCUS clusters[1]. By the mid-2030s this could increase to 50 $MtCO_2$/y, with potentially 90-170 $MtCO_2$/y captured in 2050[1].
- Analysis in this study finds that the **uptake of CCS on EfW could lead to the capture of nearly 20 $MtCO_2$/y** if applied to all EfW assets analysed. Of this, 11.8 $MtCO_2$/y could be delivered by 'Stage 1 and 2 Opportunity' assets that are strategically located near CO_2 hubs and face the lowest barriers to adoption according to this study.
- Therefore, the EfW sector alone could capture **24% of the UK's 50$MtCO_2$/y 2035 CCS ambition**.

Net Zero Industry

- CCS is a core technology for decarbonising the UK's industrial sector, however successful uptake requires development of shared CO_2 transport and storage infrastructure[1,2].
- Uptake of CCS on EfW can support such infrastructure development by providing a **consistent baseload supply of CO_2 that can act as an anchor demand,** facilitating wider industry CCS uptake.
- Stage 1 assets are all **within 25km of a Track 1 industrial cluster,** with the majority having already expressed interest in the UK government's CCUS Cluster Sequencing programme[3].
- Furthermore, the UK government has announced plans to support projects connecting to storage via **CO_2 shipping and other non-pipeline transport**[1]. Deployment of CCS on EfW assets would make a significant contribution to the development of these transport modes[3].

Breakdown of total CO_2 captured from EfW assets grouped by stage of deployment (non-cumulative) and their nearest CO_2 hub[3]





Total UK EfW CO_2 capture potential - ordered from stages 1-4 showing cumulative impact[3].

ERM's analysis[3] found that deploying CCS across all UK EfW sites would mean:

8.1 $MtCO_2$ transported by ship from hubs such as Medway and Avonmouth to storage sites, requiring **investment in 8 ships** for CO_2 shipping (each 18 $ktCO_2$ capacity).

3.2 $MtCO_2$ transported by rail connecting a total of 20 dispersed EfW sites to CO_2 hubs across the UK. Analysis found that **67% of EfW sites are within 1km of a rail network**.

1- DESNZ 2023, CCUS: a vision to establish a competitive market
2 – Element Energy 2020, Deep Decarbonisation Pathways for UK Industry
3 – ERM analysis for this study – see full report.

CCS on EfW could contribute 27% of the UK's 2035 GGR target and enable a carbon neutral electricity grid

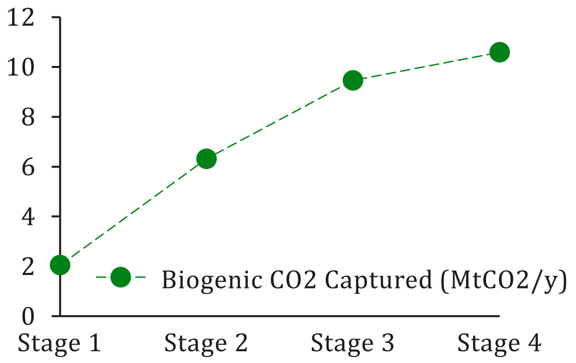
GGR Targets

- To achieve net zero, the UK is expected to deploy 45-112 Mt/y of greenhouse gas removals (GGR) by 2050[1] to offset residual emissions in hard-to-abate sectors such as agriculture, aviation, and waste.
- **Installing CCS on EfW facilities is recognised as a GGR** by the UK government due to the biogenic content of waste[1]. The route has advantages over many nature-based GGRs due to the **permanence of geological storage and relative ease of MRV** (monitoring, reporting and verification).
- The EfW could play a significant role in contributing to the UK governments GGR targets, with potential to capture **up to 6 $MtCO_2$/y of biogenic CO_2 from Stages 1 and 2 alone**[5] (deployed potentially by 2035).

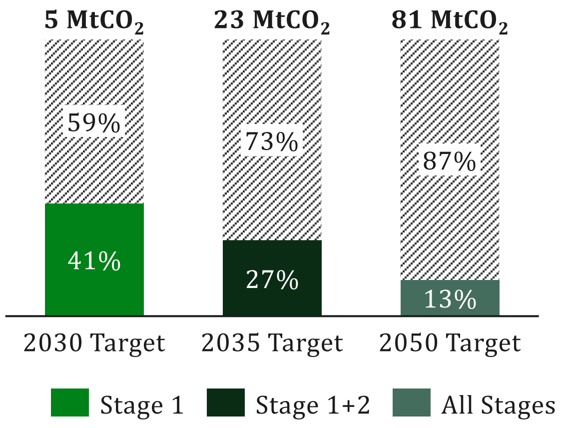
Carbon Neutral Electricity Grid

- In 2021 the UK government set a target to **decarbonise the electricity grid by 2035**[2]. The new government elected in 2024 has proposed an ambitious plan to deliver 'clean power' by 2030[3].
- Even with ambitious renewables and low-carbon power deployment, analysis for the CCC suggests that **in 2035 the grid would still use 12 GW of unabated gas power generating 11 TWh** of electricity per year to manage an increasingly extreme and volatile residual demand profile[4].
- Such generation would result in power emissions of **4.8 $MtCO_2$/y[4] which would need to be balanced** through other power generation assets to achieve a carbon neutral electricity grid.
- Installing CCS on Stage 1 and 2 EfW assets would **generate enough GGRs to balance all residual power sector emissions in 2035**, this holds even in the AFRY high scenario.

Annual biogenic CO_2 captured from EfWs across each deployment stage (cumulative)[5]

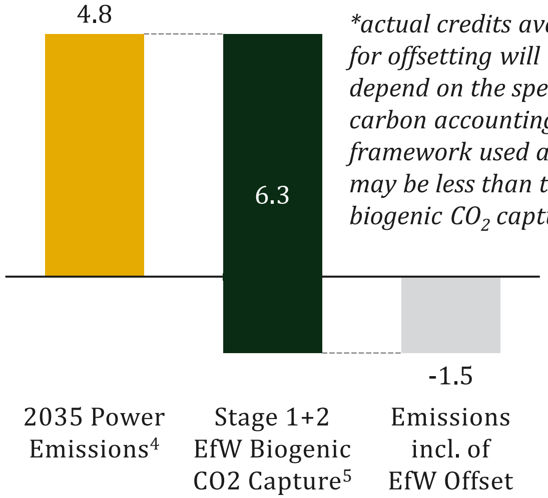


Contribution that CCS on EfW's could make to UK government GGR targets[2,5]



Stages 1 and 2 combined could store enough biogenic CO_2 to meet **27% of the governments 2035 GGR** target. This is enough to **balance all residual power emissions** in a decarbonised electricity grid.

Illustrative* impact of EfW with CCS balancing emissions from power sector ($MtCO_2$ / y)

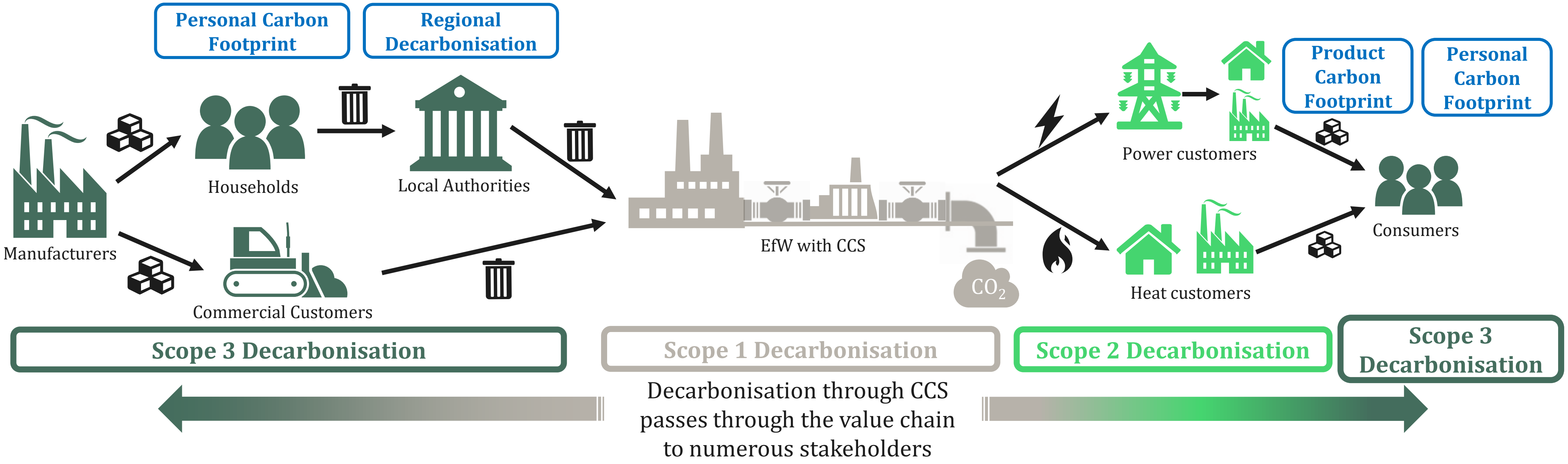


**actual credits available for offsetting will depend on the specific carbon accounting framework used and may be less than the biogenic CO_2 captured.*

1- CCC 2020, The Sixth Carbon Budget: Greenhouse gas removals
2 – HM Government Oct 2021, Net Zero Strategy
3 – DESNZ 2024, Mission Control to deliver clean power by 2030
4 – AFRY 2023, Net Zero Power and Hydrogen: Capacity Requirements for Flexibility (Central Scenario)
5 – ERM analysis for this study – see full report for details.

CCS on EfW has a cascading impact of reducing Scope 3 emissions across UK value chains, and lowering household carbon footprints

- **Scope 3 emissions** on average account for **75%** of a company's GHG emissions[1]. Therefore, their abatement is critical in reaching net zero. Corporate emissions are usually accounted as three scopes: Scope 1 (direct emissions from site), 2 (emissions from purchased energy), or 3 (other indirect). When an EfW plant reduces its direct Scope 1 emissions, this has a **cascading effect** on **reducing Scope 2 and 3 emissions** of other stakeholders across the value chain. Accounting of emissions across multiple scopes as such encourages collective action for decarbonisation whilst avoiding double counting[2]
- Stakeholders may also account for emissions reductions or removals[3] through alternative means, such as carbon intensity of products, personal carbon footprints of people whose waste is processed by an EfW + CCS facility or regional emission inventories of Local Authorities / Devolved Administrations, etc. EfW plants may seek financial support from these stakeholders or justify increasing their gate fees depending on the premium placed on such decarbonisation across the board.



[1] CDP Technical Note: Relevance of Scope 3 Categories by Sector, [2] Inventory-based GHG accounting through Scope 1, 2, 3 is developed by and based on the GHG Protocol's Corporate Standard. [3] If carbon credits are sold to parties outside of the EfW value chain, those GHG reductions or removals cannot be accounted by any of the stakeholders

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Contents

The Role of CCS on EfW

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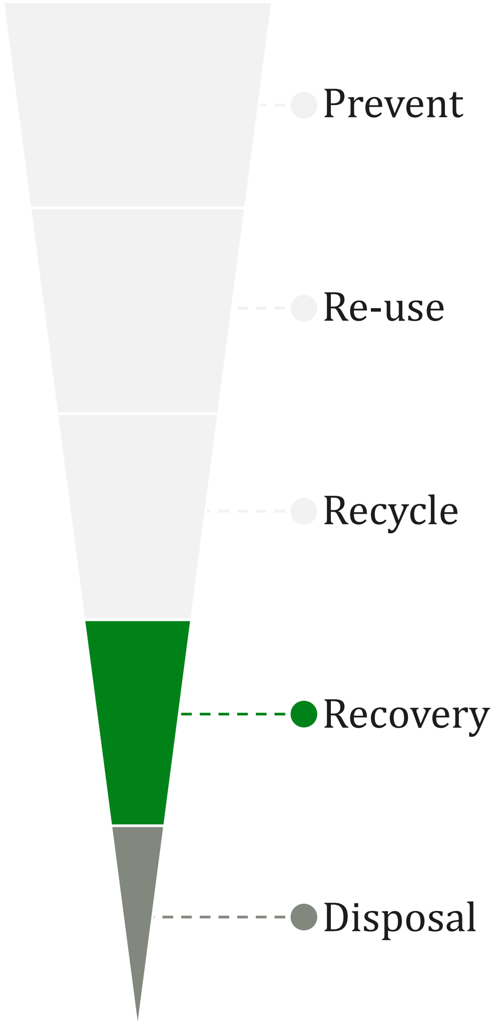

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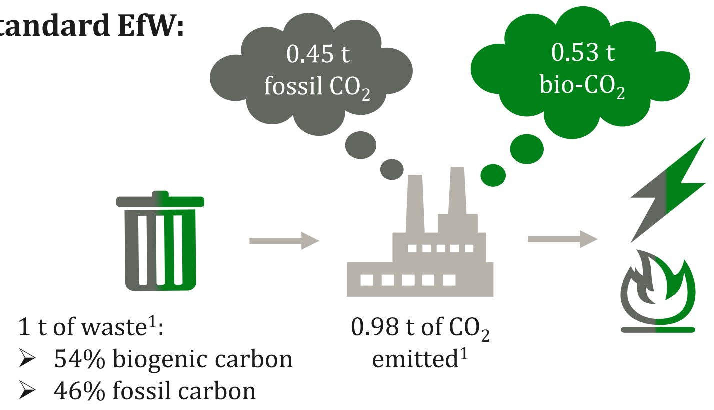
Deployment of **CCS is the only available technology for abating Scope 1 emissions from EfW** assets. Analysis for the CCC shows that in all net zero scenarios, CCS is deployed on all EfW assets operational in 2050 with deployments commencing between 2025-2040[2].

Several **EfW companies in Europe have already announced plans to adopt CCS** with a total of 38 EfW with CCS projects in Europe identified[3].

It is anticipated that EfW assets in the UK would use advanced amines for post-combustion carbon capture. This technology is anticipated to achieve a 95% capture rate[4] which, if operational for 95% of the time of EfW operations, would **result in 90% of emissions being captured** from the flue gas.

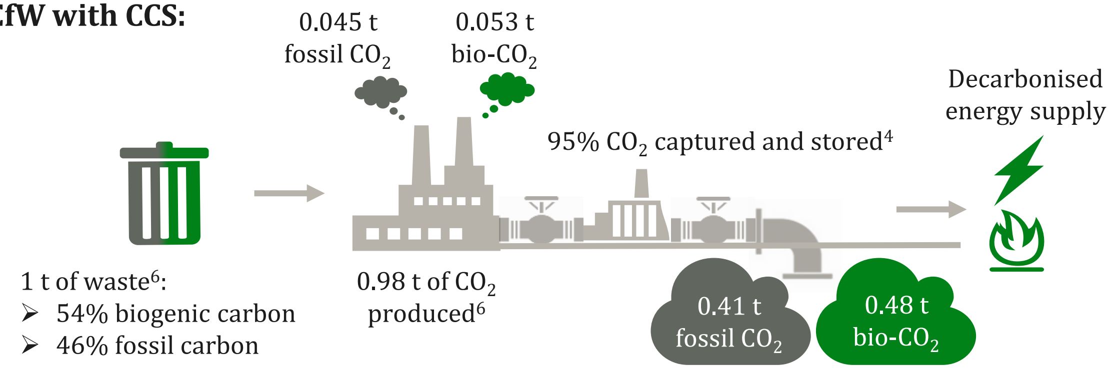
Deploying **CCS on EfW is recognised as a form of greenhouse gas removal**[5] **(GGR)**, meaning that it works to remove and permanently store CO_2 that was recently atmospheric. This is due to over half of residual waste combusted being of biogenic origin (e.g., agricultural & food waste)[6]. This GGR route has advantages over many nature-based GGRs due to the **permanence of geological storage and relative ease of MRV** (monitoring, verification and reporting).

Standard EfW:



Analysis of UK waste statistics indicates **54% of residual waste sent to EfWs is of biogenic origin**[6].

EfW with CCS:



Permanent storage of CO_2 of sustainable biogenic origin is considered a **robust form of greenhouse gas removal**[5].

1- GCCSI 2024, Global Status of CCS 2023
2 – CCC 2020, Sixth Carbon Budget: Waste
3 – ERM analysis of UK and European BECCS projects (July 2024)
4 – AECOM 2022, Next Generation Carbon Capture Technology (WP6)
5 – CCC 2020, The Sixth Carbon Budget: Greenhouse gas removals
6 - Tolvik 2024, UK Energy from Waste Statistics - 2023

Four stages of CCS deployment

The build out of CCS on EfW in the UK could occur over several stages of development, starting with larger sites in strategic locations

The UK has 60 operational EfW facilities and a further 18 facilities commissioned or under development[1]. The **retrofitting of such facilities with carbon capture technology is therefore expected to roll-out in stages, commencing with facilities where capture is technically and economically most viable.** Here we outline what the stages* of development could look like, detailing the infrastructures and investments required, the economic opportunities, and the environmental benefits.

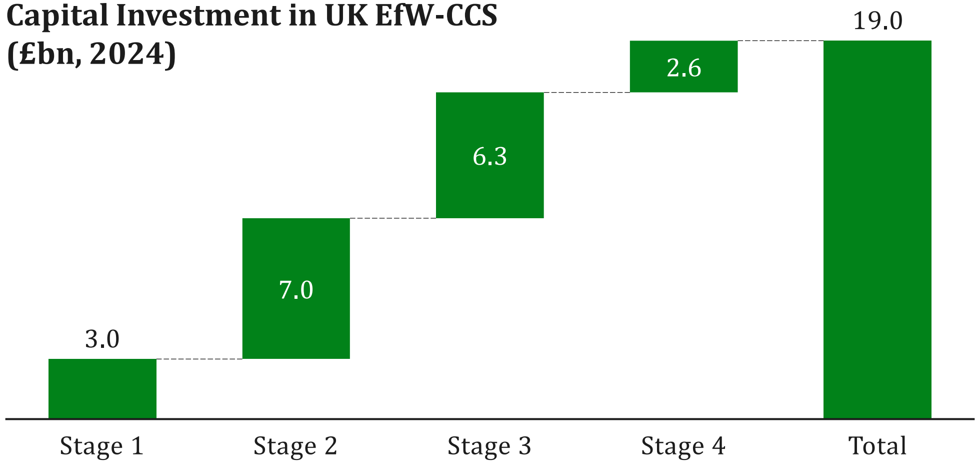
Our stages* reflect the expected phasing of CCS deployments considering the enabling development needs (e.g., shipping hubs) and the costs of CCS at individual facilities, with facilities with lower costs expected to move faster. They broadly correspond to:

- **Stage 1:** large sized assets strategically located within industrial clusters prioritised for UK government financial support.
- **Stage 2:** large-medium sized assets that are located near to industrial clusters with CO_2 storage or large ports that could become CO_2 shipping hubs.
- **Stage 3:** small-medium sized assets that today face greater economic barriers to deploying carbon capture and / or connecting to nearby CO_2 hubs.
- **Stage 4:** truly dispersed or very small assets where CCS might not be a viable solution.

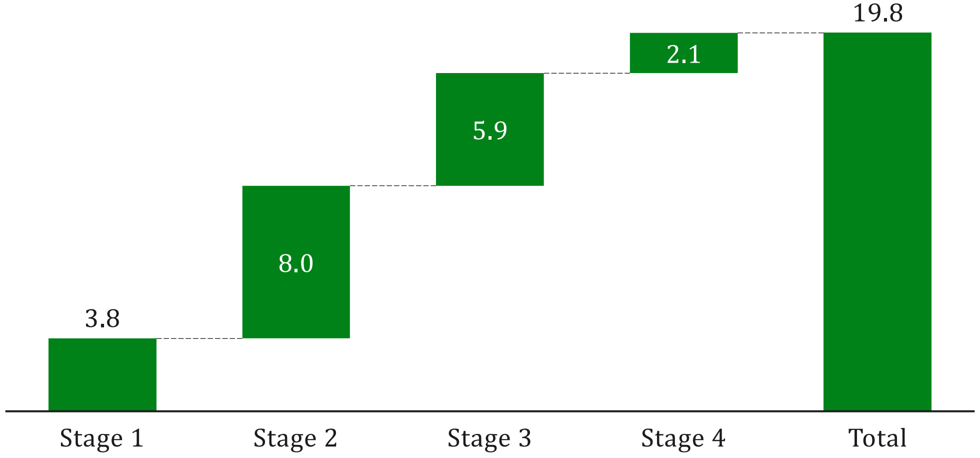
The total estimated **capital investment opportunity for carbon capture on EfW assets in the UK is £19bn** with an associated **carbon capture and storage potential of 19.8 $MtCO_2$/y**. Due to the biogenic content of waste, 54%[1] of these captured carbon dioxide emissions would be of biogenic origin, contributing **just over 10 $MtCO_2$ removals** if all facilities installed CCS.

**Stages were defined through a multicriteria assessment considering asset scale, distance to hub, proximal hub development timeline, and the total CCS cost, as detailed in the appendix.*

Capital Investment in UK EfW-CCS (£bn, 2024)



Total captured CO_2 ($MtCO_2$/y)



1 - UK Energy from Waste Statistics - 2023 – Tolvik. ERM analysis included all assets within the Tolvik 2023 EfW dataset (covering all assets that had reached financial close by end-2023) plus the addition of TV ERF and Redcar.
2 – CCC 2020, The Sixth Carbon Budget: Greenhouse Gas Removals

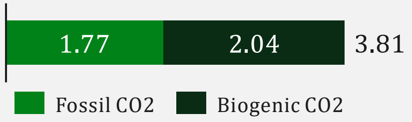
Stage 1 of Opportunity Pipeline

Stage 1 opportunities reflect assets that have **larger capacities and exist in strategic locations** within industrial clusters prioritised for UK government financial support[3]. These assets experience lower costs for CCS due to **economies of scale** for carbon capture equipment and **direct connections into shared CO_2 transport infrastructure**. Through their strategic locations, these assets also have early opportunities to **connect with the UK's prioritised CO_2 transport & storage clusters** (expected to be operational by 2027/2029) and may be **eligible to apply for UK government funding**.

Enabling infrastructure: UK Gov. Priority Clusters (Track 1)

Number of assets: 8

CO_2 capture potential ($MtCO_2$/y):



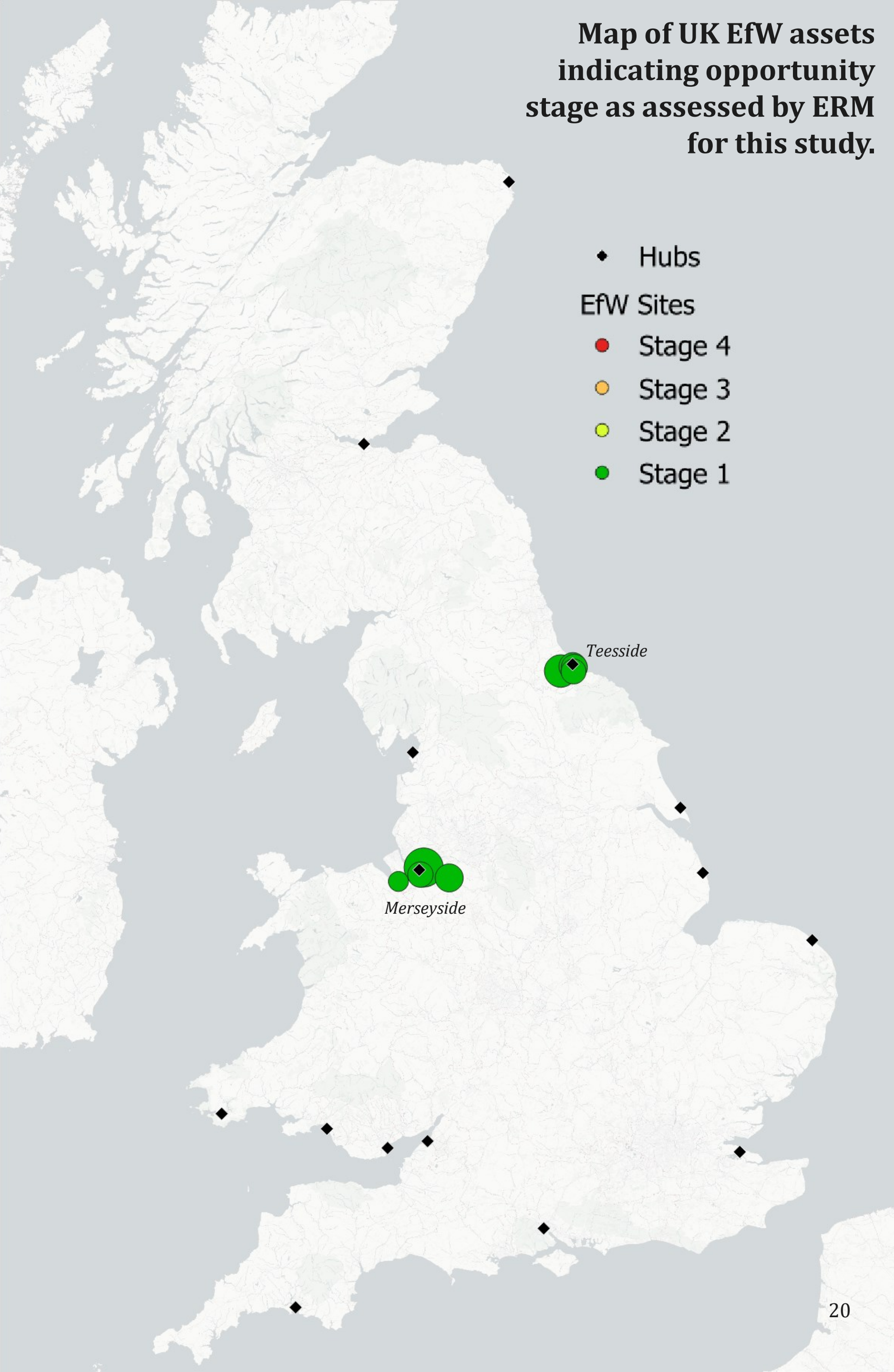
Capital investment (£bn, 2024): £3.0bn

Economic indicators[1]:

Jobs:
11,500 person-year during construction
1,370 permanent

£5.3bn GVA
Cumulative direct and indirect by 2050

Average cost of CCS[2]: £201/tCO_2



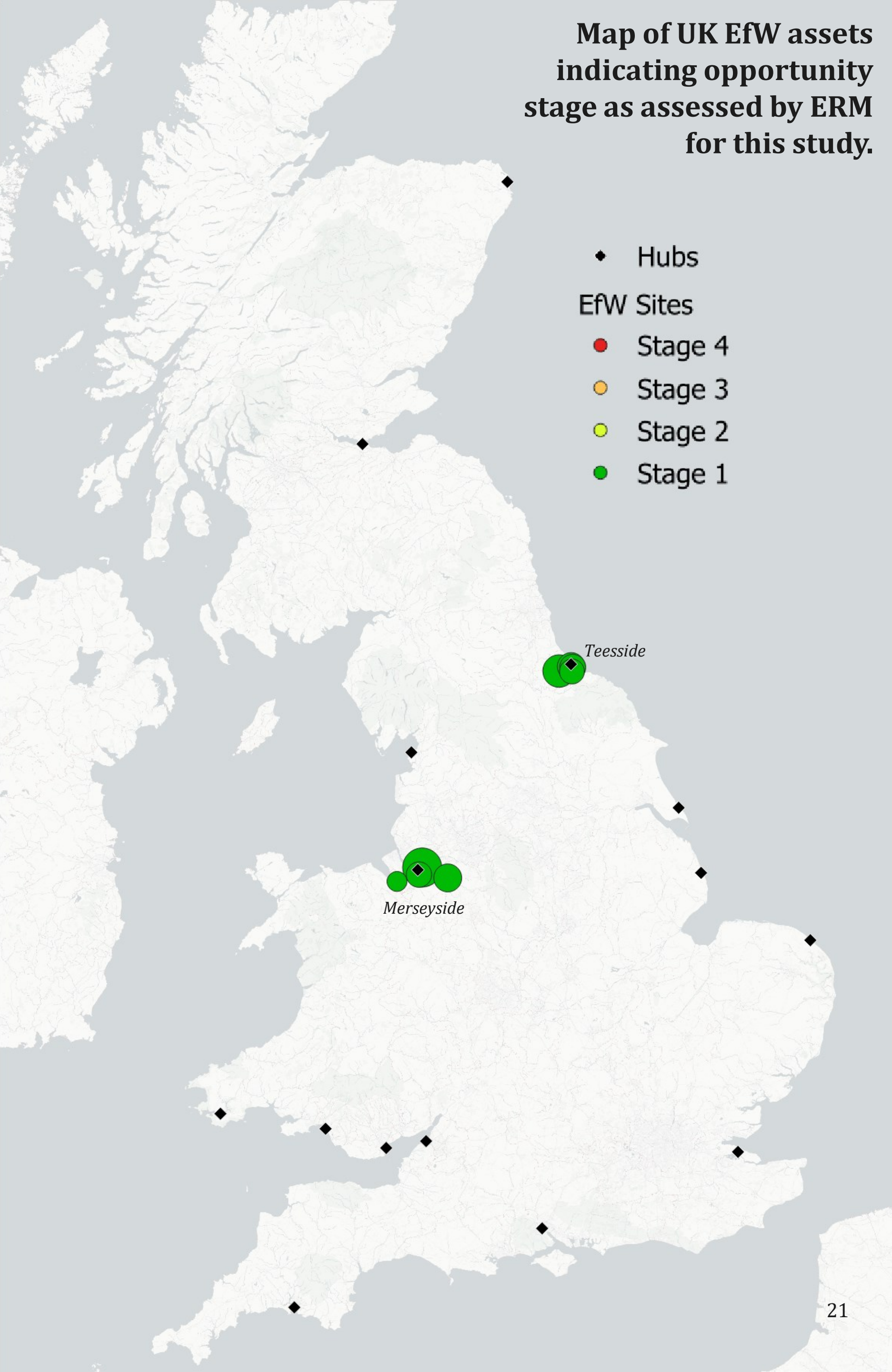
1 - Both direct and indirect jobs and GVA (gross value added) are reported. See Appendix for more information on the methodology and assumptions for economic value calculation.
2 – Includes transport and storage costs as well as the on-site capture
3 - Government pledges nearly £22bn for carbon capture projects - BBC News

Stage 1 opportunity assets are already interested in or developing carbon capture

Stage 1 opportunity assets are strategically located in or near to the governments two prioritised (Track 1) industrial clusters at **Merseyside (HyNet Cluster[1]) or Teesside (East Coast Cluster[2]).** These clusters have received funding from the UK government to develop local CO_2 transport and storage networks to be operational by 2027.[3] Facilities wishing to install carbon capture and connect to this network were invited to apply for **UK government 'CCS Business Model' support in 2021, with an extension offered for HyNet in 2023.**[3,4]

Of the eight EfW assets identified here as Stage 1 opportunities, five assets applied for the initial funding round of which two have since progressed to negotiations with government. Another asset applied for funding in the extension round, where outcomes are yet to be announced at the time of writing (for a total of six applications from Stage 1). This analysis illustrates the existing interest of our identified Stage 1 EfW assets in deploying CCS, and how government funding could support them to do so.

EfW Site	Operator	EfW Status	Capture Potential ($ktCO_2/y$)	Cluster	UK CCS funding status
Runcorn	Viridor	Operational	900	Merseyside	T1 Negotiation
TV ERF	Various LAs	Proposed	450	Teesside	T1 Shortlist
Redcar	Low Carbon and PMAC Energy	Proposed	400	Teesside	T1 Shortlist
Protos	Biffa/Encyclis	Under Construction	380	Merseyside	T1 Negotiation
Tees Valley	Suez	Operational	620	Teesside	T1 Application
Parc Adfer	enfinium	Operational	235	Merseyside	T1 Extension Application
Wilton 11	Suez	Operational	365	Teesside	No Application
Lostock	FCC/CIP	Under Construction	460	Merseyside	No Application

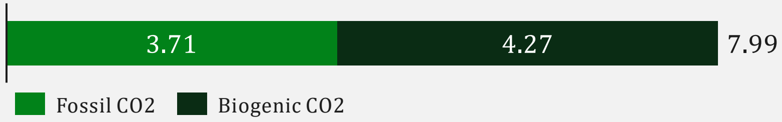


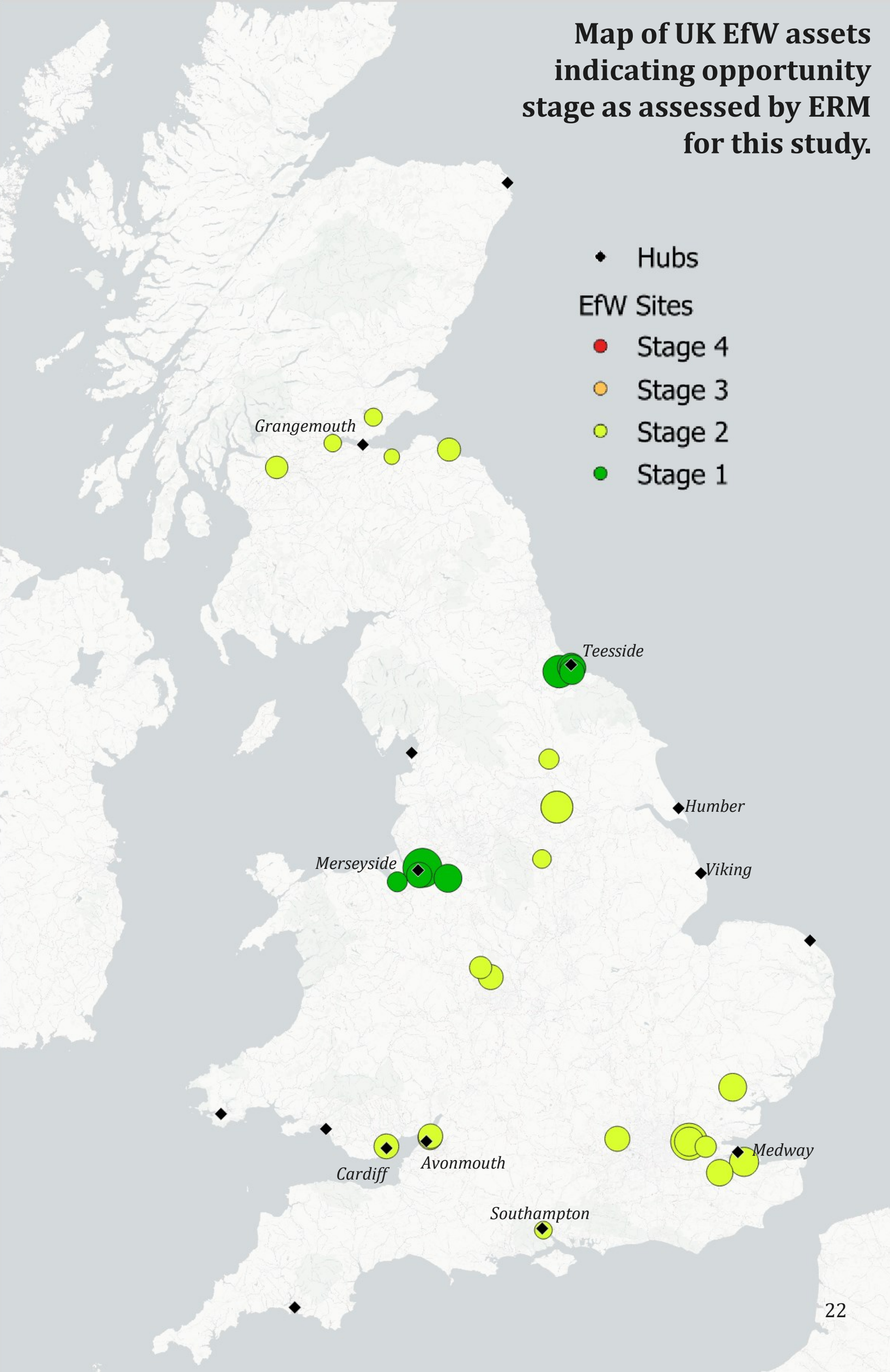
1 - HyNet North West. 2 - East Coast Cluster. 3 - Cluster sequencing for carbon capture, usage and storage (CCUS) deployment: Phase-2. 4 - Carbon capture, usage and storage (CCUS) deployment: Track-1 expansion: HyNet cluster.

Stage 2 of Opportunity Pipeline

Stage 2 opportunities reflect **large-medium sized assets that are strategically located near to CO_2 storage clusters** (primarily Acorn and Humber[3])or large **ports that could become CO_2 shipping hubs**. The combination of scale and location of these assets provide favourable costs of CCS (compared to most Stage 3 assets).

Stage 2 opportunities are expected to support extensions of hub-networks with longer-distance pipelines and the development of CO_2 shipping hubs (e.g., Medway[4], South Wales[5], and Avonmouth[6]). We estimate that the EfW sector alone (across all stages) could enable the **establishment of at least eight large 18kt dedicated ships for CO_2 transport.**

Enabling infrastructure:	UK Gov. Priority Clusters (Track 1&2); CO_2 shipping hubs
Number of assets:	22
CO_2 capture potential ($MtCO_2$/y):	
Capital investment (£bn, 2024):	£7.0bn
Economic indicators[1]:	**Jobs:** 26,800 person-year during construction, 3,700 permanent; **£15.1bn GVA** Cumulative direct and indirect by 2050
Average cost of CCS:	£237/tCO_2

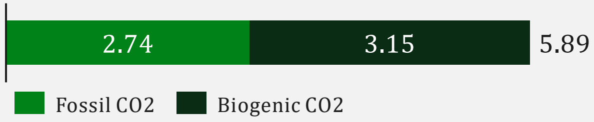


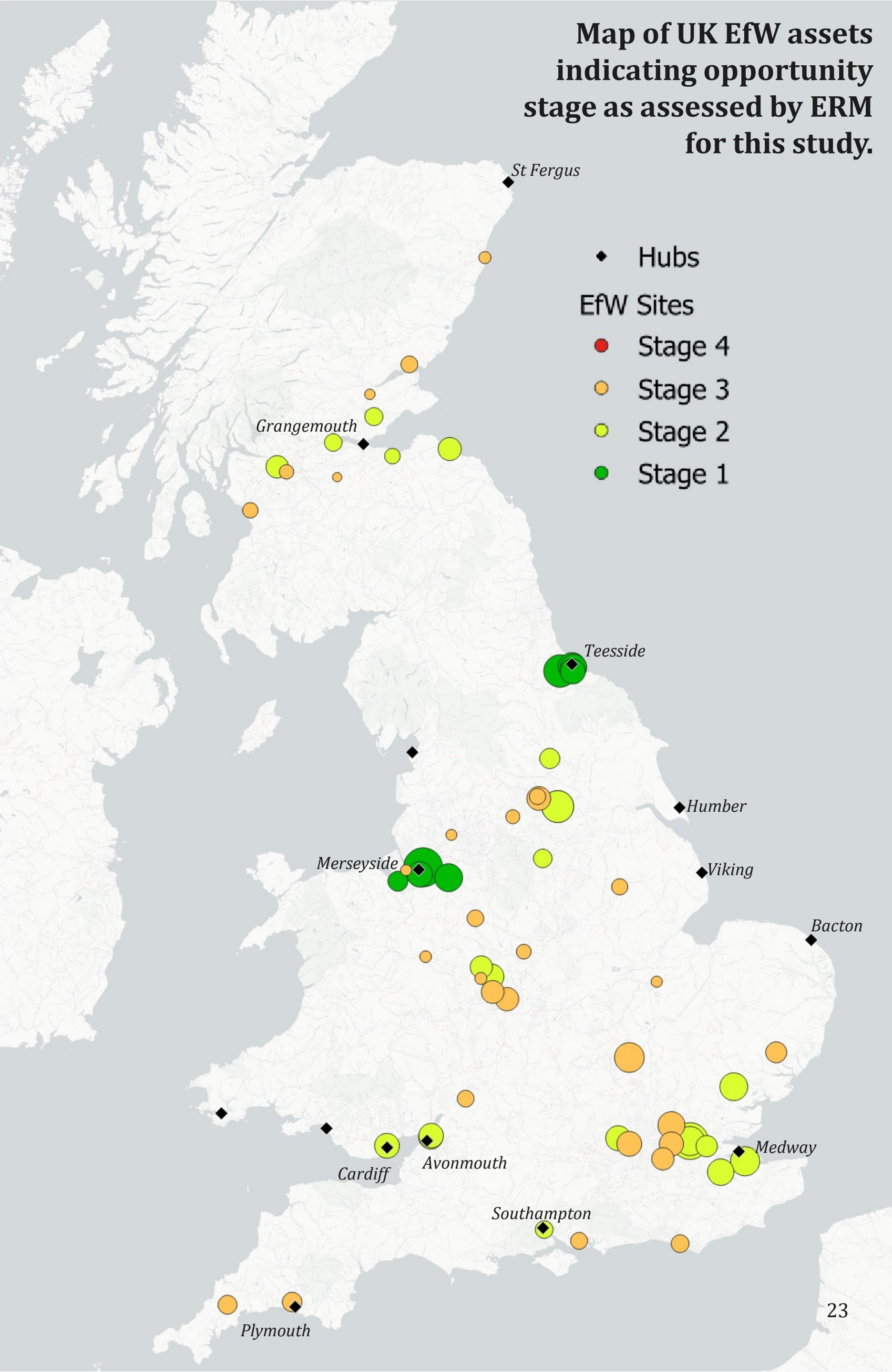
Map of UK EfW assets indicating opportunity stage as assessed by ERM for this study.

1 - Both direct and indirect jobs and GVA (gross value added) are reported. Please see the Appendix for more information on the methodology and assumptions for economic value calculation. 2 – Includes transport and storage costs as well as the on-site capture. 3 - CCUS Cluster Sequencing Track-2: Market update December 2023 - GOV.UK (www.gov.uk). 4 - Bacton Thames NetZero | Eni. 5 - SWIC | South Wales Industrial Cluster. 6 - 7CO2: The Severnside Carbon Capture and Shipping Hub.

Stage 3 of Opportunity Pipeline

Stage 3 opportunities **reflect small-medium sized assets that today face greater economic barriers to deploying carbon capture and / or connecting to nearby CO_2 hubs**. This is typically due to their smaller scale or increased CO_2 transport distances that result in high costs for CCS. Development of Stage 3 opportunities could **support the expansion of CO_2 transport networks, such as the roll-out of CO_2 transport by rail**[1]. It could also drive uptake of **smaller-scale, modular capture technologies or unique business models** (e.g., Carbon Capture as a Service, CCaaS).

Enabling infrastructure:	Expanded network of CO_2 transport to hubs; CO_2 transport via rail
Number of assets:	30
CO_2 capture potential ($MtCO_2$/y):	
Capital investment (£bn, 2024):	£6.3bn
Economic indicators[2]:	**Jobs:** 24,000 person-year during construction, 3,000 permanent; **£12.8bn GVA** Cumulative direct and indirect by 2050
Average cost of CCS[3]:	£275/tCO_2



1 - Our analysis indicates that 17 of the 33 Stage 3 opportunities are located within 1km of a railway and would benefit from the development of CO_2 transport by rail as their lowest cost transport solution. 2 - Both direct and indirect jobs and GVA (gross value added) are reported. Please see the Appendix for more information on the methodology and assumptions for economic value calculation. 3 – Includes transport and storage costs as well as the on-site capture. Stage 3 opportunities could also take learnings from earlier developments to reduce costs from that calculated here.

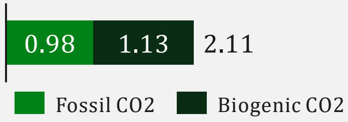
Stage 4 of Opportunity Pipeline

Stage 4 opportunities are characterised by **truly dispersed assets (>100km from hub) as well as assets that are so small such that CCS might not be a viable solution.** It is unclear today how these assets might connect to CO_2 storage sites, but it could be via the development of inland CO_2 hubs or transport networks (supported by government funding or collaboration with other dispersed industries). Alternatives to decarbonise dispersed or small EfW assets could be **possible asset re-location or aggregation, or using CO_2 utilisation techniques to avoid CO_2 transport.**

Enabling infrastructure: Inland CO_2 transport hubs; Possible asset re-location; CO_2 utilisation

Number of assets: 18

CO_2 capture potential ($MtCO_2/y$):



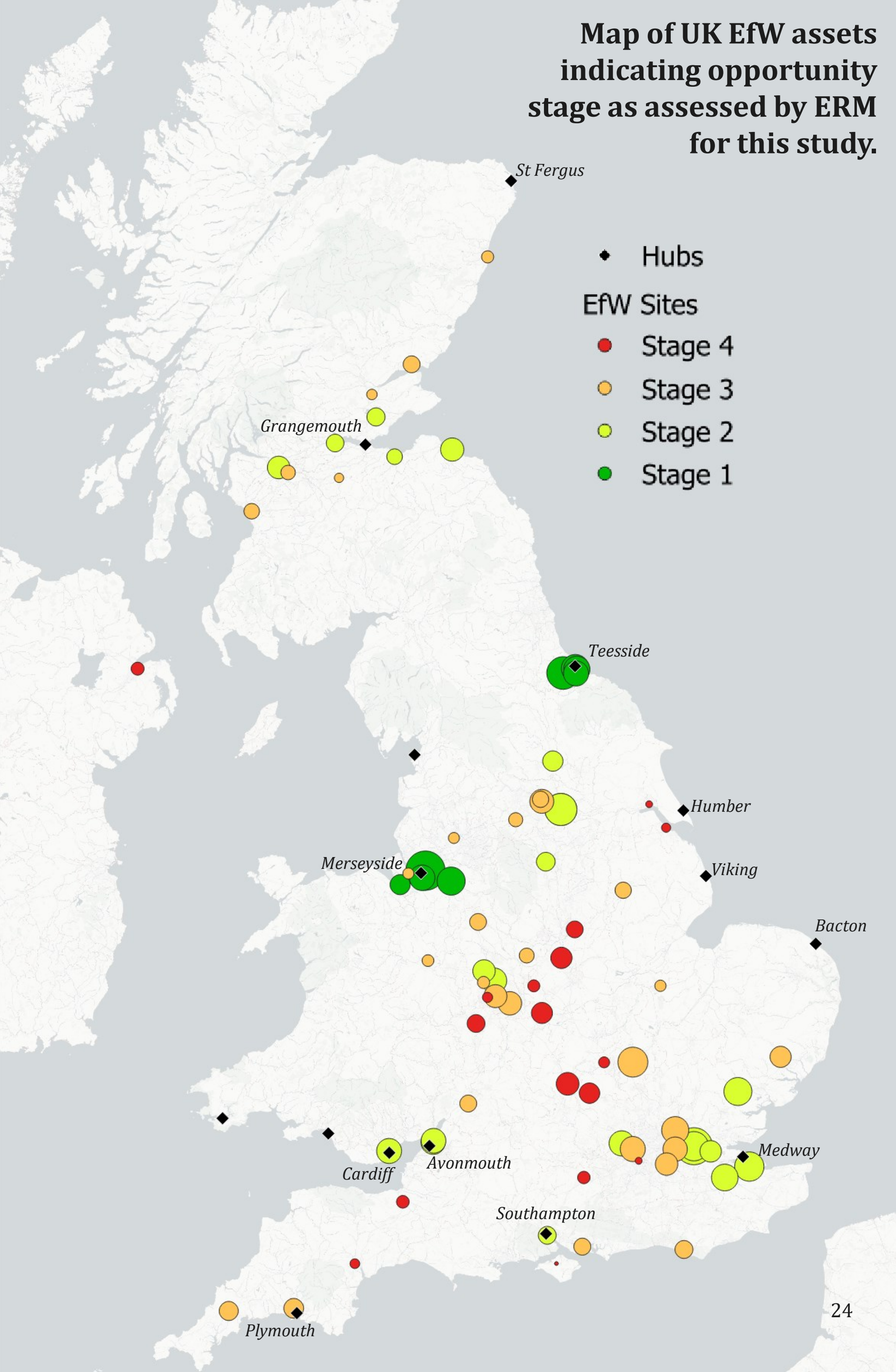
Capital investment (£bn, 2024): £2.6bn

Economic indicators[1]:

Jobs:
9,900 person-year during construction
1,280 permanent

£5.6bn GVA
Cumulative direct and indirect by 2050

Average cost of CCS[2]: £335/tCO_2



Map of UK EfW assets indicating opportunity stage as assessed by ERM for this study.

1 - Both direct and indirect jobs and GVA (gross value added) are reported. See Appendix for more information on the methodology and assumptions for economic value calculation.
2 – Includes transport and storage costs as well as the on-site capture

Enabling wider UK CCS infrastructure development

Non-pipeline transport is crucial to maximise effective decarbonisation of EfW with CCS

Most EfW assets require non-pipeline transport (NPT) to minimise the cost of CCS; **only 46% of total emissions are decarbonised using solely pipelines** around CO_2 storage clusters.

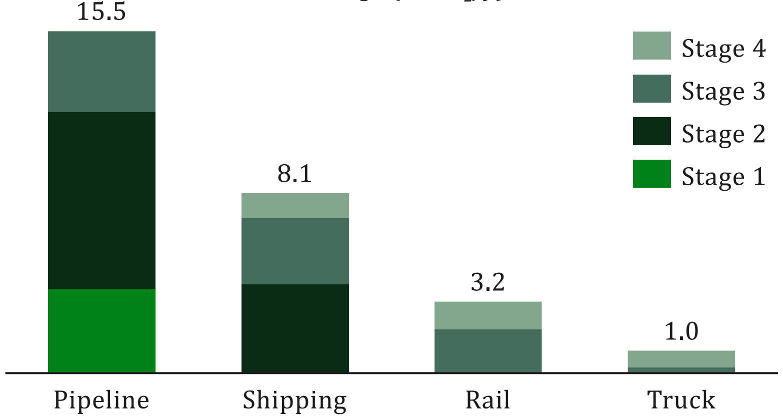
CO_2 shipping supports 41% of decarbonisation by enabling assets far from storage clusters to connect via ports. **Rail also plays a major role, enabling decarbonisation of approaching 20% of EfW emissions**.

Enabling the timely decarbonisation of these assets will require a shift in priorities from the large industrial clusters to a more dispersed approach – EfW plants can enable this transition by providing low-risk, long-term, baseload CO_2 to reliably **underpin the deployment of novel NPT solutions**.

Government and industry need to **establish the policy, regulatory, financial, liability, and safety backdrops necessary** to allow the rapid development of shipping and rail.

Stage 2 opportunities are heavily dependent on the development of a substantial CO_2 shipping infrastructure - half of this Stage's capture capacity relies on shipping. Stage 3 is equally reliant on the development of rail for CO_2 transport, enabling 34% of emissions reductions. Road transport plays a smaller role and only really contributes to Stage 4, for the smallest and most expensive sites – these sites may instead be relocated/retired given the cost of CO_2 trucking.

Total emissions reduction enabled by transport method in each stage ($MtCO_2$/y)



Breakdown of capture capacity and CAPEX investment opportunity by T&S modality

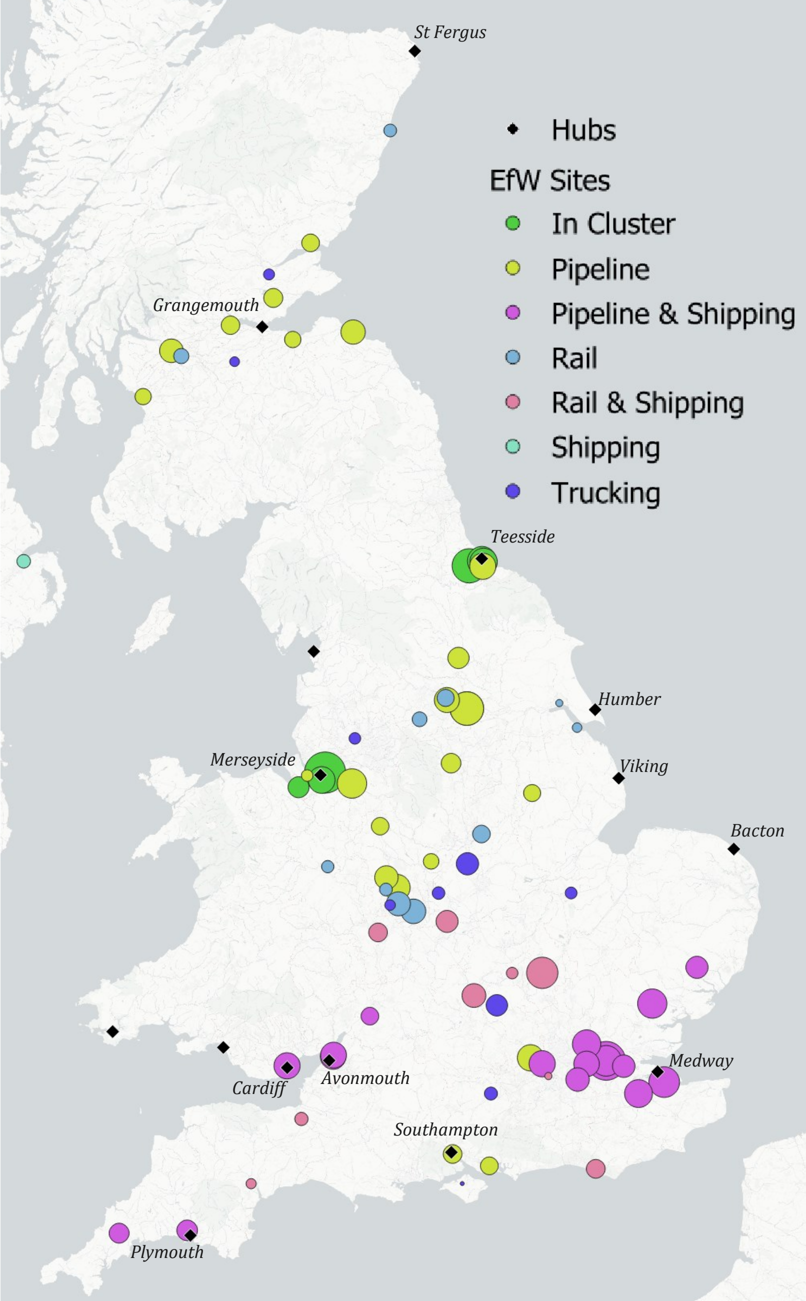
T&S Modality	Number of plants	Capture capacity ($MtCO_2$/y)	CCS CAPEX (£bn)
Pipeline	29	9.1 (46%)	8.3
Rail	11	1.5 (8%)	1.8
Pipeline & Shipping	19	6.4 (33%)	5.7
Rail & Shipping*	9	1.7 (9%)	1.8
Trucking	10	1.0 (5%)	1.3

ERM

The above analysis refers to the lowest cost transport method for sites. For some facilities there is negligible difference between the costs of pipeline and rail transport. Choice of transport mode may therefore depend on timelines for development of local enabling infrastructure.

* Rail & Shipping refers to sites that use rail to access a port and then ship to a storage cluster, just Rail refers to sites that directly connect to storage clusters.

Map of UK EfW assets indicating optimal CO_2 transport mode as assessed by ERM for this study.



CCS offtake from EfW plants could support first movers in CO_2 shipping at Medway and Avonmouth

Based on ERM's analysis of optimal transport modes, **28 EfW facilities utilise CO_2 shipping solutions as part of the lowest cost transport route to storage.** In these cases, CO_2 is transported from the EfW asset to a shoreline CO_2 hub via pipeline or rail connections, and then shipped in aggregation with other regional CO_2 to either Acorn or Viking storage sites.

Medway and Avonmouth are the two main CO_2 shipping hubs identified, and both have existing plans to develop CO_2 shipping capabilities:

- **7CO_2 is a proposed CO_2 export hub at Avonmouth Dock** which will be linked by pipeline and rail to regional large emitters of CO_2, including nearby EfW facilities, with a claimed potential to capture and transport of 8 $MtCO_2$/y.[1]
- **Synergia Energy are proposing the development of a CCS hub at Medway/Isle of Grain,** collecting CO_2 from local power CCS projects.[2] Others have also proposed CO_2 shipping from the region include the Cory Riverside EfW site and Bacton Thames Net Zero.[3,4]

Analysis indicates that the **EfW CO_2 demand alone at these two hubs could support the CO_2 shipping industry, with eight 18kt ships required**.

Alongside other industrials in these regions **EfW plants can provide diversity of supply, baseload CO_2 streams, and long-term, low risk demand** to enable the development of the first CO_2 shipping hubs in the UK.

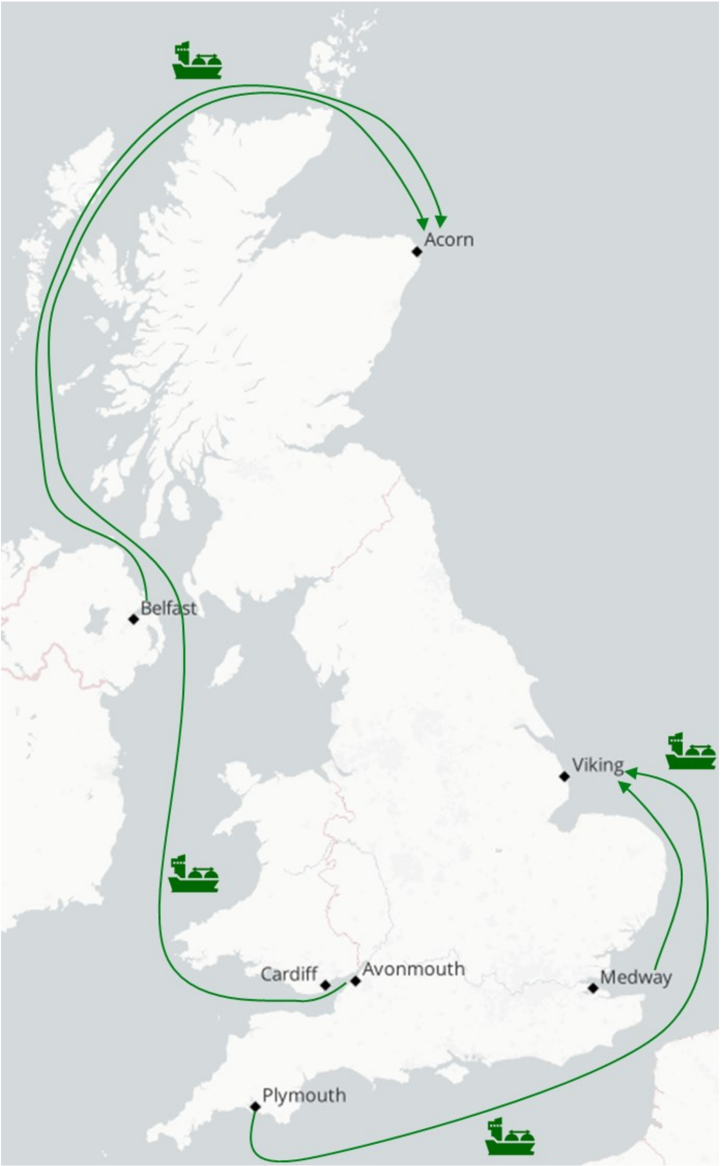
Plymouth represents a considerably smaller EfW opportunity, coupled with less nearby industry - only requiring one 18 kt vessel. There is an opportunity that **Plymouth could be serviced as part of a "milk round" to aggregate demand with other smaller ports on a shared route.**

Capture capacity and CAPEX investment opportunity disaggregated by CO_2 shipping port

Port	Number of plants	Capture capacity ($MtCO_2$/y)	CCS CAPEX (£bn)	Number of ships
Medway	15	5.4	4.7	🚢🚢🚢🚢
Avonmouth	7	1.7	1.7	🚢🚢🚢🚢
Plymouth	3	0.5	0.6	🚢
Other*	3	0.5	0.5	

** Other ports represent those hubs where only one CCS plant connects. This greatly inflates the cost of CO_2 shipping such that these facilities are highly unlikely to pursue CCS.*

🚢 = Number of 18 kt vessels required.



1 – 7CO2: The Severnside Carbon Capture and Shipping Hub: Overview. 2 – Medway hub ccs - synergiaenergy. 3 - Carbon capture and storage project | Cory Group. 4 - Bacton Thames NetZero. | An initiative for the future. – Eni.

Rail transport is important for decarbonising dispersed industrial sites

Our analysis indicates **52 of the 78 EfW sites in the UK are within 1km of an existing rail network**. This enables the opportunity for them to connect directly into the network with limited CAPEX investment in rail infrastructure.

Based on ERM's analysis of optimal transport modes, **20 of these EfW facilities utilise rail as a component of the cheapest transport pathway to export CO_2 from their site**. This corresponds to over 3 $MtCO_2$/y capture capacity, approaching 20% of the total potential from the sector.

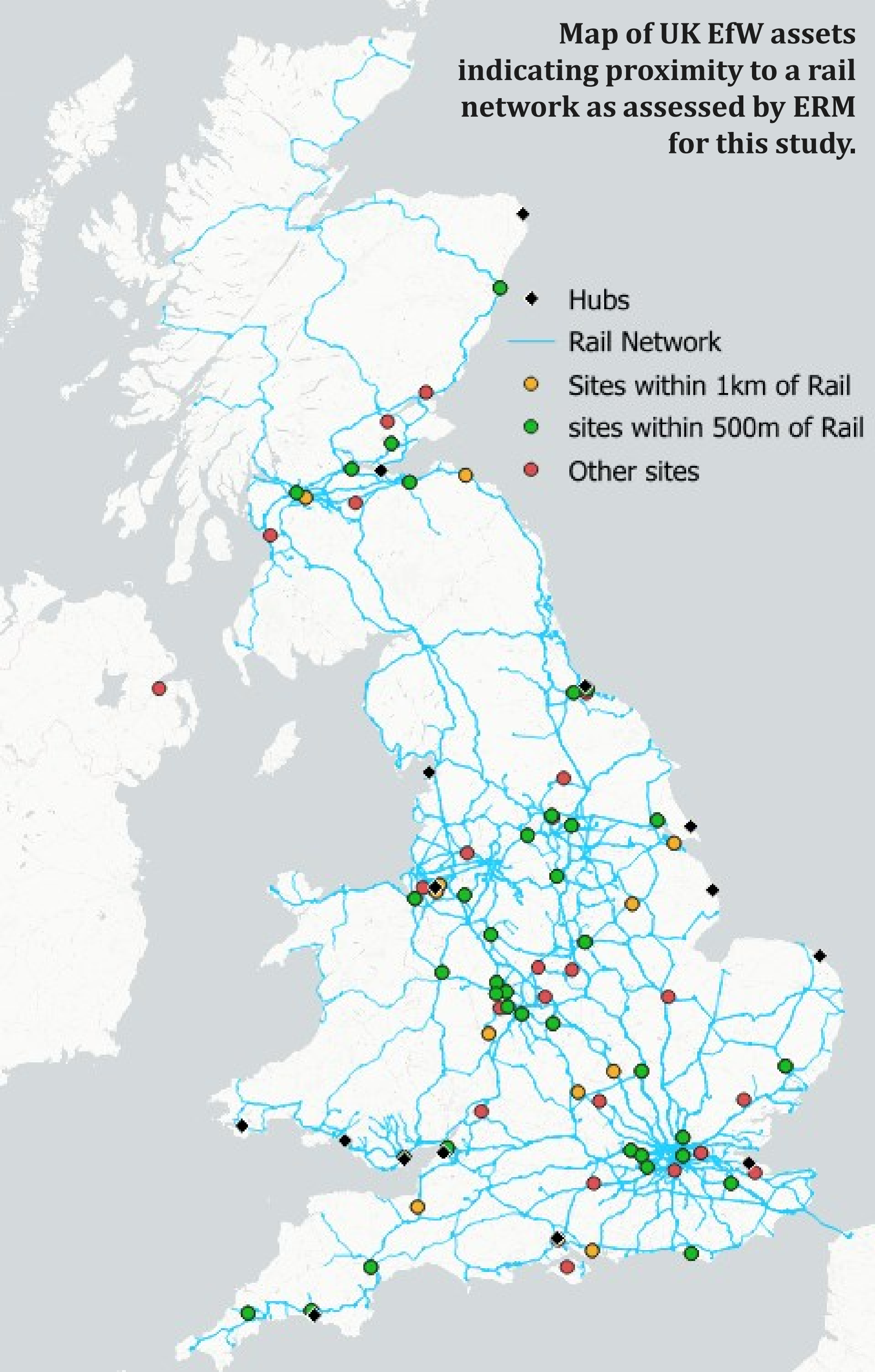
Half of the 20 sites **which utilise rail are medium-large scale EfW plants that are at least 50km from the nearest CO_2 hub, highlighting the important role rail can play in decarbonising more challenging facilities** and enabling £3.5bn in carbon capture capital investment.

Earlier this year Government released a call for evidence on the potential for non-pipeline transport (NPT) in the UK, with rail playing a central role in the consultation. Rail and road transport are often discussed together - however due to the logistical issues with additional truck movements at EfW plants and the widespread availability of existing rail infrastructure near EfW plants in the UK, rail will likely take a more dominant role in supporting the decarbonisation of the sector.

Nevertheless, **rail transport of CO_2 needs further investigation to identify and overcome potential network availability constraints, regulatory barriers, and safety requirements**.

There will also be a significant lead time for the development of rail rolling stock, which will only be meaningfully initiated once there is clear policy support and demand for rail transport of CO_2 in the UK.

Map of UK EfW assets indicating proximity to a rail network as assessed by ERM for this study.



Contribution to UK targets

Uptake of CCS across the UK's EfW facilities is aligned with the UK Net Zero strategy and supports key Government targets

Following the assessment, ERM conducted an analysis of UK policy and UK energy data to identify how CCS on EfW supports government targets focusing on the five key topics below. The outcomes are presented in more detail on the following slides.

Waste Management

EfW facilities are a critical technology for treating residual waste which cannot be recycled. They have a long-term role in UK waste management[1].

Carbon Capture Targets

Uptake of CCS on EfW contributes to the governments target to capture 20-30 $MtCO_2$/y by 2030[2]. CCS across all EfW facilities could achieve 19.7 Mt of CO_2 capture per year[6].

Greenhouse Gas Removals

As over half of residual waste is of biogenic origin[3], CCS on EfW captures biogenic CO_2 and acts as a GGR technology. The UK government has a target to deploy 23 Mt GGRs by 2035[4].

Net Zero Industry

CCS is a key technology for decarbonising UK industry. Uptake of CCS in the EfW sector supports shared CO_2 transport and storage infrastructure development[6].

Carbon Neutral Electricity

The UK government aims to deliver 'clean power' by 2030[5]. EfW with CCS can offer GGRs alongside electricity generation, offsetting residual power emissions.

Scope 3 Emission Reductions

Waste management is a component of most upstream and downstream value chains. CCS on EfW therefore contributes to Scope 3 reductions across the economy[6].

1- CCC 2020, Sixth Carbon Budget: Waste
2 – DESNZ 2023, CCUS: a vision to establish a competitive market
3 – Tolvik 2024, UK Energy from Waste Statistics - 2023
4 – HM Government Oct 2021, Net Zero Strategy
5 – DESNZ 2024, Mission Control to deliver clean power by 2030
6 – ERM analysis for this study – see full report.

CCS on EfW in the UK could capture up to 20 $MtCO_2$/y and help underpin the development of CCS infrastructure

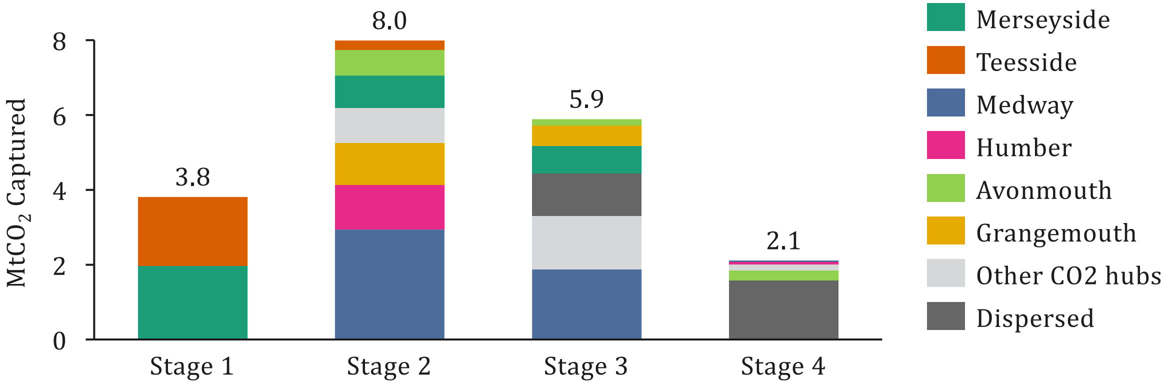
Carbon Capture Targets

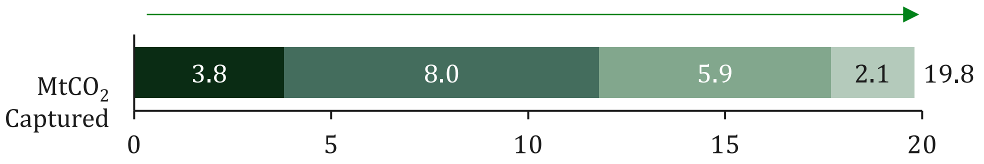
- The UK government has an **ambition to capture and store 20-30 $MtCO_2$/y by 2030** through the creation of four CCUS clusters[1]. By the mid-2030s this could increase to 50 $MtCO_2$/y, with potentially 90-170 $MtCO_2$/y captured in 2050[1].
- Analysis in this study finds that the **uptake of CCS on EfW could lead to the capture of nearly 20 $MtCO_2$/y** if applied to all EfW assets analysed. Of this, 11.8 $MtCO_2$/y could be delivered by 'Stage 1 and 2 Opportunity' assets that are strategically located near CO_2 hubs and face the lowest barriers to adoption according to this study.
- Therefore, the EfW sector alone could capture **24% of the UK's 50$MtCO_2$/y 2035 CCS ambition**.

Net Zero Industry

- CCS is a core technology for decarbonising the UK's industrial sector, however successful uptake requires development of shared CO_2 transport and storage infrastructure[1,2].
- Uptake of CCS on EfW can support such infrastructure development by providing a **consistent baseload supply of CO_2 that can act as an anchor demand,** facilitating wider industry CCS uptake.
- Stage 1 assets are all **within 25 km of a Track 1 industrial cluster,** with the majority having already expressed interest in the UK government's CCUS Cluster Sequencing programme[3].
- Furthermore, the UK government has announced plans to support projects connecting to storage via **CO_2 shipping and other non-pipeline transport**[1]. Deployment of CCS on EfW assets would make a significant contribution to the development of these transport modes[3].

Breakdown of total CO_2 captured from EfW assets grouped by stage of deployment (non-cumulative) and their nearest CO_2 hub[3]





Total UK EfW CO_2 capture potential - ordered from stages 1-4 showing cumulative impact[3].

ERM's analysis[3] found that deploying CCS across all UK EfW sites would mean:

8.1 $MtCO_2$ transported by ship from hubs such as Medway and Avonmouth to storage sites, requiring **investment in 8 ships** for CO_2 shipping (each 18 $ktCO_2$ capacity).

3.2 $MtCO_2$ transported by rail connecting a total of 20 dispersed EfW sites to CO_2 hubs across the UK. Analysis found that **67% of EfW sites are within 1km of a rail network**.

1- DESNZ 2023, CCUS: a vision to establish a competitive market
2 – Element Energy 2020, Deep Decarbonisation Pathways for UK Industry
3 – ERM analysis for this study – see full report.

CCS on EfW could contribute 27% of the UK's 2035 GGR target and enable a carbon neutral electricity grid

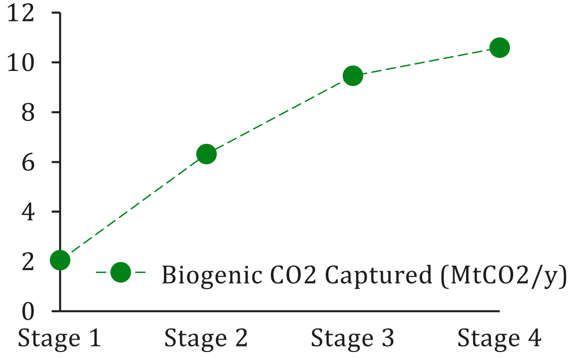
GGR Targets

- To achieve net zero, the UK is expected to deploy 45-112 Mt/y of greenhouse gas removals (GGR) by 2050[1] to offset residual emissions in hard-to-abate sectors such as agriculture, aviation, and waste.
- **Installing CCS on EfW facilities is recognised as a GGR** by the UK government due to the biogenic content of waste[1]. The route has advantages over many nature-based GGRs due to the **permanence of geological storage and relative ease of MRV** (monitoring, reporting and verification).
- The EfW could play a significant role in contributing to the UK governments GGR targets, with potential to capture **up to 6 $MtCO_2$/y of biogenic CO_2 from Stages 1 and 2 alone**[5] (deployed potentially by 2035).

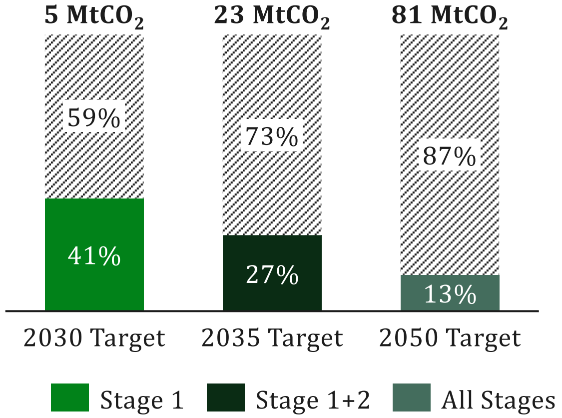
Carbon Neutral Electricity Grid

- In 2021 the UK government set a target to **decarbonise the electricity grid by 2035**[2]. The new government elected in 2024 has proposed an ambitious plan to deliver 'clean power' by 2030[3].
- Even with ambitious renewables and low-carbon power deployment, analysis for the CCC suggests that **in 2035 the grid would still use 12 GW of unabated gas power generating 11 TWh** of electricity per year to manage an increasingly extreme and volatile residual demand profile[4].
- Such generation would result in power emissions of **4.8 $MtCO_2$/y[4] which would need to be balanced** through other power generation assets to achieve a carbon neutral electricity grid.
- Installing CCS on Stage 1 and 2 EfW assets would **generate enough GGRs to balance all residual power sector emissions in 2035**, this holds even in the AFRY high scenario.

Annual biogenic CO_2 captured from EfWs across each deployment stage (cumulative)[5]

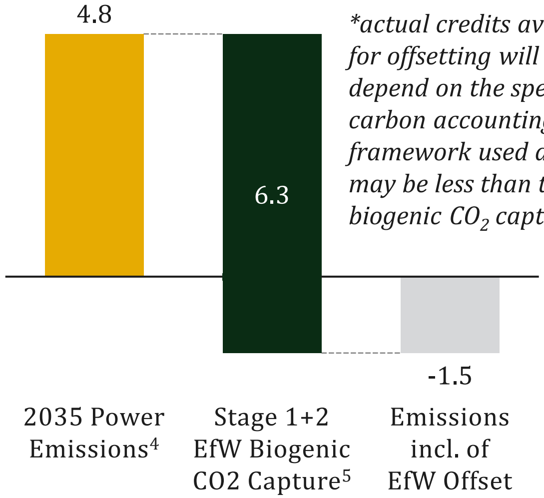


Contribution that CCS on EfW's could make to UK government GGR targets[2,5]



Stages 1 and 2 combined could store enough biogenic CO_2 to meet **27% of the governments 2035 GGR** target. This is enough to **balance all residual power emissions** in a decarbonised electricity grid.

Illustrative* impact of EfW with CCS balancing emissions from power sector ($MtCO_2$ / y)



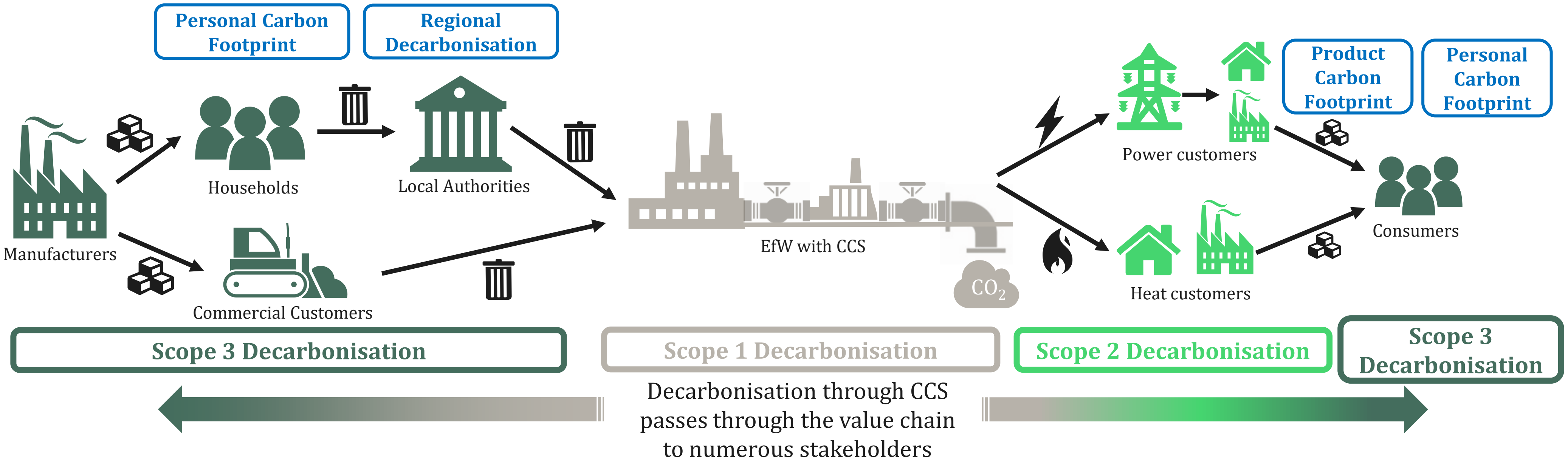
**actual credits available for offsetting will depend on the specific carbon accounting framework used and may be less than the biogenic CO_2 captured.*

1- CCC 2020, The Sixth Carbon Budget: Greenhouse gas removals
2 – HM Government Oct 2021, Net Zero Strategy
3 – DESNZ 2024, Mission Control to deliver clean power by 2030
4 – AFRY 2023, Net Zero Power and Hydrogen: Capacity Requirements for Flexibility (Central Scenario)
5 – ERM analysis for this study – see full report for details.

CCS on EfW has a cascading impact of reducing Scope 3 emissions across UK value chains, and lowering household carbon footprints

Scope 3 Emissions

- **Scope 3 emissions** on average account for **75%** of a company's GHG emissions[1]. Therefore, their abatement is critical in reaching net zero. Corporate emissions are usually accounted as three scopes: Scope 1 (direct emissions from site), 2 (emissions from purchased energy), or 3 (other indirect). When an EfW plant reduces its direct Scope 1 emissions, this has a **cascading effect** on **reducing Scope 2 and 3 emissions** of other stakeholders across the value chain. Accounting of emissions across multiple scopes as such encourages collective action for decarbonisation whilst avoiding double counting[2]
- Stakeholders may also account for emissions reductions or removals[3] through alternative means, such as carbon intensity of products, personal carbon footprints of people whose waste is processed by an EfW + CCS facility or regional emission inventories of Local Authorities / Devolved Administrations, etc. EfW plants may seek financial support from these stakeholders or justify increasing their gate fees depending on the premium placed on such decarbonisation across the board.



[1] CDP Technical Note: Relevance of Scope 3 Categories by Sector, [2] Inventory-based GHG accounting through Scope 1, 2, 3 is developed by and based on the GHG Protocol's Corporate Standard. [3] If carbon credits are sold to parties outside of the EfW value chain, those GHG reductions or removals cannot be accounted by any of the stakeholders

Conclusions

A staged deployment of CCS on EfW in the UK presents an opportunity aligned with a net zero transition

Summary of key outcomes from this analysis:

- **Energy from Waste (EfW) facilities will play a long-term role in UK waste management**, offering critical local services and energy generation.
- Uptake of carbon capture on EfW in the UK could capture up to **20 $MtCO_2$/y** and help **underpin the development of CO_2 transport and storage infrastructure.**
- Carbon capture and permanent storage (CCS) of CO_2 from EfW provides valuable greenhouse gas removals (GGRs) that could contribute **27% of the UK's 2035 GGR target** and enable a carbon neutral electricity grid.
- CCS on EfW has a cascading impact of **reducing Scope 3 emissions across UK value chains**, and lowering household carbon footprints.
- Deployment of CCS on EfW is anticipated in stages with an **estimated £19bn to be invested**, supporting the UK economy with potential to generate over **14,000 green jobs** and unlock nearly **£40bn in GVA.**

The **EfW sector is already progressing on this journey**

Six of the UK's EfW assets located near prioritised hubs for CO_2 storage have already announced CCS plans and applied to the government's CCUS Cluster Sequencing competition[1].

The government is currently in **negotiations with two EfW assets, Protos ERF and Viridor Runcorn**, to receive funding for CCS deployment and be operational by 2027[2].

A total of **30 EfW assets are well-placed to deploy CCS by 2035,** laying foundations for the development of more CO_2 hubs and rapid decarbonisation of the waste sector.

Next steps require the **connection of other suitable EfW assets** to Teesside and Merseyside hubs, the further **development of CO_2 hubs** (e.g., Grangemouth, Humber), and the development of hubs for **CO_2 shipping** (e.g., Medway, Avonmouth).

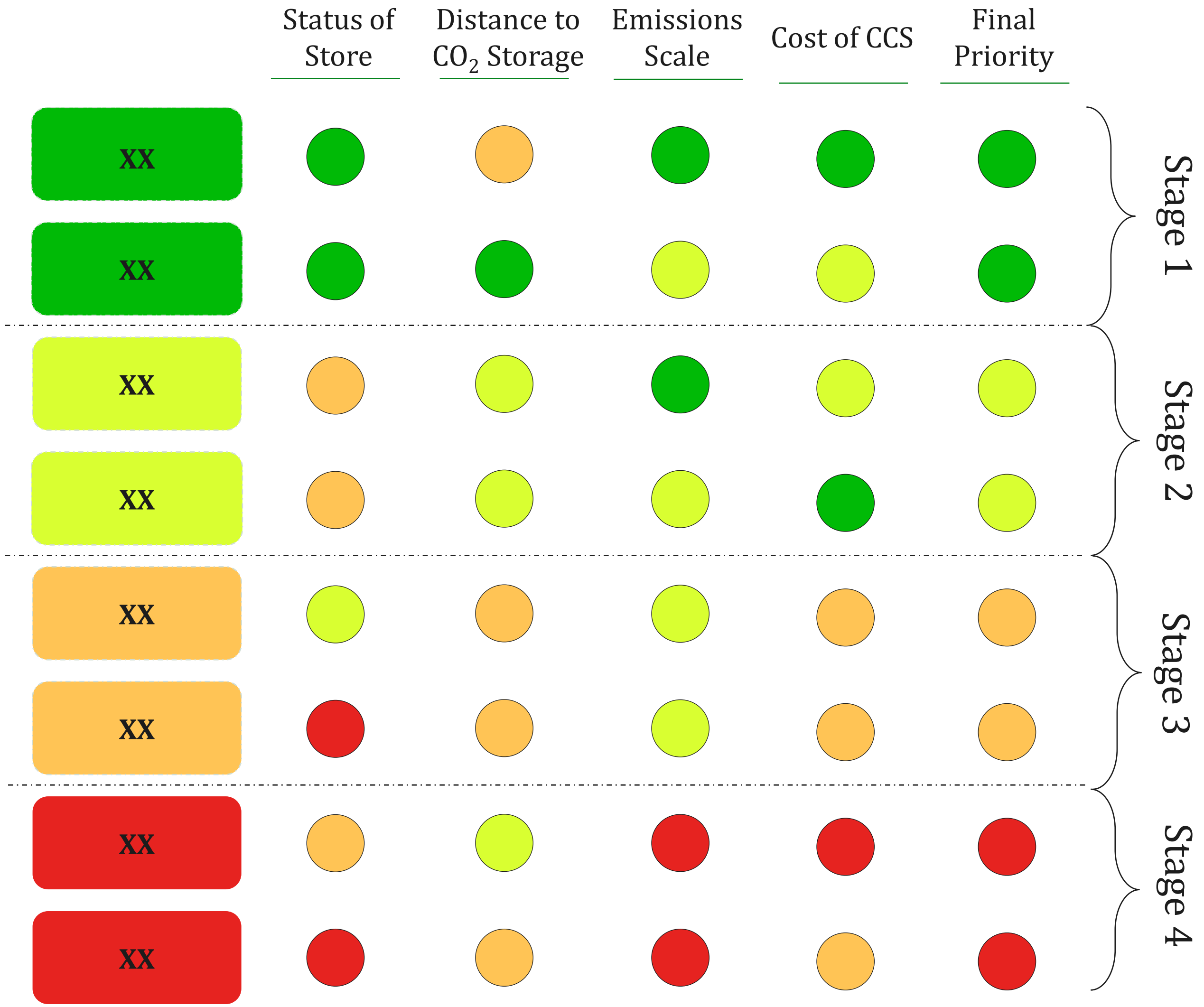
1- ERM analysis for this study – see full report for details.
2 - DESNZ 2023, Cluster sequencing Phase-2: Track-1 project negotiation list

Important assumptions & limitations of analysis

	Assumption	Limitation
Assets Included	• The EfW assets included in this analysis are all operational (60) and under construction / commissioned (16) assets included in the UK Energy from Waste Statistics – 2023 plus the addition of two planned assets (Redcar and Tees Valley ERF) due to their applications to Track 1 cluster sequencing.	• It is not guaranteed that EfW all assets commissioned or planned will become operational, and it is likely that some operational assets may be decommissioned in future. • Non-operational assets (as of the year 2023) included in this analysis represent 5 $MtCO_2$ captured and stored (26% of total for all assets) distributed across each of the four stages.
Snapshot Analysis	• The analysis considers a snapshot of EfW processing capacities and biogenic content as recorded in 2023 or otherwise announced. It was not within the scope of this work to estimate how processing capacities or biogenic content might change over time.	• The future processing capacities of EfWs and biogenic content of residual is uncertain, dependent on population growth and a range of behavioural and policy factors. For example, the CCC (CCC 2020, Sixth Carbon Budget: Local Authorities and the Sixth Carbon Budget) estimates residual waste per person could reduce by 25% from 2025 to 2050. • Most* CCC scenarios (CCC 2020, Sixth Carbon Budget) show between 6.7 – 8.9 Mt fossil CO_2 being captured by EfW facilities in 2050 (compared to 9.2 $MtCO_2$ calculated in this study) so **values could be 4-27% lower than shown** if factoring in such changes. • * the one exception is the Widespread Engagement scenario where 70% residual waste in 2050 is diverted to jet fuel production. However, the CCC notes that GHG savings from this route are unlikely to be significantly higher than EfW with CCS (CCC 2020, Sixth Carbon Budget: Waste).
Greenhouse Gas Removals (GGR)	• The analysis quantifies biogenic CO_2 captured and stored, with these quantities compared to UK GGR targets and considered as possible offset potential for grid decarbonisation. • Wider emissions from EfWs or CCS installations have not been deducted from this value (e.g., residual fossil emissions, electricity used, CO_2 leakage from pipelines, embedded emissions in capture chemicals and the CCS plant). • This is in alignment with the calculation approach taken by the CCC in which GGRs are presented as a separate sector.	• This approach was taken to align with the methodology of the CCC in which GGRs are presented as a separate sector, and on which government targets may have been based (exact accounting of government targets unknown). • However, carbon crediting standards use methodologies that consider a full lifecycle basis, and therefore net GGR volumes calculated by these standards will be lower than that shown – this is important to note if GGRs were to be sold on such markets. The assessment of lifecycle emissions was however not in scope for this study. • A gross GGR estimation (deducting residual Scope 1 fossil emissions of the EfW asset from total biogenic CO_2 captured) could be more in line with the carbon accounting approach used by the UK Emission Trading Scheme (ETS), which only recognise direct (scope 1) emissions of installations. Adopting this methodology would **reduce estimates by approximately 9.5%** to account for incomplete capture.
Grid Decarbonisation	• It was not within the scope of this study to evaluate UK grid decarbonisation. The estimate of residual emissions on the UK electricity grid is taken from AFRY 2023, Net Zero Power and Hydrogen: Capacity central scenario, a study developed for the CCC.	• There is high uncertainty of what the UK grid could look like in 2035, and the referenced study does not necessarily reflect the latest government announcements. However, this study was chosen as the most up-to-date CCC aligned reference for what a decarbonised power grid might look like with ambitious deployment. • It is noted that even using the high scenario from the ARFY study, the biogenic CO_2 captured from Stage 1+2 EfW assets would still be enough to balance total power sector emissions in 2035 (6 $MtCO_2$). • In contrast, the government's latest energy and emissions projections (March 2023, EEP) reflecting expected impacts of "all EEP ready" policies (i.e. those already implemented or those where funding is agreed with policy design near final) estimates that **in 2035 the UK power sector would emit 19 $MtCO_{2e}$**. This is **four times the emissions of the AFRY central scenario**, meaning EfW would only balance 33% of these emissions.
CAPEX and OPEX	• CAPEX is estimated based on AECOM 2022, Next Generation Carbon Capture Technology (WP6) with scaling factors applied to account for inflation, economies of scale, and optimism bias. • Cost analysis was conducted without assumptions on deployment timelines and therefore technology learning rates were not applied.	• The AECOM analysis represents a Class IV estimate, and this has been applied on a generalised basis using scaling factors to the EfW assets analysed. Given the lack of real project data available for CCS on EfW and the lack of detailed site-specific analysis, costs should be treated as high uncertainty (e.g., minimum +/- 50%). • Learning rates may reduce costs for later CCS deployments and smaller EfW assets may be able to benefit from the development of modular solutions that also reduce costs. Such future cost developments have not been factored into the CAPEX and OPEX estimates. However, equally, first-of-a-kind projects may face additional barriers that may increase costs over those estimated.
Economic Impacts	• Jobs and GVA figures are estimated based on high-level breakdown of project costs into Standard Industry Classification (SIC) codes and using ONS input-output tables and import ratios for economic impact.	• The results carry inherent uncertainties as national averages are used for projects that may cluster around specific regions in the UK. Furthermore, domestic spending of project costs for early-stage projects may be much different than imports of the wider economy. Furthermore, although average wages have been inflation adjusted, uneven wage growth across sectors may influence the results. More detailed project specific analysis is needed to improve the accuracy of these estimations.

Appendix: Defining the four stages via multicriteria assessment

The stages of opportunity for EfW-CCS in the UK are explored through a multi-criteria assessment prioritisation



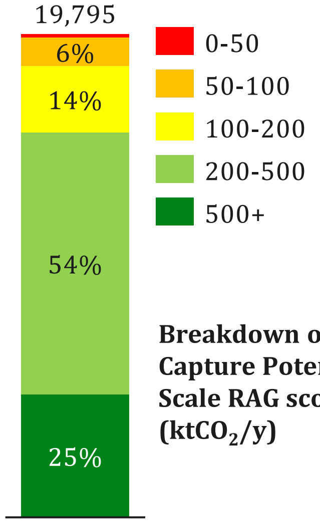
- CCS uptake will be influenced by the **operational date of the nearest cluster, the total cost, the distance to the nearest cluster, and the scale of EfW site**.
- The **cost of CCS characterizes both the distance to the store and the EfW site scale**, as these affect both the CAPEX and CO_2 transport and storage (T&S) costs.
- The multicriteria assessment (MCA) scores each asset on the four metrics from best (5 – green) to worse (1 – red), these score bands are detailed in the following slides.
- Taking the mathematical average on the fours scores, and rounding to the nearest integer, gives a final priority score that was used to inform the stages of opportunity as below:
  - Stage 1: average score of 5
  - Stage 2: average score of 4
  - Stage 3: average score of 3
  - Stage 4: average score of 2 or 1
- **Small-scale sites (<50 kt) are further deprioritised based on being unlikely to achieve R1 status** and therefore are unable to benefit from government's CCUS business models.

The annual CO_2 capture potential of UK EfW assets ranges from <50 ktCO_2 to 900 ktCO_2 impacting the economic viability of CCS

Early-stage opportunities for CCS on EfW are expected to centre around assets with higher processing capacities due to the economies of scale associated with CO_2 capture giving these assets a better business case.

UK EfW assets ordered by maximum CO_2 capture potential[1,4]:

- Economies of scale make carbon capture more challenging for smaller assets. The average scale of commercial CCS facilities operational in 2023 was 1.2 MtCO_2/y[2], with economies of scale making smaller scale capture more expensive on a per tonne of CO_2 basis. Pipeline transport is also more cost effective for larger volumes of CO_2[4].
- For the range of capacities seen in the EfW sector, it is estimated that CAPEX costs could range from £70/tCO_2 to over £300/tCO_2 dependent on scale, highlighting the benefit of larger assets[4].
- However, advancing developments in modular and small carbon capture could reduce the impact of scale on capture costs. Just one example, SLB Capturi is developing modular solutions for 40-400 ktCO_2/y.[3]
- Smaller assets may also face additional challenges to installing CCS. For example, greater constraints related to the space needed for the capture equipment and pipework, or due to environmental permitting requirements.



Breakdown of CO_2 Capture Potential by Scale RAG score[4] (ktCO_2/y)

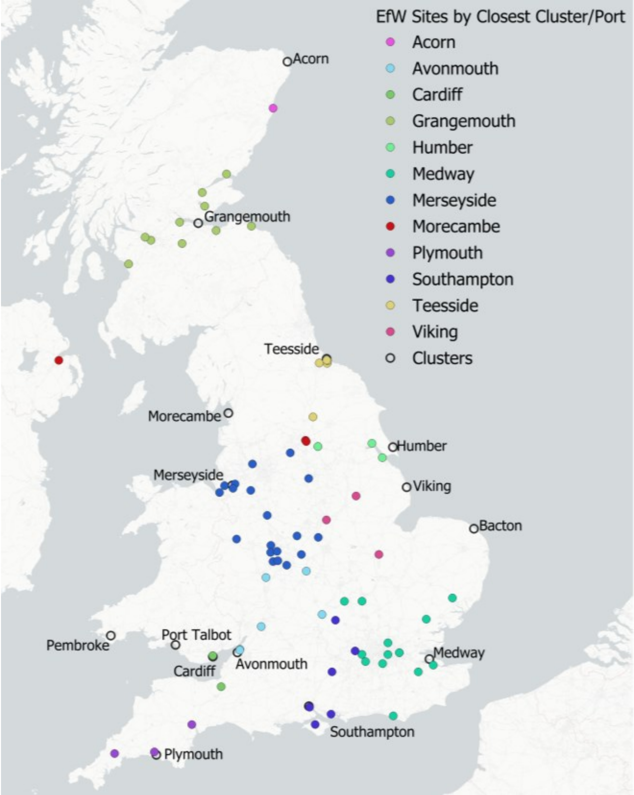
Scale MCA Score	Scale (ktCO_2/y)	# Assets
(red)	0 – 50	5
(orange)	50 – 100	15
(yellow)	100 – 200	17
(light green)	200 – 500	33
(dark green)	500 +	8

Scale bands were chosen to facilitate analysis. A distinction was made at 200 ktCO_2 to separate small-scale capture (likely to use emerging modular solutions) from more standard capture scales that might use conventional approaches. The smaller scale category was further disaggregated with a distinction at 100 ktCO_2 and the lowest score given for assets < 50 ktCO_2 due to their lack of R1 status. A distinction was made for the few assets > 500 ktCO_2 to reflect the benefits offered from economies of scale.

1 - Based on data within Tolvik 2024, UK Energy from Waste Statistics – 2023 assuming 90% CO_2 captured.
2 - GCCSI 2024, Global Status of CCS 2023 – 2023 had 41 operational commercial facilities with a total capture capacity of 49 Mtpa.
3 - Just Catch™ | SLB Capturi.
4 - ERM analysis for this study.

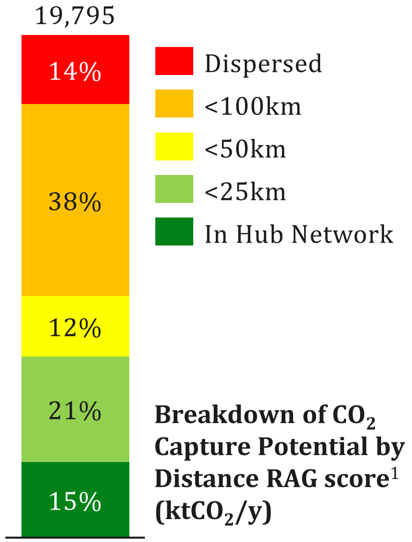
EfW assets are widespread across the UK, covering both industrial clusters and dispersed across in-land regions

EfW assets that are closer to a CO_2 hub are expected to face fewer barriers to CO_2 transport, with potential to connect via shorter or shared pipelines to a CO_2 storage or CO_2 shipping hub.



UK EfW assets ordered distance to potential shoreline CO_2 hub[1]:

- The UK's adopted approach to CO_2 transport and storage is around CO_2 hubs that can aggregate captured CO_2 using shared infrastructure before transporting it to offshore CO_2 storage sites in the North Sea and Irish Sea. Currently the focus is on major industrial clusters as hubs, but it is expected that other hubs may emerge over time (e.g., at ports).
- EfW assets that are strategically located within these hubs may be able to readily connect into a shared CO_2 transport network, bringing benefits such as economies of scale and government support (e.g., regulated asset base transport model[2]). EfW assets that are further from a hub will need to arrange for transport of their CO_2. This could be via a dedicated pipeline, via rail, or possibly via trucking.
- Pipeline transport is expected to be favoured from a logistics perspective as it avoids the need to liquefy and temporarily store the CO_2. Sites in closer proximity to a CO_2 hub and with larger volumes are more likely to be able to use a dedicated pipeline transport solution. For dispersed or small-scale sites, pipelines are expected to be too expensive, with rail or truck potentially offering lower costs. However, the additional traffic associated with trucking makes is less preferable.



Breakdown of CO_2 Capture Potential by Distance RAG score[1] ($ktCO_2/y$)

Distance MCA Score	Distance to CO_2 Hub	# Assets
(red)	Dispersed (>100km)	13
(orange)	<100km	33
(yellow)	<50km	9
(light green)	<25km	17
(dark green)	In Hub Network	6

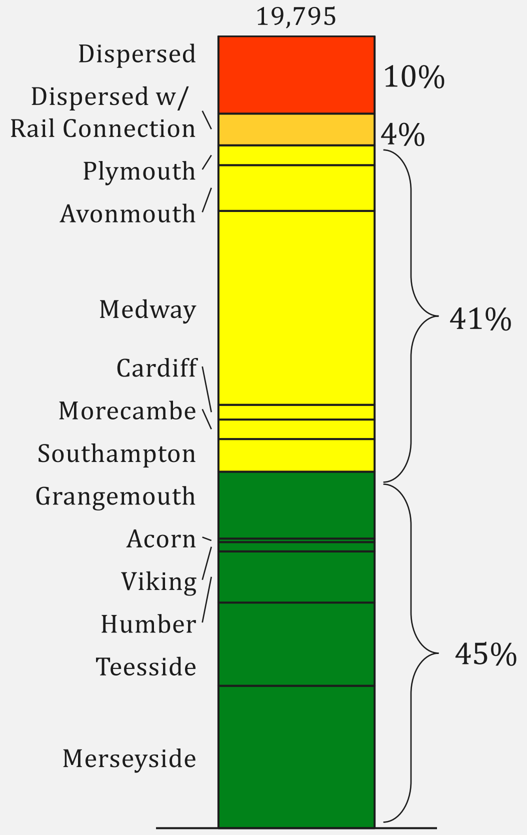
1 - ERM analysis for this study.
2 - DESNZ 2023, CCUS: a vision to establish a competitive market
* Excludes Shetland and Belfast facilities, both of which are over 200km from a storage site

The UK government has defined priority hubs for CO_2 transport & storage development, with associated funding for capture projects

Near-term CCS projects in the UK are expected to focus on those with pipeline connections to prioritised clusters, scheduled for operation by 2030. Subsequent phases could see support for CO_2 shipping to these clusters or wider storage developments.

- The UK government prioritised four industrial clusters with access to offshore storage to be developed by 2030 and receive UK government funding support.[1] Through its cluster sequencing process, the UK government is inviting CCS projects able to connect to these clusters via pipeline to apply for financial support in the form of 'CCS Business Models'.[2]
- EfW assets within close-proximity to these prioritised CO_2 hubs (or able to connect via a dedicated pipeline) may be eligible for this support, therefore driving them to make early progress on adopting CCS to benefit from such support (which may be time limited).
- In addition, the UK government is developing plans to support non-pipeline connections to these prioritised clusters, such as via CO_2 shipping or road / rail transport.[3] Such funding proposals are still under development, but several UK ports are already exploring opportunities for CO_2 shipping.
- It is expected that further CO_2 hubs and offshore storage sites will develop over time once the concept has been proven by the prioritised clusters.
- Dispersed sites are unlikely to benefit from CO_2 hubs in the near-term due to challenges in connecting to them. This may change as business models or capture technologies develop.

Breakdown of CO_2 Capture Potential by Hub Type RAG score[1] ($ktCO_2/y$)



The UK government has prioritised HyNet (Merseyside) and the East Coast Cluster (Teesside, Humber) as Track 1 clusters for development by 2027[1]. The Acorn (Grangemouth, Acorn) and Viking CCS (Viking) were identified as Track 2 clusters for development by 2030[1].

Hub	UK Gov. Priority Hub	Local Storage Plans	Port	MCA Score
Merseyside	✓	✓	✓	
Teesside	✓	✓	✓	
Humber	✓	✓	✓	
Viking	✓	✓	✓	
Acorn	✓	✓	✓	
Grangemouth	✓	✓	✓	
Southampton		✓	✓	
Morecambe		✓	✓	
Bacton		✓	✓	
Cardiff			✓	
Medway			✓	
Avonmouth			✓	
Plymouth			✓	
Belfast			✓	
Dispersed – rail accessible				
Dispersed – without rail				

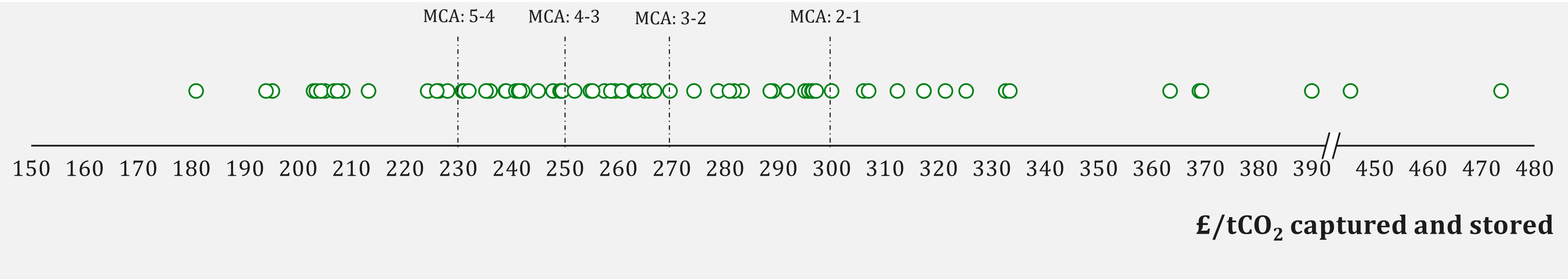
1 - DESNZ 2023, CCUS: a vision to establish a competitive market
2 – DESNZ 2023, CCUS: Industrial Carbon Capture Business Models.
3 – DESNZ 2024, Call for Evidence - CCUS: non-pipeline transport and cross-border CO2 networks.
4 – ERM analysis for this study.

ERM

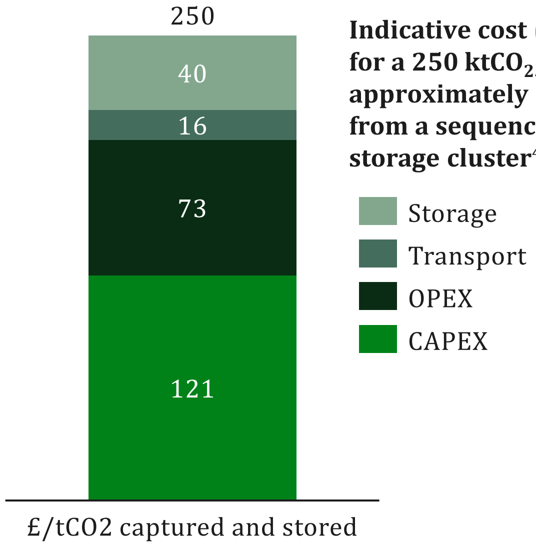
CCS costs per tonne CO_2 stored range considerably dependent on asset scale and location, with costs of £180/tCO_2 expected as a minimum

With future revenues expected from sale of CDR credits, the UK ETS, and possible sale of CO_2 for utilisation, the long-term business case for installation of carbon capture is dependent on a competitive cost per tonne CO_2.

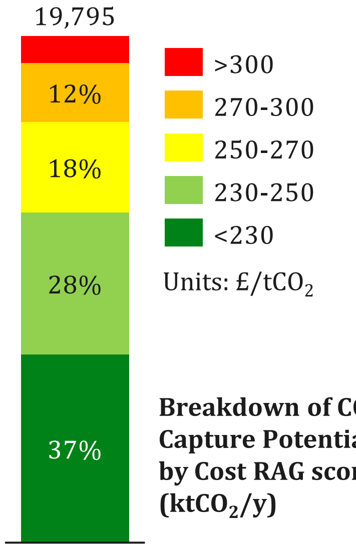
UK EfW assets ordered by estimated cost of carbon capture and storage[4]:



Indicative cost (£/tCO_2) for a 250 $ktCO_2$/y facility approximately 60km from a sequenced storage cluster[4]



- Costs for CO_2 capture, transport and storage are dependent on many factors including the volume and purity of CO_2 captured, the capture technology chosen, energy prices, the transportation method, the distance to the CO_2 hub and the hubs storage fees. Typically, larger sites in closer proximity to a CO_2 hub will have lower costs of CCS per tonne of CO_2 captured and stored.
- The costs per tonne of CO_2 are important as most revenues or benefits are expected to be incurred on a per tonne CO_2 basis. For example, avoiding the UK ETS costs, generating carbon dioxide removal (CDR) credits which could be sold on voluntary carbon markets (VCM), or selling the captured CO_2 directly for utilisation.
- In 2022, the UK ETS had an annual average price of £80/tCO_2[1]. This price is estimated to rise to £95-172/tCO_2 by 2050[1]. Therefore, additional measures such as increased pricing or additional revenue streams (such as sale of credits on VCM) will be needed to incentivise EfW with CCS projects.
- The sale price of CDR credits on VCM is highly uncertain. A recent study[2] assumed engineered CDRs could achieve prices of \$200-300/tCO_2 by 2030 and \$150-250/tCO_2 by 2050, whereas a market survey[3] showed that 58% of participants expected to pay \$100-\$250 per credit in 2030 and 2050.



Breakdown of CO_2 Capture Potential by Cost RAG score[4] ($ktCO_2$/y)

Cost RAG Score	Cost of CCS (£/tCO_2)	# Assets
(red)	>300	16
(orange)	270-300	15
(yellow)	250-270	15
(light green)	230-250	17
(dark green)	<230	15

Scale bands were chosen to facilitate analysis with distinctions chosen to distribute number of facilities approximately evenly across the bands (based on quartile analysis).

1 - DESNZ 2023, Traded carbon values used for modelling purposes
2 – BCG 2023, The time for carbon removal has come
3 - CDR.fyi 2024, 2024+ Market Outlook Summary Report
4 – ERM analysis for this study.

Appendix: CCS on EfW cost analysis and economic impacts

The carbon capture cost analysis methodology utilises scaling factors to determine the capture cost

Capture costs are based on **AECOM cost data for CCS on EfW, for BEIS** (2022).[1] The cost data assumes the use of an advanced amine **solvent capture technology,** as it is expected that such technologies will be available to most EfW plants deploying CCS in the medium-long term.

Since 2022 significant construction cost increases have been seen across industries, to reflect this we take proxies from the offshore wind and electrolyser sectors to implement a **60% price increase on CAPEX** costs and **10% on OPEX** costs.[2,3,4]

To account for the likely optimism bias in the AECOM data, which is based in a generic Class IV estimate and therefore does not represent a granular / site-specific cost basis, **CAPEX is expanded by 66% in line with Government optimism bias guidelines**.[5,6]

These technology costs are used to represent all deployment in the coming decades. N**o cost reduction from learnings are included** as the temporal nature of deployment does not drive the "stages" of development.

Costs are provided for a **350,000 t-waste/y plant**, and we use a **0.67 scaling factor** to adjust CAPEX for other sites.[7]

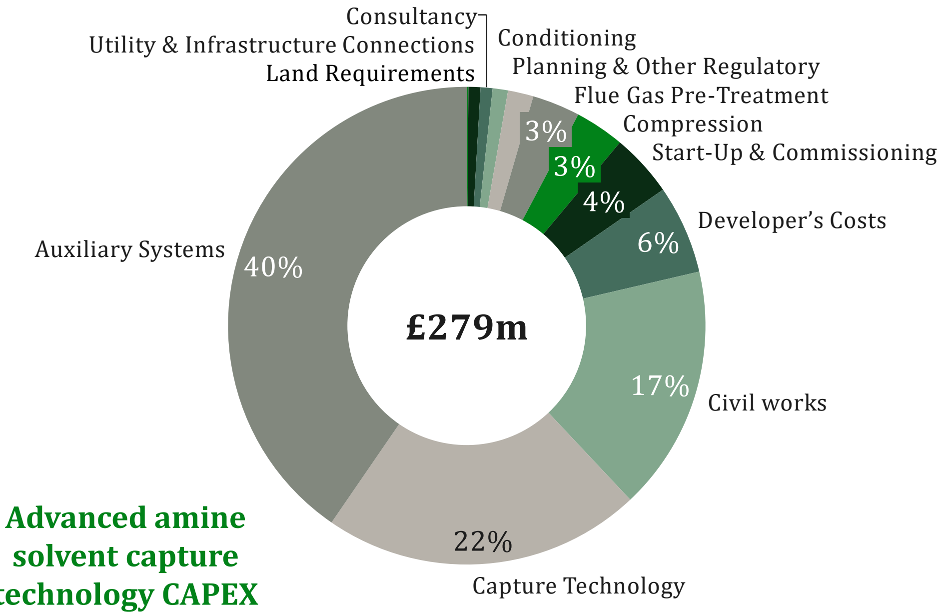
Steam and electricity for the capture process is taken from the EfW output, as per the AECOM analysis[1].

The analysis assumes an asset **lifetime of 25 years**[1]**, a 95% capture rate**[1]**, and assumes a 95% availability** of the capture unit at times of EfW operation – based on current technology developer guarantees for mature technologies and the ability to align planned maintenance with downtime for the EfW facility.

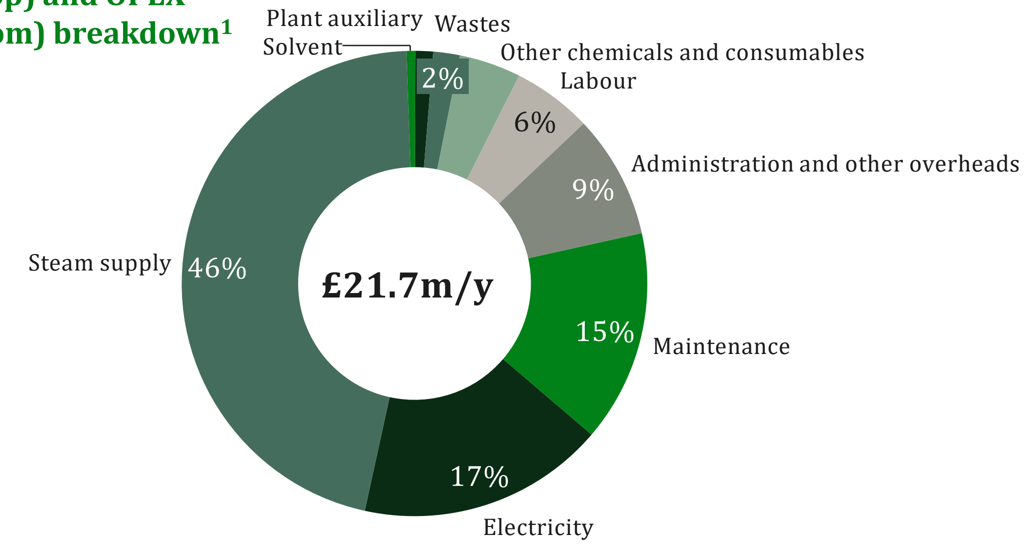
No additional EPC mark-up is included, although this can represent a substantial percentage of development costs, and the temporal nature of investment over the project development cycle is not included. **All values are in £2024**.

The CAPEX estimates do not include project returns. Project returns are only included in the levelized cost of abatement through a **10% hurdle rate**.

The cost analysis does not directly consider the potential revenue streams (e.g., CDR) and cost savings (e.g., ETS) associated with CCS deployment.



Advanced amine solvent capture technology CAPEX (top) and OPEX (bottom) breakdown[1]



1 - Next generation carbon capture technology: technoeconomic analysis – AECOM for BEIS. 2 - Energy-UK-AR6-Briefing-February-2024.pdf. 3 - Hydrogen Insights December 2023. 4 - Cost of electrolysers for green hydrogen production is rising instead of falling | Hydrogen Insight. 5 – Green Book optimism bias. 6 - Optimism Bias Study. 7 - Technology Readiness and Costs for CCS – GCCSI 2021.

The CO_2 transport and storage cost analysis methodology combines a range of datasets and models

For **transport and storage**, sites choose between pipeline, rail, or trucking to the nearest hub depending on the location of the site.

- **Sites up to a direct distance of 100 km from a hub consider pipeline options**, this is supported by examples such as RWE Staythorpe and Drax, as is seen as a conservative constraint.
- **Sites within 1 km of an existing rail network consider the potential for a rail connection** option.
- **All sites consider the potential for trucking**.

To convert from direct distance to the likely distance covered by each transport modality scaling factors are used (see table).

Sites connecting to hubs/ports without storage potential then utilise CO_2 shipping to their nearest Track 2 cluster, as these are explicitly obliged to accept NPT CO_2.[1] EfW emissions are aggregated to give more realistic shipping costs, and in South Wales Mt-scale CO_2 shipping is assumed based on the SWIC cluster plans.

Transport Modality	Travelled length to direct distance ratio [3]
Pipeline	2.0
Road	1.5
Rail	1.5

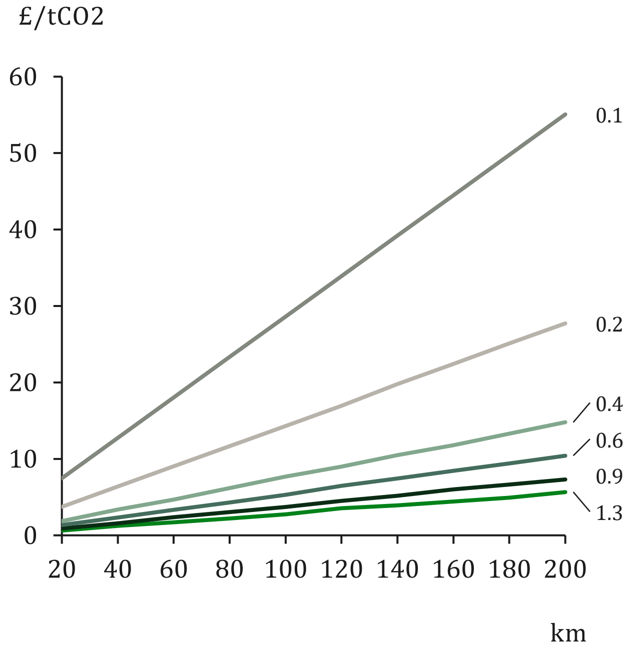
<u>**Data/Model Sources:**</u>

- **Pipeline:** National Energy Technology Laboratory (NETL) CO_2 Transport Cost Model (2023)[2]
- **Shipping:** ERM CO_2 Shipping Cost Model, originally developed for IEAGHG (2020)[3]
- **Trucking:** ERM CCS and Dispersed Industrial Sites Model, originally developed for BEIS (2020)[4]
- **Rail:** Freight transport costs are derived from national averages (5.8p/t-km) with CO_2 specific cost components (compression, storage etc.) from the ERM CCS and Dispersed Industrial Sites Model, originally developed for BEIS (2020)[4,5,6]
- **Storage:** Indicative cluster storage fee of £40/tCO_2, from Xodus analysis of UK and EU storage projects (2022)[7]

1 - Cluster Sequencing for CCUS: Track-2 guidance. 2 - FECM/NETL CO2 Transport Cost Model (2023): Description and User's Manual. 3 - New IEAGHG Report: The Status and Challenges of CO2 Shipping Infrastructures - IEAGHG. 4 - CCUS deployment at dispersed sites. 5 - Rail industry finance –2022 to 2023. 6 - Freight rail usage and performance 2023. 7 - Xodus Public Report.

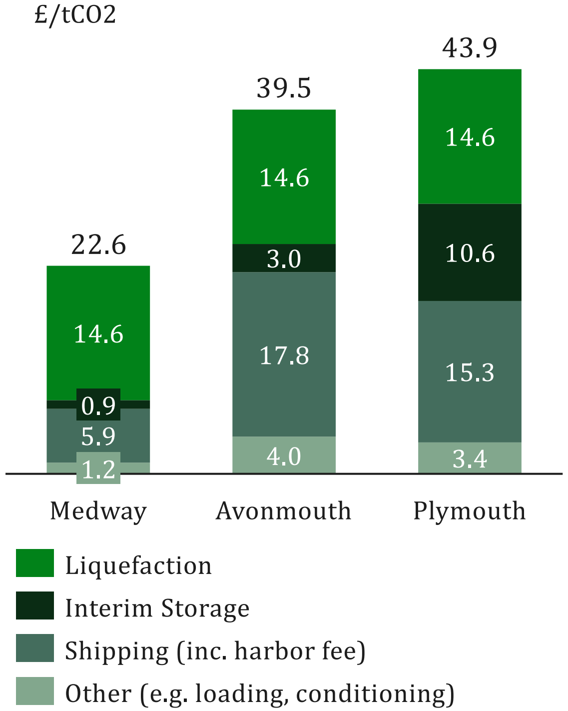
Transport cost breakdowns show the major cost components related to each transport methodology

Pipeline



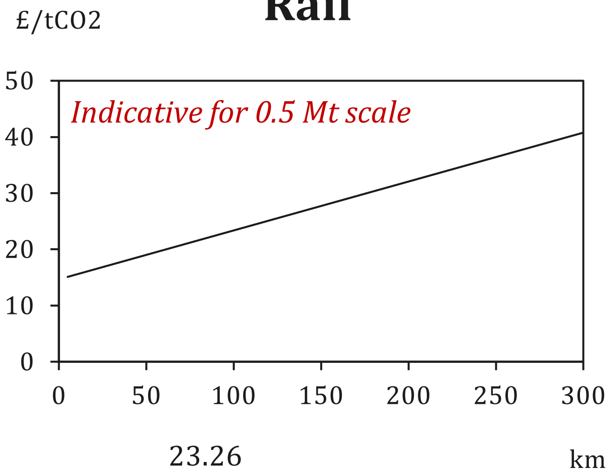
Pipeline CAPEX (y-axis) varies substantially with the distance to the terminal (x-axis) and the flow rate (labelled for each line in $MtCO_2/y$).

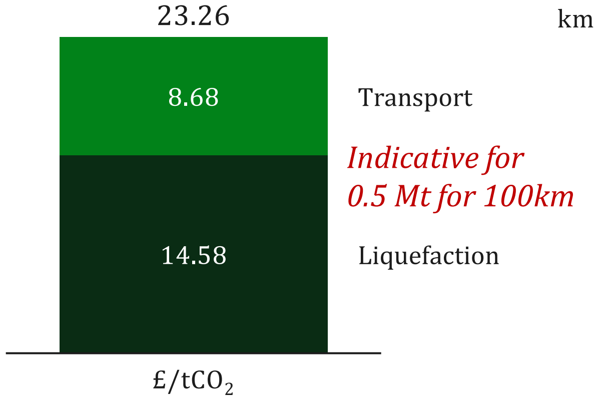
Shipping



For shipping costs, we assume ships from Medway travel to the Viking storage in Humber, and that both Avonmouth and Plymouth ship to Grangemouth, to connect into the Acorn/Scottish Cluster storage.

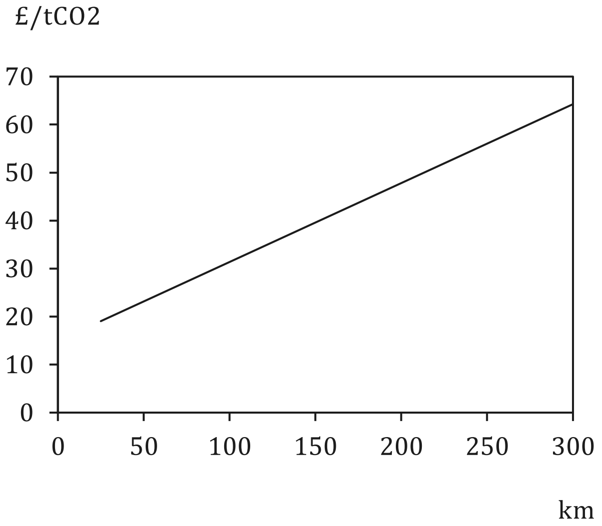
Rail





Rail transport has fixed costs for liquefaction, loading and regasification (£14.58/tCO_2) and an additional cost per km travelled (£0.06/km).

Trucking



Trucking has a fixed fee (£14.58/tCO_2) for liquefaction, storage, loading and regasification combined with an additional cost per km travelled (£0.16/km).

Methodology for estimating the GVA and jobs impacts of EfW CCS

The macroeconomic impact of CCS deployment is modelled by calculating sectoral investment profiles and applying the UK's input-output multipliers

The following steps were taken in this study to estimate the macroeconomic impact of CCS activities in the EfW sector:

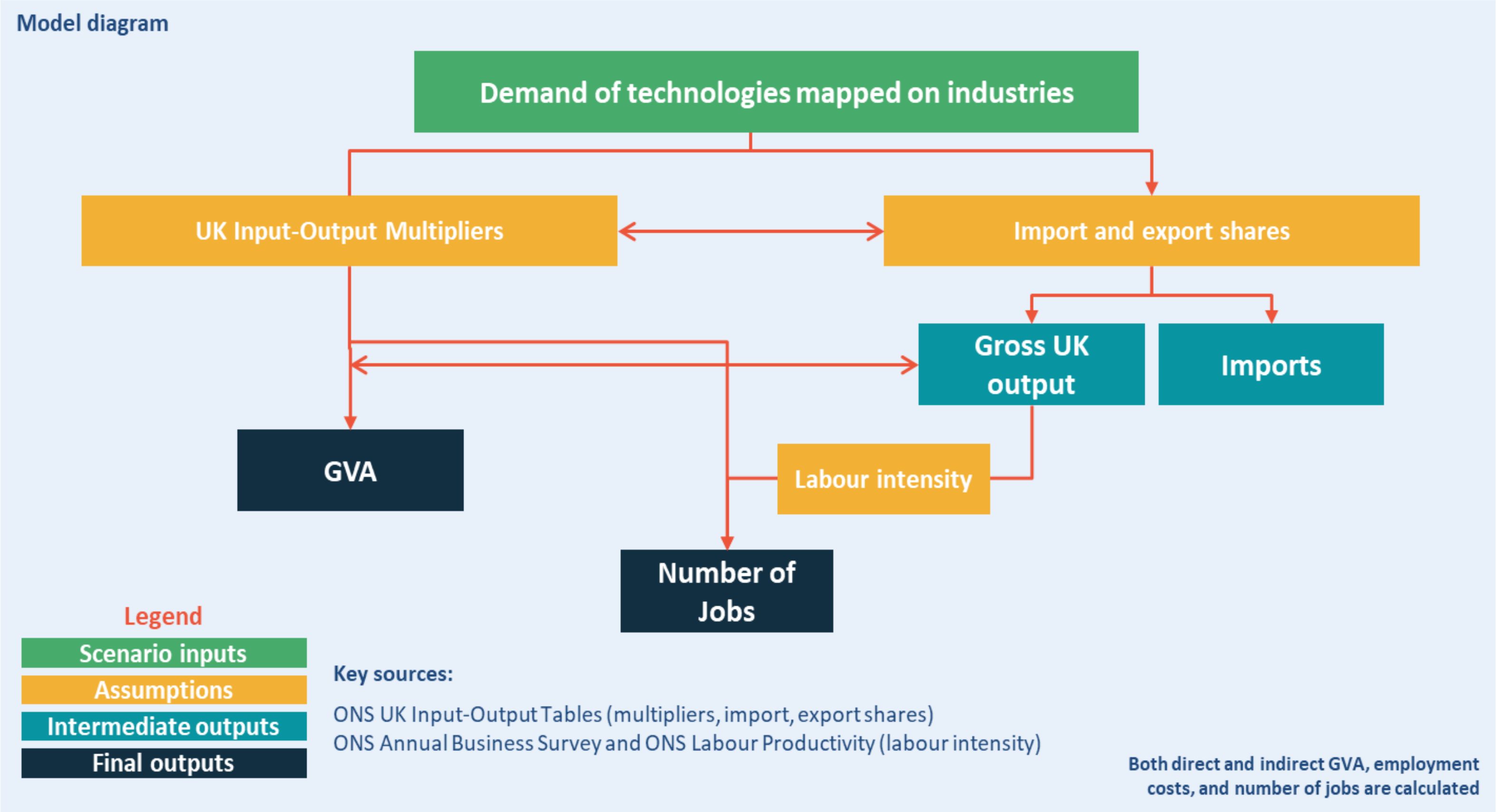
1. **Investment requirements** for each EfW plant, including Capex and Opex of carbon capture and CO_2 transport & storage, are broken down into Standard Industrial Classification (SIC) codes.
2. **Economic impacts, such as GVA and job creation**, are calculated from the investment figures by UK input-output tables and various business surveys produced by the Office of National Statistics (ONS).

The chart on the right illustrates this process at a high-level.

All plants are assumed to operate for 26 years. Figures are provided in 2024 GBP. Loss of revenue from curtailed energy export is not included in the analysis.

Jobs for the "construction" stage are provided as person-year. In reality, these would be spread over a period of development and construction time.

This is only a very high-level estimation of economic benefits treating plants mostly the same. Individual projects are expected to have different jobs and GVA impact depending on supply-chains and other circumstances.



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