TEES VALLEY

Tees Valley Net Zero

Cluster Plan Full Report

Issue: Final Full Report 27.07.23

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Layout of the Report

This report is presented in 5 sections:

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- Theme 1: Decarbonisation in the Tees Valley Industrial Cluster
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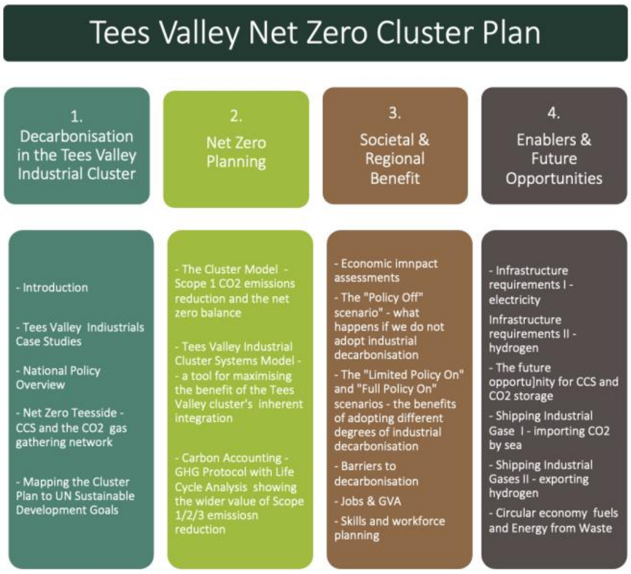
- Theme 4: Enablers & Future Opportunities

The structure of the Cluster Plan is shown with graphically in the first section:



This graphic is also used as the key for the following sections which describe the separate Themes in the Cluster Plan:

Theme 1:
Decarbonisation in the Tees Valley Industrial Cluster

Theme 2:
Net Zero Planning

Theme 3:
Societal & Regional Benefit

Theme 4:
Enablers & Future Opportunities

Description of the Project

1 Foreword

This is the full report for the Tees Valley Net Zero Cluster Plan project. The project that has been carried out as part of the Industrial Decarbonisation Challenge which is run by Innovate UK on behalf of the Department for Energy Security and Net Zero.

The principal aim of the project has been to provide the roadmap to create a low-Carbon industrial cluster in the Tees Valley by 2030 and reach Net Zero by 2040. This was initially conceived as decarbonisation by reducing Scope 1 CO2 emissions. However, the project evolved to take in a wide range of industrial decarbonisation projects.

The project has been completed by three organisations working in collaboration – bp, the North East Process Industries Consortium (NEPIC) and Tees Valley Combined Authority (TVCA).

Readers are encouraged to look at our Key Findings document, which summarises the work reported in this document in a readily accessible format. Our concept for the Key Findings was that it should be more than an executive summary. It gives a good depth of understanding of the Cluster Plan backed by relevant data; information on the COC2 abatement opportunity; the economic opportunity; and the actions and timeline to achieve Net Zero.

The Key Findings document is available at:

https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/03/Net-Zero-TV-Key-Findings-Document-8.pdf

The Cluster Plan has been developed from a series of underlying reports which describe the key themes:

(i) Decarbonisation in the Tees Valley Industrial Cluster

(ii) Net Zero Planning

(iii) Societal & Regional benefit

(iv) Enablers and Future Opportunities

Each of these themes is developed from a number of supporting reports. In this full report, we reference each of the supporting reports and provide a description of its content and meaning for the Cluster Plan.

Addendum

Recent developments at CF Fertilisers since the analysis was completed suggest that the recommissioning of the Ammonia plant might be under consideration and therefore its' emissions may not be available for capture. This possibility is mentioned within the report but should be born in mind when looking at the analysis.

2 Key Project Names & Glossary

Tees Valley Net Zero (TVNZ)	This is the Cluster Plan project that we are reporting on in this document. It is the work to develop the roadmap to Net Zero 2040 in the Tees Valley industrial cluster. The Tees Valley Net Zero project has been completed by bp, NEPIC (the North East Process Industry Cluster) and TVCA(the Tees Valley Combined Authority).
Net Zero Teesside (NZT)	This is the project to develop the Carbon Capture and Storage system for the Tees Valley industrial cluster. It will comprise a power station with carbon capture, the CO_2 gas gathering network and pipeline to the Endurance store.
NZT Power	This will be the world's first commercial scale gas-fired power station with carbon capture and will serve as the anchor project at Teesside that will connect into the CO_2 transportation and storage infrastructure being developed by the Northern Endurance Partnership.
Northern Endurance Partnership (NEP)	This is the CO_2 transportation and storage company (T&S Co) which will deliver the onshore and offshore infrastructure needed to transport CO2 from a range of emitters across Teesside and the Humber to offshore storage, starting with the Endurance store under the southern North Sea.
East Coast Cluster (ECC)	Net Zero Teesside (NZT) and Zero Carbon Humber (ZCH) together form the East Coast Cluster, enabled by the Northern Endurance Partnership CO2 transportation and storage infrastructure. It is the CO_2 Transportation and Storage company for the Tees Valley and Humber industrial clusters. Now selected as one of the first two carbon capture, usage and storage clusters to be taken forward by the UK government

The Tees Valley region covers the 5 local authority regions of Darlington; Stockton-on-Tees; Middlesbrough; Redcar & Cleveland; Hartlepool

Occasionally in this report and in the supporting reports from our sub-consultants, reference is made to 'Teesside'. Formally, 'Teesside' refers to the 3 local authority areas that have banks on the river Tees – i.e., Stockton-on-Tees; Middlesbrough; Redcar & Cleveland. However, for the purposes of this report, 'Tees Valley' and 'Teesside' should be considered as synonymous.

3 Introduction

The Tees Valley region is the leading location in the UK for developing a decarbonised industrial cluster.

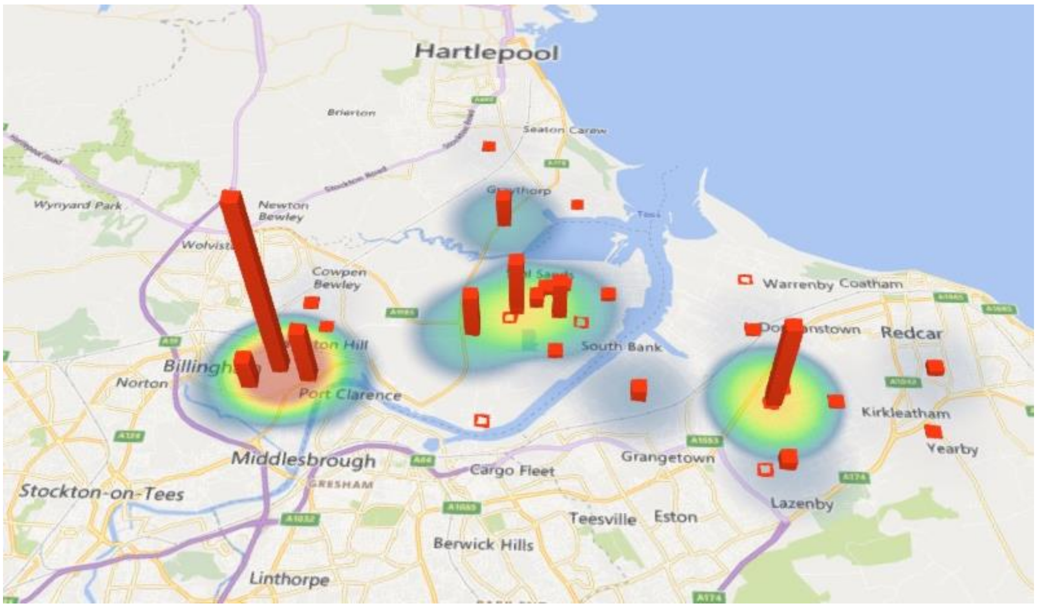
Historically the CO2 emissions in the Cluster have been very high – circa 14 MtCO2/yr in 2008 – due to the Teesside Integrated Iron & Steel works. After a period of uncertainty this finally closed in 2016 and this was key in the reduction of regional CO2 emissions reduction to the 4.5 MtCO2/yr we see today. However, this represents de-industrialisation, not decarbonisation as that steel is still made elsewhere in the world – the CO2 emissions have been "offshored".

The Tees Valley has a unique set of attributes to enable a decarbonised industrial cluster:

- The legacy of the world's first integrated chemical works, opened by ICI in 1947. This spans Teesside and although ICI no longer operates in the region, the infrastructure, facilities and many of the industries remain and are in operation today.
- The legacy of the steelworks – now redeveloped as Teesworks. This is a very large brownfield site which will be developed for many new decarbonised industries: CCUS, CCGT power station + CCS; blue and green hydrogen production; energy from waste; biofuels; lithium refining; and others.
  - Deep water port and access to the North Sea – this currently serves the chemical industry in the cluster. In the future this will enable the import and export of industrial gases such as CO_2 (potential future import for long-term storage helping to decarbonise other regions and countries) and hydrogen (which in the future will be exported as a fuel to decarbonise industry, transport and domestic heating across the UK and beyond)
  - The Teesside Freeport provides investment incentives, and tax-efficient import of goods for manufacture on Teesside and export of finished products.
- CATS pipeline coming onshore in the region supplying 26% of the UKs natural gas and the future feedstock for blue hydrogen production.
- Onshore landing for the new offshore windfarms: Dogger Bank C and Sofia, which will generate 2.6 GW of renewable electricity between them, and the existing EDF Teesside windfarm. These have the potential to power the new green hydrogen production on Teesside.
- A nuclear power station and nuclear licensed site adjacent to the industrial cluster at Hartlepool with the potential to deliver power and heat directly to the cluster.
- A tightly packed industrial cluster with around 66 industries within a 5-mile radius.
- Existing hydrogen production, pipeline network and storage caverns.
- Existing railheads and quays to enable non-pipeline transport of industrial gases (CO2 and H2) into and out of the cluster.
- A history of planning for CCUS through the One North East and Teesside Collective projects
- Government selection of key Carbon Capture and Storage projects, including the bp-led Northern Endurance Partnership, Net Zero Teesside Power and H2Teesside Projects, and BOC's Teesside Hydrogen CO2 Capture project as one of two Track 1 clusters nationwide.

The opportunity to unite these attributes into a coherent roadmap for a decarbonised industrial cluster is described in the Tees Valley Cluster Plan. It provides the roadmap to delivering a low-carbon cluster by 2030; and to achieving Net Zero in the industrial cluster by 2040.

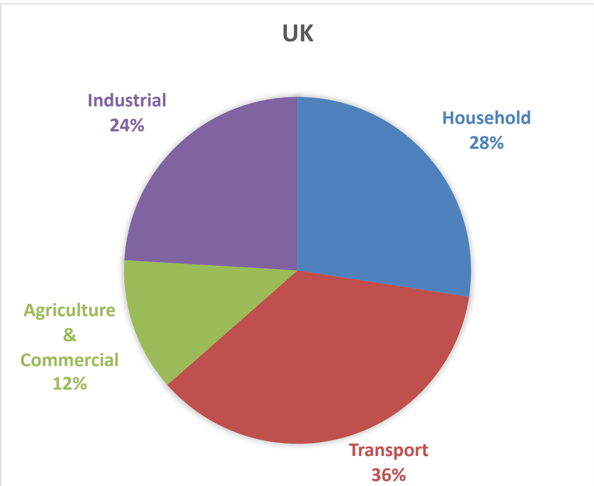
The plot shows CO_2 emissions in the Tees Valley industrial cluster taken from the NAEI 2020 data. This shows how the industrial cluster is currently centred around three main locations – Billingham, North Tees and Wilton.

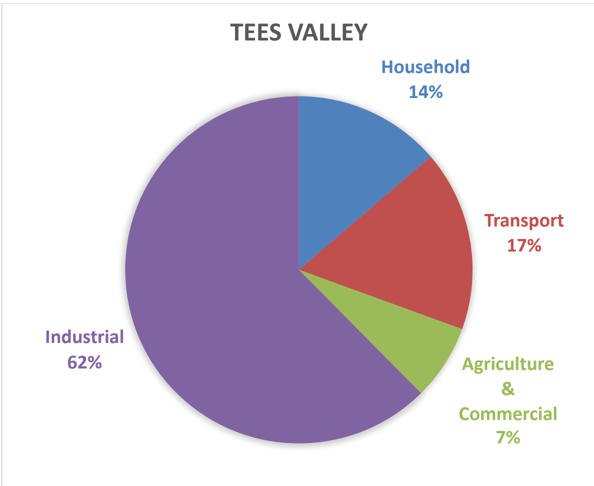


The Cluster Plan recognises that deep decarbonisation is not just the remit of a select few companies. Many industries in the Tees Valley will have an impact on decarbonisation and we worked with 46 separate industrials to develop the plan. Of these, 31 were able to provide detailed data on their operations, emissions and decarbonisation planning. Together these have provided a highly detailed data set for the cluster which we have leveraged for our decarbonisation planning.

This shows a high level of engagement across the industries in our cluster, which recognises the cluster's widely held commitment to Net Zero; and also, the sense of community in the Tees Valley industrial cluster.

In the journey to Net Zero, decarbonising industry is key to decarbonising the Tees Valley as a whole. Across the UK, 24% of total CO_2 emissions are due to industry – locally in the Tees Valley industry accounts for a much greater proportion of the total - 64% of the total CO_2 emissions. In the Tees Valley there are 6.40 tCO_2/yr emitted per person compared with the national average of 1.24 tCO_2/yr. This demonstrates the importance of industrial decarbonisation to the Tees Valley.





4 Delivery and Governance

4.1 Project Partners

The Tees Valley Cluster Plan project has been completed in collaboration between three partners each bringing valuable attributes to the work:

- bp – the leading industrial company developing CCUS, blue hydrogen and green hydrogen projects on Teesside.
- North East Process Industries Cluster (NEPIC) – a membership organisation promoting the interests of the chemical and process industries in the region.
- Tees Valley Combined Authority (TVCA) – a mayoral combined authority with devolved responsibility from Westminster for: business growth and inward investment; transport; education, employment and skills; culture and tourism; research, innovation and development; and towns and communities.

4.2 Project Board

The project board was convened with senior representatives from each of the project collaborators:

- Hamish Bennell, bp
- Philip Aldridge, CEO NEPIC
- Chris Rowell, Head of Net Zero, TVCA

4.3 Project Manager

The project manager was appointed by TVCA:

- Chris Robinson, seconded from CER Technologies Ltd.

4.4 Funding Body & Client

The work has been funded by Innovate UK as part of their remit to manage the Industrial Decarbonisation Challenge for the Department of Energy Security and Net Zero. The responsible persons at Innovate UK and our clients for the work are:

- Dr Bryony Livesey, Director of the Industrial Decarbonisation Challenge
- Will Joyce, Technical Officer
- Natalie Roberson, Technical Support
- Seyhan Turan, Monitoring Officer

5 Project Progress

5.1 Initial Intention

The project programme was formulated around 4 work packages:

- WP1 – project management and governance
- WP2 – engineering / decarbonisation studies
- WP3 – economic studies
- WP4 – project reporting and dissemination

The initial plan was that the project would carry out decarbonisation studies for around 12 – 15 industrials (WP2). These would be selected as the main CO2 emitters in the Tees Valley industrial cluster. These studies would identify appropriate CO2 reduction technologies and pathways and hence provide the roadmap to net zero.

The data from these studies would also be used to inform the economic studies (WP3), including jobs, Gross Value Added (GVA)[1], business case, skills and workforce planning.

5.2 Early Actions

We began the work by collating contacts for the key industrials in the cluster for both existing and proposed industries under planning. It was evident very quickly that most of the key industrials had already carried out significant decarbonisation planning.

There were a number of drivers for this:

- The Department of Energy Security and Net Zero (formerly the Department for Business, Energy and Industrial Strategy, BEIS) 'Cluster Sequencing' competition which many of the Tees Valley industries were bidding in to.
- Carbon taxes applied through UK ETS.
- Market drivers from customers.
- The ability to supply to "green infrastructure" projects.
- Corporate strategy and Environmental, Social & Governance (ESG) commitments.

It was apparent that the BEIS Cluster Sequencing process, which had been put in place after the initiation of the Cluster Plan project, was going to be very influential to the development of the plan.

This had occurred between the development of the ideas and proposal for the cluster plan, our bid to Innovate UK for the project funding, and the commencement of the project itself.

5.3 Reconfiguring the Plan

We determined that it was important to develop a new approach as carrying out our own decarbonisation studies for the industrials would just have re-iterated work that they had completed themselves.

Instead, we decided to incorporate into the Cluster Plan the new level of decarbonisation planning that we found in the separate industrials within the industrial cluster. We would do this by carrying out interviews and

[1] which is the value generated by any unit engaged in the production of goods and services (ONS Definition)

a data survey with each of the industrials to determine their current decarbonisation planning, energy use, CO2 emissions, economic impact and corporate policies. This would ensure that the Cluster Plan reflected the current conditions within the Tees Valley cluster and capture future developments.

Carrying out interviews and surveys of existing data would use considerably less than the allocated budget. So, at this point we widened the remit to include all industries in the cluster that had impact on decarbonisation. We felt that this gave a much better representation of the current industrial cluster and the wider opportunities that decarbonisation would bring.

The Cluster Plan now included:

- CO2 Transport & Storage - the Northern Endurance Partnership
- The large CO2 emitters – chemical and process industries, typically with thermal processes > 20 MW and engaged with UK ETS
- Smaller CO2 emitters – chemical and process industries, typically with thermal processes < 2 MW.
- Gas-fired power stations including Net Zero Teesside (NZT) Power with pre- and post-combustion carbon capture.
- Green hydrogen projects
- Blue hydrogen projects
- Renewable power generation (offshore wind).
- Bio-energy power generation.
- Energy from Waste (existing and new proposed)
- Biofuels (existing bioethanol & biodiesel)
- New circular economy fuels (Fuels from Waste – SAF(sustainable Aviation Fuel and rDME (renewable Di Methyl Ether)
- Infrastructure providers: Northern Gas Networks; Northern Powergrid.

We took the decision to make the cluster plan modular and dynamic, so that we could include new companies and industries as they were developed in the cluster.

This is an enduring feature of the Cluster Plan and we currently have ~ 46 industrials included, with sufficient data from 30 of these to allow them to be included in the CO2 modelling. The modular approach to the models we use in the Cluster Plan mean that more industrials and projects can be added as they emerge.

5.4 Key Developments

5.4.1 Data Gathering

The data gathering process from the 40+ industrials has been key to the success of the Cluster Plan. We are very grateful to all the Industrials who took part in this with much enthusiasm and goodwill.

The data was collected in two parts:

(i) a case study – this provided a description for each of the industrials, their operation, markets, drivers and decarbonisation planning. These were written to go in the public domain and all the case studies from the project are available with the full report.

(ii) spreadsheet data – this captured data on emissions, energy, fuel and other operational data. As far as possible, this was projected out to 2040. Much of this was proprietary and commercially sensitive. We arranged NDAs with the industrials and our supporting sub-consultants to provide the necessary protections and to ensure that the data was only used within the confines of the Cluster Plan project.

The process of collecting the data allowed us to develop very thoroughly our relationships with the industrial stakeholders and gain direct information on their opportunities, risk and barriers to decarbonisation. It also gave us a broad perspective of the interactions in the cluster and the systems planning needed for successful decarbonisation.

5.4.2 Industrial Advisory Group

The Industrial Advisory Group was a regular meeting hosted by TVCA for the industrials contributing to the Cluster Plan. It was originally conceived as the group of leading industrials who could advise and influence the Cluster Plan. However, as we expanded the project to include all industrials involved in decarbonisation, we also expanded this group's membership also to include all these industrials.

The meeting was held online on a 6-weekly cycle. It was our opportunity to update the industrial cluster; let them know the developments, activities and outputs form the plan; and the opportunity for them to raise issues.

The IAG was a very effective means for us to communicate directly across the industrial cluster, inform them of progress, and spread information on national developments and funding streams.

We have transitioned this group into a new Net Zero Leadership Group which will continue to coordinate and represent Net Zero activities in the Tees Valley industrial cluster beyond the end of the Cluster Plan project.

5.4.3 Multi-Cluster Forum

The multi-cluster forum was the informal group of the 6x industrials clusters funded through the IDC (Tees Valley, Humber, South Wales, Black Country, North West England, Scottish) joined also by the Solent Cluster.

There is a degree of competition between the clusters, driven by government policy in the Cluster Sequencing process, Net Zero Hydrogen Fund and other initiatives; and also, by regional development aspirations. This competition was intended to deliver value for money from national budgets.

The multi-cluster forum was a valuable opportunity to provide balance and for the clusters to share knowledge and experiences between themselves. Two important points of interaction for the Tees Valley Cluster Plan were:

- Carbon Accounting – we were able to share and test our work with South Wales and Black Country
- Resilience – we had discussions with the Scottish cluster around ideas for shipping CO2 between CCS systems to provide an overall resilience capability in the UK's CO2 storage projects.

5.4.4 Membership of CCSA

TVCA is a member of the Carbon Capture and Storage Association (CCSA)– an industry group which acts as an advocate for member companies who are engaged with developing a CCUS industry in the UK.

We have found that the CCSA has been a very effective conduit for information in both directions between the Tees Valley cluster and DESNZ.

- CCSA has committees and working groups which review policy proposals, business model proposals etc – these have allowed us to understand the impacts and opportunities for the Tees Valley industrial cluster.
- We have been able to pass on data and information gathered from the Tees Valley industrials to CCSA to help provide evidence and weight to their discussions and lobbying activities.

5.4.5 CCUS Council

The Tees Valley cluster plan project manager (Chris Robinson) was invited to join the CCUS Council – this group was set up to review progress and support the government's ambition to deploy CCUS from the mid-2020s and at scale during the 2030's.

This provided us with the opportunity to describe developments, concerns, and barriers to CCUS in the Tees Valley to government ministers and the senior responsible civil servants delivering CCUS at DESNZ.

5.5 Suppliers Framework

To deliver the engineering/technical (WP2) and economic (WP3) assessments needed to inform the Cluster Plan, we used subcontractors.

For the engineering / technical studies we carried out an open procurement exercise and appointed 6x engineering consultancies to a framework managed by TVCA. We then awarded pieces of work on the framework either by mini-competition or direct award depending on the requirements of each study and the suppliers' specialist capabilities.

For the economic studies we used an existing framework vehicle at TVCA and invited bids form companies already on that framework.

6 The Cluster Plan - Structure

The Tees Valley Net Zero Cluster Plan is presented in 4 themes – the detail for these will be provided with the full report, scheduled for publication at the end of May 2023.

Theme 1: Decarbonisation in the Tees Valley Industrial Cluster

- Net Zero Teesside - CCS and the CO2 gas gathering network.
- National Policy Overview.
- Tees Valley Industrials' Case Studies.
- Mapping the Cluster Plan to UN Sustainable Development Goals.

Theme 2: Net Zero Planning

- The Cluster Model - Scope 1 CO2 emissions reduction and the net zero balance.
- Tees Valley Industrial Cluster Systems Model - a tool for maximising the benefit of the Tees Valley cluster's inherent integration.
- Carbon Accounting - GHG Protocol with Life Cycle Analysis showing the wider value of Scope 1/2/3 emissions reduction.

Theme 3: Societal & Regional Benefit

- Economic impact assessments.
- The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation.
- The "Limited Policy On" and "Full Policy On" scenarios - the benefits of adopting different degrees of industrial decarbonisation.
- Barriers to decarbonisation.
- Jobs & GVA.
- Skills and workforce planning.

Theme 4: Enablers & Future Opportunities

- Infrastructure requirements I – electricity.
- Infrastructure requirements II – hydrogen.
- The future opportunity for CCS and CO2 storage
- Shipping Industrial Gases I - importing CO2 by sea
- Shipping Industrial Gases II - exporting hydrogen
- Circular economy, fuels and Energy from Waste

Tees Valley Net Zero Cluster Plan

1. Decarbonisation in the Tees Valley Industrial Cluster

- Introduction
- Tees Valley Industrials Case Studies
- National Policy Overview
- Net Zero Teesside - CCS and the CO2 gas gathering network
- Mapping the Cluster Plan to UN Sustainable Development Goals

2. Net Zero Planning

- The Cluster Model - Scope 1 CO2 emissions reduction and the net zero balance
- Tees Valley Industrial Cluster Systems Model - - a tool for maximising the benefit of the Tees Valley cluster's inherent integration
- Carbon Accounting - GHG Protocol with Life Cycle Analysis showing the wider value of Scope 1/2/3 emission reductions

3. Societal & Regional Benefit

- Economic imnpact assessments
- The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation
- The "Limited Policy On" and "Full Policy On" scenarios - the benefits of adopting different degrees of industrial decarbonisation
- Barriers to decarbonisation
- Jobs & GVA
- Skills and workforce planning

4. Enablers & Future Opportunities

- Infrastructure requirements I - electricity
- Infrastructure requirements II - hydrogen
- The future opportunity for CCS and CO2 storage
- Shipping Industrial Gase I - importing CO2 by sea
- Shipping Industrial Gases II - exporting hydrogen
- Circular economy fuels and Energy from Waste

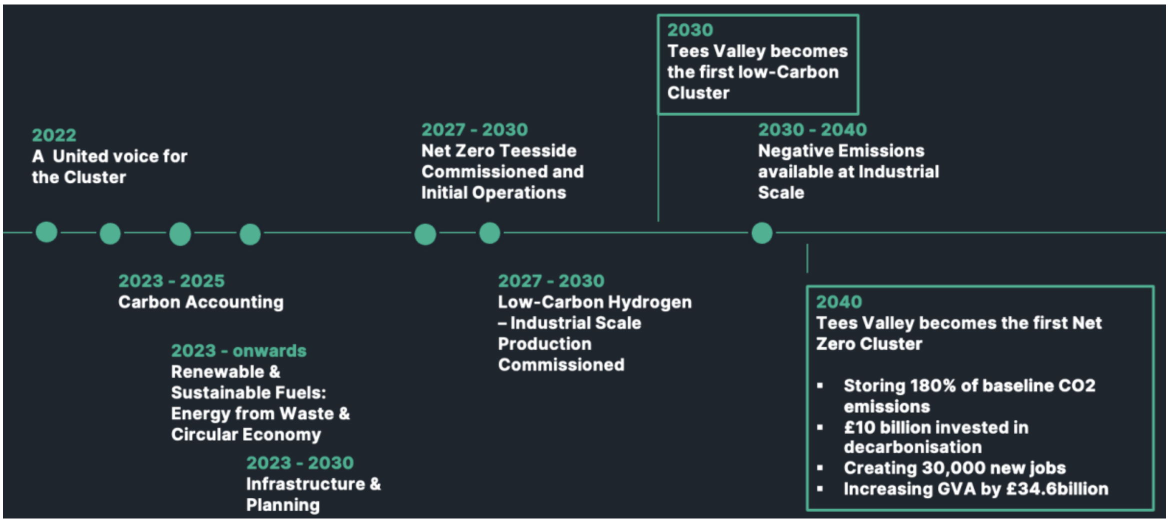
7 The Cluster Plan - Actions

We have defined 8 actions to take forward and build on the learning from the cluster plan and ensure that Net Zero is achieved and the economic opportunity is realised.

1. A Unified Voice for the Cluster 2023
   Industrial Net Zero Leadership Group has the aim to ensure Net Zero is delivered in the Cluster.
2. Carbon Accounting 2023-2025 & onwards
   Using the methodology defined in the Cluster Plan. Demonstrating & quantifying the positive impact of the Tees Valley on the wider UK economy.
3. Infrastructure & Planning 2023-2030
   Working with our electricity, gas and water providers to develop their networks to support and optimize decarbonised industries.
4. Renewable & Sustainable Fuels 2023- onwards
   Support to renewable and circular economy fuels, creating the conditions for investment here, bringing production technologies for SAF, rDME and more.
5. Carbon Capture & Storage 2027 – 2030
   Working with and supporting NZT, NEP and East Coast Cluster. Promote and support all CO2 emitters including those not on Cluster Sequencing.
6. Low Carbon Hydrogen at Scale 2027-2030
   Working with support and supporting the new hydrogen supply/demand economy in the region. Creating a centre for industrial scale low-carbon hydrogen production.
7. Negative Emissions at Scale 2030-2040
   These will be essential to balance residual Scope 1 emissions and ensure Net Zero is achieved. We will continue to promote, support and highlight the importance of developing negative emissions at scale in the region.
8. Local & National Coordination
   Working with our local and national stakeholders to communicate plans, exchange knowledge and ensure the pace of decarbonisation is maintained.

7.1 Timeline

Our timeline for implementing the actions in the Cluster Plan is as follows. It shows how we build on actions now, to enable the low-Carbon cluster aim by 2030 and Net Zero 2040.



8 Enduring Legacy

In addition to the Cluster Plan actions and the reports that we have developed to build the plan itself, the project has created enduring legacies.

8.1 Data

The data collection process from over 40 industrials in the Tees Valley has been one of the major achievements of the project. This has provided two-way communication between the Cluster Plan partners and the industrials and driven many features of the Cluster Plan:

- It has enabled us to understand a very broad range of projects, decarbonisation activities, impacts and needs across the Tees Valley industries.
- It has given access to the Cluster Plan project for a wide range of industrials, with both current and future proposed projects. This has allowed them to demonstrate their needs to enable decarbonisation and given them influence over the planning.
- It has allowed us to take a whole-system approach to decarbonisation, in which the needs for some industrials can be balanced with opportunities for others. This builds the momentum to make the Tees Valley a thriving decarbonised industrial cluster.
- It has allowed us to take a modular and dynamic approach to decarbonisation planning. The cluster model, systems model and carbon accounting methodology developed for the project are all capable of bringing in or taking out additional industrials to allow for different scenario planning and policy decisions.

8.2 Net Zero Leadership Group

Throughout the project, the Industrial Advisory Group that we set up and extended to all the industrials in the Cluster Plan has been a valuable touchpoint and means of communication. It has allowed us to meet directly and disseminate relevant information on funding, projects and opportunities.

We are continuing the group in a new guise and with its own remit – and this is our new Net Zero Leadership Group. The remit of the group is to promote and drive forward the activities needed in the industrial cluster to achieve Net Zero by 2040. We will be appointing an independent Chair to lead the group in these objectives.

8.3 Working with the Department for Energy Security and Net Zero

We have been able to develop good working relationships with senior officers at DESNZ due to our work on the Cluster Plan. This has been through different routes: firstly, the Cluster Plan project manager has been a member of the CCUS Council; secondly we have been able to present at a range of industry events on decarbonisation that DESNZ have also been present at.

One of the benefits of this dialogue is that TVCA will shortly be hosting a visit by a delegation of senior officers from DESNZ on Teesside. The purpose it for DESNZ to engage with the Teesside industrials as a group and individually. It will be an opportunity:

- To learn directly about the proposed Cluster Sequencing Track-1 Expansion and Electrolytic Hydrogen Allocation Round 2.
- For industrials to voice their concerns and highlight opportunities that can be achieved from projects not currently under support from DESNZ.

8.4 Wider Influence

As described earlier in this report, the Cluster Plan project has allowed us to engage with the CCSA to understand and influence policy decisions; and the multi-cluster forum to learn from and share experience with the other industrial clusters.

The work has also allowed us to engage with and inform our contacts across the local political spectrum: the Tees Valley mayor, Local Authorities and local MPs. We have engaged with the Energy Systems Catapult, Energy Institute, and Institution of Mechanical Engineers.

Theme 1:

Decarbonisation in the Tees Valley Industrial Cluster

Tees Valley Net Zero Cluster Plan

1. Decarbonisation in the Tees Valley Industrial Cluster	2. Net Zero Planning	3. Societal & Regional Benefit	4. Enablers & Future Opportunities
- Introduction - Tees Valley Industrials Case Studies - National Policy Overview - Net Zero Teesside - CCS and the CO2 gas gathering network - Mapping the Cluster Plan to UN Sustainable Development Goals	- The Cluster Model - Scope 1 CO2 emissions reduction and the net zero balance - Tees Valley Industrial Cluster Systems Model - - a tool for maximising the benefit of the Tees Valley cluster's inherent integration - Carbon Accounting - GHG Protocol with Life Cycle Analysis showing the wider value of Scope 1/2/3 emissions reduction	- Economic imnpact assessments - The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation - The "Limited Policy On" and "Full Policy On" scenarios - the benefits of adopting different degrees of industrial decarbonisation - Barriers to decarbonisation - Jobs & GVA - Skills and workforce planning	- Infrastructure requirements I - electricity Infrastructure requirements II - hydrogen - The future opportunity for CCS and CO2 storage - Shipping Industrial Gase I - importing CO2 by sea - Shipping Industrial Gases II - exporting hydrogen - Circular economy fuels and Energy from Waste

9 Net Zero Teesside - CCS and CO2 gas gathering network.

9.1 Underlying Report

Title	Industrial Decarbonisation Plan Work Package 6 – CO2 Transport & Storage
Author	WSP
Filename	Task 1 CO2 Transport & Storage.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-1-CO2-Transport-Storage.pdf

9.2 Description

In the Climate Change Act (2008) the UK has set into law that the country as a whole must reach Net Zero by 2050. Industrial clusters around the UK are relatively easy to abate due to their concentration of CO_2 emitters. They also provide much of the power, fuels and goods that will help the rest of the UK meet the Net Zero 2050 target. The Industrial Decarbonisation Challenge[2] is the enabler for the Tees Valley Cluster Plan and through this the Tees Valley is set to become a low-carbon industrial cluster by 2030 and potentially the world's first Net Zero cluster by 2040.

Up to 4.9 $MtCO_2/yr$[3] is emitted by the Tees Valley industrial cluster. These are Scope 1 Greenhouse Gas (GHG) emissions – i.e., CO_2 released from the direct burning of fossil fuels. In the Tees Valley most of these CO_2 emissions are from chemical processes, and electricity and heat generation to power chemical processes.

[2] https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/industrial-decarbonisation/
[3] Source WSP analysis of NAEI data

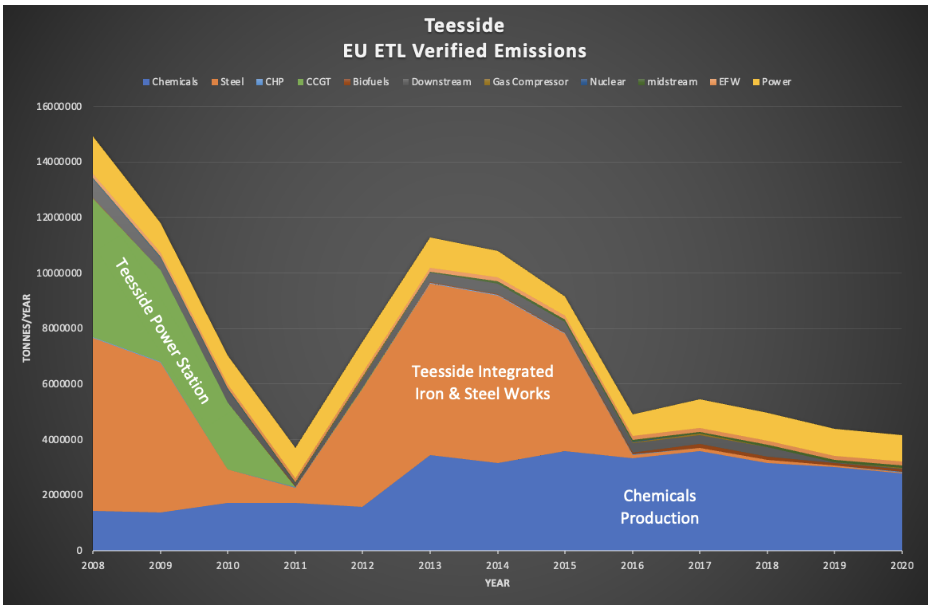


Figure 01 Teesside Emissions MTCO2E

In the recent past, CO_2 emissions in the Tees Valley were substantially higher at around 15 $MtCO_2$/yr. The closure of the Teesside power station and the loss of the steelworks resulted in large drops in CO_2 emissions. However, this de-industrialisation, is not de-carbonisation, and has a negative impact on the local economy. The CO_2 emissions from these industries still exist – the steel and power are made elsewhere, and the CO_2 is still released to atmosphere. The greatest challenge in deep decarbonisation is to ensure economically viable decarbonised industries remain and there is a positive impact on the local economy.

CO_2 produced as a by-product in chemical processes is a commodity – it is used in the nuclear industry as a coolant; in food production and packaging; and in carbonated drinks. Much of the CO_2 produced in the Tees Valley as by-products from industrial processes is already captured and utilised in this way – this is Carbon Capture and Utilisation, or CCU.

The Teesside region and its industries have a substantial history in CCS planning. This is due in equal parts to:

- the opportunities that the compact industrial cluster provides to use CCUS technology;
- the geological resources available due to proximity to the North Sea carbon stores;
- the legacy infrastructure of the former Teesside Integrated Iron & Steel works (now being developed as Teesworks) and the ICI integrated chemical works (now operated by a range of separate companies);
- the opportunity to regenerate industries in the region.

This history is useful in understanding the current developments for CCUS in the region and the strength of the offering in industrial decarbonisation in the region.

We asked WSP to provide this report describing both the history of CCS planning in the region and the currently proposed developments. The full scope of the report is provided below – (note: this includes some elements of the "Future Opportunity for CCS" which is part of the "Enablers and Future Opportunities" section of the Cluster Plan):

- Brief history of CCUS in Teesside, including the Teesside Collective, to show that the current work is a development of long-term planning.

- Description of East Coast Cluster project; aims and ambitions; volumes of CO_2 to be transported and timeline for development.
- Description of the CO_2 pipeline route, main features; barriers and enablers to completion.
- Description of the principal CO_2 emitters and outline of their projects to deliver CO_2.
- Define a baseline of historic CO_2 emissions on Teesside.
- Description of BEIS Cluster Sequencing Phase 2 successful and unsuccessful projects.
- Detail on barriers to the full development and optimisation of the CO_2 T&S system; also the enablers that need to be put in place.
- A review of the business model that BEIS are proposing for this regulated asset (note that this is limited to the point of development of the business models at the time of WSP writing their report in October 2022)
- Discussion of the business model flexibility to allow transfer of CO_2 into the cluster for storage, from non-cluster emitters. Either emitters not in clusters; or transport from other clusters.
- Description of CO_2 infrastructure roll out in Teesside, including project timelines, lost projects and risks.
- Opportunities for efficiencies in the CO_2 T&S system operation and future proofing should be drawn out and highlighted.
- Transport of CO_2 into the Industrial Cluster– how can the CO_2 T&S system be optimised or enhanced to receive CO_2 from outside the Tees Valley Industrial Cluster?
- What are the energy demands for delivering CO_2 at industrial-scale volumes; and what limits does that place on the range that can be served by pipeline transport from outside the cluster.
- What infrastructure would be required to receive CO_2 from outside the Cluster by sea. This could be from Clusters or non-cluster industries which are not CO_2 T&S enabled.

9.3 History of CCS Planning in Teesside

Progressive Energy – Eston Grange Power Station (2007)

The Eston Grange1 Power Station was the first project to emerge in the region where CCUS was integral. The proposed plant was an 850MW pre-combustion power plant, an integrated gasification and combined cycle facility. It was proposed for a brownfield site to the west of Lackenby in Eston, Middlesbrough within what is now Wilton International. It was expected that the project would qualify for the UK CCS competition launched in 2007, however the competition decided not to include pre-combustion or gas fired power plant, only post combustion coal CCS and the project was discontinued.

One North East (2009)

During the UK CCS competition, the regional development agency One North East commissioned a study on common infrastructure, carbon capture and economics for the region. In part a reaction to Eston Grange not being selected but also the decision by the government at the time to not permit consideration of common infrastructure in the selected projects. Teesside remained a very tight cluster, with integrated systems and industry and high emissions per square kilometre and a very short distance across the area. The goal was to inform the economic development of the region as well as local industry as to the potential costs for capture. The project considered technical and economic issues.

Process Industries Carbon Capture and Storage Initiative (PICCSI)

Following the ONE study the North East Process Industries Cluster (NEPIC) which had supported the ONE study and ONE's ongoing CCS activity brought together a formal group to consider CCS on

Teesside. The group included the local authorities and the new LEP Tees Valley Unlimited, members of NEPIC, industrial partners in the region and worked closely with other stakeholders including UK government and the CCSA. This became the first industry led cluster in the UK. The group worked to inform the region on CCS, to represent the clusters views and to engage with projects. Key elements remained as the economic and business cases for deploying CCS and promoting common infrastructure.

Teesside Low Carbon (2013)

The Teesside Low Carbon project was an evolution of the Eston Grange Project by the same developer, but with GDF and BOC as operators of the units and Premier Oil for storage. The project was again a pre-combustion facility, smaller than Eston Grange, but would capture 2.3million tonnes of CO_2. Here the syngas produced by pre-combustion was to be used by GDF in a syngas 330Mwe power plant on the Teesside Power Station plant at Wilton.

The project was considered for the second UK competition and EU NER300 funding. Again, it was one of the few projects to consider enabling a networked CCS infrastructure. It was selected as a reserve project; but the competition closed in 2015 without proceeding on either of the selected projects.

Teesside Collective (2015)

Drawing from the discussions within the PICCSI group, the LEP and with government the Teesside Collective was formed, replacing PICCSI. For its launch the group aimed to address the economics and business case issues. To do so required further examination of the emitters at a more detailed level than the ONE study. The Teesside collective reports were procured by Teesside's LEP appointing Pale Blue Dot (now Storegga) as the project manager, Societe Generale on the economics and AMEC for the technical analysis, although the technical work overlapped with the Teesside Low Carbon project, so Progressive Energy joined AMEC in producing the technical reports.

Four emitter sites were considered in detail and included the SSI steel works, BOC's Teesside Hydrogen Unit, Lotte Chemicals PET plant (now Alpek) and CF Fertilisers. The Pipeline Network examined potential routes across the region for the example plant and a reasonable phase 1 scenario, but also the complete network for all emitters. An offshore pipeline and storage element was also included, assuming a CNS location for a saline formation and the two proposed storage sites within the UK CCS competition at Goldeneye and Endurance.

Teesside 2017 – 2022

the Teesside Collective report became an important benchmark for the region and the argument for clusters in the UK. In 2017 the Tees Valley Combined Authority commissioned a project programme report, to examine the timeline for deployment in the cluster, whilst further work on the business model was underway.

The TVCA work was presented to BEIS in early 2018, laying out deployment pathways for CCS in the region and typical programmes for emitters. It highlighted that clusters could be achieved in a reasonable and beneficial timescale. At around the same time the Oil and Gas Climate Initiative, OGCI, was progressing a generic CCGT+CCS power plant concept design, previously mooted by the Energy Technologies Institute, ETI.

Around late 2018 OGCI commenced feasibility studies for a CCS scheme, which in 2019 became focused on deployment on Teesside. This project became the Net Zero Teesside project, later forming part of the wider East Coast Cluster linking Humber and Teesside through the Northern Endurance Partnership Track 1 submission in 2021.

9.4 Currently Proposed System

The Tees Valley has a rich history in CCS, with common infrastructure projects considered in 2010 and 2015, and several aspects of the current cluster planning approach building upon the experiences of later 2015 Teesside Collective project.

The Cluster is compact both geographically and physically, the former meaning that there is no requirement for any new cross-country pipelines and the latter reflecting the presence of many existing pipe corridors into which new CCUS infrastructure might be readily added. Also, there is local social acceptance of and familiarity with large process, chemical and energy assets operating often in contiguous sites across the region. Few barriers are thus anticipated to the inclusion and implementation of a future Carbon Capture and Transportation pipeline network within the existing industrial cluster.

Initial onshore pipeline routing envisaged a possible route along existing corridors where available, to demonstrate ability to connect all emitters who were shortlisted in the current Cluster Sequencing Competition. These organisations are summarised in the table and figure below and the proposed network might usefully be considered as a long northern 'leg' covering North Tees and Billingham and a short southern 'leg' reaching back through Redcar to the Wilton International site.

The current development consent order (DCO), however, only covers the northern and longest leg and the expected connection model is one whereby each 'connected emitting project' could be served through a spur from this initial backbone. It should be appreciated that there remains much detailed engineering to complete, and it is during this process that the exact limits of the common collection infrastructure and the interface points connecting the individual projects would be finalised.

There will be much value in some level of 'pre-investment in capacity' of connection opportunities at the early stages with a small additional cost as opposed to later re-engineering of an operating system to allow new projects to connect later at a greater cost.

Table 01– Projects shortlisted in the stage 2 Cluster Sequencing Competition

Emitter	Category	Location	Cluster Sequencing Negotiation Stage (May 2023)
Net Zero Teesside Power	Power CCUS	Redcar/Wilton	Yes
Whitetail Clean Energy	Power CCUS	Redcar/Wilton	
bpH2Teesside	Hydrogen	Redcar/Wilton	Yes
H2NorthEast	Hydrogen	Seal Sands (N Tees)	
CF Fertilizers Ammonia Production	Industrial CCUS	Billingham (N Tees)	
Conoco Phillips Norsea Carbon Capture	Industrial CCUS	Seal Sands (N Tees)	
BOC Hydrogen Production	Industrial CCUS	Seal Sands (N Tees)	Yes
Tees Valley Energy Recovery Facility	Industrial CCUS	Redcar/Wilton	
Redcar Energy Centre	Industrial CCUS	Redcar/Wilton	

Figure 02 Onshore Capture Network Schematic

Fig 03 Teesside Industrial Cluster Significant CO2 Emitters

Current industrial activity across the cluster, combined with all the currently known future projects, is expected to generate circa 14 million tonnes per annum of CO2, although it is clear that this demand will only become realised over an extended timescale. The onshore network currently proposed will accommodate up to 10 million tonnes/CO2 per year, which is more than adequate to accommodate the current emissions from the region together with several of the new projects plus the Net Zero Teesside Power anchor project.

There is potential to increase this capacity further to address additional emissions although this would require further engineering studies and operational data following startup of the initial network. One approach is to increase maximum operating pressures with mitigations for the range of ambient conditions. There is evidence of future planning and thinking in the DCO currently submitted.

As currently designed, all onshore pipelines will run at up to 20barg, i.e., in the gaseous phase. CO2 quality will be managed so as to achieve a defined specification for entry into the system. The offshore pipeline will operate in dense phase at considerably higher pressure (over 100barg).

The Northern Endurance Project (NEP) as the Transport & Storage (T&S) Company will deliver and operate the onshore and offshore transportation network which brings together emissions originating from both the Tees Valley and Humber clusters for storage in the southern North Sea with the ambition of reaching a peak annual injection capacity of 27 million tonnes per annum.

WSP note in the report that the onshore network will need to be designed so as to be able to readily accommodate future additions. These for example, might include the SUEZ waste to energy facility at Haverton Hill for which CCUS plans are already well developed as well as the opportunity to establish a future CO2 import/export facility, for which there is ready Deep Water Port capacity adjacent to Seal Sands on the northern leg of the onshore network.

10 National Policy Overview.

10.1 Underlying Report

Title	Summary of Government Decarbonisation Strategies Hydrogen Strategy, Net Zero Strategy, Industrial Decarbonisation Strategy
Author	WSP
Filename	Task 2 Summary of Government Decarbonisation Strategies.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-2-Summary-of-Government-Decarbonisation-Strategies.pdf

10.2 Description

We tasked WSP with carrying out a review of the national policy landscape relating to industrial decarbonisation. Most of the relevant policy has come from Government through what was until March 2023 the Department for Business, Energy and Industrial Strategy, and is now primarily the responsibility of the Department for Energy Security and Net Zero.

The more recent policy announcements and support programmes are the most relevant, though the history of how these have come about, and the progression in increasing targets for net zero, hydrogen and decarbonisation are useful to understand. The work we have commissioned here is intended to provide that background and detail.

10.3 The Climate Change Act (2008)

This is the UK's legislation which commits the nominated Secretary of State to ensuring that the UK's greenhouse gas emissions reach Net Zero by 2050. In the Act, Net Zero is defined for carbon dioxide as 100% less than the 1990 equivalent CO2 emissions. Other greenhouse gases have similar targets based on a different baseline year.

10.4 Cluster Sequencing for Carbon Capture Usage and Storage Deployment (May 2021)

The Cluster Sequencing competition underpins much of the work in industrial decarbonisation being carried out in the Tees Valley industrial cluster. The view we have held for the Cluster Plan project is that successful decarbonised industrial clusters will need three prime movers: Carbon Capture and Storage; Renewable Electricity; Hydrogen supply/demand economy.

CCUS is in fact doubly important as it underpins the production of the "blue" methane-reformed hydrogen which is currently required to generate hydrogen in industrial quantities and will do until "green" electrolytic hydrogen can displace this.

The Cluster Sequencing competition has two Phases and two Tracks:

- Track-1 describes the two clusters that were successful in the first round of bidding. These were the East Coast Cluster (comprising Net Zero Teesside; Zero Carbon Humber; and the Northern Endurance Partnership CO2 store); and HyNet in the northwest of England. These clusters are intended to be operational by the mid-2020s.

- Track-2 describes the following two clusters that are intended to be operational by 2030. At the time of writing , the Scottish Cluster and Viking CCS were shortlisted for Track-2 with expressions of interest open to other CCS schemes.
- Phases – within each “Track” there are two phases. Phase 1 describes the deployment schemes (e.g., East Coast Cluster and HyNet) which develop the CO2 transport and storage (T&S) systems; Phase 2 describes the emitters connecting to the T&S networks.

As of May 2023, East Coast Cluster had progressed to the contract negotiation stage with DESNZ under Track-1 / Phase-1. However, under Track-1 / Phase-2 only three emitters have passed to the negotiation stage. These are:

- NZT Power – bp’s CCS enabled dispatchable CCGT power station;
- bp’s H2 Teesside blue hydrogen project;
- BOC’s project to develop CCS for their existing steam methane reformed hydrogen production on Teesside.

As none of the Phase 2 projects are on the Humber, the development of the Humber leg of the East Coast Cluster is awaiting further policy decisions.

DESNZ has also announced a Track-1 Expansion programme and at the time of writing we are still waiting to learn what this will entail.

10.5 The Ten Point Plan for a Green Industrial Revolution (November 2020)

The UK Government launched this plan as part of the Covid recovery strategy and to boost investment in the UK’s “green” technology sector.

This Ten Point Plan committed to mobilising £12 billion of government investment, and an estimated £42 billon of private investment by 2030 across energy, buildings, transport, innovation and the natural environment. This aimed to created up to 250,000 jobs in these sectors. An additional aim was to position the UK to take advantage of export opportunities presented by low carbon technologies and services into new, global emerging markets .

The Ten Point Plan demonstrated the UK’s commitment to tackling greenhouse gas emissions. It was a means to provide the investment in technology that could meet the UK’s obligations under the Paris Accord (2015) to limit average global warming to 1.5 °C and the UK’s own Climate Change Act.

The Ten Points outlined in the plan were:

- Point 1 Advancing Offshore Wind
- Point 2 Driving the Growth of Low Carbon Hydrogen
  - The stated aim was for the UK to develop 5GW of low carbon hydrogen production capacity by 2030 with the potential to create 8,000 new jobs. This would be supported by a range of measures, including the £240 million Net Zero Hydrogen Fund, and the Hydrogen Business Model.
  - The 5 GW low carbon hydrogen production included both methane-reformed hydrogen (“blue” hydrogen) and electrolytic hydrogen (“green” hydrogen). The target was increased to 10 GW in later strategies and for the Net Zero Hydrogen Fund.
- Point 3 Delivering New and Advanced Nuclear Power
- Point 4 Accelerating the Shift to Zero Emission Vehicles

- Point 5 Green Public Transport, Cycling and Walking
- Point 6 Jet Zero and Green Ships
- Point 7 Greener Buildings
- Point 8 Investing in Carbon Capture, Usage and Storage
  - The plan described how CCUS would be developed in two industrial clusters by mid 2020s, and aimed for four of these sites by 2030, capturing up to 10 Mt of carbon dioxide per year. A £1 billion CCUS Infrastructure Fund was set up to provide industry with the certainty required to deploy CCUS at pace and at scale. These clusters would be the starting point for a new carbon capture industry, which could support up to 50,000 jobs in the UK by 2030.
- Point 9 Protecting Our Natural Environment
- Point 10 Green Finance and Innovation

10.6 Industrial Decarbonisation Strategy (March 2021)

The UK government launched the Industrial Decarbonisation Strategy in 2021 to set out a clear strategy and direction for the sector. Its stated aim of the strategy is to demonstrate how the UK government can ensure the industrial sector can thrive whilst aligned to a net zero target and retaining the UK based industry or offshoring emissions.

The strategy is complemented by later documents, statement and policy but has not received an update since publication. The pathways set out are based on the economic outlook at that point and do not include current world events influencing energy, particularly gas, pricing or energy security which was addressed in 2022. The strategy also develops on previous policy and papers, including the Ten Point Plan for a Green Industrial Revolution, the 2020 Energy White Paper.

Key elements

- 2021 – Design of UK Emissions Trading Scheme, aligned with net zero
- 2025 – Voluntary product standards (potential)
- Carbon Capture clusters
- Industrial decarbonisation plans

Key schemes

- 2021 – Industrial clusters receive funding for engineering studies
- 2021 – Companies receive funding for industrial energy transformation
- 2023 – Worlds first net zero aligned ETS
- 2025 – Two carbon capture clusters
- 2040 – World's first net zero industrial cluster

Key targets

- 2030 – 20TWh fossil fuels replaced with low carbon alternatives
- 2030 – 3 million tonnes/year captured
- 2035 – emissions down by 66.67% by 2018
- 2040 – Worlds first net zero industrial cluster

- 2050 – Almost no fossil fuels unless with capture
- 2050 – Emission down by at least 90% from 2018

10.7 The UK Hydrogen Strategy (August 2021)

The UK Hydrogen Strategy documents how the Government propose to boost the energy sector through the simulation of the hydrogen industry, including setting an initial target of 5GW of low carbon hydrogen production capacity by 2030. The strategy was published to establish the role of hydrogen for the UK to be Net Zero by 2050. BEIS have estimated that to achieve Net Zero by 2050, 20% to 35% of the UK's energy consumption would need to be from hydrogen.

The Hydrogen Economy roadmap has been split into four time periods:

- Early 2020s (2020-2024);
- Mid-2020s (2025-2027);
- Late 2020s (2028-2030); and,
- Mid-2030s onwards

The periods show the rapid accelerated growth required within the 2020s to enable 5GW of hydrogen production to come online by 2030. In the Energy Security Strategy, published April 2022, an increased production aim of 10GW of low carbon hydrogen production by 2030 was published. The Hydrogen Strategy outlines the key challenges for low carbon hydrogen production, distribution, storage and usage that need to be overcome for hydrogen to be a part of the UK's energy landscape.

10.8 Net Zero Strategy: Build Back Greener (October 2021)

The Net Zero Strategy sets out clear policies and proposals for keeping on track for coming carbon budgets, ambitious Nationally Determined Contribution (NDC), and then sets out a vision for a decarbonised economy in 2050. Whilst there are a range of ways in which net zero could be achieved in the UK, a delivery pathway was set out showing indicative emissions reductions across sectors to meet our targets up to the sixth carbon budget (2033-2037).

Industry: Key Policies from the Net Zero Strategy regarding industry are:

- Following the Phase 1 of the Cluster Sequencing process, the Hynet and East Coast Clusters, will act as economic hubs for green jobs in line with our ambition to capture 20-30 MtCO2 per year by 2030. This puts Teesside and the Humber, Merseyside and North Wales, along with the North East of Scotland as a reserve cluster, among the potential early SuperPlaces which will be transformed over the next decade.
- Future-proofing industrial sectors, and the communities they employ through the £315 million Industrial Energy Transformation Fund (IETF), (£289 million for England, Wales and Northern Ireland, £26 million for Scotland).
- Incentivise cost-effective abatement in industry at the pace and scale required to deliver net zero, through the UK ETS by consulting on a net zero consistent UK ETS cap (in partnership with the Devolved Administrations).

Based on whole system modelling, by 2050, emissions associated with industry could need to drop by 87-96% compared to 2019, down to 3-10 MtCO2 e. In the interim, to meet the NDC and Carbon Budget 6 targets, emissions are expected to potentially fall by 43-53% by 2030 and 63-76% by 2035, compared to 2019 levels. These figures are based on an indicative industry pathway contributing to the whole-economy net zero and interim.

Power: Key Policies from the Net Zero Strategy regarding power are:

- By 2035 the UK will be powered entirely by clean electricity.
- 40GW of offshore wind by 2030, with more onshore, solar, and other renewables – with a new approach to onshore and offshore electricity networks to incorporate new low carbon

generation and demand in the most efficient manner that takes account of the needs of local communities like those in East Anglia.

- Moving towards 1GW of floating offshore wind by 2030 to put the UK at the forefront of this new technology that can utilise our North and Celtic Seas – backed by £380 million overall funding for our world-leading offshore wind sector.
- Deployment of new flexibility measures including storage to help smooth out future price spikes.

10.9 Powering Up Britain (March 2023)

This is the government's blueprint for the future of energy in this country. By bringing together our Energy Security Plan, and Net Zero Growth Plan, it explains how UK will diversify, decarbonise and domesticate energy production by investing in renewables and nuclear, to power Britain from Britain. It sets out the extraordinary opportunities opening up in technologies like Carbon Capture, Usage and Storage, Floating Offshore Wind Manufacturing, and hydrogen, which will not only help UK reach net zero, but also consolidate Britain's position as a global leader in green energy. It details how this leadership can influence energy decarbonisation internationally.

10.10 Funding Provision

A number of programmes have been in development or have been initiated since 2020. These include the development of business models to support the deployment of CCUS infrastructure, power generation with CCS, decarbonised hydrogen production, Energy from Waste with CCS, Bioenergy with CCS, engineered Greenhouse Gas Removal and industrial carbon capture.

£1bn was allocated to the CCS Infrastructure Fund to support the development of the 10-point plan including the operation of the initial models.

10.11 The Net Zero Hydrogen Fund (April 2022)

The fund is aimed at helping the government meet the 10GW of production target by 2030 it set itself in 2020 by providing £240m in funding to Low Hydrogen production projects. Projects focusing on hydrogen blending schemes are currently not eligible to apply as DESNZ have not yet published an official decision on permitting a 20% hydrogen (by volume) into the gas network, DESNZ currently view hydrogen blending as a transitional fuel and does not want hydrogen blending to displace potential hydrogen supplies for industry, transport or power generation. Until hydrogen is permitted into the network through legislation hydrogen is not eligible. However, the Government see the potential for hydrogen blending to be used to manage volume risk and a contract re-opener will be considered once BEIS complete their assessment on hydrogen blending.

11 Tees Valley Industrials' Case Studies.

11.1 Underlying Report

Title	Industrial Case Studies
Author	Element Energy; Frazer Nash Consulting; Kent Energies; Mott Macdonald; WSP.
Filename	Task 3 Case Studies 1.zip Task 3 Case Studies 2.zip
Location	https://www.dropbox.com/scl/fi/oqohfw91vbo7pki39gc3y/Task-3-Case-Studies-1.zip?rlkey=br1zej3cepp04433kx4opi3ql&dl=0 https://www.dropbox.com/scl/fi/11gv62q5leozd0st02mnj/Task-3-Case-Studies-2.zip?rlkey=hty7asw7sk1b9hfxkgh6v7qbp&dl=0

11.2 Description

The Industrials' Case Studies underpin all of the work on the Cluster Plan, and they are provided here as a resource to any parties wanting to understand in depth the organisations that comprise the Tees Valley industrial cluster.

Our concept for developing the Cluster Plan has been that it would include all the industrials that have some influence in decarbonisation in the Tees Valley. These include:

- Net Zero Teesside / Northern Endurance Partnership CCS project – this is the "anchor" project for industrial decarbonisation that enables the largest portion of the cluster to move into a decarbonised future.
- CO_2 emitter industries
- Current and future hydrogen economy
- Renewables
- Biofuels
- Circular Economy companies - Energy from Waste
- Industries that are not large CO_2 emitters and will decarbonise by reducing Scope 2/3 emissions through the uptake of renewable electricity and hydrogen.

Having separate data for each of the industrials has also allowed us to make the Cluster Plan modular and dynamic. It is simple to add in new projects that are emerging or remove projects that do not progress.

We have included over 40 industrials in the Cluster Plan. The data was collected by a team of consultants that we appointed through our engineering framework, and we would like to acknowledge the efforts of: Element Energy; Frazer Nash Consulting; Kent Energies; Mott Macdonald; WSP.

The data was collected in two formats:

- A case study which describes each individual industrial's business on Teesside; their energy use and feedstocks; energy that they produce; their corporate policies; and their decarbonisation plans.
- A spreadsheet with data on energy usage, feedstocks, decarbonisation strategy, hydrogen uptake and CO_2 reduction projected out to 2040.

The spreadsheet data was developed as the input decks for the Cluster Model and allowed us to plan and interrogate various decarbonisation scenarios. This has defined the strategy for decarbonisation and the mix of CO2 reduction and negative emissions that will be necessary to decarbonise the cluster. The spreadsheet data contains a lot of commercially sensitive data about different organisations' data and their own customers operations. For these reasons all the data was subject to non-disclosure agreements and can only be used in specific ways within the remit of the Cluster Plan project.

However, the Case Studies have been written as publicly available documents and are available to download en masse. Readers are cautioned that the Case Studies were written in mid-2022 and reflect the state of the industries and their decarbonisation planning at that time. Since then the Cluster Sequencing programme has moved forward. Some of the companies that were on the Track1 / Phase 2 shortlist did not pass through to the negotiation stage. Similarly there have been awards on the Net Zero Hydrogen Fund; and industries regularly engage in MOU processes to develop their decarbonisation planning.

The list of Case Studies currently available, presented in alphabetical order is as follows. There are 37 industrials represented here – there were a small number of industrials that we spoke to and included in the Cluster Plan who have not been able to supply Case Studies at the time of writing.

ID	Company	Clean Power	Hydrogen Economy	Chemicals	Biofuels & Circular Economy	Infra-structure
1	alfanar				SAF	
2	Alpek			Polyester		
3	Anglo American			Fertiliser		
4	BOC		Blue H2	Ind. Gases		
5	British Steel			Steel		
6	CF Fertilisers			Fertiliser		
7	Circular Fuels Ltd				rDME	
8	Dogger Bank C (SSE)	Wind				
9	EDF Energy	Nuclear				
10	EDF Renewables	Wind				
11	Ensus				Bioethanol	
12	Fujifilm Diosynth Biotech.			Pharma		
13	Greenergy				Biodiesel	
14	H2Teesside		Blue H2			
15	HyGreen		Green H2			
16	Kellas Midstream (H2 NorthEast)		Blue H2			
17	Lianhetech			Chemicals		
18	MGT Teesside	Bioenergy				

ID	Company	Clean Power	Hydrogen Economy	Chemicals	Biofuels & Circular Economy	Infra-structure
19	Mitsubishi Chemicals			Chemicals		
20	Navigator Terminals					Storage
21	Northern Gas Networks					Gas
22	Northern PowerGrid					Electricity
23	Net Zero Teesside & NEP	CCGT				CCS
24	PD Ports					Logistics
25	Protium		Green H2			
26	Quorn (Marlow Foods Ltd)			Vegan food		
27	Redcar Energy Centre				EfW	
28	SABIC			Olefins/Poly olefins		
29	Sembcorp	CHP				Site
30	SEQENS			Custom chemicals		
31	Sofia Windfarm (RWE)	Wind				
32	SUEZ Recycling & Recovery				EfW	
33	TATA Steel			Steel		
34	Tees Valley ERF				EfW	
35	Venator			Tioxide		
36	Verdant Health (P3P Partners)			Hemp		
37	Whitetail Power (8 Rivers)	NET-power				

Table 02 List of Case Studies

12 Mapping the Cluster Plan to the UN Sustainable Development Goals.

12.1 Underlying Report

Title	Task 12- Mapping the Cluster Plan to the UN Sustainable Development Goals
Author	Fraser Nash Consultancy
Filename	Task 4 UN Strategic Development Goals.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-4-UN-Strategic-Development-Goals.pdf

12.2 Description

The principal aim of the Cluster Plan is to demonstrate how the Tees Valley industrial cluster can decarbonise, become a low-carbon cluster by 2030 and reach Net Zero by 2040. Decarbonising the industrial clusters is an important step towards reaching the Climate Change Act requirement for the UK to reach Net Zero by 2050 and meeting the UK's nationally Determined Contributions through the Paris Accord.

Industrial Clusters account for around 24% of the UK's current CO_2 emissions. In addition to this the industrial clusters produce – or will produce in the future – goods which will help the rest oi the UK to decarbonise. A prime example of this is hydrogen which will be used in industry, transport and potentially domestic heating also.

The Tees Valley Cluster Plan also sits in the wider context of global sustainable development and in this section of the Cluster Plan we demonstrate how the decarbonisation in the industrial cluster can help meet these wider aims.

The UN has a programme for Sustainable Development Goals[4] which outlines 17 Goals and 169 Targets. The underlying principles stated by the UN are:

People

We are determined to end poverty and hunger, in all their forms and dimensions, and to ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment.

Planet

We are determined to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations.

Prosperity

We are determined to ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature.

Peace

[4] https://sdgs.un.org/goals

We are determined to foster peaceful, just and inclusive societies which are free from fear and violence. There can be no sustainable development without peace and no peace without sustainable development.

Partnership

We are determined to mobilize the means required to implement this Agenda through a revitalised Global Partnership for Sustainable Development, based on a spirit of strengthened global solidarity, focussed in particular on the needs of the poorest and most vulnerable and with the participation of all countries, all stakeholders and all people.

We are fortunate in the UK to be part of the developed world and there is less need within the Tees Valley industrial Cluster to focus on "People" and the goals for poverty, hunger and so on. However, many of the goals are directly relevant to developments within the Tees Valley industrial Cluster.

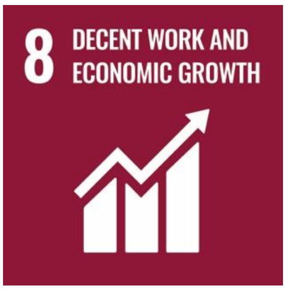
Through our suppliers' framework, we tasked Frazer Nash Consultancy (FNC) to conduct a mapping exercise to demonstrate how the Tees Valley Cluster Plan related to the UN Sustainable Development Goals. Their report demonstrates how seven of the SDGs are highly relevant to the Cluster Plan and the actions that will result from its delivery.. These are:

5. Gender Equality – Achieve gender equality and empower all women and girls.

Within the UK there is a strong legislative and policy framework to deliver gender equality. The Cluster Plan project has taken steps to promote gender equality by sponsoring a University Women in Engineering and Computing Network; and ensuring equal representation for women in events organised within the Cluster Plan.

7. Affordable and Clean Energy – Ensure access to affordable reliable, sustainable and modern energy for all.

Decarbonisation of the industrial cluster is being driven by a range of modern energy technologies, including Carbon Capture & Usage and Storage, Renewable Energy generation from Wind and Solar, which will support Green Hydrogen Production.



13. Decent Work and Economic Growth – Promote sustained inclusive and sustainable economic growth, full and productive employment and decent work for all.

Delivering the Cluster Plan requires significant financial investment in the Tees Valley. This investment is predicted to create thousands of new skilled jobs as well as thousands more safeguarded in the existing chemicals and processing industry that are critical to the Tees Valley economy.

13. **Industry Innovation and Infrastructure** – Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

Delivering the Cluster Plan requires the development and implementation of a range of sustainable, innovative industrial infrastructure across the industrial cluster, including the Carbon Capture Storage (CCS) network.

11. **Sustainable Cities and Communities** – Make cities and settlements inclusive, safe, resilient and sustainable.

The Cluster Plan focuses on delivering Net Zero within an industrial cluster. In doing this, the plan will benefit local communities through improved air quality and support the wider objectives of the Tees Valley Decarbonisation Strategy.

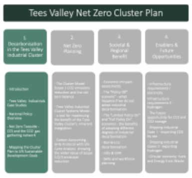
12. **Responsible Consumption and Production** – Ensure sustainable consumption and production patterns.

The Cluster Plan includes a number of projects that promote circularity and support the sustainable management and efficient use of resources. This includes Energy from Waste, Fuel from Waste and Chemicals from Waste projects.

13. **Climate Action** – Take urgent action to combat climate change and its impacts.

The Cluster Plan will deliver direct action to combat climate change by preventing more than 8,000,000 tonnes of CO2 being emitted into the atmosphere each year.

The development of a net zero cluster by 2040, as outlined by goals above, will enable the delivery of actions which will directly address the concerns of the United Nations and demonstrate UK commitment.


Tees Valley Net Zero Cluster Plan


Tees Valley
Net Zero
Cluster Plan
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Theme 2:

Net Zero Planning

Tees Valley Net Zero Cluster Plan

1. Decarbonisation in the Tees Valley Industrial Cluster	2. Net Zero Planning	3. Societal & Regional Benefit	4. Enablers & Future Opportunities
- Introduction - Tees Valley Indiustrials Case Studies - National Policy Overview - Net Zero Teesside - CCS and the CO2 gas gathering network - Mapping the Cluster Plan to UN Sustainable Development Goals	- The Cluster Model - Scope 1 CO2 emissions reduction and the net zero balance - Tees Valley Industrial Cluster Systems Model - - a tool for maximising the benefit of the Tees Valley cluster's inherent integration - Carbon Accounting - GHG Protocol with Life Cycle Analysis showing the wider value of Scope 1/2/3 emissiosn reduction	- Economic imnpact assessments - The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation - The "Limited Policy On" and "Full Policy On" scenarios - the benefits of adopting different degrees of industrial decarbonisation - Barriers to decarbonisation - Jobs & GVA - Skills and workforce planning	- Infrastructure requirements I - electricity Infrastructure requirements II - hydrogen - The future opportu]nity for CCS and CO2 storage - Shipping Industrial Gase I - importing CO2 by sea - Shipping Industrial Gases II - exporting hydrogen - Circular economy fuels and Energy from Waste

13 The Cluster Model – Scope 1 CO2 emissions reduction and the net zero balance.

13.1 Underlying Report

Title	Cluster Plan Framework Task7 – Development of the Cluster Model
Author	Element Energy
Filename	Task 5 Development of the Cluster Model.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-5-Development-of-the-Cluster-Model.pdf

13.2 Description

The principal aims of the Cluster Plan are to demonstrate how the Tees Valley industrial cluster can become a low-Carbon cluster by 2030 and the UK's first Net Zero industrial Cluster by 2040.

<u>Low-Carbon 2030</u>

"Low Carbon" does not have a formal definition. For this project our aim is that by 2030, the Tees Valley industrial cluster will have an operational Carbon Capture and Storage (CCS) system operating, which collects captured CO2 emissions from a range of industries, storing the CO2 permanently. The amount of CO2 stored by the 2030 will be approximately equivalent to current CO2 emissions, circa 4 MtCO2/yr.

<u>Net Zero 2040</u>

Net zero" is a higher target than "low-Carbon". The target will require the UK to bring all greenhouse gas emissions to net zero by 2050. Net zero means any remaining emissions would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere. This is difficult to apply on a sectorial and regional basis – for example, closure of the Teesside Integrated Iron & Steel works in 2016 reduced CO2 emissions by around 6 MtCO2/yr alone. The iron and steel formerly produced on Teesside is still required by UK infrastructure and buildings projects – it is now largely supplied by imports from countries where effective carbon taxes do not exist, the CO2 is not captured, and so these emissions have been "offshored".

A benefit of achieving Net Zero in the Tees Valley cluster is that the Net Zero Teesside CCS system enables many new industries with ambitions to be decarbonised to come to the region. This will be a huge benefit to the local economy in terms of jobs and GVA. \Many of these industries will have CO2 emissions that can be captured and stored by Net Zero Teesside CCS project via the NEP. For example – NZT Power and the two proposed "blue" hydrogen projects – bp's H2 Teesside and Kellas Midstream's H2 NorthEast – could produce decarbonised electricity and hydrogen at scale whilst capturing their CO2 emissions through the T&S network.

A fundamental principal for Net Zero is that once atmospheric CO2 emissions have been reduced as far as practicable, the remining emissions must be balanced by "negative" emissions. This is the definition that we have followed in the Cluster Plan to demonstrate how the Tees Valley industrial cluster can achieve Net Zero.

13.3 The Cluster Model

We commissioned Element Energy through our suppliers' framework to develop a modelling tool for decarbonisation in the Tees Valley industrial cluster. This tool has a range of features:

<u>Operation</u>

The model was written in Python and can be operated via a MS Excel interface, it does not need any programming expertise to operate and carry out scenario planning and analysis.

<u>Data Access & Modularity</u>

It accesses the data provided by the Tees Valley industrials and collates this in different scenarios defined by the user. The format for the spreadsheet data that was collected for each industrial during the Cluster Plan project was defined by Element Energy so these datasheets could be used directly as the input data for the model.

The model is modular and dynamic – each industrial is treated as a separate module of data. It is easy to omit industrials from a specific analysis (e.g., decarbonisation without hydrogen projects; or analysis of existing industries only). Similarly, it is easy to bring in new industrials to the analysis as more industries come to the Tees Valley.

<u>Data Used in Analysis</u>

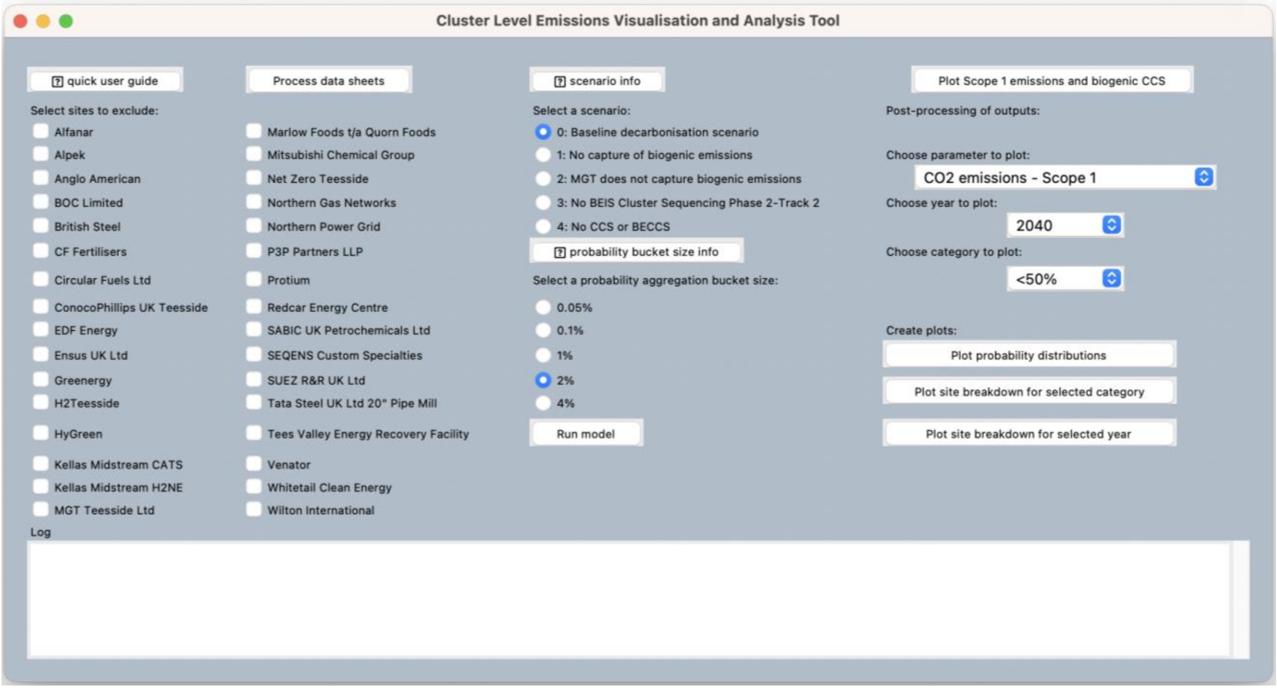
Depending on data availability, the model can carry out scenario analysis for:

- CO2 emissions to atmosphere – Scope 1 emissions
- CO2 emissions captured – i.e., Scope 1 emissions to CCS.
- Biogenic CO2 emissions (i.e., non-Scope 1 emissions)
- Biogenic CO2 captures (i.e., negative emissions)
- Hydrogen export (HHV)
- Natural Gas fuel demand (HHV)
- Oil fuel demand (HHV)
- Biomass/biofuel demand (HHV)
- Other fuel use (HHV)
- Electricity imports
- Steam imports
- Waste heat rejected to environment.

Enabling all these features in the model depends on the data being available and supplied by the industrials in the cluster. This range of data possibilities in the model will allow it to be used for different types of scenario planning over time. To date, it has not been possible to gather data from the cluster industrials over all these variables and the analysis presented in this Cluster Plan report focuses on Scope 1 CO2 emissions (captured and release to atmosphere) and biogenic CO2 emissions (likewise captured and released to atmosphere. This is sufficient for us to carry out scenario planning for Net Zero 2040.

Interface & Defined Scenarios

The User Interface for the model is shown below. It allows different industrials to be included/excluded from the analysis and includes 5 pre-set options for analyses. These were selected during the Cluster Plan project as examples of different decarbonisation scenarios:



0. Baseline decarbonisation scenario – this includes all the decarbonisation planning scenarios of all the industrials without further restriction from government policy, Cluster Sequencing or other lack of funding.
1. No capture of biogenic emissions – this follows the baseline but excludes negative emissions to demonstrate how dependent the Tees Valley cluster will be on negative emissions.
2. MGT Teesside does not capture biogenic emissions – this is a modification of Scenario 1. MGT Tee Teesside is potentially a large contributor to negative emissions. However, under the current rules they are not eligible for a CfD to implement CCS as they hold equivalent support from the government for bioenergy.
3. No BEIS Cluster Sequencing Phase-2 / Track-2 – this investigates the outcome of a limited number of CO2 emitter projects gaining support under the Cluster Sequencing programme.
4. No CCS or BECCS – this is the counter-factual used to describe what would happen without any CO2 capture projects progressing in the Tees Valley.

Each of these scenarios is addressed in Element Energy's report. To some extent these have been superseded by events: (i) currently the only emitter projects supported under Cluster Sequencing Track 1/Phase 2 are NZT Power, H2 Teesside and BOC's carbon capture project; (ii) there is no information currently available from DESNZ on the Track-1 Expansion project; (iii) more new industries are developing their projects in the Tees Valleys. Significant additional sources of CO2 may be

generated by the Green Lithium and Tees Valley Lithium projects which we are currently bringing in to the Cluster Plan.

<u>Statistical Analysis</u>

The model has been configured to provide statistical analysis to determine the likelihood for a given amount of CO2 to be emitted or captured by a given date. We understand that there is a large degree of uncertainty amongst the industrials over which projects and processes will be eligible for decarbonisation; which decarbonisation method will be implemented (e.g., CCS or fuel-switching to hydrogen); which projects will be given backing and financial support by the government; and the commitment at board level and of investors towards decarbonising industries in the Tees Valley. When we collected data from the industrials, we asked them to provide a likelihood for each decarbonisation pathway that they presented. This provides the underlying probabilities for the statistical analysis.

13.4 The Route to Net Zero

The Tees Valley industrial cluster is made up of a small number of large CO_2 emitters and a larger number of small emitters. Currently the large emitters include chemical works; power and heat (steam) generation; and waste processing and recovery. Bioenergy also generates a large amount of CO_2 emissions, but this is not included in the Scope 1 total as these emissions are not due to combustion of fossil fuels. Capturing the emissions from bioenergy can provide "negative emissions" which are vital in establishing Net Zero in the industrial cluster to offset residual CO_2 emissions which cannot be captured and stored.

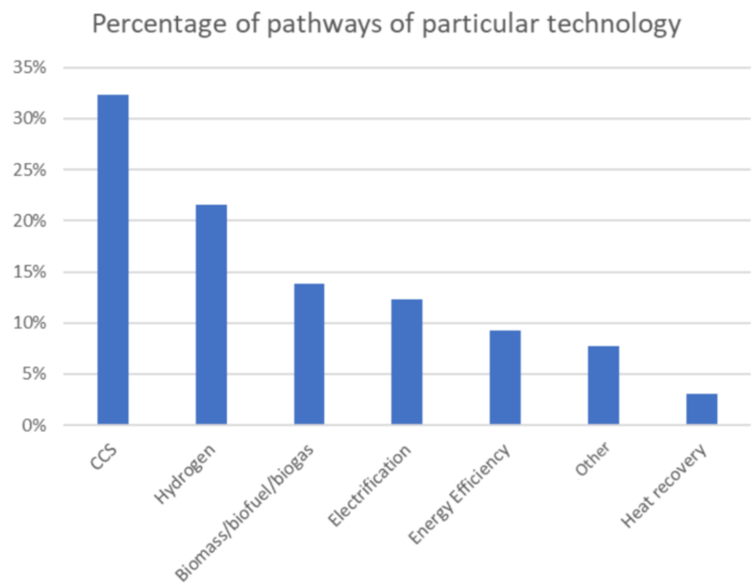


Fig 04 Contribution of different technologies

The data provided by the industries in the cluster show that 32% of the potential decarbonisation pathways will require CCS – this includes both capture of biogenic and non-biogenic emissions.

Fuel switching to hydrogen, biomass/biofuel/biogas, and electricity are the next three largest fractions of technology options. Though it's important to remember that the bulk of the hydrogen available will be "blue" hydrogen – i.e., steam methane reformed hydrogen produced from natural gas with CCS to remove the CO2 by-product. Also, much of the electricity available in the cluster will be provided by new power stations with pre- and post-combustion CCS.

This means that in total 53 – 65% of the decarbonisation pathways in the Tees Valley industrial cluster will be reliant on CCS in some way.

The cluster decarbonisation model looks at both the technological opportunity for decarbonisation and the probability that the decarbonisation technologies will be implemented. The probabilities have been assigned by the industrials themselves based on their current understanding of the drivers affecting their business: carbon taxes; markets; corporate policy; and technology availability. This allows us to look at and plan for many pathways to deep decarbonisation.

13.5 Low-Carbon 2030 Target

At the time of writing this report, Net Zero Teesside and Northern Endurance Partnership – together forming the East Coast Cluster – have passed into the negotiation stage of DESNZ's Track 1 Cluster Sequencing project. Final Investment Decision will be made in 2024 with the current intention that the CCS will be operational in 2027. It is likely that the initial capacity for NZT will be around 4 MtCO2/yr, building to 10 MtCO2/yr in later years.

The current position under Cluster Sequencing Track-1/Phase-2 is that the only CO2 emitters entering the negotiation stage for government support will be: NZT Power, bp's H2 Teesside and BOC's carbon capture project for their existing steam methane reform hydrogen production.

- Between then these projects will capture around 3.8 MtCO2/yr, split as follows:

• NZT Power	• H2 Teesside	• BOC CCS
• 1.6 MtCO2/yr	• 2.0 MtCO2/yr	• 0.2 MtCO2/yr

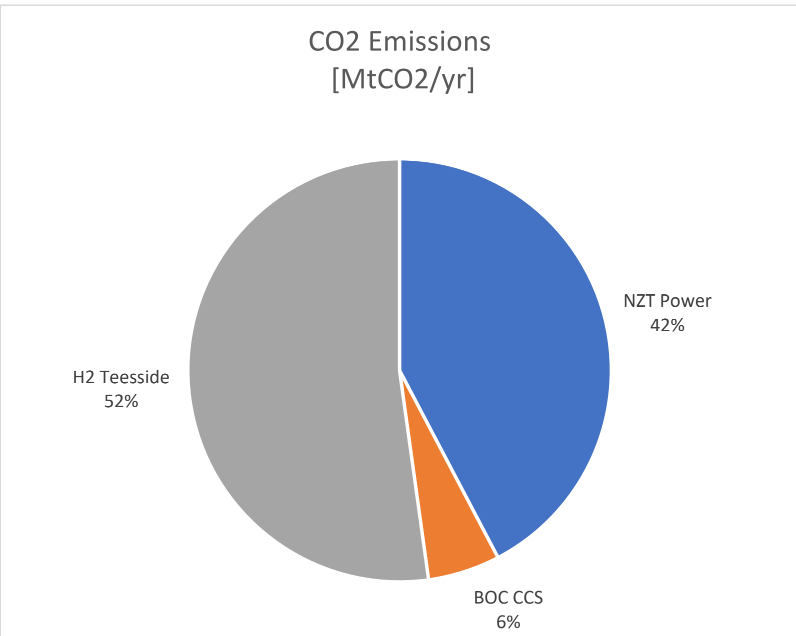


Fig 05 Shares of capture capacity

This is roughly equivalent to the typical annual emissions of the Tees Valley industrial cluster, which are often stated at around 4.6 MtCO2/yr from the 2019 reported emissions data. However, throughout 2022 and in 2023 CF Fertilisers – one of the major CO2 emitters in the cluster have not been operating their SMR process which itself emits around 1 MtCO2/yr. If this continues up to 2030 then the

emissions from the Tees Valley industrial cluster may be around 3.6 MtCO_2/yr matched closely by the CO_2 captured at stored by Net Zero Teesside and it is reasonable to claim that the cluster will be operating as a low-Carbon cluster.

There are some subtleties to this. Firstly, the bulk of the CO_2 captured will be from new industries – NZT Power and H_2 Teesside. Only 6% of the emissions captured will be from an existing process. However, the hydrogen produced by H_2 Teesside will be used by other industries in the cluster as they fuel-switch away from natural gas for process heat and power. Similarly, NZT Power will provide decarbonised electricity to other industrials, reducing their Scope 2 emissions.

It is difficult to quantify the cumulative effect of these actions – especially as the hydrogen offtake agreements from H_2 Teesside are not currently formalised or public. However, the 1 GW of blue hydrogen produced by H_2 Teesside will go a long way to further reducing Scope 1 CO_2 emissions to atmosphere below the 3.6 – 4.6 MtCO_2/yr range we have described here.

13.6 Net Zero 2040 Target

The modelling shows that by 2040 the cluster could be capturing 8.4 MtCO_2/yr of Scope 1 CO_2 emissions for storage in the Net Zero Teesside CCS system. These are the CO_2 emissions from burning fossil fuels for power and heat and those released from chemical processes. Comparing the captured Scope 1 emissions with the current baseline of 4.6 MtCO_2/yr shows that by 2040 the industrial cluster will capture over 180% of the baseline emissions.

The plot below shows the industries with the major contributions to Scope 1 CO_2 emissions that can be captured and stored in the Net Zero Teesside system. The different colour bands indicate the different industrials and looking at the “blue hydrogen” projects in particular – these will account for nearly 50% of the CO_2 captured and stored. This demonstrates how the Net Zero Teesside CCS project both enables new decarbonised industries in the Tees Valley and will be essential for decarbonising existing industries.

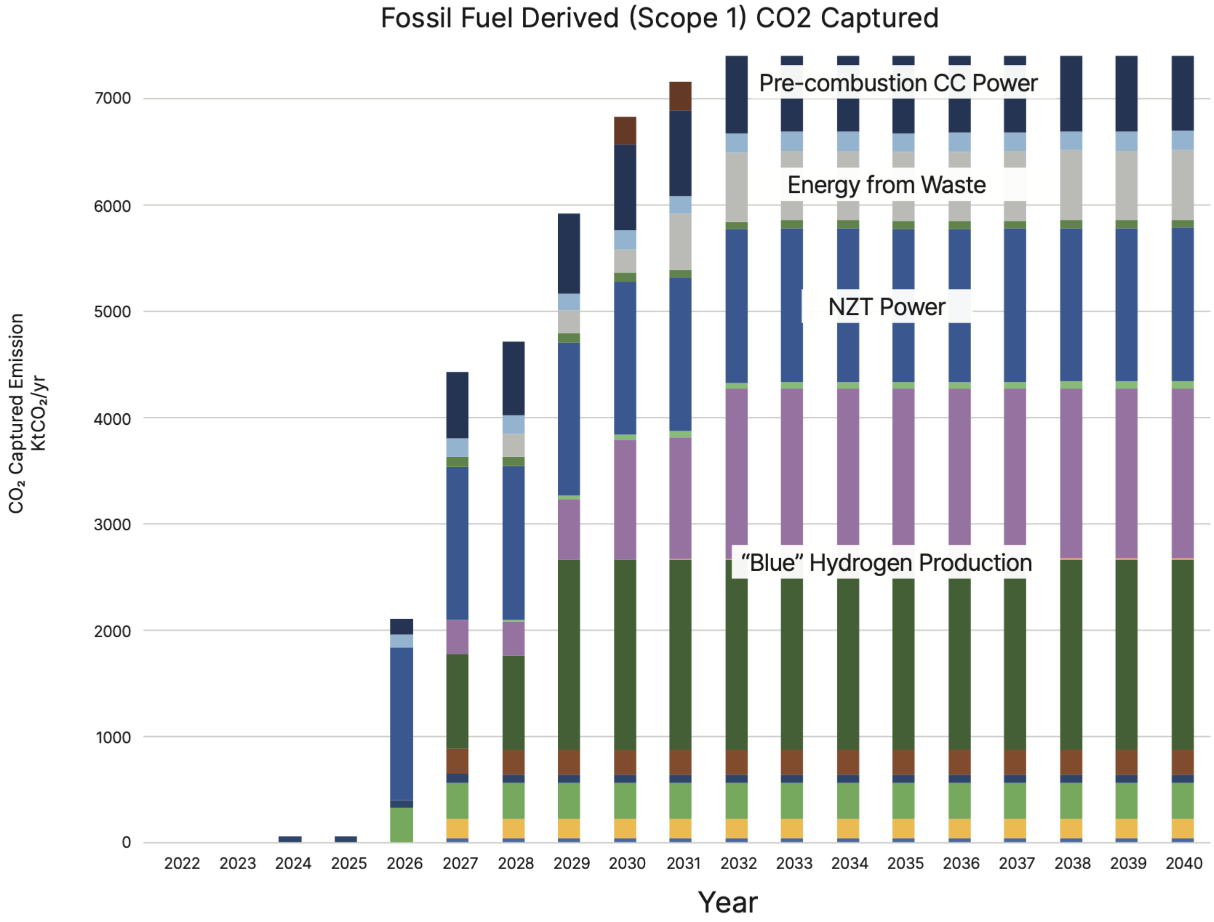


Fig 05 Captured Emissions by source

Decarbonisation technologies are not 100% efficient and other industries will not be able to decarbonise. The residual CO2 emissions from these industries could be up to 1.5 MtCO2/yr as shown in the plot below.

However, the cluster also has bio-energy power and circular economy chemical and fuels production. CO2 emissions from these have a high biogenic content and a large potential for negative emissions. Up to 2.7 MtCO2/yr of CO2 from these biogenic sources will be available for capture and storage. Storing CO2 with biogenic origin effectively removes CO2 from the atmosphere creating the "negative emissions" and can potentially more than offset the residual Scope 1 CO2 emissions.

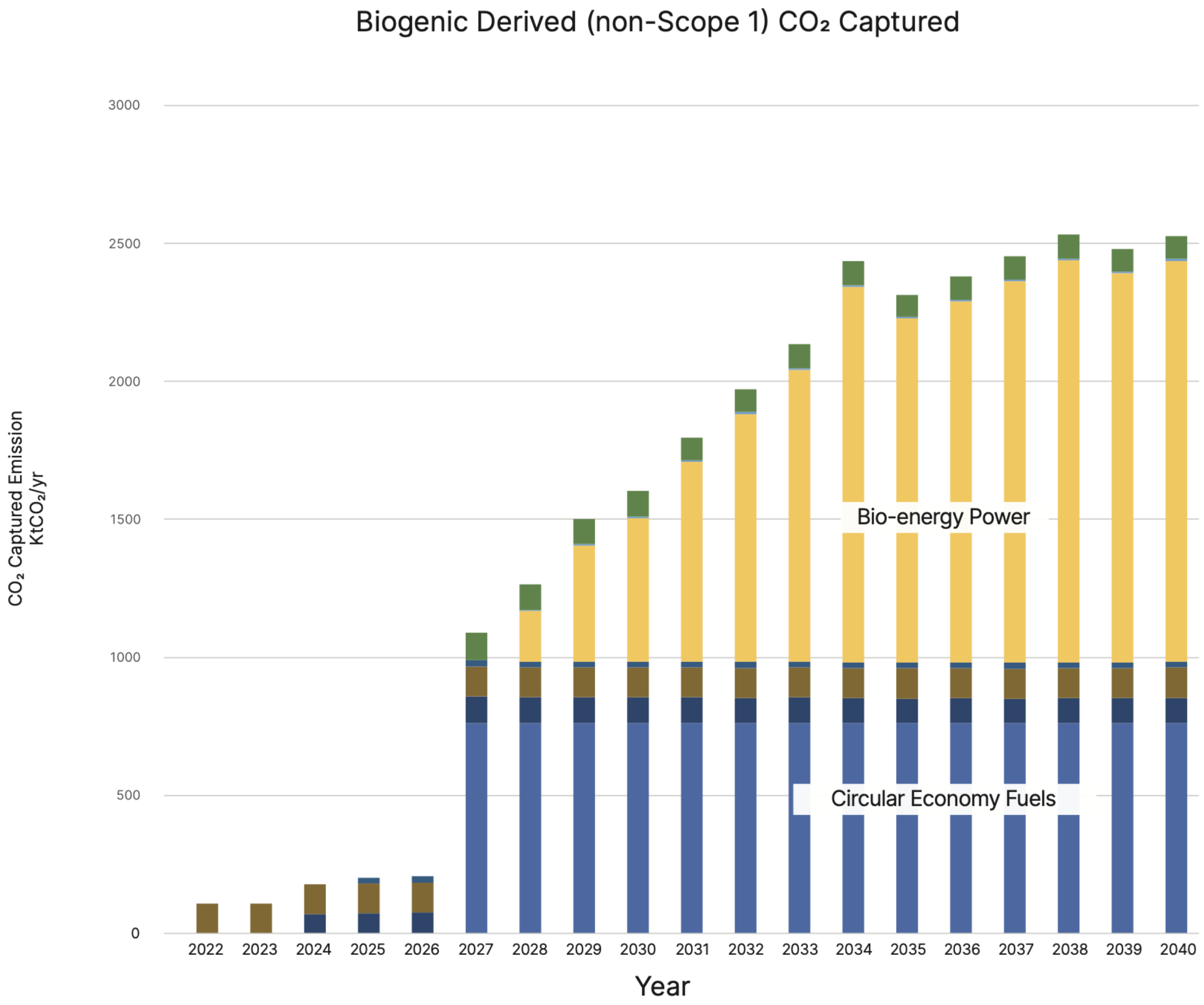


Fig 06 Biogenic CO2 captured.

Net Zero Teesside is being designed to transport and store up to 10 $MtCO_2$/yr. Our analysis shows that if 8.4 $MtCO_2$/yr of the capacity is from Scope 1 CO_2 emissions, then the remaining 1.6 $MtCO_2$/yr capacity can be taken by captured CO_2 of biogenic origin.

This balances the 1.5 $MtCO_2$/yr residual Scope 1 CO_2 emissions and ensures the industrial cluster meets Net Zero.

Headline Results from the Analysis

The headline results from the CO2 modelling and analysis show that the Tees Valley industrial cluster will:

- 2030 – capture and store CO2 volumes equivalent to our current industrial clusters' emissions
- 2030 – become a low-Carbon cluster by 2030
- 2040 – become the world's first Net Zero integrated industrial cluster
- 2040 – capture and store 180% of the 2020 baseline CO2 emissions

Due to the influx of new decarbonised industries enabled by NZT CCS, and the large number of emitters currently unable to connect to the CCS due to government policy and other drivers, the cluster will be reliant on negative emissions to maintain the Net Zero balance.

Negative emissions at 1.6 $MtCO_2/yr$ – or 16% of the total CO_2 stored – is a relatively high value. To put this in context:

- The Science Based Targets Initiative limits organizations' residual emissions to 10% (reduction = 90%)
- The IEA's Net Zero Emissions Scenario reduces industrial CO_2 by 95%.

These are both tighter constraints on residual emissions than we have modelled in the Tees Valley. It is important to bear in mind that residual emissions and negative emissions are not created by the same industries. This shows us that to reach Net Zero in the Tees Valley industrial Cluster we will need, alongside further expansion of CCS capacity:

- Legislation and government support to allow negative emissions to be attributed to industries with residual emissions.
- Collaboration between different industrials.
- Carbon accounting – to understand where the different captured, emitted and negative emissions lie within the cluster.
- And most importantly – a sense of shared purpose.

13.7 Key Risks

The statistical approach that we have taken in the cluster modelling has allowed us to identify key risks. These are presented below in a 4-box model that shows the combinations of Low CO_2 Stored and High CO_2 Stored vs. High and Low probabilities.

- High probability of large volumes of CO_2 stored:
  This is the outcome and set of scenarios that defines the decarbonised industrial cluster.
- Low probability of small volumes of CO_2 stored:
  This is not particularly troublesome as it describes an undesired outcome that is unlikely to happen.
- High probability of small volumes of CO_2 stored:
  This is an undesired outcome, and we need to identify and mitigate the pathways that lead to this outcome.
- Low probability of large volumes of CO_2 stored:
  This is similar to the previous point and also need to be understood and mitigated.

Some of the CO2 pathways and influences that Element Energy identified in their report leading to these different outcomes are shown below:

	Likelihood	
	Low	High
High CO2 Stored / Low Residual CO2	Capture of biogenic emissions by Redcar Energy Centre, TV ERF, SUEZ, Greenergy, Ensus, and Circular Fuels are much smaller than the potential of MGT Teesside and alfanar. If there is doubt over successful high rates of capture from the EfW and bio-fuels projects this is unlikely to have a large impact on achieving Net Zero. The corollary to this is that there is a high dependence on MGT Teesside and alfanar implementing CCS as these are the largest potential sources of negative emissions.	Production of low-carbon hydrogen on Teesside will enable industries to decarbonise by fuel-switching. An example of this is SABIC. When the Olefins-6 cracker is converted to hydrogen fuel (anticipated by 2034) SABIC's scope 1 CO2 emissions will be zero. As one of the largest emitters currently, this would be a laudable success.
Low CO2 Stored / High Residual CO2	Sufficient supply chains for low carbon hydrogen, renewable electricity, and sustainable sources of biofuel/biomass need to be established. These are three key "fuels" that the industrials are counting on for decarbonisation. It is particularly important that sufficient supply chains are developed for low-carbon hydrogen projects in the Tees Valley cluster as these will support decarbonisation options for the other Industrials. This is a two-way process as Industrials with supply-chains set up to fuel-switch to hydrogen will support low-carbon hydrogen projects by anchoring and securing a hydrogen demand close to its production.	There are several large CO2 emitters who are currently not able to carry out decarbonisation planning. An example is the Suez Recycling and Recovery facility at Haverton Hill. Currently Suez are excluded from the cluster sequencing process. Although they are able to make robust engineering and financial plans for CO2 capture – under current DESNZ policy they will not be allowed to connect to NZT. Without carbon capture infrastructure, 1/3rd of all decarbonisation pathways cannot be implemented, and Scope 1 emissions will remain high. Without subsequent Tracks in the Cluster Sequencing program, capture of biogenic emissions will remain small. MGT Teesside and alfanar should be enabled to execute their plans to maximise capture of biogenic emissions

14 Tees Valley Industrial Cluster Systems Model

14.1 Underlying Report

Title	TVCA Task 8 – Systems Study User Guide to the Tees Valley Systems Model Systems Model Viewpoints
Author	Frazer Nash Consulting
Filename	Task 6a User Guide to Tees Valley Systems Model.pdf Task 6b Systems Model Viewpoints.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-6a-User-Guide-to-the-Tees-Valley-Systems-Model.pdf https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-6b-Systems-Model-Viewpoints.pdf

14.2 Description

The Tees Valley industrial cluster has a full history of integration and legacy infrastructure which enables many of the industries in the cluster and will drive forward decarbonisation projects. Much of this has been developed through the former Teesside Integrated Iron & Steel works – now being redeveloped as the Teesworks brownfield site; and the originally ICI built integrated chemical works – now operated by a range of separate companies.

Some of the features that this enables are:

- Co-located site services – such as Sembcorp's operation of the Wilton International site supplying electricity and heat (steam) to other industries on the site.
- Steam supply between industries – e.g., when CF Fertilisers is operating it supplies steam to Marlow Foods (Quorn).
- Service corridors for liquids, gases, steam, electricity
- Electrical supply infrastructure and licences
- Water supply – the steelworks' operation formerly had a large requirement for water.
- Natural gas supply for power generation and process heat
- Industrial gases and liquids pipe networks – there are pipe networks and river crossings for multiple industrial products around Teesside, including hydrogen.
- Existing hydrogen pipe network and storage caverns.
- Tank storage operations – notably Navigator Terminals – with the ability to import / export hydrocarbons and industrial gases.

TVCA is also talking with project developers in Teesside who want to operate CO2 hubs to aggregate sources of CO2 either for onward delivery to CCS or for use in Sustainable Aviation Fuel, and other Fuels-from-Waste projects.

Looking to the more distant future post-2030, there are aspirations to develop new nuclear technology at the current EDF Hartlepool site. Known as the Hartlepool Heat Hub project – this may either be through SMR or other modular reactor technology and has the potential to supply steam at different grades across Hartlepool and Teesside.

TVCA wanted to capture these multiple interactions with the industrial cluster in a Model Based Systems Engineering approach and appointed Frazer Nash Consulting to provide this “Systems Model” of the industrial cluster. This model is an important tool for understanding the current configuration and interdependencies in the cluster, and for future planning, efficiencies and effectiveness of the cluster.

The Systems Model developed for TVCA by FNC has already been used in some of the studies under Theme 4: Enablers & Future Opportunities.

14.3 Model Description

The overall objective of the model is to be a tool which can support interrogation of the existing and future relationships between industries within Tees Valley, in particular those associated with the transportation of carbon and other materials into and out of the system.

Tees Valley industrial cluster is a complex entity comprising a large number of industrials spanning a range of industries within a relatively compact footprint which are, to varying degrees, interconnected. The interactions between industrials take various forms such as the transfer of material, shared resourcing, or ownership agreements. At a whole system level there are commonalities or complementary requirements between some industrials meaning that a macro-economic factor could present barriers and enablers which apply to the whole system when it comes to decarbonisation. Further to the cluster-wide interactions, Tees Valley can also be considered by analysing each component geographic “mini-cluster” in turn, these are: Billingham, Wilton, Seal Sands, South Bank and Hartlepool.

The Industrial cluster is a “system of systems” which contains sufficient complexity to require a flexible systems model to support its interrogation from the desired range of perspectives. The overarching objective of a proposed systems model is to characterise the system of systems in the Tees Valley industrial cluster in such a way as to support decision making aligned with a successful transition to low-Carbon operation by 2030 and net zero operation by 2040.

Model Base Systems Engineering (MBSE) is a formalised methodology which centres around flexible modelling to connect elements together and characterise relationships and was deployed to construct this model. The tool used Cameo Systems Modeller which is specialist MBSE software; the model exists as an export from this software as an explorable html.

The core systems engineering views used to support the assessment are:

- A source element view: A mechanism for capturing all relevant source information and standardising sources by tagging information such as date, version, and location.
- A definition rule set view: A simple view of how materials (e.g., carbon and other emissions, energy vectors and feedstocks) flow in the system at present and any known actors these are associated with.
- A product breakdown structure: A description of the physical assets at a useful level of abstraction and their locations within the system and constituent clusters

The model was generated via a parallel approach of building a structured model using key systems engineering principles, whilst also retaining an end view of the key questions for which an answer was being sought. These key questions were derived from the overall system objective to constitute a more tangible suite of outputs which might be useful in the immediate term. It should be noted that this is not an exclusive list and that the model lends itself to explore a range of other aspects of the industrial cluster. They are:

- How is this energy currently generated and where could it be replaced with green alternatives?

- Could the excess carbon be captured/stored/transferred/used as part of the circular economy?
- What is the current hydrogen production rate from the cluster?
- What is the planned hydrogen production rate for the cluster?
- How is the hydrogen captured/stored/transferred/emitted?
- Could the excess hydrogen be captured/stored/transferred?
- Are there new industrials in the cluster seeking additional hydrogen supply?
- What hydrogen pathways are available in the cluster?
- What wastes are currently produced within the cluster?
- How are the wastes produced dealt with?
- Could these wastes be utilised by another industrial?

The model considered a range of industrial maturity status, that is, those which are **operational, under construction or planned.** Each industrial was treated as a black box with respect to the transfer of material; the key processes happening at each site are not detailed explicitly. By establishing the **inputs** and **outputs** as well as **waste**, **other revenue streams**, and **pathways,** a functional viewpoint was developed for each industrial.

The model is not intended to be a site layout document but rather to support functional interrogation. For instance, where a pathway exists this does not necessarily mean that the same material which leaves an industrial is all delivered to another but rather that this material is a communal model pathway.

14.4 Model Navigation

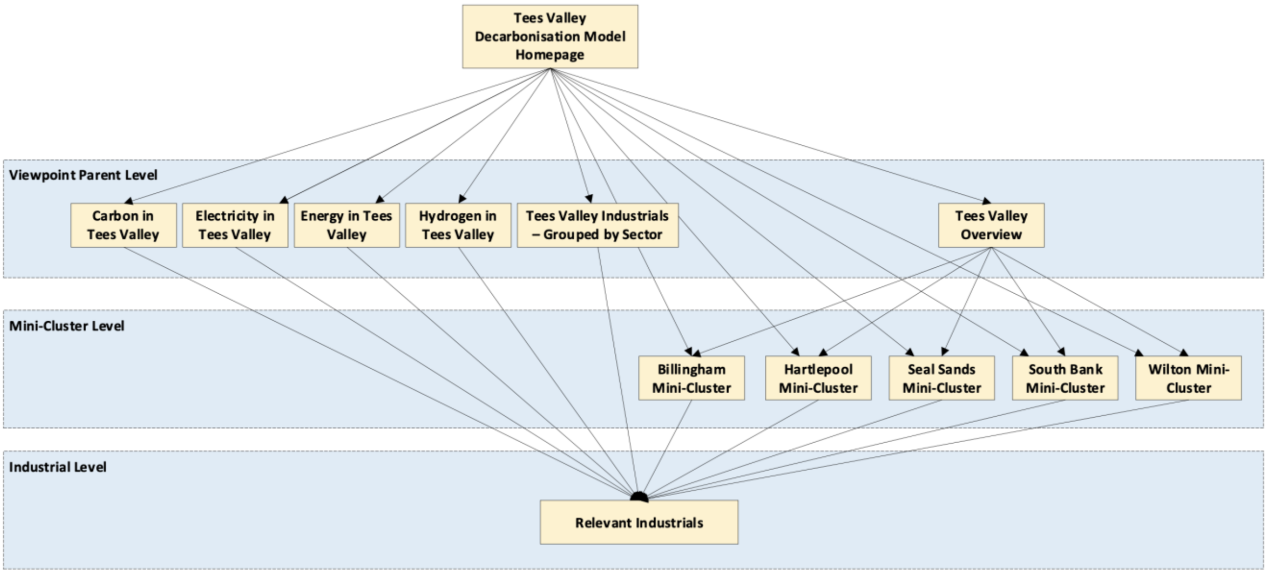
The model's homepage contains links to 11 key model overviews. These are the primary access points for potential model users and so have been selected to cover the main categories of potential query. The numbers in the list refer to the index number of each viewpoint – in total FNC have assembled 271 separate viewpoints for the cluster:

- Tees Valley Overview (#1)
- Carbon in Tees Valley (#4)

- This also refers to the "Key emissions" diagrams which do not strictly include only carbon but also other greenhouse gas emissions.

- Electricity in Tees Valley (#23)
- Energy in Tees Valley (#11)
- Hydrogen in Tees Valley (#29)
- Tees Valley Industrials – Grouped by Sector (#37)
- Each of the mini cluster views, that is:
  - Billingham Mini-Cluster Overview (#46)
  - Hartlepool Mini-Cluster Overview (#92)
  - Seal Sands Mini-Cluster Overview (#132)
  - South Bank Mini Cluster Overview (#179)
  - Wilton Mini-Cluster Overview (#223)

The viewpoint structure is shown below:



The available downloads for the Systems Model include:

- A user guide.
- A large PDF containing all the viewpoints from the model, so that the entire model can be accessed without specialist software.
- A HTML version of the model.
- The Systems Model itself in Cameo Systems Modeller format (requires licence).

15 Carbon Accounting – GHG Protocol with Life Cycle Analysis

15.1 Underlying Report

Title	Industrial Cluster Carbon Accounting Methodology
Author	Fraser Nash Consultancy
Filename	Task 7a Industrial Cluster Carbon Accounting Methodology.pdf Task 7b Industrial Cluster Carbon Accounting User Guide.pdf Task 7c Industrial Cluster Carbon Accounting Workbook.xlsx Task 7d Carbon Accounting Methodology Example Workbook Redacted.xlsx Task 7e Review of Cluster Decarbonisation Papers.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-7a-Industrial-Cluster-Carbon-Accounting-Methodology.pdf https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-7b-Industrial-Cluster-Carbon-Accounting-User-Guide.pdf https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-7c-Industrial-Cluster-Carbon-Accounting-Workbook-.xlsx https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-7d-Carbon-Accounting-Methodology-Example-Workbook-Redacted.xlsx https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-7e-Review-of-Cluster-Decarbonisation-Papers.pdf

15.2 Description

The principal aim of the Cluster Plan project as set out by Innovate UK in the Industrial Decarbonisation Challenge, is to provide a roadmap to decarbonisation in the Tees Valley industrial cluster through Scope 1 CO2 emissions. For clarity under the Greenhouse Gas Protocol[5]:

Scope 1: Direct GHG emissions Direct

- GHG emissions occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment.
- Direct CO2 emissions from the combustion of biomass are not included in scope 1 as the source of CO2 is not from fossil fuels.

Scope 2: Electricity indirect GHG emissions

[5] https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

- GHG emissions from the generation of purchased electricity consumed by the company. ‘Purchased’ electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company.
- For industries that also purchase heat energy (as steam) we include the GHG emissions from the generation of the steam.

Scope 3: Other indirect GHG emissions

- Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

In the Tees Valley there are current industries and future planned industries that provide or will provide a positive impact on decarbonising the UK as a whole. In terms of the GHG Protocol definitions, these come under ‘Scope 3’ as avoided emissions. There are many examples – some of which are:

- Greenergy Bio-diesel production
  - Greenergy make biodiesel from Used Cooking Oil (UCO) which is sourced globally. The biodiesel is widely used in the UK and forms 7% of the content of diesel fuels for transport bought at the forecourt. It is the ‘B7’ content of the diesel that is marked on pumps. Greenergy pay carbon taxes through UK ETS for this production process.
- Marlow Foods (Quorn) vegan food
  - Vegan food displaces meat from diets across the UK. Manufacture of Quorn requires some CO2 emissions – in the past these have been mainly ‘Scope 2’ emissions from steam purchased from CF Fertilisers. Marlow Foods have moved towards generating their own heat and are investigating ways to decarbonise this process. Their food is marketed as “Carbon Neutral’ and ‘Net Positive’ due to the avoided emissions.
- Fuels from Waste – SAF and rDME
  - Alfanar are developing their Lighthouse Green Fuels project to produce Sustainable Aircraft Fuel (SAF) from waste. Circular Fuels Limited are developing their production of rDME from waste – a drop-in replacement for patio gas. These are new projects and if they exceed the minimum standards for UK ETS, they will pay carbon taxes through this system.

Others that could potentially be added to this list, but have a subtly different impact are:

- Ensus Bio-ethanol production.
  - Ensus produce bioethanol from fermentation of biomass. The CO2 produced – from process heat and the fermentation process – is not a Scope 1 emission as it does not originate from fossil fuels. The bioethanol is used widely across the UK and forms 10% of petrol bought at forecourts. It is the ‘E10’ content of petrol marked on pumps.
- Blue Hydrogen production.
  - Blue hydrogen production will provide the industrial-scale quantities of hydrogen needed to decarbonise industry in the first instance and potentially also domestic heating in the longer term. With suitable purification it may also be used to decarbonise transport. Blue hydrogen production is dependent on CCS and may avoid or minimise its carbon taxes through the UK ETS scheme as around 95% of the Scope 1 CO2 emissions will be captured and stored.

Within the Cluster Plan it is important for us to recognise the impact that Tees Valley industries have in decarbonising the rest of the UK economy. We looked at current methods for carbon accounting, including the GHG Protocol and realised that these did not contain all the features we needed to

ensure that these industries were being properly recognised for the contributions that they make to decarbonising the wider UK economy.

We appointed Frazer Nash Consultancy (FNC) to research and develop the bespoke carbon accounting methodology for the Tees Valley cluster plan.

15.3 Other Carbon Accounting Methods

Within the Cluster Plans programme, both the Black Country and South Wales cluster plan projects have had similar concerns for carbon accounting and have carried out their own research for carbon accounting and as part of the download documents we have included a review of the three studies (Tees Valley; Black Country; South Wales).

We have also provided input to the Energy Systems Catapult review of carbon accounting methodologies[6]

15.4 Carbon Accounting Methodology

The methodology is aligned to the Greenhouse Gas Protocol and extends the principles to enable cluster-wide accounting. It aims to provide the means to track all forms of carbon across the cluster, enable organisations within the cluster to understand their carbon emissions and transfers in more detail, build greater alignment and consistency of reporting and assist in designing solutions to meet net-zero goals.

It Is intended that the Tees Valley Cluster can use this methodology to track progress to being a net-zero cluster, and beyond net-zero to 'carbon negative', when the cluster's removal of carbon dioxide from the atmosphere will exceed its emissions, in support of net-zero UK.

The methodology maps out four levels of data granularity, with Level 1 being the least granular, designed for the first year of adoption when the availability of data may be a limiting factor. It may take several years to reach Level 4, the level of data maturity required for a full mapping of cluster-wide emissions and transfers.

Currently, carbon accounting generally only occurs at an organisational or product level. Existing methodologies, e.g., GHG Protocol standards and guidance, are not designed for groups of organisations such as industrial clusters. However, adaptation of the available guidance has enabled the development of a cluster-wide carbon data collection and aggregation approach.

Current Practice:

- Organisational & product level carbon accounting; Limited scope 3 emissions data.
- Calculations are made at an organisational level.
- Limited guidance on aggregation of carbon accounting for multiple inter-related organisations.

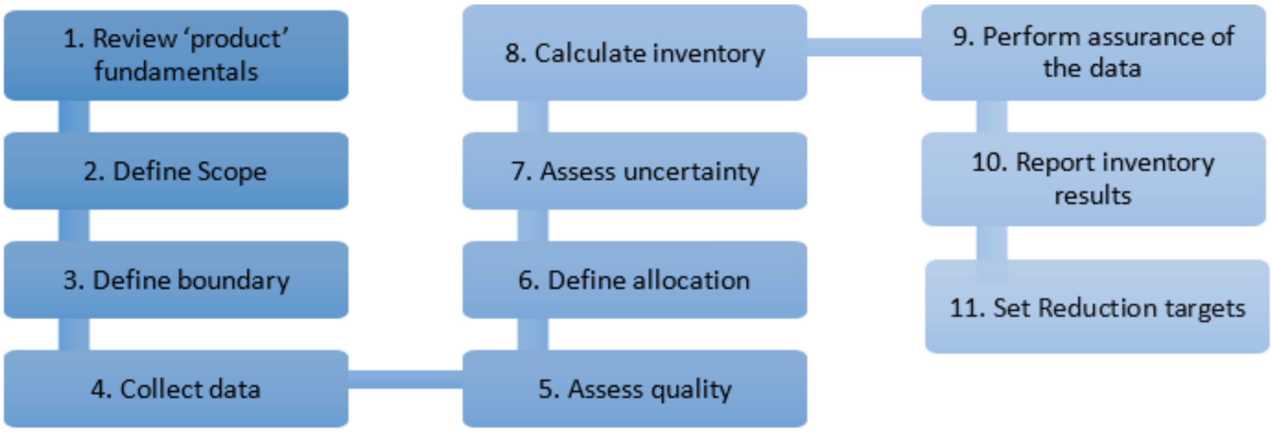
Cluster Methodology:

- System-wide carbon data collection and aggregation.
- Identify interfaces between organisations.
- Incorporate transfers of carbon.
- Provide recognition of avoided carbon and carbon reductions.
- Align different organisations' data and accounting practices to minimise gaps, double counting, misalignment and misreporting.

The methodology is based on the GHG Protocol Product Life Cycle Accounting and Reporting Standard, with the introduction of additional calculation steps to capture cluster-level pathways, transfers and outcomes such as avoided carbon.

[6] https://es.catapult.org.uk/news/existing-carbon-accounting-practices-holding-back-decarbonisation-efforts/

The methodology looks at carbon emissions using a life cycle approach, in which the 11 life cycle accounting steps have been adopted:



The cluster carbon accounting methodology has been developed to capture the carbon data within separate inventories. Whilst all data falls into scope 1, 2 or 3, recognition of how the data flows, and moves into, across and out of the cluster provides information that can support:

- Capture of existing carbon management arrangements,
- Identify opportunities for decarbonisation, and
- provide an understanding of how carbon is used as a commodity.

GHG Inventories
Scope 1 Carbon Emissions
Scope 2 Carbon Emissions
Scope 3 Carbon Emissions
Carbon Pathway Inventories
Carbon Removal
Carbon Transfer Inventories
Carbon moving into the Cluster as fuel/ products
Carbon transferred within the Cluster
Carbon transferred out of the Cluster
Carbon Capture & Storage
Carbon Outcome Inventories
Carbon Avoided
Carbon Reductions
Increased Carbon
Carbon Reduction Targets
Carbon Targets (tCO$_2$e) – total reduction, starting baseline and delivery timeframe
Annual Progress to targets (tCO$_2$e) to date
Planned actions

15.5 Maturity Level Approach

The methodology acknowledges that the cluster carbon mapping methodology is an evolving process where all cluster industrials are at different stages in their decarbonisation journey. As a result, not all

industrials will have the capability to record and calculate all inventories. A phased approach has been developed, comprising 4 data maturity levels.

With an aligned accounting and reporting approach the Tees Valley Combined Authority will be able to create a baseline of emissions and have clarity on the total carbon pathways and transfers across the cluster, as well as visibility of the industrials' decarbonisation plans.

Capture of data by the cluster industrials will evolve and improve over time. As data granularity increases, the cluster will be able to develop stronger, more focussed net-zero strategies.

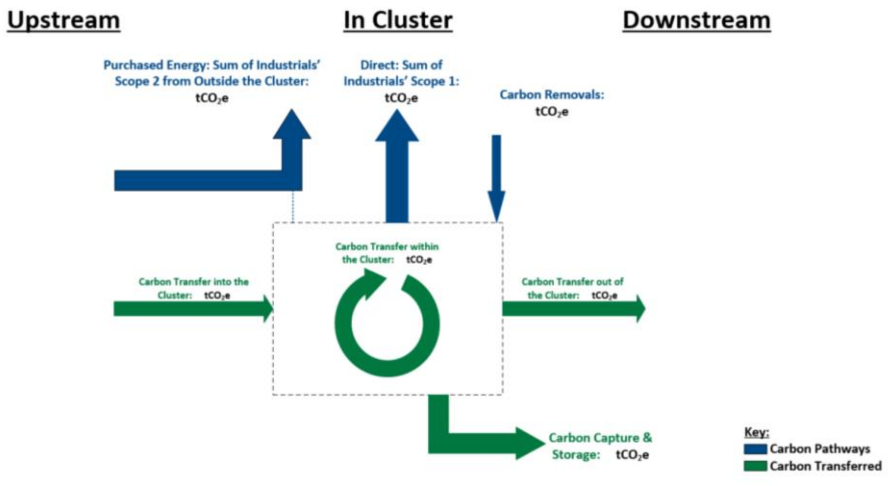
Reporting carbon emissions on a regular basis will enable tracking of changes in each scope and inventory. As the picture develops over time, it will enable progress towards net-zero to be monitored and communicated.

15.6 Graphical Representation

One of the important aims we set FNC in developing this work is that there should be a graphical reporting method to sit alongside the numerical reporting. We wanted the new carbon accounting methodology to have a visual impact which users could become familiar with, and which would allow easy comparison for industrials between their reporting intervals; and between different industrials themselves.

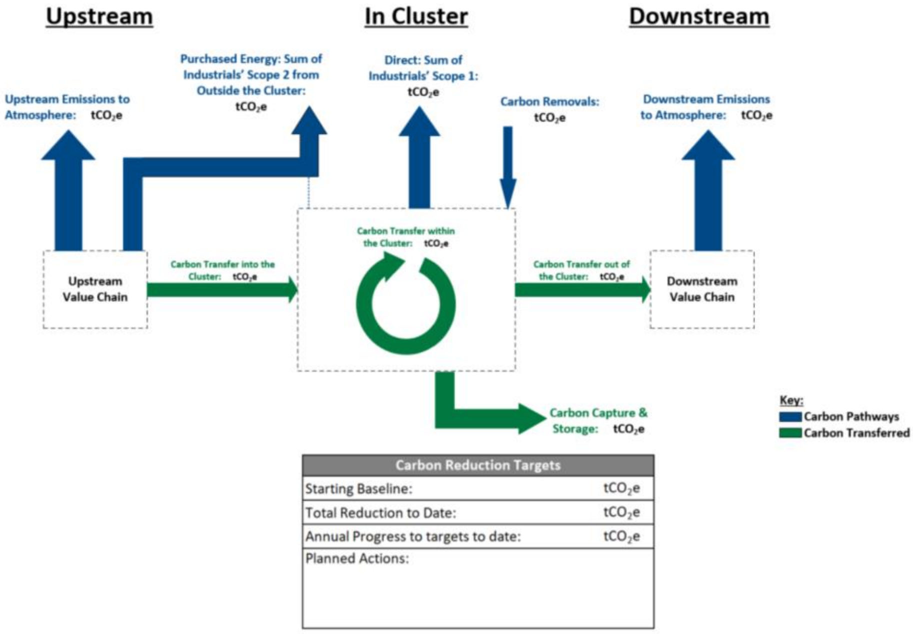
The graphical reporting method for each of the reporting Levels follow – and this gives an appreciation of the detail of the data that is required at each level.

Level 1: Scope 1 & 2 transfers, removals & reductions:

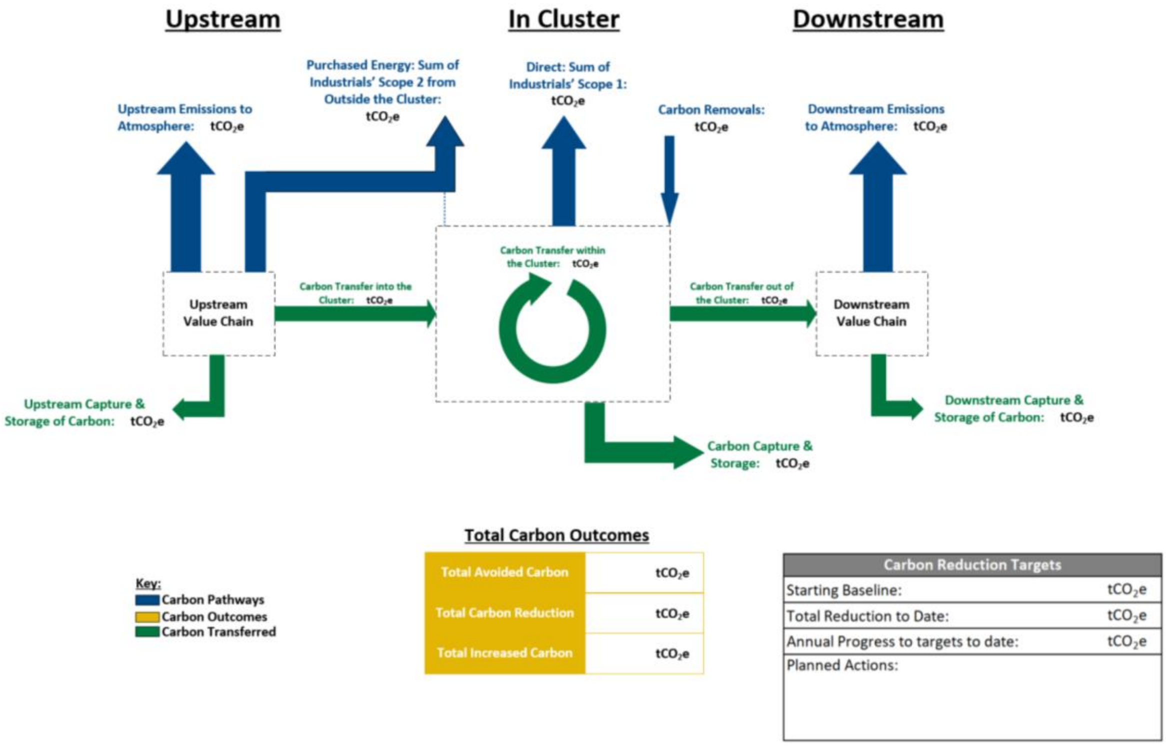


Carbon Reduction Targets	
Starting Baseline:	tCO_2e
Total Reduction to Date:	tCO_2e
Annual Progress to targets to date:	tCO_2e
Planned Actions:	

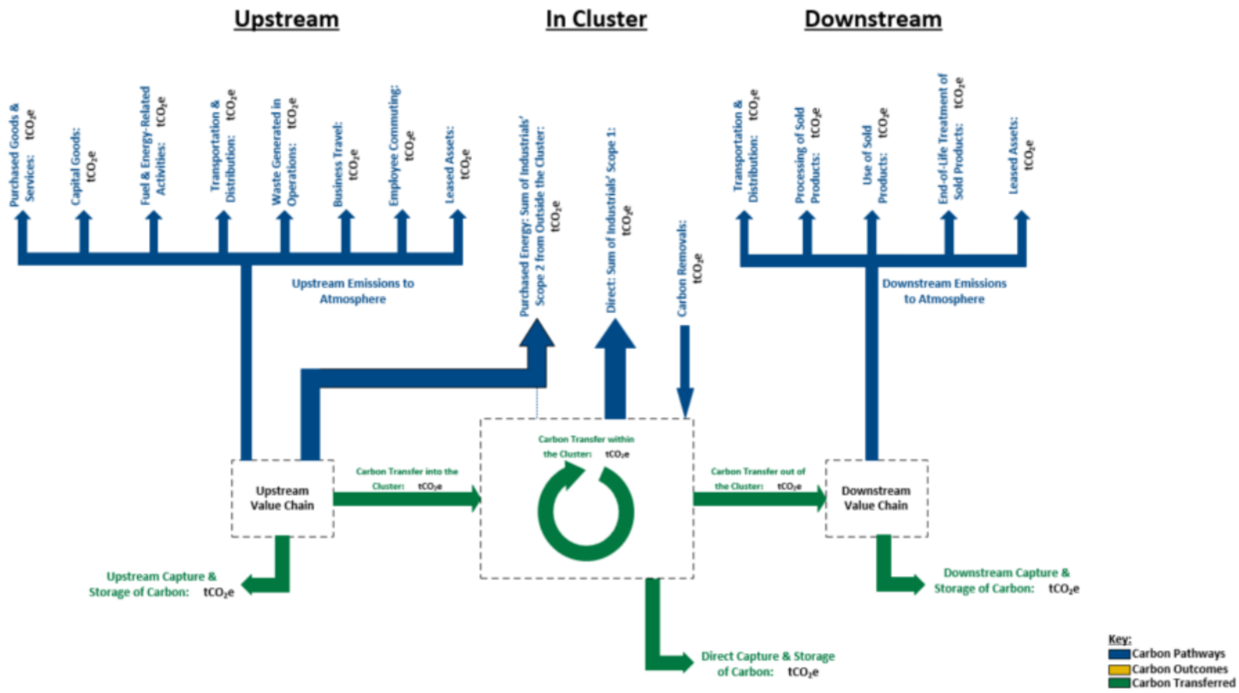
Level 2: Scope 1, 2 & 3 (where available), transfers, removals, outcomes and reductions:



Level 3: Scope 1, 2 & 3 (total upstream and total downstream), transfers, removals, outcomes and reductions



Level 4: Scope 1,2 & 3 (by each category), transfers, removals, outcomes and reductions:



Upstream Carbon Outcomes

Avoided Carbon	tCO_2e
Carbon Reduction – Decrease	tCO_2e
Carbon Reduction – Phase-Down	tCO_2e
Carbon Reduction – Transitional	tCO_2e
Increased Carbon	tCO_2e

Cluster/Industrial Carbon Outcomes

Avoided Carbon	tCO_2e
Carbon Reduction – Decrease	tCO_2e
Carbon Reduction – Phase-Down	tCO_2e
Carbon Reduction – Transitional	tCO_2e
Increased Carbon	tCO_2e

Downstream Carbon Outcomes

Avoided Carbon	tCO_2e
Carbon Reduction – Decrease	tCO_2e
Carbon Reduction – Phase-Down	tCO_2e
Carbon Reduction – Transitional	tCO_2e
Increased Carbon	tCO_2e

Carbon Reduction Targets	
Starting Baseline:	tCO_2e
Total Reduction to Date:	tCO_2e
Annual Progress to targets to date:	tCO_2e
Planned Actions:	

Theme 3:
Societal & Regional Benefit

Tees Valley Net Zero Cluster Plan

1. Decarbonisation in the Tees Valley Industrial Cluster	2. Net Zero Planning	3. Societal & Regional Benefit	4. Enablers & Future Opportunities
- Introduction - Tees Valley Indiustrials Case Studies - National Policy Overview - Net Zero Teesside - CCS and the CO2 gas gathering network - Mapping the Cluster Plan to UN Sustainable Development Goals	- The Cluster Model - Scope 1 CO2 emissions reduction and the net zero balance - Tees Valley Industrial Cluster Systems Model - - a tool for maximising the benefit of the Tees Valley cluster's inherent integration - Carbon Accounting - GHG Protocol with Life Cycle Analysis showing the wider value of Scope 1/2/3 emissiosn reduction	- Economic imnpact assessments - The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation - The "Limited Policy On" and "Full Policy On" scenarios - the benefits of adopting different degrees of industrial decarbonisation - Barriers to decarbonisation - Jobs & GVA - Skills and workforce planning	- Infrastructure requirements I - electricity Infrastructure requirements II - hydrogen - The future opportu]nity for CCS and CO2 storage - Shipping Industrial Gase I - importing CO2 by sea - Shipping Industrial Gases II - exporting hydrogen - Circular economy fuels and Energy from Waste

16 The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation.

16.1 Underlying Report

Title	Do Nothing Scenario TVCA Decarbonisation Cluster Plan
Author	WSP
Filename	Task 8 Do Nothing Scenario.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-8-Do-Nothing-Scenario.pdf

16.2 Description

The economic analysis which estimates societal and region benefit through jobs and GVA has been a major aim of the Cluster Plan project.

Achieving Net Zero is a valid aim on its own. However, we can't view this in isolation and the energy transition must be fair and just across society. Central government talks about policies in different arenas: net zero; energy security; cost-of-living crisis; levelling-up. These are not isolated activities and are all aspects of the same overall problem.

To put this into proper context, we tasked WSP with developing the 'counter-factual' arguments – what happens if there are no policies for decarbonisation in the Tees Valley and what would be the impact on jobs and GVA.

We have already seen the impact of high natural gas prices on households and some industries - CF Fertilisers' current shut-down is foremost amongst these. The natural assumption is that increasing in Carbon Taxes, and the lost opportunity for new decarbonised industries in the region, will impact jobs and GVA. WSP's work in this section of the Cluster Plan provides the detail behind these assumptions.

16.3 Scope

The scope of the work incorporated the impacts of a "do-nothing scenario" on the economy in the region, with particular focus on the following:

- What will be the impact on the Tees Valley industrial cluster if no decarbonisation processes are implemented?
- What will the regions' future CO2 emissions be?
- What will be the impact on industries of increased carbon prices (through UK ETS, etc.)?
- What opportunities will be lost and what is the value in terms of jobs and GVA opportunities lost?
- Will industries be lost in their entirety – either to other parts of the UK or overseas?

The Tees Valley industrial cluster includes high emission-intensive industries in the region, which were used to model the 'do- nothing scenario'. These can be divided into current (and former) industries in the cluster and future planned industries which are yet to be built. For this study we selected the 26 industries – including former, current and planned – which have the most emissions in the Tees Valley:

Current	Future
Alpek	alfanar
BOC	Anglo American
British Steel	H2 Teesside
CF Fertilisers	H2 NorthEast
ConocoPhillips	Net Zero Teesside
Ensus	Redcar Energy Centre
Greenergy	Whitetail Clean Energy
Huntsman	
MGT Teesside	
Mitsubishi Chemical	
Navigator Terminals	
Northumbrian Water	
PX	
Quorn (Marlow Foods)	
SABIC	
Sembcorp	
SUEZ	
Venator	
Teesside Integrated Iron & Steelworks	

The objectives for the work were:

- To develop a baseline economic profile, in terms of jobs and GVA, linked to carbon emissions from the main plants in the Tees Valley industrial cluster.
- To establish a relationship between jobs / GVA and emissions in the industrial cluster.
- To develop two decarbonisation scenarios to capture the economic impact of higher carbon prices under the UK and ET ETS carbon scheme.
- To analyse the impacts of carbon price increase on jobs and GVA, utilising varying emission scenarios and the established relationship between jobs / GVA and carbon spend.
- To identify the region's industrial specialisation advantage relative to other similar industrial areas in the UK.

16.4 Historical trends

The economic baseline analysis covered jobs, GVA, emissions, and carbon price per plant for 2015-2020, based on a set of assumptions. There was a positive relationship between jobs and emissions between 2015-2020 for the 34 industries considered, indicating that as emissions increased, jobs also increased, and vice versa. GVA, on the other hand, showed a negative relationship against emissions from 2015-

2020. This indicated that decarbonisation technologies might have been already implemented for some of the companies, as indicated in the survey responses.

The historical carbon spend for the TVCA cluster increased between 2015-2020, indicating that the carbon price increase offset the decrease in emissions. There was a negative relationship between jobs and carbon spend for the TVCA industrial cluster between 2015-2020. There was a positive relationship between GVA and carbon spend for the TVCA industrial cluster over the same period. This demonstrates that as carbon spend increased, GVA also increased. The impact from future carbon price scenarios on jobs and GVA can be forecasted using the relationships for jobs-carbon spend and GVA-carbon spend for each plant.

16.5 Future trends

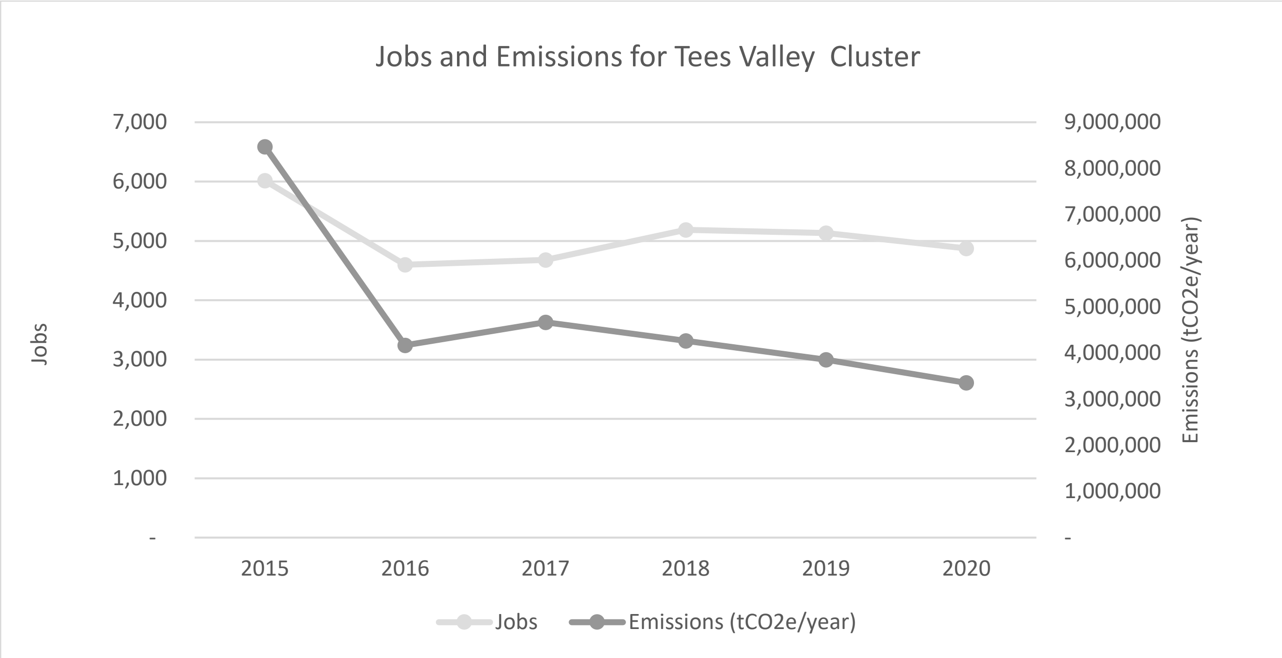
Four scenarios were developed to forecast the impact of future carbon spend on jobs and GVA, based on two carbon emissions and two carbon price scenarios. Carbon spend is expected to increase over time based on emission level and carbon price changes.

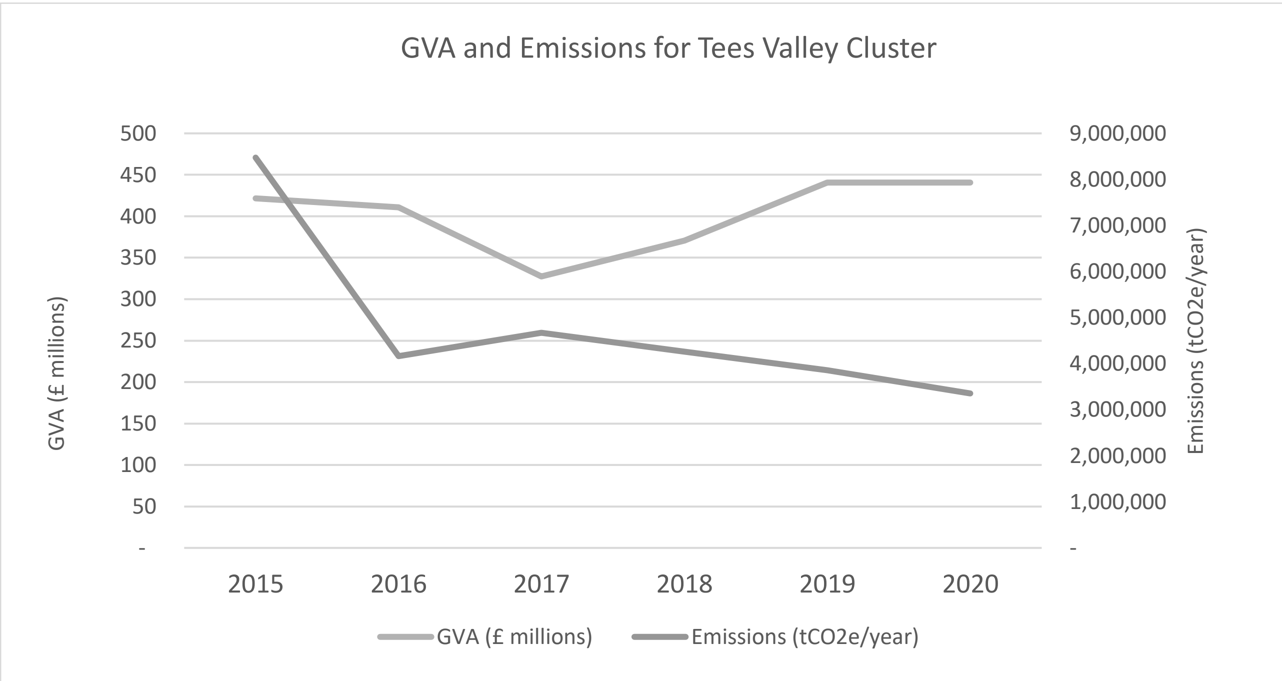
Across all four scenarios more than 55% of the industries studies in the Tees Valley will experience a neutral or positive outcome on future jobs. Greater positive job outcomes will occur for plants that have already adapted to rising carbon prices and have already begun to reduce their emissions. In the 'Variable emissions – high carbon price' scenario, 39% of industries can expect positive or very positive job outcomes, and another 17% would experience no change. The greatest negative job outcomes will also occur in the same scenario but from industries that have rising variable emissions and face high future carbon prices, with 44% of industries expecting a negative or very negative outcome.

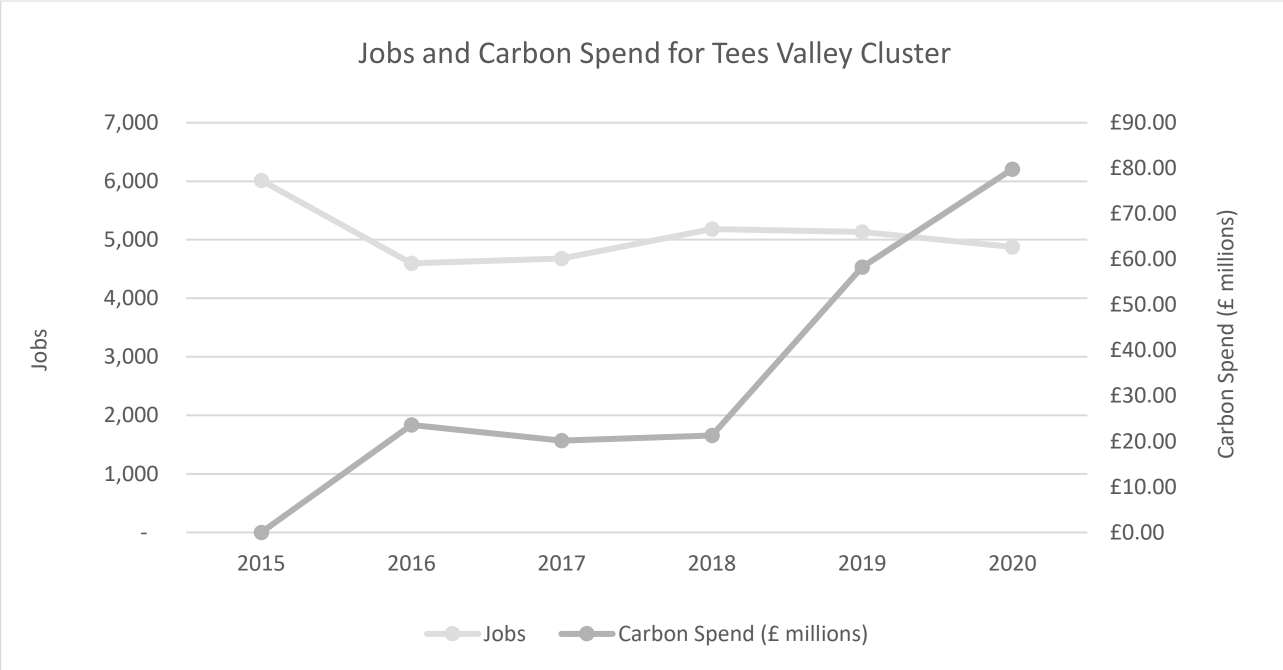
Across all scenarios 78% of industries will experience a neutral or positive outcome on future adjusted GVA. Plants that are already reducing their emissions, will see a greater positive impact on their GVA as their carbon price burden will not be as significant as those that have not begun adapting. This occurs in scenario 'Variable Emissions Low' and 'Variable Emissions High' with 61% of industries expecting positive or very positive adjusted GVA impacts. Industries already facing a negative relationship with adjusted GVA and carbon spend will continue to do so as their carbon price burden will continue to be high. This occurs in all scenarios, as 21% of industries will face negative adjusted GVA outcomes.

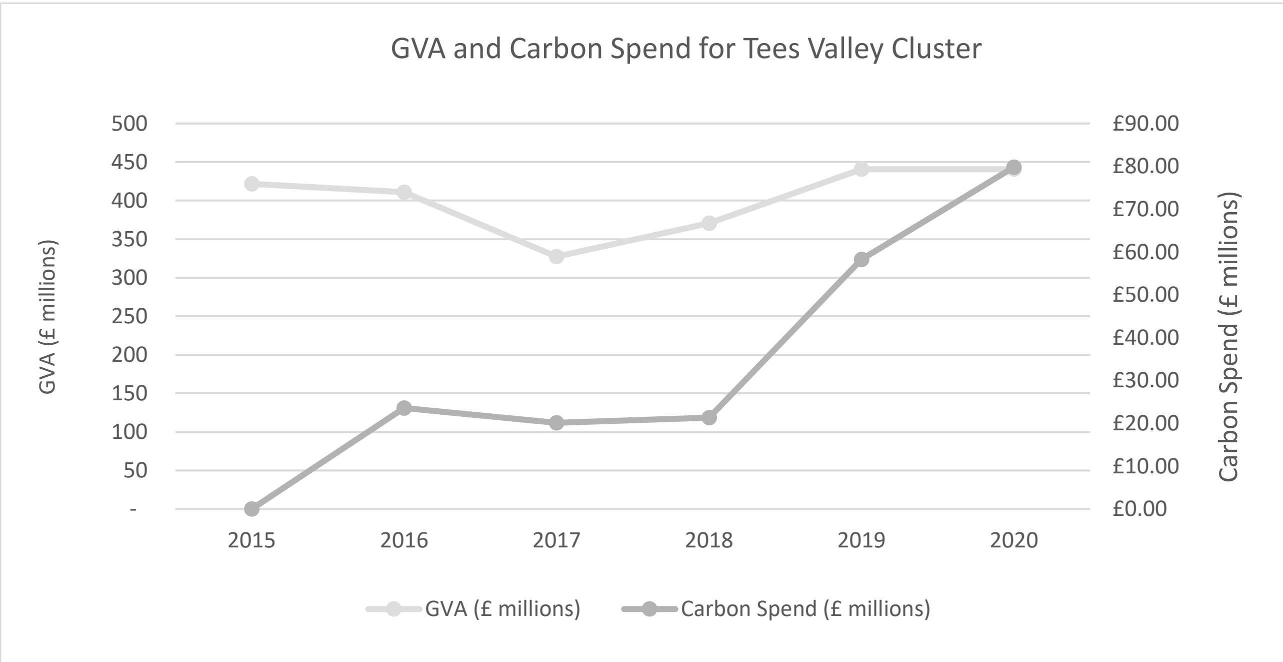
Overall carbon spend will have a greater impact on shifts in jobs than that of adjusted GVA, with little to no movement in GVA from changing carbon prices. This could also suggest that industries may rely more on capital investments to comply with carbon costs, and automation could lead to some job losses.

Some of the pertinent graphs from WSP's work are duplicated here – the originals are available in the downloadable copy of their work. These show the relationships between: Jobs/GVA vs Emissions and Jobs/GVA vs. Carbon Spend which were developed in the study.






Jobs and Carbon Spend for Tees Valley Cluster
Jobs
7,000
6,000
5,000
4,000
3,000
2,000
1,000
-
£90.00
£80.00
£70.00
£60.00
£50.00
£40.00
£30.00
£20.00
£10.00
£0.00
Carbon Spend (£ millions)
2015
2016
2017
2018
2019
2020
Jobs
Carbon Spend (£ millions)


GVA and Carbon Spend for Tees Valley Cluster
GVA (£ millions)
500
450
400
350
300
250
200
150
100
50
-
£90.00
£80.00
£70.00
£60.00
£50.00
£40.00
£30.00
£20.00
£10.00
£0.00
Carbon Spend (£ millions)
2015
2016
2017
2018
2019
2020
GVA (£ millions)
Carbon Spend (£ millions)

17 The "Limited” and "Full” Policy On scenarios - Jobs, GVA, Skills & workforce planning.

17.1 Underlying Report

Title	Industrial decarbonisation cluster plan economic impact analysis- Economic scenarios
Author	Cambridge Econometrics
Filename	Task 9 Economic Impact Analysis – Economic Scenarios.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-9-Economic-Impact-Analysis-Economic-Scenarios.pdf

17.2 Description

This work provides one of the most significant contributions to the Cluster Plan. As described in the previous section – reducing CO2 emissions and achieving Net Zero is the principal aim of the Cluster Plan; but in addition to that, maximising the economic potential of Net Zero is a target the Tees Valley needs to attain.

We tasked Cambridge Econometrics with carrying out the economic analysis to determine the potential benefit to the region in terms of the jobs and GVA that can be secured through developing decarbonisation in the industrial cluster.

The “Limited Policy On” and “Full Policy On” scenarios refer to different levels of investment and were chosen so that we could understand the range of potential outcomes for the Tees Valley economy.

“Limited Policy On”

- This assumed that only Net Zero Teesside CCS and the decarbonisation projects that were included in the Cluster Sequencing Track-1 / Phase-2 shortlist (as of August 2022) would be implemented. These were:
  - Power CCS: Net Zero Teesside Power; Whitetail Clean Energy
  - Hydrogen: H2 Teesside; H2 NorthEast
  - Industrial: CF Fertilisers; BOC CCS; Norsea CCS (Teesside Oil Terminal); Redcar Energy Centre; Tees Valley Energy Recovery Facility.

“Full Policy On”

- This assumed that all the decarbonisation projects that we were aware of during the Cluster Plan project would progress and be fully implemented.

The choice of industrials for the “Limited Policy On” scenario was somewhat arbitrary. However, in the time between Cambridge Econometrics carrying out their analysis and this Cluster Plan report being written, the policy landscape has moved considerably.

In March 2023, the Secretary of State for the new Department of Energy Security and Net Zero announced the “Powering Up Britain” strategy. This was a wide-ranging set of announcements for current and future energy policy, energy security, net zero and CCS. Part of the announcements included the projects that would move from the Track-1 / Phase-2 shortlist to the negotiation stage, and there were only 3 projects in the Tees Valley that were successful in this:

- Power CCS: Net Zero Teesside Power
- Hydrogen: H2 Teesside
- Industrial: BOC CCS

(Kellas Midstream's H2 NorthEast project was awarded funding under the Net Zero Hydrogen Fund to proceed with their FEED process. This is a smaller amount of funding and lower standard of support for their project which does not currently provide them access to the Net Zero Teesside CCS system).

The three projects selected will have a total of captured CO2 between them of around 3.8 MtCO2/yr. In the early years of operation (2027 onwards) the capacity may be limited to around 4 MtCO2/yr, for engineering development and well stability considerations in the Endurance store.

The Secretary of State also announced that there would be a "Track-1 Expansion" project under Cluster Sequencing. We are still waiting to hear details of whether this will allow some of the formerly shortlisted projects to progress to negotiations for CCS; or indeed whether other projects not previously on the shortlist can progress to negotiations for CCS.

The impact of this on the economic analysis carried out by Cambridge Econometrics is that the jobs and GVA gain that can be realised from the projects currently in negotiation with DESNZ will undershoot the "Limited Policy On" scenario by a considerable margin.

17.3 Macroeconomic Modelling

Cambridge Econometrics used their Local Economy Forecasting Model (LEFM) to develop macroeconomic forecasts based on the data collected from the industrials in the cluster. The model produced baseline projections, from which three decarbonisation scenarios were developed.

The baseline LEFM projections are economic projections based on historical growth in Tees Valley relative to the region (North East) or UK depending on which area it has the strongest relationship with, on a sector-by-sector basis. They assume that those relationships continue into the future. Thus, if a sector in Tees Valley outperformed the sector in the region (or UK) as a whole in the past, then it will be assumed to do so in the future. Similarly, if it underperformed the region (or UK) in the past then it will be assumed to underperform the region (or UK) in the future.

Using these as a starting point, three alternative scenarios were then modelled to estimate the overall economic impacts of the Tees Valley Industrial Decarbonisation plan, summarised here, but described in more detail in subsequent sections:

Policy Off

- This counterfactual scenario captures the impacts of the DESNZ (formerly BEIS)Clustering Sequencing Plan not being enacted at all. Dependent projects are therefore not enacted either, and the impact of this on the local economy is estimated.

Limited Policy On

- This scenario only captures the short-term impacts of the DESNZ (formerly BEIS) Clustering Sequencing Plan itself, its immediate supply chain impacts and knock-on local spending impacts. No assumptions are made about the long-run evolution of the Tees Valley industrial cluster after the completion of the plan.

Full Policy On

- This scenario captures the impacts of the BEIS Clustering Sequencing Plan Phases 1 and 2 and all dependent investments, projects and likely knock-on economic impacts. This includes estimates of both long-run upstream and downstream impacts on the local industrial cluster as a result of the Plan (increasing industrial capacity in hydrogen, carbon capture, and other manufacturing within the region), and induced household spending effects in the local economy.

17.4 Policy Off Scenario Assumptions

The Policy Off scenario assumes that no DESNZ cluster plan-funded projects occur within TVCA, delaying or knocking back industries within the region's attempts to switch to less carbon-intensive methods of production. A review of the evidence suggests that relative demand for carbon-intensive industrial production is declining and will continue to decline in the future, and any delay in decarbonisation will dent market share in the laggard clusters.

Cambridge Econometrics assumed there would be decreasing levels of demand for the industrial sectors in Tees Valley that continue to use existing technologies, in the face of increasing competition from "green" competitors, higher levels of carbon pricing, and reduced demand for carbon-intensive products.

As well as no additional above baseline investment or job creation being modelled, they additionally estimated gradual job losses among the industrials that have current operations in Tees Valley within sectors that are vulnerable to contraction for the above reasons over 2022-40. As no reliable estimates for the actual rate of future demand reduction were available, they made a conservative assumption of a 50% reduction in demand for industrial output over the 17-year period compared to the top-down baseline forecast.

Assuming no substantial effects on productivity, 50% of the current workforce in selected industrials located in Tees Valley (those that have current operations within the region and that are at risk of losing market share without decarbonisation efforts) would therefore be lost. Job losses by sector were assumed to occur at a steady rate over 2022-40.

Sector	Estimated job losses by 2040
Chemicals	1,085
Metals & metal products	350
Warehousing & postal	350
Total	1,785

17.5 Policy On Scenario Assumptions

Both 'Policy On' scenarios assume that the Cluster Plan is enacted, and participating industrials make some amount of investment that spurs job creation and economic activity within Tees Valley. We collected this information from comprehensive survey data of those firms.

The Limited Policy On scenario only includes investment and job creation from industrials explicitly included in the BEIS cluster plan, while the Full Policy On scenario includes all participating industrials, regardless of their inclusion in the BEIS cluster plan. These two scenarios allow the analysis to distinguish between the impacts of the BEIS cluster plan project (Limited Policy On) and the wider impacts that the plan could produce by encouraging additional investment in Tees Valley (Full Policy On).

The **Limited Policy On** scenario includes:

- The direct impacts of the BEIS Cluster Sequencing Phase 1 and Phase 2, including the activities that firms participating in the plan, which included firms in the clean energy, CCS, and hydrogen sectors, told us they planned to undertake.
- The impact on economic activities involved in delivering this investment, for example construction activity, and manufacture of the specialist machinery and equipment that would be required.

- Upstream supply chain impacts of all operational and investment activity.
- Knock-on induced impacts on the local economy as a result of increased employment and wages being spent in the local economy.

In addition, the Full Policy On scenario also includes:

- An estimate of the likely additional growth of dependent industrial activity in the medium and long run. This includes growth in industrial activity induced and facilitated by access to CCS infrastructure, clean energy, and green and blue hydrogen networks, including both upstream and downstream value chain impacts.

Both Policy On scenarios share certain assumptions about the distribution of capital spending, the inputs to production within the Electricity & Gas sector, and the local supply content of the inputs to production in the Chemicals and Electricity & Gas sectors.

17.5.1 Distribution of Capital Spending

Capital spending projects ranged from retrofitting existing facilities to utilise clean fuels, upgrading and expanding equipment in anticipating of increased production, to the construction of entirely new facilities. Based on a breakdown of responses, capital spending (investment) was therefore distributed between four sectors in the following proportions:

- Electronics: 5%
- Electrical equipment: 15%
- Machinery: 35%
- Construction: 45%

17.5.2 Electricity & Gas – inputs to production

As part of the BEIS plan to decarbonise industrial clusters across the UK, it is expected that there will be a transition away from fossil fuel-based energy production toward more sustainable energy production. Using historic I/O table relationships to identify upstream supply chain effects would therefore likely misrepresent this. For example, the primary inputs to the Electricity & Gas sector were adjusted from Mining & Quarrying (which includes oil extraction and refining) and from Electricity & Gas itself (which includes natural gas distribution) to other sectors that include activities to support offshore wind farms, biomaterial energy plants, energy from waste plants and hydrogen plants. Based on the details of the planned projects, assumptions for inputs to production in Electricity & Gas were changed from the proportions used in the baseline to the following proportions by sector:

- Agriculture, forestry & fishing: 5.01% (previously 0.01%)
- Mining & quarrying: 2.00% (17.99%)
- Chemicals: 7.05% (0.05%)
- Electricity & gas: 30.92% (42.92%)
- Water, sewerage & waste: 13.06% (0.07%)
- Water transport: 3.01% (0.01%)

17.5.3 Local Supply Content

The impact of an investment within a local area is dependent on how much of the spending on inputs to production associated with the investment occurs within the local area (the local supply content).

Given both Policy On scenarios model an increase in the production of hydrogen and sustainable energy within Tees Valley, the local supply content of Chemicals (which includes hydrogen production) and Electricity & Gas (which includes sustainable energy production) were increased in both scenarios.

It was assumed that 20% of demand for inputs to production from these two sectors was met by local producers in 2022 (up from 10% in all years in the baseline). In line with the sequencing of the cluster plan, this was assumed to increase to 40% by 2028 and held constant thereafter until 2040.

17.6 Macroeconomic modelling: Results

The macroeconomic modelling results show that, relative to the Policy Off scenario, the two Policy On scenarios are projected to have better outcomes for the Tees Valley economy in terms of employment and GVA.

Compared to the Policy Off case, the Full Policy On scenario is projected to add 28,800 jobs and £34.6bn cumulative GVA to the Tees Valley economy by 2040. The Limited Policy On scenario is projected to add 8,500 jobs and £14.7bn cumulative GVA by 2040.

While Tees Valley employment is projected to increase from 2022 to 2040 in all three scenarios, jobs in the ‘Industry’ sector grouping (including manufacturing) are projected to fall by 6,900 in the Policy Off scenario and by 3,500 in the Limited Policy On scenario. Only the Full Policy On scenario projects an increase in these jobs: an additional 8,700 by 2040.

The three sectors with the greatest employment impacts by 2040 are: Chemicals (3,200 jobs), Metals & Metal Products (3,000 jobs), and Electricity & Gas (2,400 jobs). Chemicals (£10.7bn) and Electricity & Gas (£7.2bn) represent nearly 52% of the cumulative GVA impacts over 2022-40.

17.7 Total Employment and GVA results

This section presents the results of the macroeconomic modelling by scenario for the Tees Valley economy as a whole (i.e., not broken down by sector). The impact of adopting industrial decarbonisation on the Tees Valley economy is inferred from the difference between each of the Policy On scenarios and the Policy Off scenario (i.e., what would happen if investment occurs relative to the investment not occurring).

Total employment and GVA are projected to grow over 2022-40 in all three scenarios. As would be expected, employment and GVA growth is strongest in the Full Policy On scenario, followed by Limited Policy On scenario, and then Policy Off scenario. The trajectories of the Full and Limited Policy On impacts can be interpreted as the upper and lower bounds of the likely overall economic impact.

The total employment impact is measured as the difference between each of the Policy On scenarios and the Policy Off scenario by 2040:

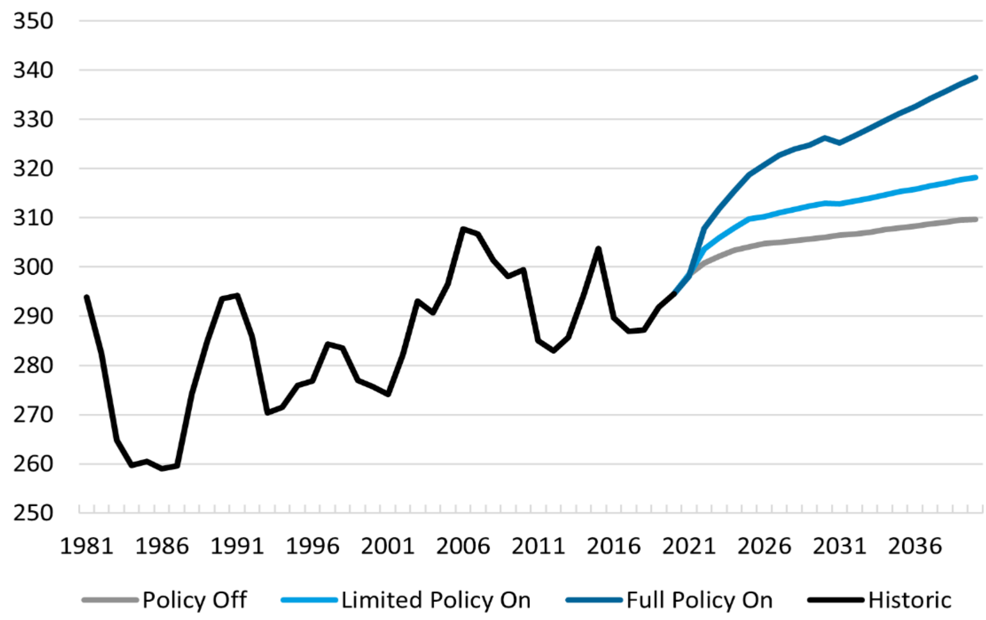
- Full Policy On scenario: 28,800 additional jobs
- Limited Policy On scenario: 8,500 additional jobs

The total GVA impact is measured as the cumulative difference between each of the Policy On scenarios and the Policy Off scenario over 2022-40:

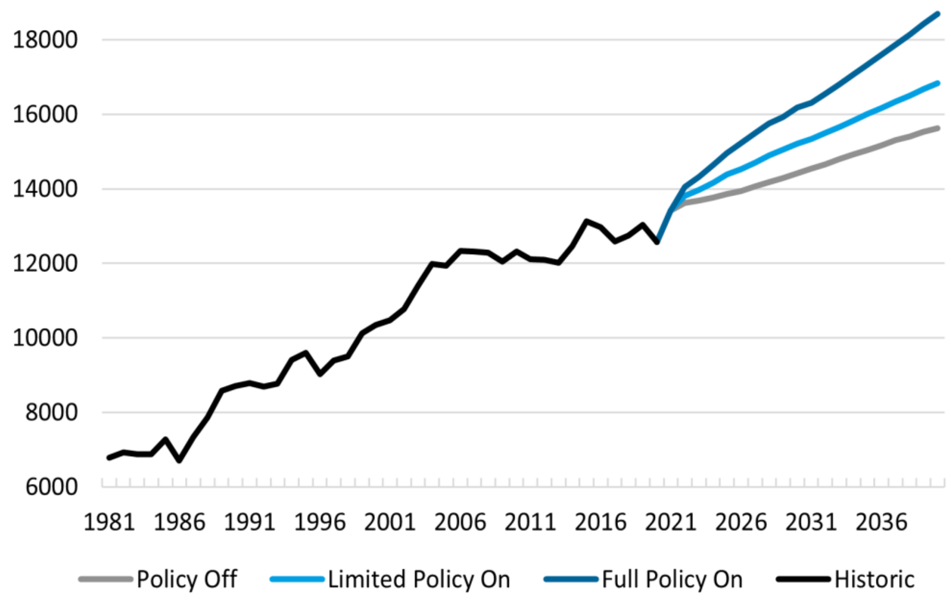
- Full Policy On: £34.6bn additional GVA (2022-40)
- Limited Policy On: £14.7bn additional GVA (2022-40)

By 2040, (non-cumulative) GVA is about 10% higher in the Full Policy On Scenario relative to Policy Off, and 3% higher in the Limited Policy On scenario.

Total employment projections by scenario, 1981-40 (000s jobs)



Total GVA projections by scenario, 1981-40 (£m)



17.8 Sectoral Results

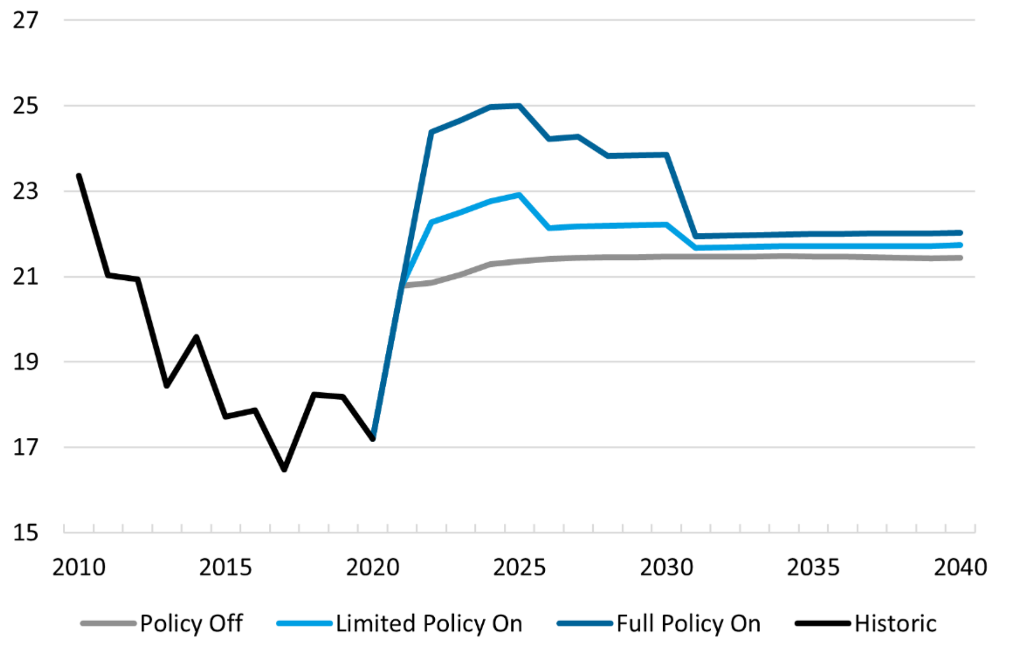
This section presents the results of the macroeconomic modelling broken down by sector. Employment impacts are most acute within the 'Industry' sector grouping, which includes mining and quarrying, manufacturing, and utilities (SIC industry codes B, C, D and E).

Employment within the 'Industry' sector grouping falls over 2022-40 in the Policy Off scenario (reduction of 6,900 jobs) and in the Limited Policy On scenario (reduction of 3,500 jobs). In the Full Policy On scenario, employment within the 'Industry' sector grouping increases by 8,700 jobs over 2022-40. Employment within the 'Industry' sector grouping has been falling in the historic period and is projected to continue to fall in the absence of substantial investment, such as in the Full Policy On scenario.

The Construction sector (SIC industry code F) also stands to gain from infrastructure investment projects, especially those that involve constructing new facilities and plants. Many of the jobs added in Construction are not permanent, as they are only viable over the period construction takes place.

There will be substantial construction taking place in the 2020s in the Policy On scenarios to complete industrials' infrastructure projects. A general increase in construction employment is projected in both Policy On scenarios past 2030, when construction for the industrials' capital projections is assumed to be finished. This permanent increase in construction employment is due to increased economic activity in the rest of the economy after the infrastructure projects are complete.

Projected employment within Construction sector by scenario, 2010-40 (000s jobs)



The employment impacts vary in the Full Policy On and Limited Policy On scenarios when looking at impacts by sector. There is an expected increase in employment in 2040 for the two Policy On scenarios compared with the Policy Off scenario for the ten most affected sectors. The top ten sectors with employment impacts are within the manufacturing and utilities industries, as well as service sectors that support these, such as Business support services and Wholesale trade.

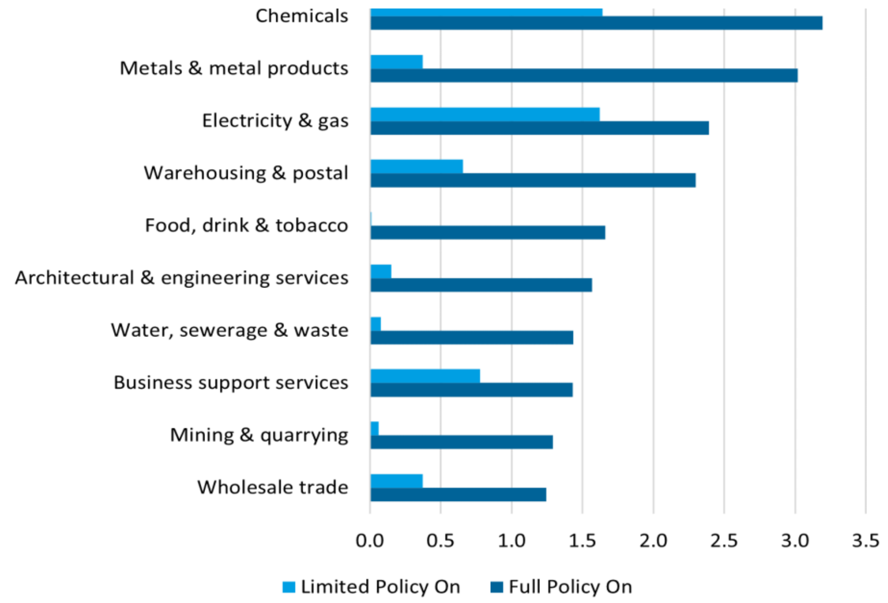
For example, in the Full Policy On scenario, Chemicals (3,200 jobs), Metals & Metal Products (3,000 jobs), and Electricity & Gas (2,400 jobs) have far higher employment by 2040 over the Policy Off scenario. It is worth noting here that in the Chemicals and Electricity & Gas sectors, these are largely new jobs, whereas in the Metals & Metal Products sectors, these are primarily avoided job losses.

The overall employment impacts are higher in the Full Policy On scenario, especially within sectors that are not direct recipients of investment funds but that stand to benefit indirectly from increased industrial and construction activity (e.g., Architectural & engineering services and Water, sewerage & waste).

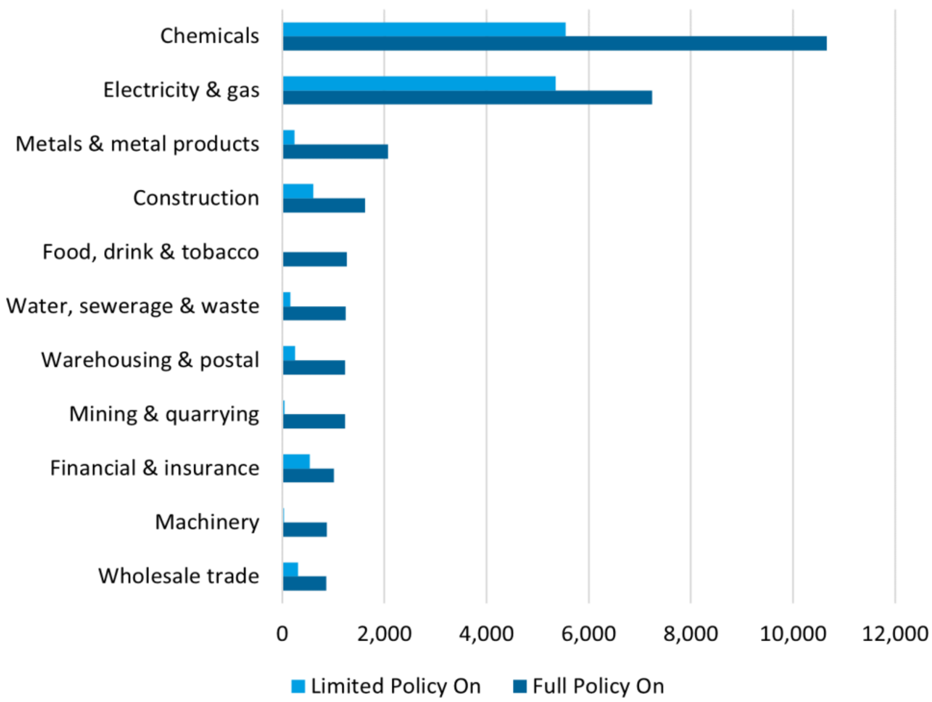
There is an expected increase in cumulative GVA over 2022-40 for the two Policy On scenarios compared to the Policy Off scenario over the ten most affected sectors. These top ten sectors are similar to the top ten in employment impacts: manufacturing sectors, utilities sectors, and the sectors that provide support services to them.

GVA impacts in the Limited Policy On scenario are concentrated in the Chemicals (£10.6 bn) and Electricity & Gas (£7.2 bn) sectors, which constitute approximately 52% of the total GVA impacts across the Tees Valley economy. The Full Policy On scenario results show how impacts could be more widely spread through the economy if investments beyond the BEIS cluster plan projects are included.

Top ten sectors by cumulative Employment impacts, 2022-40



Top ten sectors by cumulative GVA impacts, 2022-40 (£m)



17.9 Plans for Growth & Skills Impact

Central to our growth plans is our ambition to become the national capital of clean growth and green energy, delivering a Net Zero industrial cluster by 2040, providing good jobs with long term prospects that local people can access. This supports Government's ambition for two million green jobs in the UK by 2030. The Green Jobs Taskforce 'Report to Government, Industry and the Skills Sector' (July 2021)

states: “Achieving net zero by 2050 will require a system-wide transformation of the economy; most occupations, to varying extents, will become green.”

The **Net Zero Strategy for the Tees Valley**[7] sets out our Ten Point Plan and our top priorities include ‘delivering training and employment opportunities aligned to the new green economy’.

The **Tees Valley Employment and Skills Strategy – 2022 and beyond**[8] sets out our future skills priorities and is aligned to the significant economic opportunities across the whole of the Tees Valley over the coming years. In developing this strategy, it was important to recognise that every job of the future will be directly or indirectly shaped by the transition to Net Zero as all sectors will go through a transformation on this journey.

Delivering industrial decarbonisation projects will depend on businesses having access to the skills they need to grow, as well as residents having the opportunity to develop and acquire the required skills and experience, at the required levels, to secure these roles. The data that we have gathered on the economic benefits due to Net Zero and decarbonisation policies complements the Employment and Skills Strategy and help us to identify the skills needed to enable the new decarbonised industries and to plan accordingly.

A key focus of this strategy will be to ensure that capital investment decisions create opportunities for all our residents through new jobs that will become available and to support the retraining and upskilling of workers. Our vision for employment and skills in Tees Valley includes:

- Every business has access to a readily available skilled workforce and know where to go to find the workforce they need.
- Every business has access to workforce development and skills support, to sustain and grow their business.
- Every Tees Valley resident can access a good and progressive job.

In developing the strategy, it was important to recognise that every job of the future will be directly or indirectly shaped by the transition to Net Zero as all sectors will go through a transformation on the journey to Net Zero.

The Department for Education Skills for Jobs white paper[9] set out an ambitious plan to put employers more firmly at the heart of the skills system to help ensure businesses and people have the skills they need to thrive and progress. Local Skills Improvement Plans (LSIPs) are a key part of achieving this aim.

LSIPs set out the key priorities and changes needed in a local area to make post-16 technical education or training more responsive and closely aligned to local labour market needs, identifying where skills needs are converging across different sectors, as well as within sectors, including the transition to carbon Net Zero. The Statutory Guidance for the Development of a Local Skills Improvement Plan states that, ‘LSIPs need to go beyond simple statements about the need for more engineers or digital skills. This means understanding the actual skills employers need in the workplace but are struggling to find.’

The economic benefits and occupational data that we have gathered in the Cluster Plan will help inform the programme of skills activity to be delivered under the Tees Valley Employment & Skills Strategy and the recommendations for the Tees Valley Local Skills Improvement Plan (LSIP). The data will help us

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[7] https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/03/Net-Zero-strategy-Digital.pdf

[8] https://teesvalley-ca.gov.uk/wp-content/uploads/2022/07/9-Tees-Valley-Employment-Skills-Strategy.pdf

[9] https://www.gov.uk/government/publications/skills-for-jobs-lifelong-learning-for-opportunity-and-growth

better understand and identify the current and future skills needed to enable and mobilise the new decarbonised industries in the Tees Valley industrial cluster.

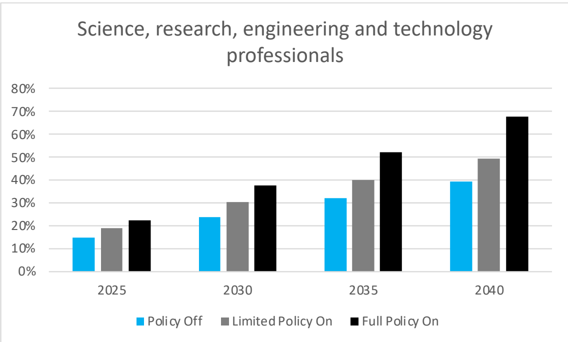
Comparing with the 2019 baseline – the new decarbonisation projects will:

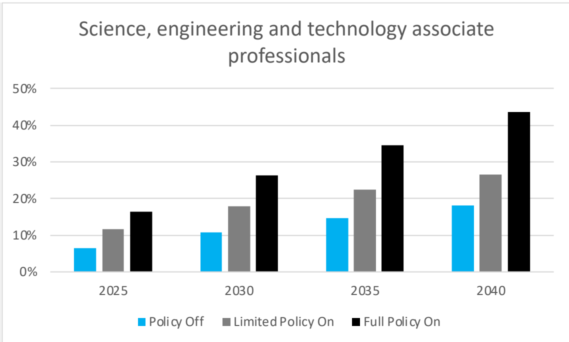
- Drive the growth of skills required categories such as science, research, engineering, technology professionals and associate professionals.
- Provide a boost in construction and building trades.

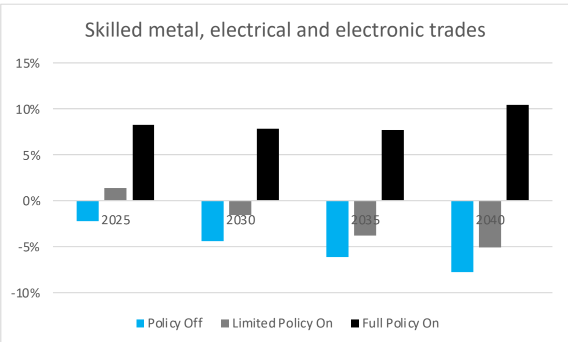
17.10 Skills Projections

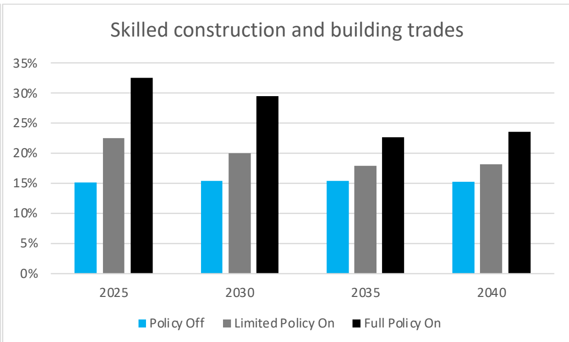
In the Economic Case, we describe the “Limited” and “Full Policy-On” Scenarios and the resulting economic impacts. We have used these same scenarios for our skills planning and this has allowed us to forecast required numbers of skills needs by occupational groups to implement the Net Zero policies:

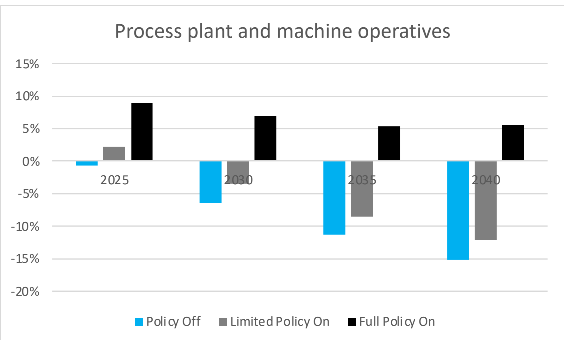
- Reverse the decline in the “skilled metal, electrical and electronic trades” and “process plant and machine operatives”.











The **Tees Valley Job Vacancies Report (January 2023)** already shows an increase in demand for these skills over the last year.

- Tees Valley Job Vacancies by Occupational Groups (2-digit SOC)
  - Skilled metal, electrical and electronic trades had 185 vacancies in January 2023 compared to 159 in January 2022.
  - Process, Plant and Machine Operatives vacancies increased by 116% from the January 2022 figures (37 to 80), there was also a rise of 63% from December 2022 (49 to 80).

Delivering this will depend on businesses having access to the people and skills they need to grow, as well as residents having the opportunity to develop and acquire the required skills and experience, at the required levels, to secure these roles. Our strategic approach to achieve this is underpinned by three pillars of support - Retention, Preparation, and Intervention.

  - Retention – support for those in employment and accessing work; (our new and existing workforce and their employers)
- Enhancing the skillset of those in employment and ensuring that employers are able to clearly articulate their existing and future skills gaps whilst achieving change in the skills offer to address these gaps.
  - Preparation – support for those still in education and training (our pipeline future workforce)
- Ensuring that those still in education and training are equipped to make the right education and career decisions, and that education and training providers and employers regularly engage to ensure emerging training opportunities address current and future businesses skills demands.
  - Intervention – support for those seeking work (our potential future workforce)
- Enhancing the employability of those who are close to employment and addressing the constraints faced by those more distant from the labour market as well as fulfilling that the training and support system meets the needs of local businesses.

The Combined Authority in the Tees Valley and devolution of responsibilities from Whitehall provides us with the opportunity to make this happen. We are able to engage with government departments and secure investment in new ways that enable us to better align and maximise our employment and skills programmes and funding streams. This ensures a more effective and joined-up system that addresses local challenges and seizes opportunities to improve outcomes for our businesses, young people and adults.

18 Barriers to decarbonisation.

18.1 Underlying Report

Title	Industrial Decarbonisation Cluster Plan Economic Impact Analysis Analysis of blockages, review of investment models and summary of business models
Author	Risk Policy Analysis/Cambridge Econometrics
Filename	Task 10 Economic Impact Assessment Barriers
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-10-Economic-Impact-Assessment-Barriers.pdf

18.2 Description

We carried out the data collection exercise with the industrials in the cluster to understand their operations, decarbonisation plans and drivers for decarbonisation. In this process we also determined the barriers to decarbonisation.

We tasked Risk Policy Analysis Ltd (RPA) - who were supporting Cambridge Econometrics in their work on the cluster plan - to review the current status of the investment models, business models and the current barriers to successful implementation of the Cluster Plan. We also conducted interviews with six of the industrials jointly with RPA to discuss their barriers to decarbonisation in greater detail.

Some of the main barriers to decarbonisation that concern industrials in the Tees Valley cluster are highlighted here and the full report from RPA is available with the download documents.

18.3 Department for Energy Security & Net Zero programmes

There have been multiple delays to the Cluster Sequencing and other programmes, which creates uncertainty for investors. The limited number of Track-1 Phase-2 projects passing to the negotiation stage, and the lack of information of following Track-1 Expansion, Track-2 and following processes are all barriers to development.

Some industrials have highlighted the need for increased clarity, action, and commitment from Government, with improvements in these areas being perceived as beneficial in overcoming barriers. One particular issue that was highlighted was the inconsistencies in end-user market support. For example – decarbonising a transport sector that is heavily supported by Government whilst off-grid and industrial fuels are not.

It was emphasised that the Government departments needed to be joined up to ensure that waste streams are not unfairly allocated and the Department for Energy Security and Net Zero and Department for Transport do not compete with each other for residual waste.

As industrial decarbonisation is still a relatively new area, there is a rapidly developing policy landscape which creates uncertainty for investors. Many of their concerns were related to the business case and incentivising the move to decarbonisation.

18.4 Restrictions to the connections to Net Zero Teesside CCS

As of March 2023, there are only 3 projects in the Tees Valley industrial cluster passing forward to the negotiation stage for Cluster Sequencing Track-1/Phase-2. As well as this, there is the wider problem that CCS is currently being developed as a regulated national asset with DESNZ as the regulator. It is

likely to be 10 – 20 years before CCS is matured sufficiently to be operated on a market basis with Ofgem as the regulator.

However, there are industrials in the Tees Valley who do not necessarily need government financial support and have a viable business case without this. They are capable of being a CCS customer on a market basis already. Allowing companies to operate on a market basis now, could reduce costs across the CCS operation and provide a more rapid transition to full market operation.

There is currently no option for companies to use or discuss using the NZT CCS system on a market basis.

18.5 Timescales of hydrogen offtake agreements

The current position of the Hydrogen Business Model (HBM) is that the hydrogen producers must arrange their offtake agreements. The HBM contracts are for 15 years. This is poorly aligned with the chemical industries where global markets move much more rapidly and investment decisions are usually taken with a much shorter timescale – typically 3 years.

The chemical industries will be the main users of hydrogen and without flexibility in the HBM that matches their operations, there will be a barriers to the uptake of hydrogen.

18.6 Fuel Switching & Infrastructure

Some industrials have emphasised that to implement fuel switching to hydrogen, there needs to be clarity over the infrastructure availability, timelines and volumes of supply.

Other industrials are planning fuel-switching to electricity, and this generates similar concerns. The National Grid has a number of infrastructure restrictions to the north and south of the Tees Valley, and this has knock-on impacts to the programme for allowing uprated and new electrical connections to industrials in the Tees Valley. TVCA is currently working with Northern Powergrid to identify these blockages and develop policies to overcome the restrictions.

The Cluster Plan includes work on the needs for hydrogen and electricity infrastructure planning, and we will be taking these forward as actions to implement the Cluster Plan.

18.7 Policy for Energy from Waste projects

Energy from Waste projects combine waste treatment, clean electricity production and negative emissions. These need to be recognised in DESNZ policy so that EfW projects are given the right treatment and access to support as other industries providing clean electricity and negative emissions.

18.8 Bio-energy projects and CCS

The Tees Valley has a requirement for negative emissions to ensure that Net Zero is achieved. This is mirrored in industrial clusters across the country and across other sectors in the economy. Bioenergy has the potential to provide large amounts of negative emissions.

However, there is limited support for bioenergy to implement CCS. Industrials already holding a CfD (Contract for Difference) for bioenergy are barred from the Cluster Sequencing process. If we wait until the current bioenergy CfDs run their term in the mid-2030s, there is no certainty that CCS will be supported for bioenergy and the opportunity to capture these negative emissions will be lost.

18.9 CO2 aggregators

Currently only CO2 emitters are eligible to apply for CCS under DESNZ's Cluster Sequencing rules. This loses the opportunity to optimise CO2 transport with aggregators providing the necessary infrastructure.

A prime example of this in the Tees Valley is the MOU signed between Navigator Terminals (at North Tees / Seal Sands) and Enfinium EfW at Ferrybridge (West Yorks.) Enfinium have plans to capture their CO2 and a railhead to transport the CO2 for storage. Navigator Terminals also operate a railhead at

North Tees – they have land available to develop a CO2 reception and onward transport facility. The planned onshore CO2 pipeline crosses this land.

In project engineering terms it would be very simple to use the existing rail infrastructure and Navigator's facilities to transport the CO2 for storage in the Net Zero Teesside CCS system.

If Navigator and Enfinium are not supported in this ambition to connect to NZT, the alternative would be for the CO2 to be shipped to the Northern Lights project in Norway – using Navigators existing port facilities. This would represent an opportunity lost for the UK.

18.10 Innovation and Technical Challenges

Technical challenges are a potential barrier. Decarbonisation is still a developing technology with a range of implementation strategies and there are difficulties in decarbonising certain plants. There are innovation challenges in decarbonising production processes - this could be a long-term issue and is dependent on technological advances.

Linked to this is the risk of technology lock-in and stranded assets. Some industrials have long replacement cycles, (up to 50 years) and new machinery would need to be hydrogen or carbon capture ready to avoid missing the window of opportunity for decarbonisation.

18.11 Investment & Financial Challenges

The financial costs of decarbonisation is a common concern amongst the Tees Valley industrial cluster.

For companies operating on a global marketplace - the cost of decarbonised energy has impacts on competitiveness. The high cost of decarbonised electricity means that price rises would be passed onto the customer, losing competitiveness on the global market with other countries which do not have deep decarbonisation policies.

The high UK industrial energy prices were also stressed by a number of industrials as a major barrier as decarbonised solutions were likely to require more electricity. There is a clear need for decarbonisation plans to be affordable and cost effective.

18.12 Pricing Structures

Pricing structures were repeatedly highlighted as a concern and issues with the UK Emissions Trading Scheme (UK ETS) were quoted by more than a quarter of the industrial cluster companies.

Although the system is intended as a driver for decarbonisation, it is not universally applied and therefore there is not a level playing field and the sector risks losing competitiveness. Without a universal application of the ETS, it becomes a taxation on industry and production volumes, which leads to the potential for "offshoring" industries.

- Renewable fuels industrials in the cluster highlighted the lack of carbon caps in the UK ETS. They can be charged for CO_2 emissions under UK ETS even though their product decarbonises another sector in the UK economy.
- An overhaul of carbon accounting was also "desperately needed" changing direct emission accounting to complete supply chain accounting.
- There are concerns for competitiveness in regard to the EU Carbon Border Adjustment Mechanism (CBAM) as it is unclear if the UK will be a part of this.

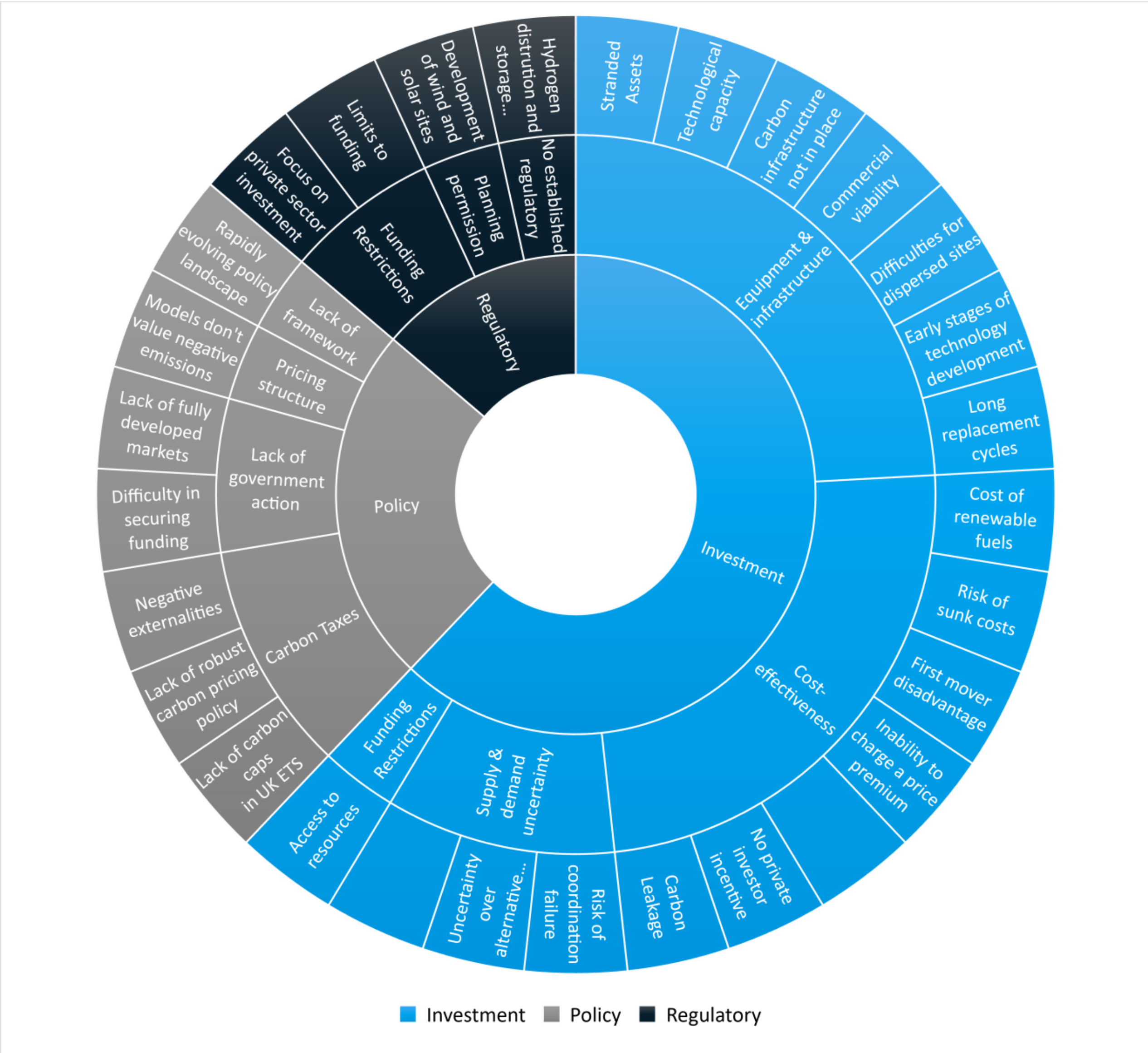
In specific sectors such as hydrogen, there was much uncertainty surrounding the pricing structure. Industrials highlighted the lack of Government direction in relation to this and also emphasised their concerns over Government strategy when moving to business models.

18.13 Competitiveness

Competitiveness was also linked to carbon prices and taxes. Although this was seen as a driver of progress to net zero, there were multiple concerns.

Carbon taxes are not seen to be optimal and even though the carbon impacts of projects are considered in some cases, this is purely on an economic basis. This will impact progress to net zero unless there is a suitable incentive and driver to get there. This emphasises the importance of creating business incentives to move towards net zero. Businesses wanted more economic drivers to help support the move, requiring these before any decisions were made.

Particular support is needed for the steel sector with emphasis on the need for Government intervention to support the cost of carbon reduction.



Barriers for Decarbonisation

Theme 4: Enablers & Future Opportunities

Tees Valley Net Zero Cluster Plan

1. Decarbonisation in the Tees Valley Industrial Cluster

- Introduction
- Tees Valley Indiustrials Case Studies
- National Policy Overview
- Net Zero Teesside - CCS and the CO2 gas gathering network
- Mapping the Cluster Plan to UN Sustainable Development Goals

2. Net Zero Planning

- The Cluster Model - Scope 1 CO2 emissions reduction and the net zero balance
- Tees Valley Industrial Cluster Systems Model - - a tool for maximising the benefit of the Tees Valley cluster's inherent integration
- Carbon Accounting - GHG Protocol with Life Cycle Analysis showing the wider value of Scope 1/2/3 emissiosn reduction

3. Societal & Regional Benefit

- Economic imnpact assessments
- The "Policy Off" scenario" - what happens if we do not adopt industrial decarbonisation
- The "Limited Policy On" and "Full Policy On" scenarios - the benefits of adopting different degrees of industrial decarbonisation
- Barriers to decarbonisation
- Jobs & GVA
- Skills and workforce planning

4. Enablers & Future Opportunities

- Infrastructure requirements I - electricity

Infrastructure requirements II - hydrogen

- The future opportunity for CCS and CO2 storage
- Shipping Industrial Gase I - importing CO2 by sea
- Shipping Industrial Gases II - exporting hydrogen
- Circular economy fuels and Energy from Waste

19 Infrastructure requirements I – electricity.

19.1 Underlying Report

Title	Task Order T11 Cluster Electrical Grid Constraint Study
Author	Fraser Nash Consultancy
Filename	Task 11 Cluster Electrical Grid Constraint Study.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-11-Cluster-Electrical-Grid-Constraint-Study.pdf

19.2 Description

In developing the Cluster Plan for the Tees Valley our initial focus has been on the projects that will lead to Net Zero and the economic benefit for the region. Our overarching view is that to create a viable decarbonised industrial cluster there are three principal components:

Carbon Capture and Storage

- This will be present in the Tees Valley from 2027 onwards with the development and implementation of the Net Zero Teesside & Northern Endurance Partnership CCS project.

Renewable and low-Carbon Electricity

- The Tees Valley already has renewable electricity supply from EDF's Teesside Windfarm with 62 MW generating capacity which in the future can provide the power to generate green hydrogen. This will be greatly expanded by SSE's Dogger Bank Windfarm (1.2 GW) and RWE's Sofia Windfarm (1.4 GW) both coming onshore in Teesside.
- The Tees Valley also has low carbon electricity generated at EDF Energy's Hartlepool power station for a limited period and in the future the NZT Power dispatchable power station (CCGT + CCS).

Hydrogen Supply & Demand

- The Tees Valley has an existing hydrogen supply /demand economy with around 50% of the UK's commercially available hydrogen generated by BOC at North Tees. The Tees Valley has a Hydrogen Vision[10] with the GW-scale blue hydrogen projects – bp's H2 Teesside and Kellas Midstream's H2 NorthEast – and the green hydrogen projects from Protium, EDF, bp and Kellas Midstream I all instrumental in growing the new hydrogen economy.

However, these projects cannot be successful without the infrastructure needed to deliver the new sources of energy. The first two sections under Theme 4 address this for electricity and hydrogen.

The challenge for electricity infrastructure is that the National Grid is constrained both to the north and south of the Tees Valley. The UK as a whole typically uses around 30 – 35 GW of electrical power. The National Grid in theory can transmit near to double this – although in practice, the constraints in the system limit power transmission to around 40 GW.

The impact of this for industrials wanting to decarbonise in the Tees Valley is that the Distribution Network Operator (DNO) – Northern Powergrid (NPG) – does not have control over which new

[10] https://teesvalley-ca.gov.uk/business/market-intelligence/a-vision-for-hydrogen-in-the-tees-valley/

connections to the electricity grid may go forward, or the timescales to plan for new connections. These largely rely on infrastructure improvements in the National Transmission System (NTS) rather than within the DNO.

This is a problem for both new generators of clean electricity and power consuming industries wanting to decarbonise by fuel-switching to electricity.

We have been in discussion with NPG to understand these issues and how they are affecting the industrials in the Tees Valley. NPG themselves are investigating different approaches to tackle the problems. To support NPG we tasked Frazer Nash Consultancy with carrying out a study to look at different Grid Supply Points and how they could potentially be managed in a way to ease new supply/demand on the DNO’s local network.

19.3 Electrical Grid Constraint Study - Summary

Three grid supply points (GSPs) were selected for study: Norton GSP, Lackenby GSP and Saltholme GSP. GSPs are the interface between the local distribution network and the national transmission network. The transmission network that supplies the Tees Valley area is highly constrained, in part due to considerable high-voltage north-to-south electricity flow from wind farms based in Scotland.

It was found that if all currently contracted generation in the Tees Valley exported to the transmission network without mitigation, this export would significantly exceed current transmission network limits. This leads to significant delays to the Tees Valley decarbonisation efforts. With major transmission upgrades scheduled for completion in 2031, intermediary options are critical in progressing the decarbonisation programme.

Balancing generation and demand at the distribution network level offers an effective solution to these constraints by minimising the transmission impact. The added generation and demand could be aggregated and controlled in the form of a Virtual Power Plant (VPP) which would ensure that net import and export from each GSP remains within existing transmission limits. The VPP is effective as it utilises headroom in the distribution network that is available during non- peak times. Commercially, Restricted Available Access (RAA) contracts could be used to connect customers under the VPP.

The studies have predominantly focussed on the connection of generation to the Tees Valley network due to the high volume of generation connections in the area. However, Virtual Power Plants are also capable of controlling demand and efforts to increase the installed capacity of generation in the area will also enable future demand connections by increasing import headroom.

Transmission reinforcement in the North of England[11] will eventually be required to unlock the full potential of the generation and demand in the Tees Valley area. Distribution reinforcement – particularly fault level mitigation – would also be required should high volumes of participants enter the VPP.

Compared against the counterfactual of traditional transmission network design, the following results were obtained at each of the GSPs under study:

Norton GSP

- The VPP would enable 890 MW to 1080 MW of distribution contracted generation to be connected under the existing transmission constraints. This is approximately double the counterfactual but would likely require mitigation of new distribution constraints that would occur. It is assumed that this mitigation is already known to the contracted generation as this should have been included in the distribution offers to these customers as per standard industry practice.

[11] https://www.nationalgrideso.com/document/275611/download

Lackenby GSP.

- The VPP would enable the 90 MW of distribution contracted generation plus approximately 140 to 185 MW of solar to be connected under current transmission constraints, subject to distribution constraints as above.

Saltholme GSP

The VPP would enable the 270 MW of distribution contracted generation plus approximately 80 MW to 135 MW of solar to be connected under current transmission constraints, subject to distribution constraints as above.

Infrastructure map, highlighting Norton GSP, Saltholme GSP and Lackenby GSP

19.4 High Level Roadmap

FNC developed a high-level roadmap to outline what the future steps might be to progress the development of the constrained network in the area of interest. These are classified as short-term (6 months – 1 year), medium-term (1 – 5 years), and long-term (5 – 10 years).

19.5 Design & Planning

Engagement with NPG on their opinions for installation of VPP system (short-term).

- VPP deployment at each GSP offers a flexible solution to the clear constraints on contracted generation on the NPG network. Engaging with NPG as a key stakeholder will be fundamental to realising the advantages and mitigating the challenges of this methodology.

Sizing of distribution constraint mitigation given anticipated VPP capacity and the future transmission works (short-term).

- Following the case studies above, work with the Northern Powergrid to size the VPP capacity relative to contracted generation and transmission network development. This would enable a more refined business case to be prepared.

VPP specification and architecture design (medium-term).

- Specify and design the virtual powerplant solution at each GSP. Following the case study methodology above, each remaining GSP in the region will have an individual profile to be considered and fed into VPP design when appropriate to proceed.

Detailed analysis of transmission constraints including frequency of events (medium-term).

- A detailed analysis of the constraints affecting the transmission network will need to be undertaken in order to inform all stakeholders of the real curtailment frequency and scale to be expected under the VPP deployment. Data from National Grid will be required to undertake this task.

19.6 Commercial & Stakeholder Engagement

Design of commercial arrangements within the VPP (short-term).

- The commercial arrangements of VPPs can vary between first-come first-served, or an even split; this will need to be considered ahead of VPP rollout. Seeking information from successful implementations elsewhere would be beneficial, as well as considering the commercial specifics of likely interested parties in this region.

Engagement with generators and demand customers within the VPP (short-term)

- Consideration of the commercial deployment of the VPP is important in ensuring the success of the VPP deployment, and stakeholder buy-in. Accordingly, it is important for generator and demand customers to be engaged during the VPP commercial design. Marketing and education of the technical and commercial benefits would be necessary.

All generators without a BEGA / BELLA to apply for an RAA (medium-term)

- Generators without an existing transmission contract will need to apply for a National Grid RAA contract to form the VPP.

Discussions with National Grid on 'dynamic constraint' signals (medium-term)

- As discussed, dynamic constraints would free up export capacity, when possible, on the transmission grid. This could be a boon for improving export conditions, particularly as the transmission over the B6 and B7 boundaries may be highly temporally dependent due to varying weather conditions for wind farm generation.

19.7 Implementation

Identification of trial GSP to implement VPP (short-term).

- Identification of a GSP to trial VPP could be quickly undertaken to practically develop the solutions proposed as part of the cluster plan.

Review of transmission reinforcement based upon distribution management solutions and TVCA requirements (long-term).

- With a developed comprehension of distribution constraints from the deployment of regional power management solutions, work with the National Grid to help consider transmission infrastructure development requirements.

20 Infrastructure requirements II – hydrogen.

20.1 Underlying Report

Title	Decarbonisation Cluster Plan Works Framework Task 12- Hydrogen Study
Author	Fraser Nash Consulting
Filename	Task 12 Hydrogen Study.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-12-Hydrogen-Study.pdf

20.2 Description

The Tees Valley has a standing ambition to be a "SuperPlace" for hydrogen. "SuperPlace" was a term which first appeared in the DESNZ (then the Dept. for Business Energy & Industrial Strategy) Ten-point Plan for a Green Industrial Revolution. The term has not been used as frequently in subsequent government strategy documents, but the ambition for the Tees Valley remains:

- The Tees Valley aims to be a leader in the new hydrogen economy, leading the UK and internationally with industrial-scale production of hydrogen which will be used to decarbonise industry, transport and home heating, with the potential to develop an export market for hydrogen also.

In a separate activity to the Cluster Plan, TVCA worked alongside bp, Kellas Midstream and Northern Gas Networks (NGN), commissioning Arup to provide a Hydrogen Vision[12] for the Tees Valley.

Within the Cluster Plan project itself we tasked Frazer Nash Consultancy (FNC) with developing a systems approach to enabling the new hydrogen economy.

Both these reports are summarised in this Section of the report – the FNC study is available with the downloadable documents for the Cluster Plan

20.3 The Hydrogen Vision

The Hydrogen Vision for the Tees Valley written by Arup describes how the Tees Valley is well placed to achieve its status as a SuperPlace for hydrogen and already has a significant hydrogen economy. Low carbon hydrogen will accelerate its journey towards becoming one of the world's first net zero industrial clusters by 2040 and help to accelerate the UK towards its overarching 2050 net zero goal.

The Tees Valley will produce 25% of the government's 2030 hydrogen production target of 10GW. Due to its significant existing hydrogen capabilities, the Tees Valley has all the necessary components to create a hydrogen economy, supporting the production and local use of hydrogen as

[12] https://teesvalley-ca.gov.uk/business/market-intelligence/a-vision-for-hydrogen-in-the-tees-valley/

a fuel and feedstock for indigenous and new industries, supporting them to decarbonise, adapt, grow, and thrive.

The vision is for the Tees Valley to maximise its inherent potential and to become a hydrogen SuperPlace. Hydrogen provides a platform for accelerating the Tees Valley's current growth into new industries, giving it the opportunity to rebalance the economic future of the north, especially the East Coast. Transporting hydrogen to the wider UK and abroad will provide a catalyst for industrial decarbonisation and green growth. At home, the Tees Valley's SuperPlace status will see it become a showcase for economic regeneration and inward investment. It will create secure, high value jobs and support up to 3,000 jobs in existing manufacturing and transport sectors, and thousands more during construction.

20.4 Why should Teesside pursue a hydrogen powered future?

The Hydrogen Vision outlines how a step change deployment of low carbon hydrogen will achieve the 2040 net zero goal. Hydrogen will power transport and industry and provide heat for buildings and local homes, across the UK and beyond. The steps needed to make that vision a reality, and to reach carbon net zero, extend beyond the Tees Valley. They point to many actions that are already in play and need to accelerate.

Across the nation, we will need to retrofit buildings, adapt infrastructure and transform our use of heat and transport. Expanding hydrogen production capabilities in the Tees Valley will provide multiple benefits. Low carbon hydrogen will provide energy for industries and processes that are hard to decarbonise, such as steel making. Hydrogen storage at scale offers seasonal energy storage and can manage variations in renewable energy production. In addition to these benefits, developing a hydrogen economy can stem the rise in energy costs. Hydrogen can deliver fuel security, support local manufacturing, meaningful local employment and industrial regeneration.

20.5 Policy and governance

Teesside already has the components needed for successful deployment; strategically located, it has pre-existing hydrogen production and mature infrastructure and markets. To transform the Tees Valley into a hydrogen SuperPlace, boosting local industries, several practical steps are needed. Firstly, all aspects of the hydrogen ecosystem need to coordinate efforts.

TVCA's re-energised Net Zero Leadership Group will lead regional coordination efforts. This will create increasing demand for hydrogen and hydrogen products, support skills development across the supply chain and ensure the benefits of their efforts are effectively communicated. On the policy side, robust local policies must compliment national regulations, fully utilising appropriate subsidies and decision-making.

The Tees Valley has an opportunity to go beyond the government's Low Carbon Hydrogen Standards, demonstrating leadership in full-lifecycle hydrogen emissions governance. In practice, this will require measuring and minimising all emissions from construction, operation, maintenance and demolition.

20.6 Looking to the future

Looking ahead to 2040, it is easy to envisage the Tees Valley as a thriving hub of clean industry with a global impact, exporting low carbon hydrogen and hydrogen products across the world. The fundamental components to a hydrogen SuperPlace are already in the Tees Valley; these include a

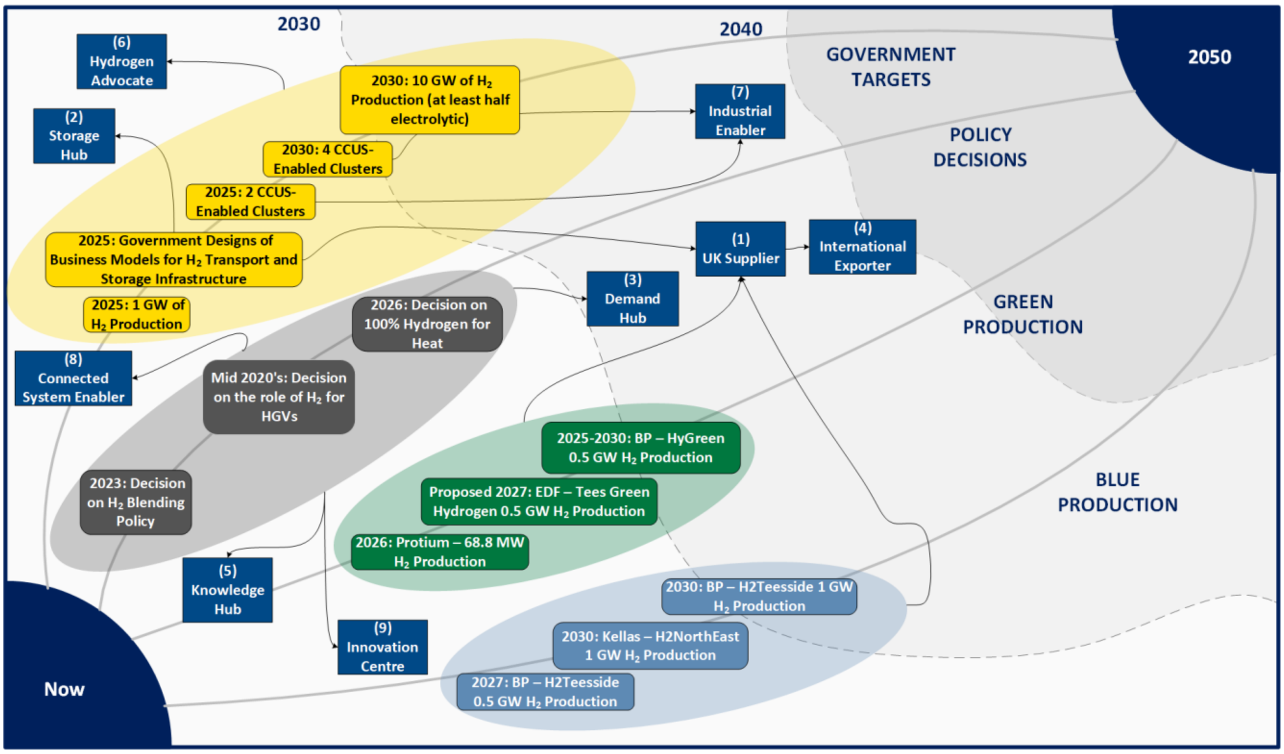
history of industrial excellence with legacy assets suitable for repurposing, strategic location around major transport links and a skilled workforce.

20.7 Enabling the Hydrogen Economy

The Tees Valley industrial cluster decarbonisation plan targets full participation in the future hydrogen economy. The FNC study into enabling the new hydrogen economy explores the current plans for the region and considers a broad range of scenarios for the future UK energy landscape, targeting Tees Valley's engagement appropriately. The region aims to become a "SuperPlace" for hydrogen; this study devises a suite of interventions to enable this, as well as articulating what a Super-Place could look like.

Nine criteria have been identified which, together, describe a full-system approach to enabling this Super-Place. These criteria were devised by considering the challenge from a (future energy) systems perspective, deconstructing it into component elements and interrogating the system architecture. A set of recognised scenarios (National Grid Future Energy Scenarios) were applied to investigate the local impact of the UK energy landscape and extract a set of insights which could then be translated into recommendations.

These recommendations were then grouped by theme and checked against a recognised framework (Smart Grid Architecture Model) to verify their comprehensiveness. These criteria are: UK Supplier; Storage Hub; Demand Hub; International Exporter; Knowledge Hub; Hydrogen Advocate; Industrial Enabler; Connected System Enabler; Innovation Centre. Within each strategic theme, a series of more tangible recommendations have been made to best exploit opportunities for the region.



Hydrogen SuperPlace Roadmap

20.8 Methodology

Baseline Assessment A baseline assessment was conducted to explore the various phases that make up the hydrogen value chain. Desktop research, stakeholder engagement, and internal expertise were combined to develop an overview of the existing hydrogen landscape in the Tees Valley and the planned hydrogen projects that will transform this landscape.

Explore Future Hydrogen Ambitions Information gathered in the baseline assessment was combined with a National Grid's recognised future energy scenarios to develop regional scenarios to frame the possible pathways of hydrogen development in the Tees Valley. A collaborative exercise was then conducted to identify macroeconomic factors (concerns) that are likely to affect the development of hydrogen infrastructure in the Tees Valley.

Interrogate Hydrogen Scenarios The concerns were applied to the scenarios to identify the vulnerabilities or areas of resilience of each scenario. Commonalities and distinctions that appeared between the scenarios were captured and translated into insights.

Tees Valley – a Hydrogen Super-Place. A combination of the information from the regional scenarios and the insights drawn from testing them against the concerns was then used to shape and inform a more detailed Hydrogen Super-Place vision that describes a best-case outcome. Additionally, the criteria for developing a strategy to support a Hydrogen Super-Place were outlined and verified against a recognised systems framework to ensure that it was suitably comprehensive.

20.9 Baseline Assessment

Steam Methane Reformed (SMR) hydrogen is currently produced in the North Tees region by BOC – this is unabated and the CO2 by product is released to atmosphere. The hydrogen is delivered to Huntsman for chemical manufacturing using the pipeline infrastructure and a river Tees crossing (tunnel). CF Fertilisers also use an SMR process; the hydrogen produced is used within the plant for NH_3 manufacture and is not commercially available.

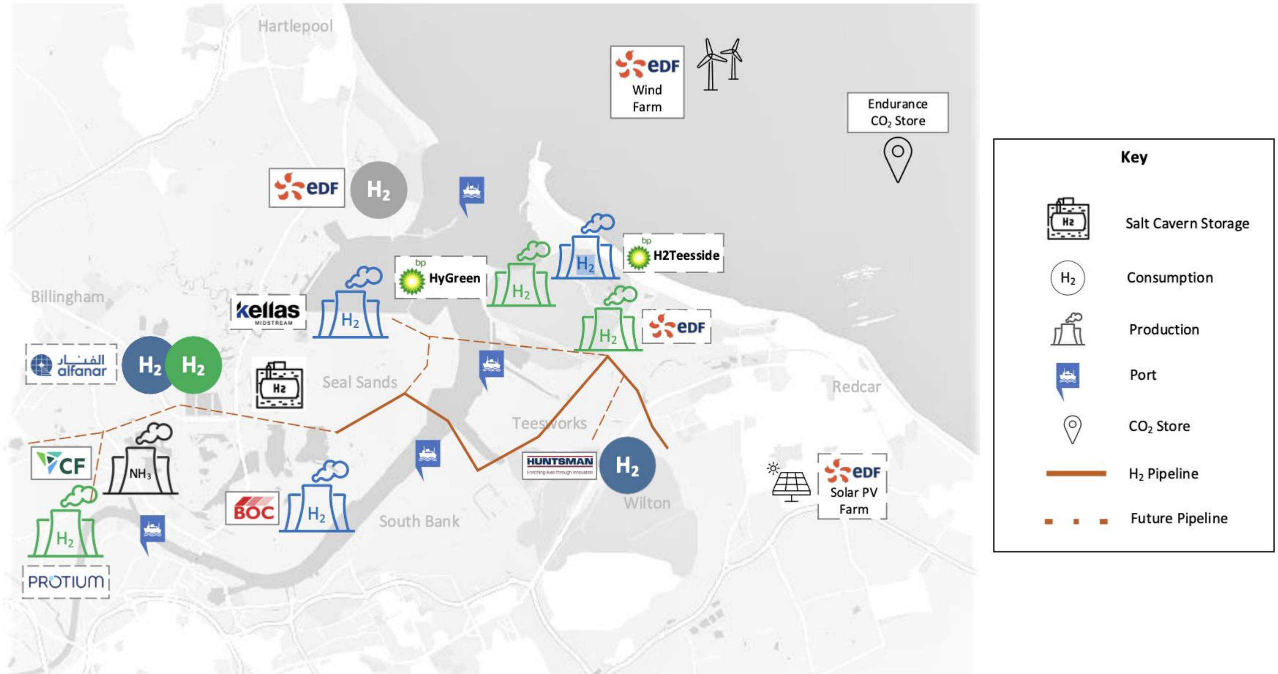
There are current plans for both "blue" and "green" forms of low-Carbon hydrogen in the Tees Valley that will reach at least 25% of the government's 2030 target for 10 GW of low-Carbon hydrogen.

Blue (SMR + CCS) Hydrogen

- bp's H2 Teesside project; Kellas Midstream's H2 NorthEast Project; BOC's project to apply CCS to the existing hydrogen production at North Tees.

Green (electrolytic) Hydrogen

- Protium; bp's HyGreen project; EDF's Tees Green Hydrogen project; Kellas Midstream's green hydrogen project.



Future hydrogen landscape (suppliers and users) in the Tees Valley 2030

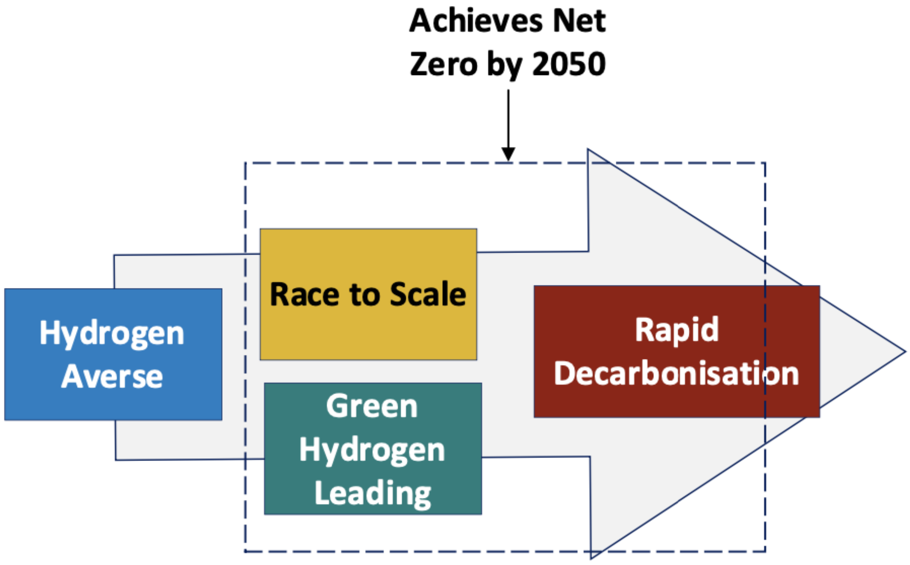
20.10 Hydrogen Scenarios

The role of hydrogen in decarbonising various aspects of the UK energy system is not yet clear, with uncertainty existing around the core technologies, supporting infrastructure, and supporting operating market.

A set of credible scenarios were developed to support the exploration of the future hydrogen landscape within Tees Valley. The four scenarios have been developed based on the National Grid Electricity Operator (ESO) Future Energy Scenarios (FES). The adaptations provide a greater focus on the role of hydrogen in industrial and commercial applications, as well as considering the local factors. However, care is taken not to isolate the Tees Valley from the wider energy system, acknowledging its role as a system change leader (as well as adopter). When developing each scenario, the temporal, operational and physical schemes were all considered.

The four scenarios developed in the study for hydrogen and their equivalents in the ESO Future Energy Study were:

ESO Future Energy Scenarios	Tees Valley Hydrogen
Falling Short	Hydrogen Averse
System Transformation	Race to Scale
Consumer Transformation	Green Hydrogen Leading
Leading the Way	Rapid Decarbonisation



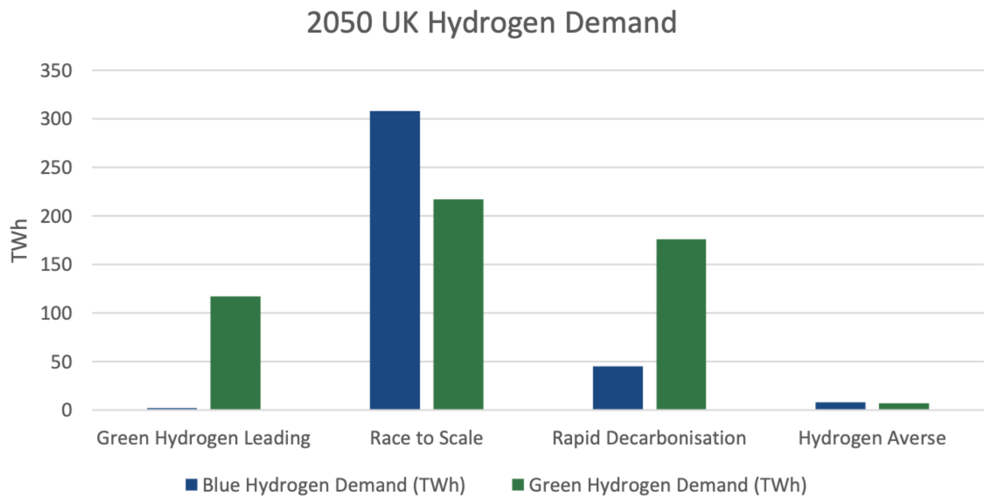
Tees Valley hydrogen scenarios

In all four scenarios, offshore wind is the most prominent source of renewable electricity supply in the UK. Decarbonisation efforts in Green Hydrogen Leading and Rapid Decarbonisation are focused on electrification and so both of these scenarios see a rapid uptake in renewable energy generation by 2030, and continued growth, particularly in offshore wind and solar, by 2050.

The North East (along with Scotland) will be the favoured location for offshore and onshore wind projects, whereas solar PV projects will be located towards the South. Race to Scale and Hydrogen Averse see lower levels of electrification compared to the other two scenarios. Renewable energy generation capacity still increases towards 2050, but at lower rates.

Blue Hydrogen is used to quickly scale up overall UK hydrogen production in the UK, before electrolysis capacity is expanded. As a result, Race to Scale sees a significantly higher proportion of blue hydrogen demand in 2050. This is followed by (albeit at much lower levels) in Rapid Decarbonisation.

Green Hydrogen Leading shows the lowest levels of blue hydrogen demand, with all decarbonisation efforts by 2050 directed at using green hydrogen produced via electrolysis. There is little difference between the level of blue and green hydrogen demand in the UK for Hydrogen Averse, with neither being selected as the preferred route to decarbonisation.



20.11 Macroeconomic Factors (Concerns)

A set of macro-economic factors were identified and applied in turn to each scenario to assess the degree of impact they might have on the ability of Tees Valley to decarbonise. These factors, known as concerns, were considerate of overarching decarbonisation objectives such as enabling a just transition, and were developed using a STEEPLE framework.

Social

- Hydrogen may have a reputation as being unsafe with the general public; End-user consumers may be unfamiliar with hydrogen; Working with hydrogen comes with a salary premium; Availability of locally qualified staff; Local training pipeline of Suitably Qualified and Experienced Personnel (SQEP).

Technological

- Learning curve of new technologies; Challenges associated with scaling; Suitability of existing infrastructure (for blending, road capacity etc.); Whole system integration; Uncertainty around technology potential (how to best exploit); Whole life reliability of equipment (SQEP).

Economic

- Interest rates continue to increase; Learning rates of new technologies; Investment incentive is uncertain for private equity investment; Cost compared to counterfactual; Competitiveness in international market; Coupling of hydrogen price with gas and electricity; Regional growth ambition; Access to public finance.

Environmental

- Indirect greenhouse gas emissions; Fugitive Emissions; Up-front carbon cost of infrastructure; Local health and safety; Ecological impact; wildlife etc.

Political

- Delays on key decisions from central government (e.g., hydrogen blending, hydrogen for HGVs); Lack of clear vision for a future hydrogen economy; Stability of central government; Government favours electrification to decarbonise; Government lack support for green generation projects; Government lack support for green innovation (e.g. subsidies, carbon tax, green certificates); Volatile global political landscape; Significant change in energy ownership model in UK; Changing regional concerns in Tees Valley.

Legal

- Failure or delay in key UK regulations (safety, environmental, trading); Maturity of regulations for global market; Ownership of enabling legal infrastructure; Tier of COMAH site.

Ethical

- Levels of acceptance of risks; Hydrogen used inappropriately; Enabling a just transition.

20.12 CCUS Insights

Across all four scenarios, albeit at different rates, there is a demand for blue hydrogen in 2050, which is used to support the levelling up of hydrogen across the UK. In Race to Scale, the demand for blue hydrogen production in 2050 exceeds the demand for green hydrogen.

FNC's view from a consultant's perspective is that this is the only scenario whereby the Tees Valley should focus primarily on the scaling up of blue hydrogen and CCUS technologies and processes, over green hydrogen. FNC state that in the other three scenarios, blue hydrogen is not favoured over green hydrogen as the preferred route to decarbonisation. Despite this, the Tees Valley should still exploit blue hydrogen to support the decarbonising of their processes and hydrogen production.

20.13 Green Hydrogen Insights

The demand for green hydrogen across the UK is expected to increase across all four scenarios. In Green Hydrogen Leading and Rapid Decarbonisation, the UKs efforts to decarbonise are primarily focused on electrification and therefore the demand for green hydrogen exceeds the demand for blue hydrogen.

The hydrogen landscape in 2030 at Tees Valley shows a number of green hydrogen players, including bp, EDF, Kellas Midstream and Protium. Several of these projects have, since the original project announcement, increased the proposed size of their electrolyser and overall hydrogen capacity. It can be assumed that these decisions are a response to the likelihood that green hydrogen demand increases across the UK. These decisions will influence the footprint required for hydrogen producers and consumers at Tees Valley, as they relocate to the cluster, or scale up existing technologies.

Tees Valley can expect that the number of green hydrogen projects interested in securing space within the industrial clusters will continue to grow. The decision to locate hydrogen projects within industrial clusters, including Tees Valley, will be in order to exploit the existing hydrogen supply chain. Tees Valley will see an increase in demand for hydrogen ready services, including distribution routes, transportation and bunkering facilities, and safe hydrogen working practices. This will also influence the available footprint for hydrogen technologies at Tees Valley, as they relocate to the cluster, or scale up existing technologies.

The scaling up of renewable energy generation technologies will be invested with respect to the environmental strengths and weakness across the UK. For this reason, it is expected that Tees Valley are likely to benefit from the investment of offshore and onshore wind investment more heavily than solar. The proposed EDF Solar PV farm is an important part of the scaling up of renewable energy technologies at Tees Valley, and provides flexibility, but further investment should look to other forms of renewables.

20.14 TVCA Viewpoint

TVCA itself is 'agnostic' in the choice of 'blue' and 'green' hydrogen and supports the central government move to talk about these together as 'low-Carbon' hydrogen. TVCA recognises firstly that to produce hydrogen at scale, blue hydrogen is required, as current electrolyser technology is not sufficiently developed. The long-term future is likely to favour green hydrogen as the UK reduces its dependence on fossil fuels to near zero.

However, green hydrogen is not without challenges also. There is an efficiency loss in converting energy from electricity to hydrogen, compared with using the electricity directly. This has to be taken into account in future energy scenarios.

In this regard, the Race to Scale scenario fits best to the Cluster Plan.

20.15 Tees Valley – a Hydrogen Super-Place

At a high level, a Super-Place represents a UK hub for hydrogen activity which is recognised by and has influence in the global market, independent of how this market looks. By collating the insights from the study, FNC has developed the following criteria for realising this ambition.

1. UK Supplier

   Tees Valley will supply a significant % of the total UK Hydrogen demand by 2030, increasing this % by 2050.

2. Storage Hub

   Tees Valley will provide resilience in the order of days of storage to serve UK demand.

3. Demand Hub

   Hydrogen will be used ubiquitously by industrials in Tees Valley for energy and will serve non-industrial consumers too.

4. International Exporter

   Tees Valley will be the primary UK exporter of hydrogen and scale to the demands of the international market.

5. Knowledge Hub

   Tees Valley will enable knowledge sharing and generate new understanding between government, industry and academia.

6. Hydrogen Advocate

   Tees Valley will champion hydrogen at a national and international level.

7. Industrial Enabler

   Tees Valley will provide access to hydrogen and compatible infrastructure for existing and prospective industrials.

8. Connected System Enabler

   Tees Valley will participate in and support non-industrial hydrogen consumers by providing system solutions.

9. Innovation Centre

   Tees Valley will host pilot projects and support innovation schemes in the region.

21 The future opportunity for CCS and CO2 storage

21.1 Underlying Report

Title	Industrial Decarbonisation Plan Work Package 6 – CO2Transport and Storage
Author	WSP
Filename	Task 1 CO2 Transport & Storage.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-1-CO2-Transport-Storage.pdf

21.2 Description

The Net Zero Teesside / Northern Endurance Partnership CCS project is well under way, with good support from the government through the DESNZ Cluster Sequencing Track-1/Phase-1 programme. This is intended to be operational from 2027 depending on the cluster FID date achievable by DESNZ, initially collecting and delivering around 4 MtCO2/yr for permanent storage in the Endurance field, rising to 10 MtCO2/yr as the project reaches its full development via a series of carbon stores.

The Net Zero Teesside CCS project is essential for the Tees Valley's ambition to be a low-Carbon cluster by 2030 and to reach Net Zero by 2040.

This section of the Cluster Plan report is not a commentary on the Net Zero Teesside Power and NEP projects. Instead, it provides some 'blue skies' discussion on how CCS might be optimised and developed in the future for the wider benefit of the region and UK as a whole. This includes enabling Net Zero in the UK and providing a commercial opportunity from CO2 import.

We tasked WSP to provide this study as part of their 'Industrial Decarbonisation Plan' report.

21.3 CCS System Volume Limits

The currently stated design is for a capacity of 10 million tonnes per year for the onshore CO2 collection infrastructure which, whilst well in excess of current cluster emissions of c 4.5 Mt/yr (6.5 Mt/yr with Net Zero Teesside Power included) and of course the combined emissions of those projects which are currently shortlisted in the BEIS cluster sequencing process, still remains somewhat below the full future potential cluster demand.

This section discusses some aspects of what might follow on from the current demand.

Firstly, there is a much larger list of potential industrial projects all of which may come to realisation over time, and some of these are presented by WSP. These range from waste to energy, large scale Hydrogen production, novel products and process such as SAF production and minerals processing, at various stages of maturity from feasibility studies through to final EPC. In addition to the projects listed by WSP – there are new potential additions to the Tees Valley cluster in lithium refining (Green Lithium and Tees Valley Lithium) and biofuels (SAF production). If all these potential projects were to come to fruition, then the capacity of the designed system is likely to require expansion.

21.4 CO2 Transport

The Cluster already has experience of and indeed regularly exports CO2 by road and sea as an 'industrial gas' for use in a variety of industries nationally and internationally and also has extensive

expertise and Port Facilities for the storage of and seaborn shipment of a wide range of tonnage fuels, hydrocarbons and chemical feedstocks in very large volumes.

Shipping CO2 between clusters, to accommodate operational, planned (maintenance) and emergency shutdowns of T&S networks - and also to accommodate any short-term imbalances between Clusters - will be necessary. There is also the need to offer an 'import' capability for the reception, local storage and ultimately secure disposal into undersea storage of the CO2 arising from those clusters and wider centers of UK industry who do not have access to suitable 'local' CCS systems. This will be absolutely necessary, in order to support achievement of the current national objective of achieving Net Zero by 2050.

Some such projects are already under development with no government support. A prime example of this on Teesside is the Navigator Terminals plan for a regional CO2 hub. Navigator have land available to develop a CO2 reception, storage and onward delivery facility. Critically, this is co-located with their deep-water quay on the river Tees and access to the North Sea; and the planned NEP CO2 pipeline crosses this land. In addition to this, Navigator have a railhead which can be developed for reception and delivery of CO2. Navigator have an MOU with Enfinium EfW in West Yorks who also operate a railhead. Shipping CO2 from Enfinium to Navigator for storage would be a readily achievable goal, (This is also discussed in the 'Theme 3 – Barriers' section of this report)

In more general terms, there are few barriers to the establishment of CO2 'import' to the Tees Valley with:

- extensive river facing land and deepwater berth capability to the North of the Tees.
- existing chemical and fuel import/export facilities already in place.
- clear space for further extension and/or the establishment of new facilities within extant COMAH sites.

When potential sources of 'supply' are considered, the most likely route of import is probably by road or rail as pipeline connection to regions where CO2 emission is less concentrated or at lower levels is considered highly unlikely to be economical. For some regions (westwards towards Cumbria) the local geology/geography is also unlikely to be suitable for pipeline construction.

The existing chemical and fuel shipping facilities to the north of the Tees are already rail and road connected and there are minimal barriers to establishing CO2 import/export facilities. To further enable this - the planned 'northern' leg of the NEP CO2 gas gathering network runs close to these facilities and any connection spur would be short and relatively easy to implement.

Also there appear to be few barriers for such a facility to be marketed internationally in similar manner to that proposed for the Norwegian 'Northern Lights' project. This would ultimately provide a new national commercial opportunity. Although not reflected by any single detailed project within the current suite of cluster planning projects it is known that one industrial is now working up a commercial proposal along these lines.

21.5 Opportunities and efficiencies

The optimisation of a CO2 collection network, or any similar network depends on a number of parameters. Those parameters can be the required volumes to transport, economic influences such as £/tonne or minimised CAPEX, technical aspects – size of reservoir, resilience, enabling wider strategies, or defending local strategies.

Ultimately a future proofed system will consider scenarios that include all of the aspects above and the system designed accordingly. This planning includes plans for what changes may need to occur in the future, an expansion philosophy, or equally what cannot be achieved – to highlight system limits.

The future potential for Teesside might take regional CO2 emissions above 14 MtCO2/yr which could impact the network in a number of ways.

- Onshore pipelines may need to be added, or examined to understand if the MAOP could be raised from 20 barg. This would need some mitigation from cold ambient conditions allowing the MAOP to be raised closer to 90% of saturation pressure whilst maintaining a minimum temperature or controlling heat loss.
- Offshore expansion may utilise increased pressure at the compressor discharge to use the same pipeline, which is achievable assuming compression and pipelines have the ability to increase the pressure.
- The impact on the storage wells of increased flow is another consideration and it may need to be mitigated against or managed, most likely by an increase in physical offshore infrastructure, additional well and well lines, or by using well capacity installed but not realised to accommodate high flows from Humber.

For Teesside the network is split in three directions. Firstly, NZT Power will have a short connection to the gathering header of the main compressors required for offshore transportation as it is co-located with the NEP compression station. The Network as shown in the DCO only connects to transits to Seal Sands and not to Wilton, it is assumed that the individual projects across Teesside will be connected via pipeline spur from the central trunk line proposed by NEP,. This is a reasonable position to take for a network operator and typical of oil and gas pipeline systems..

An future proofed design would include facility for connections to any emitter or area, to ensure that the ability to gain revenue and volumes, whilst minimising CAPEX. The diagram below, shows the current NZT network overlaid with the Teesside Collective work and where such connection nodes may be required.

Each node is not the shortest distance for each emitter but was assessed to reasonably shorten distances balanced with reducing the number of connection points on the network. The pipelines and equipment are then sized to accommodate future volumes from those nodes.

- The connection point at Billingham would offer a natural entry point for local emitters to collect as one and enter the system.
- A connection near Saltholme, although small would enable Hartlepool emitters and those small emitters toward Port Clarence in the south.
- A further connection, third from left would be located near BOC enabling projects to the south and to the CATS and TGPP gas terminals.
- A fourth node adjacent to Navigator terminal would enable those emitters west of the road adjacent to Conoco Phillips/Norsea. To enable shipping another connection node in this area would likely be required prior to Tunnel 2.
- A final connection opposite Bran Sands, far right, would enable connection with any pipeline originating from MGT Teesside and from the Wilton International complex. Here though if needed the pipeline could avoid the complexities of a connection and the connections could be run to the NZT Power site and terminate there.

Ultimately ensuring that the system can be expanded, putting in future expandable AGIs and block valves would be an efficient aspect for the project, even at a marginally higher cost.

21.6 Non-Pipeline Transport (NPT) Requirements

The capacity for T&S networks to be able to accept CO_2 from dispersed sites and international sources, either transported by ship, road or rail - collectively known as non-pipeline transport or NPT - will be vital for their long-term objectives of achieving their Carbon Budgets and Net Zero.

21.7 Imports – Shipping

The potential to accept shipped volumes for CO2 from remote clusters or isolated emitters is a critical element of the future roll out of CCS and the enablement of all emitters to contribute to net zero goals. A fixed pipeline network enables low cost, reliable access to storage whilst allowing shipping to connect onshore with the main compressors and conditioning equipment. Shipping can also be enabled offshore, the reverse of the FPSO and shuttle service configuration that is used in oil extraction. Here shipping could connect offshore, although conditioning equipment would be required on the ship or a platform, a significant infrastructure and operational cost.

The concept of importing/exporting by ship as part of an integrated infrastructure solution assumes that a shipped volume of CO2, typically liquid phase, connects to pipeline infrastructure or delivers offshore to storage infrastructure. For projects with fixed access to storage via a pipeline, shipping represents an opportunity for additional revenue and technical benefits such as the ability to maintain minimum flows or if configured to provide buffer volumes for high flow periods.

Shipping remains a critical option for many, with UK projects in Scotland and the Humber already proposing shipped solutions, tying into pipeline assets and storage. In addition, the operating model of a shore side storage receiving shipped volumes for injection into a pipeline system is being delivered by Equinor's Northern Lights project in Norway.

Teesside already receives and exports significant volumes of chemical and unrefined crude by ship from the region and has significant port and storage capability. There are two key elements – the first the ability to receive CO2 particularly infrastructure and storage, the second the network capacity to the additional volumes.

Infrastructure needs are relatively simple, and a typical facility would consist of, but not limited to:

- Storage – sufficient to receive loads and buffer the flow to the network.
- Off gas management.

- Compression/Pumping.
- Network metering connection.
- Unloading facilities.
- Pipeline access.
- Utilities.

This also assumes that imported CO2 meets the entry specification of the network, otherwise conditioning process plant will be required.

The physical space for such facilities is also required, preferably close to the pipeline network. The size of the facility is dependent on the required buffer storage volume. This is determined by the rate of injection into the pipeline system and the frequency of imported volumes being delivered. There are significant storage facilities on Teesside already located adjacent shipping terminals along the Tees, specifically the northern banks as far down river as Billingham.

The final requirement is access to the network and storage physically and commercially. Commercial agreements should be possible under the proposed business model and network code. Development of those models will be crucial to ensure access and pathways forward for remote clusters where shipping is likely to become an early, or vital long-term requirement for decarbonisation. Physically a connection would be required to the network, either as an entry point to the network, or a separate connection to the high-pressure compression plant and offshore pipeline. In each case the required allocation for the volume would be required, ensuring that onshore emitters are not excluded from or constrained within the network.

21.8 Exports – Shipping

Exporting CO2 from Teesside could target other North Sea storage facilities or access to other infrastructure. Export equipment would likely operate as part of any import terminal, sharing storage facilities, but would require process equipment to compress the CO2 to the require shipping specification. In addition, it would require a network exit point, where CO2 flows from the network to the export facility, and the associated facilities in the network code and business model. Independent volumes could be supplied by additional pipelines or road vehicle, which would require additional buffer storage.

The capability to export directly supports network resilience, as does import. Export however allows for the network to access other infrastructure should capacity limits in the network be reached or an outage occur, planned or unplanned. This directly increases the resilience of the network.

21.9 Road

The transport of CO2 by road and rail is another viable method of connecting users to the network. In both cases buffer storage and unloading/loading facilities would be required. Once the CO2 is unloaded into the buffer storage it would be brought to entry specification standards and injected into the network. Like importing by ship volumes within the network would have to be allocated accordingly.

Receiving CO2 would most likely require that on receipt the fluid is at the entry specification composition, placing the onus on the emitter to provide conditioning at site, or conditioning at the offloading facility. It is not clear if the network code or T&S business model consider the requirement for conditioning, or if this could be changed. For the individual emitters the issue becomes of commonality of entry specifications. An emitter reliant on this type of transport arrangement needs to have clarity contractually on the destination of the CO2 and the period of time the contract may exist. There are technical issues to address on entry specification and long-term commitments could reduce CAPEX for the emitters.

For Teesside the import of CO2 into the cluster network would be achievable by road as the area already exports CO2 by road from a small facility supplied by CF Fertilisers. Any terminal would need to be located adjacent to pipeline infrastructure, like the ship import option, which is easily achieved in North Tees adjacent the Navigator Terminal near Tunnel 2, or at Wilton. Access could even be provided adjacent the NZT site, negating entry into the network with direct import into the main compressor suction header.

21.10 Rail

Rail infrastructure plays a significant role in the region for cargo transfers and has in the past provided the movement of chemicals and crude. Railheads have existed on North Tees, at the Navigator site, Conoco Phillips and the Ineos Nitrile site. The use of these systems has declined. The NZT Power project has also proposed that the new natural gas line to the plant runs along the route of the North Tees rail spur, which would possibly affect re-use of the line. South of the Tees rail infrastructure is still widely in use at PD Ports for Cargo movements and at Wilton International, for the supply of biomass to the Wilton 10 and 11 power plants.

22 Shipping Industrial Gases I - importing CO2 by sea

22.1 Underlying Report

Title	Low carbon Gas Shipping to Teesside – CO2
Author	Element Energy
Filename	Task 13a Low Carbon Gas Shipping to Teesside CO2 Summary.pdf Task 13b Low Carbon Gas Shipping to Teesside CO2 Detail.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-13a-Low-Carbon-Gas-Shipping-to-Teesside-CO2-Summary.pdf https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-13b-Low-Carbon-Gas-Shipping-to-Teesside-C02-Detail.pdf

22.2 Description

The previous section of this part of the Cluster Plan describes how the CO2 gas gathering network of NZT might be optimised to bring in CO2 by non-pipeline transport from outside the Cluster. To develop some of these ideas further – in particular the opportunity to ship CO2 to Teesside using the deep-water port facilities – we tasked Element Energy with carrying out this additional study.

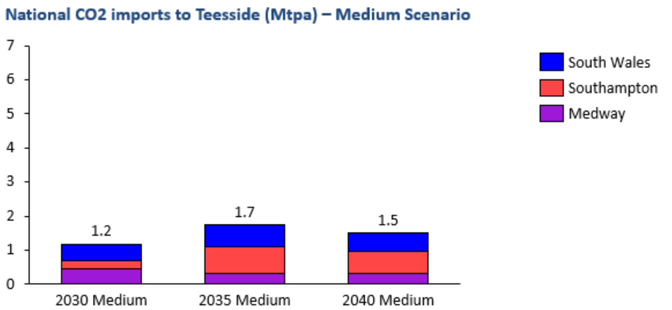
Element Energy assessed how demand for CO_2 storage is likely to grow in the UK and in Europe, to a significant extent in locations that will need to rely on shipping in order to access to CO_2 storage.

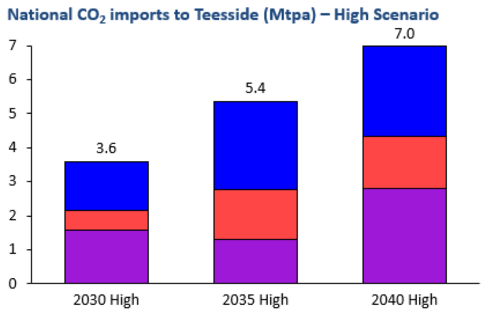
Imports of CO_2 from industrial clusters in the UK and Europe could provide opportunities for the Tees cluster to grow the local low carbon economy while also enabling other clusters to accelerate their decarbonisation and benefit from economies of scale. This study assesses technical and commercial feasibility of such imports, focusing on their scale, required infrastructure, economics, and regulatory barriers and enablers.

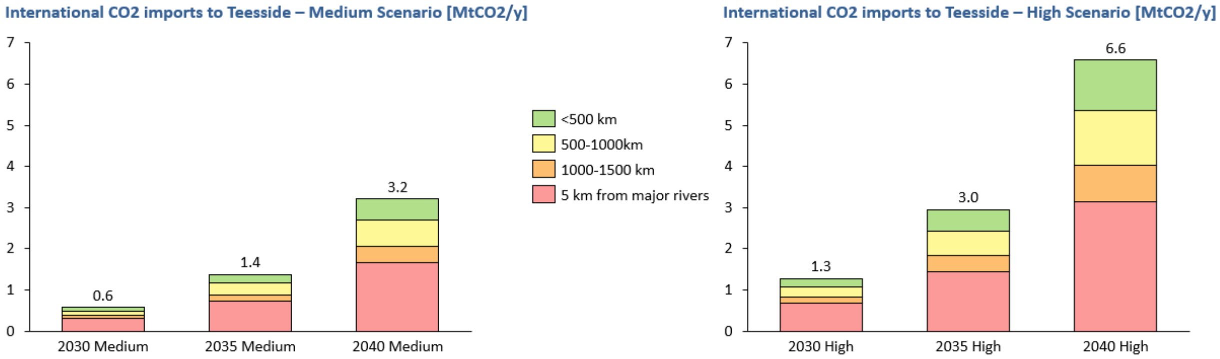
22.3 Volume of CO2 Imports

Up to 7 $MtCO_2$ could be shipped within the UK to Teesside by 2040 from industrial and power sector emitters in the UK, with similar contributions from the Solent (up to 2.6 $MtCO_2$/year), South Wales (up to 1.5 $MtCO_2$/year) and the Medway (up to 2.8 $MtCO_2$/year) industrial clusters.

Imports of CO_2 from Europe could reach up to 6.6 $MtCO_2$/year by 2040. The highest share of these possible imports is from industrial clusters in Germany, located within 5 km of the Rhine.







While combined national and international CO_2 imports could reach up to 14 $MtCO_2$ by 2040, **uptake of CCS in the UK and Europe is highly uncertain** due to development of alternative decarbonisation options and limited transport infrastructure being currently available. In particular, no or very limited (at Teesside) CO_2 shipping infrastructure currently exists at the CO_2 storage sites under development in the UK. The key sectors which could rely on CO_2 shipping to Teesside for access to permanent CO_2 storage are power generation, refining, iron & steel and the future blue hydrogen sector. For all these sectors, decarbonisation alternatives exist which don't involve CCS.

A further **factor that could limit CO_2 imports to Teesside is competition from other storage** sites in the UK and Europe. Ruling out emitters which are likely to connect via pipeline to nearby storage and accounting for opportunities to ship to alternative storage destinations reduces imports by 75-90% in our analysis (the above-mentioned values already account for these reductions).

Considering these uncertainties in uptake, three scenarios representing low, medium, and high estimates for imports have been developed in this study. In the 'Low' scenario there are no imports to Teesside up to 2040. In the 'Medium' scenario, imports reach 4.7 $MtCO_2$ in 2040.

The 14 $MtCO_2$/y **imports** in our 'High' scenario **could accelerate further storage appraisal and development in the Southern North Sea**. Storage capacity would need to be scaled up, for example by using the additional 1 $GtCO_2$ storage identified approximately 70 km offshore Humberside.

22.4 Infrastructure

CO2 imports via ship require deployment of significant onshore infrastructure at the Teesside port. Existing infrastructure, in particular deep-water jetties and available land, in Teesside could be utilised for CO2 shipping. The CO2 shipping chain includes all steps following carbon capture and preceding injection at the final storage site. Each of these steps requires infrastructure to be upgraded or built in Teesside, as listed below:

- Temporary/buffer storage to bridge the gap between (semi-)continuous CO2 capture and batch transportation by ship. Sufficient amount of land is available at Teesside at which storage could be located.
- Jetties with unloading and loading equipment to transfer liquified CO2. There exist underutilised jetties at Teesside port which could be used for CO2 imports.
- Onshore transport of the imported CO2 to the offshore pipeline is required. This could be realised either through connecting to the planned pipeline through the Teesside cluster (gas phase) or to the offshore pipeline (dense phase) through a direct pipeline in dense phase. The latter would be preferable for efficiency reasons as it would avoid the energy intensive phase change from gaseous to dense phase.
- Liquefaction is necessary for cost efficient transport by ship. If Teesside became both an import and export terminal for CO2, a liquefaction plant would need to be located in or close to the port. At the port, sufficient land is available to host such a plant.

The onshore part of NZT's gas gathering network will be gas phase and the offshore pipeline to NEP will be operated in dense phase. To minimise energy losses from liquified CO2 used in shipping when it enters the NZT system, it may be practicable to connect imported CO2 to the offshore pipeline of NZT rather than the onshore pipeline.

22.5 Costs

Shipping costs are dominated by liquefaction (~40% of total cost) **and shipping** (~50% of total cost). Temporary storage and loading facilities only account for ~10% of the total cost. Shipping requires a much lower CAPEX spending than pipeline transport as costs are dominated by fuel costs and other OPEX. Overall, shipping CO_2 is lower cost than pipeline transport at low volumes (<5 $MtCO_2$/year) and large distances (>500 km). Shipping costs have a low sensitivity to distance, ranging between ~30-45 €/tCO_2 for emitters which are 500-1500 km from Teesside, assuming a fixed ship size. By connecting with other local emitters, synergies can be used to exploit economies of scale associated with larger ship sizes and thus further reduce the cost of shipping.

The business model currently proposed by DESNZ sees CO_2 pipelines as the short-term priority with non-piped transport options becoming relevant for later geographical expansion. Multiple business models may work but BEIS has not yet declared which one they will support. **Stakeholder engagement has identified uncertainty around the regulatory framework** as **a key factor delaying investment** in CO2 shipping infrastructure.

Further key regulatory barriers are present for international imports of CO_2. These include the London Protocol, which requires a formal declaration to the International Maritime Organisation if two countries want to import or export CO_2 between one another. Furthermore, the EU-CCS directive does not recognise storage outside the EEA as long-term storage. Since the EU-ETS only recognises storage sites which are compatible with the CCS directive, this currently presents a regulatory barrier for imports from the EU to the UK.

22.6 Resilience

Resilience provides the ability to quickly adapt to disruptions of the CO_2 transport and storage system while maintaining continuous operations, i.e., not releasing CO_2 to the atmosphere. This requires avoiding shutdowns of the CO_2 transport and storage system as much as possible as well as managing shutdowns where unavoidable.

There will be a wide range of planned and unplanned shutdowns across the whole transport and storage system of varying duration (hours to years) and frequencies (from once in the project lifetime to every two years). Causes of major shutdowns include failure of compressors, failure of safety valves on the wellbore, routine maintenance, physical damage to the offshore pipeline and risk of leakage from the geological store.

Options to increase resilience and mitigate the impact of shutdowns include the following:

- Line packing involves increasing the total volume in the pipeline by increasing the pressure. This mitigation option can be used as a buffer store for outages up to a few hours and is dependent on the pipeline MAOP.
- Onshore temporary storage tanks/barges could mitigate storage shutdowns for a few days. However, the high CAPEX associated with the construction of these will be hard to justify unless already installed for CO_2 shipping.
- Shipping to an alternative store/cluster would cover long-term shutdowns but collaboration between clusters is currently curbed by concerns around UK competition law and is also reliant on the development of shipping infrastructure.

Within the emerging regulatory framework there exist multiple opportunities to incentivise CO_2 transport and storage resilience. These include allowing profits to increase in case of high availability of storage, defining availability metrics and service levels for a T&SCo to meet, and

allowing an emitter to end their contract with a transport and storage company for outages of more than 6 months (in the Dispatchable Power Agreement). However, the detailed design and impact of these incentives are still uncertain.

23 Shipping Industrial Gases II - exporting hydrogen

23.1 Underlying Report

Title	Low Carbon Gas Shipping – Hydrogen & Methanol Streams
Author	Element Energy
Filename	Task 14a Low Carbon Gas Shipping to Teesside CO2 Summary.pdf Task 14b Low Carbon Gas Shipping to Teesside CO2 Detail.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-14a-Low-Carbon-Gas-Shipping-to-Teesside-Hydrogen-Summary.pdf https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-14b-Low-Carbon-Gas-Shipping-to-Teesside-Hydrogen-Detail.pdf

23.2 Description

For the second part of our Theme 4 study on future opportunities for industrial gases in a decarbonised Tees Valley, we tasked Element Energy with a study to understand the market opportunity for hydrogen – both as a regional 'export' to the wider UK market and as an international export.

Although the policy announcement isn't due until late 2023, it is likely that in the future hydrogen will be blended with natural gas in the national grid. Hydrogen can be blended with natural gas up to around 20% w/w without significant loss in performance. Natural gas is the principal source of home heating in the UK – blending hydrogen in the national grid will require large volumes and deliver emissions reductions across the UK.

The mechanism and benefit for delivering hydrogen blended with natural gas is reasonably well understood. In light of this we specifically asked Element Energy not to include this in their study, or other pipeline transport of hydrogen out of the Tees Valley cluster. Instead, we tasked Element Energy with looking at other delivery routes – principally shipping – to regions in the UK and overseas which are more remote from the Tess Valley,

Element Energy's study has two principal parts:

- **Excess demand:** An assessment of hydrogen demand at other UK industrial clusters and key locations internationally to determine whether there is 'excess' demand that cannot be met by currently announced supply projects.
- **Techno-economic modelling:** An assessment of the costs of distributing hydrogen via a number of different methods/technologies. These include compressed gas hydrogen (CH_2), liquid hydrogen (LH_2), ammonia (NH_3), liquid organic hydrogen carriers (LOHC), and methanol. This will allow TVCA to determine how much additional cost would be incurred to distribute the hydrogen over long distances, and which technology option makes the most economic sense.

23.3 Demand Assessment

The approach to assessing demand has been kept relatively high level because:

- Orders of magnitude are all that is needed for the distribution cost model to determine the optimum technology choice.
- There is significant uncertainty regarding the development of the hydrogen energy sector, and it is an ever-evolving space, so too granular an approach is not appropriate.

The assessment also included a stakeholder outreach programme to provide insight into each of the UK cluster's views on the need for importing hydrogen, and the case for importing from Tees Valley specifically. Results from these discussions are mentioned throughout the Demand Assessment slide report.

23.4 UK cluster demand

For this study, a 'cluster' has been defined as the area within a radius of 50km from the epicentre of industrial activity, unless otherwise stated. The four major sectors relevant to hydrogen were considered – industry, power, mobility (including shipping and aviation) and domestic heating.

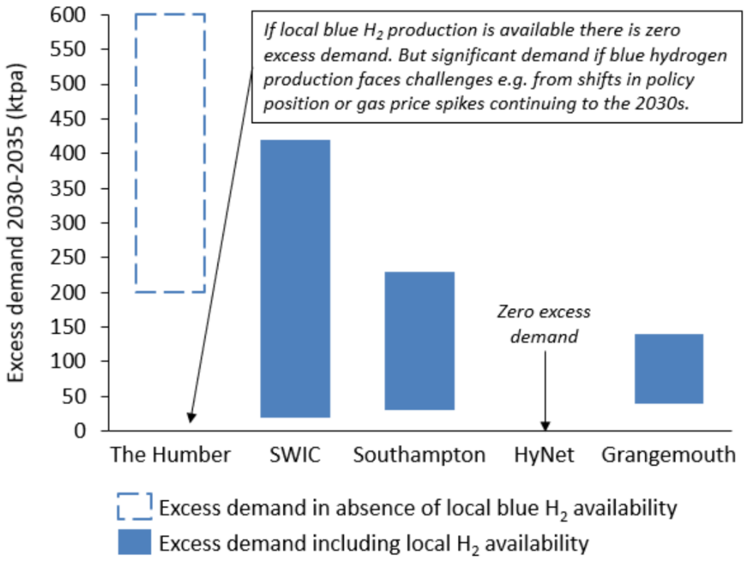
Three scenarios were modelled, considering various levels of hydrogen uptake:

- **'High' demand**: In this scenario, high levels of hydrogen uptake is assumed for all sectors, due to increased innovation and scaling in the hydrogen sector, as well as high levels of policy support. Hydrogen technologies are thus able to capture market share in sectors that are usually reserved for other zero-emission technologies (e.g., passenger vehicles).
- **'Base' demand:** Hydrogen demand increasing to 2050 in a balanced pathway, where innovation and policy support evolves for all technology options equally. Hydrogen is reserved for harder-to- abate sectors, such as shipping, and steel making.
- **'Low' demand:** Representing minimal growth in the use of hydrogen in energy applications. Slow technology development and lack of infrastructure (e.g., hydrogen refuelling station network) means hydrogen technologies are reserved for only the most niche applications, with little government support.

To define a range of excess demand, local supply is compared with the modelled scenarios. The case where blue hydrogen projects do not proceed, thereby reducing local supply, is also considered when characterising the ranges for each cluster. Blue hydrogen may prove challenging, either due to a sustained high natural gas price or in the event of a policy position shift away from blue hydrogen.

- **Humber:** The Humber nominally has no excess hydrogen demand in 2030–2035, due to large local blue hydrogen production. However, in the high scenario and the case where blue hydrogen is uncompetitive, the Humber may not be able to scale up green production (due to water constraints) to meet its local demand. This makes the Humber unique in that it either has zero, or the largest excess demand, because it is positioned to become one of the UK's most important blue hydrogen hubs.
  - TVCA note: Element Energy wrote this report before the 30th of March 2023 'Powering Up Britain' announcements when no projects were selected from the Humber region to progress to the negotiation stage of Cluster Sequencing Track-1/Phase-2. It is difficult to imagine Net Zero in the UK without decarbonised industries in the Humber region. However, for the time being there are no current government-supported plans for blue hydrogen production in the Humber region.
- **South Wales Industrial Cluster:** SWIC struggles to meet base demand with local supply, consequently, it is the cluster with the highest excess demand in the base case. Even in a low scenario, 20 KTPA of imports may be needed in 2035 (the chosen lower bound). The significant supply deficit may discourage consumers and limit hydrogen uptake at the scale projected.

  - **TVCA note:** Since Element Energy delivered this study, the newly formed Net Zero Industry Wales group South Wales has described their ambitions for floating offshore wind. This may lead to a large production capacity for green hydrogen in South Wales.
- **HyNet:** The HyNet cluster had zero excess demand between 2030–2035 in all scenarios modelled, and so has not been considered in the techno-economic analysis.
- **Southampton:** The Solent cluster has excess demand between 40–225 KTPA, depending on whether additional green supply is constructed near the Isle of Wight.
- **Grangemouth:** The upper and lower bounds correspond to 2030 and 2035 excess demand in the high scenario. Supply is exposed to risk as it is dominated by a single blue hydrogen project.



Range of excess H2 demand across all industries modelled for UK industrial clusters in 2030.

23.5 International demand

Considering every export market in the world is beyond the scope of this project, so only the most promising markets were evaluated in this demand assessment. The European market is the most advanced hydrogen market in the world (alongside China).

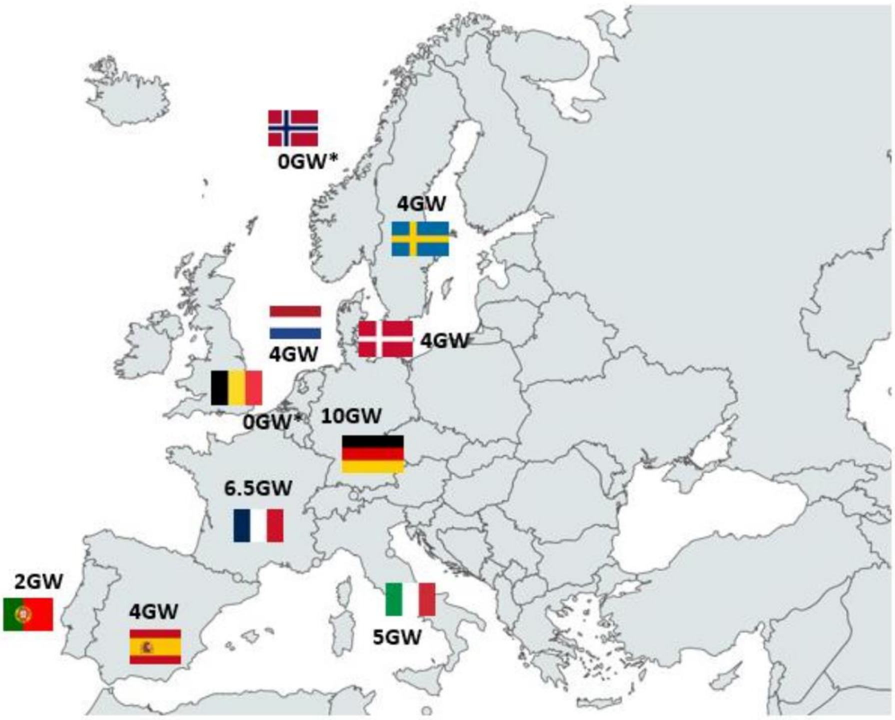
- The EU has some of the most advanced policy (e.g., the Renewable Energy Directive, RED II) and funding mechanisms (Innovation Fund, Clean Hydrogen Partnership) for low carbon hydrogen.
- Almost half the announced MW-scale hydrogen projects are located in Europe.

The North West European region is also in close proximity to Tees Valley, meaning shipping distances are short. This may allow Tees hydrogen to compete with hydrogen from places such as Morocco or Saudi Arabia, where the renewable energy resource is stronger (particularly for solar), but distribution distance is longer. Therefore, it is logical for Tees Valley to focus on export markets that are closer to the UK, given they have an inherent proximity advantage and represent relatively mature markets.

The countries of focus for this analysis are shown on the map. The map shows the national 2030 hydrogen production targets (in gigawatts of electrolyser capacity) for each of these countries, derived from their national hydrogen strategies. These can be converted into tonnes per annum by assuming a standard electrolyser utilisation (5,000 full load hours, or 57%) and efficiency (60%). Both of these are IEA assumptions. As a rule of thumb, 1 GW is roughly equal to 90 KTPA.

Some regions have bespoke import targets, such as Germany. These are also factored into the total demand equation.

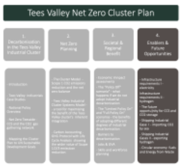
- **Germany:** National hydrogen strategy targets 76+ TWh (2,300 KTPA) of hydrogen import in 2030 on top of 10 GW domestic production.
- **Belgium:** Targeting 20 TWh (600 KTPA) hydrogen import in 2030, moving to 200–350 TWh in 2050.



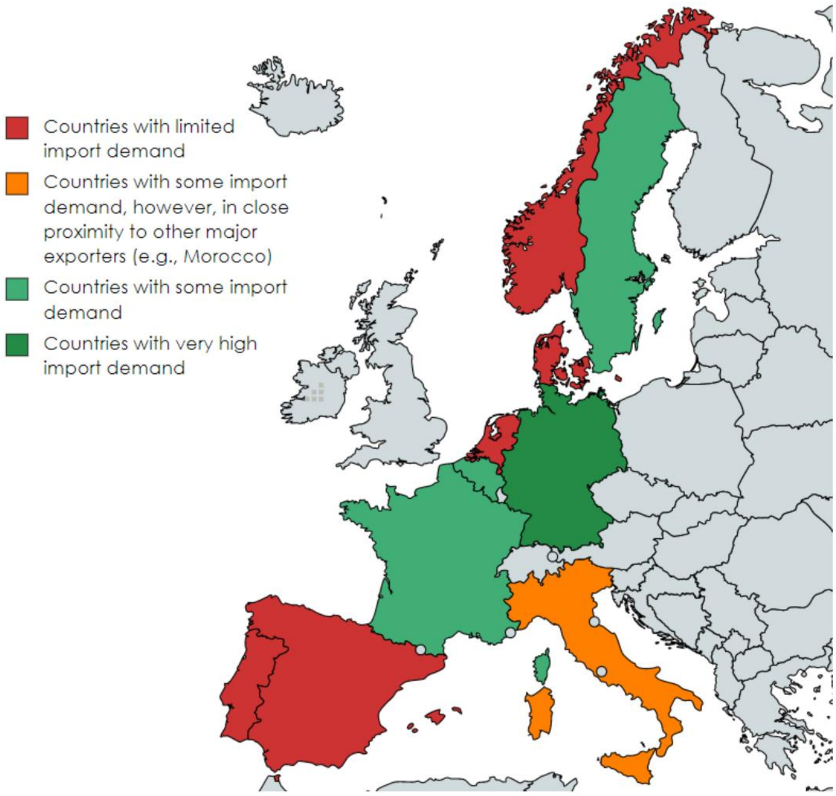
National hydrogen strategy production targets in Europe (2030) * Belgium and Norway do not have formal hydrogen production targets.

Hydrogen import demand for each relevant nation was estimated by comparing national production targets to announced supply projects.

- The most promising export markets are Germany, Belgium, France, and Sweden.
- Italy also has significant import demand; however, it is in close proximity to Morocco and the Middle East, and further from Tees Valley, making it a less promising target due to competition. For example, the European Hydrogen Backbone project is aiming to develop hydrogen pipelines between Italy and North Africa by 2030 [2]. This does not mean Tees Valley cannot capture market share, but it will be more competitive.
- Spain, Portugal, the Netherlands, and Denmark have sufficient announced domestic supply to satisfy their targets.



- Norway does not have a formal hydrogen production or hydrogen import target. The country has vast CCUS potential, and so is likely able to satisfy industrial demands with domestic blue hydrogen production. In addition, the region is generally pro-electrification due to its highly decarbonised grid with high penetration of renewables (notably hydropower).



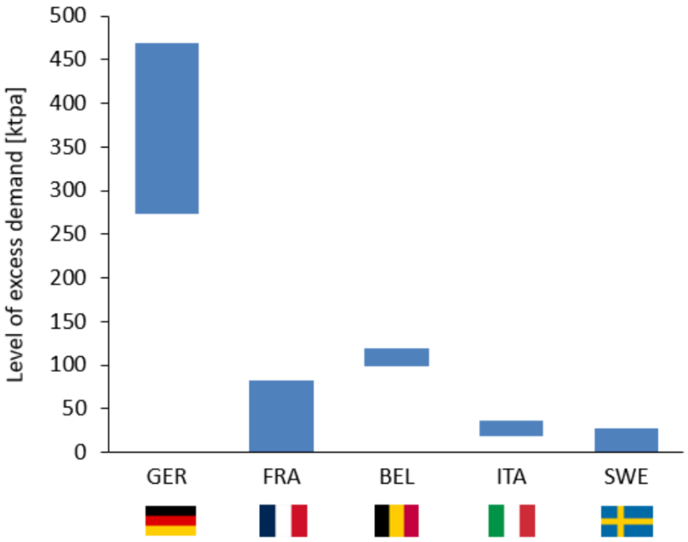
Map of the most promising EU countries for export

The exact fraction of the market that can be captured by Tees vs these exporters will depend on the cost- competitiveness of Tees hydrogen, the scale of production, and other factors. As modelling this is beyond the scope of the project, it is assumed that Tees Valley will be able to supply a maximum of 20% of the total export demand. For the special case of Italy, which is in close proximity to North Africa, the total percentage assumed is 10%, to reflect the more competitive market. These are only indicative assumptions to account for the competitiveness of other export projects (with strong solar resource and large scale).

Details of the demand assessment for each of the countries of interest (Germany, Belgium, France, Sweden, and Italy) can be found in the downloadable documents.

- Germany is the most promising international export market for Tees Valley. The nation has ambitious plans for a hydrogen economy and has targeted over 2,000 KTPA of hydrogen to be imported by 2030. While some of this hydrogen will come from neighbouring countries (such as the Netherlands) via European Hydrogen Backbone pipelines, assuming that Tees Valley could capture a modest market share of up to 20% implies a potential market of up to 475 KTPA.
- Belgium also has a hydrogen import target (600 KTPA by 2030). Again, some of this can be supplied by planned pipelines connected to the Netherlands, but > 100 KTPA could be captured by Tees Valley.

- **France** is an interesting case study as it has no formal import target, and its policy position tends to favour domestically produced hydrogen for the economic benefits it brings. However, Element Energy's database suggests that current supply is > 400 KTPA short of meeting their production target. Assuming 20% of this can be met by Tees, a c. 80 KTPA market could be captured. European Hydrogen Backbone pipelines connecting France to Spain could reduce this to zero.
- **Italy** has a modest excess demand and is in close proximity to North Africa, limiting the opportunity for Tees Valley. Pipeline initiatives connecting Algeria to Italy could limit the amount of the export market that Tees Valley can capture.
- **Sweden** represents a promising export market for Tees Valley, as it does not neighbour the two major hydrogen exporters in the EU (Netherlands and Spain). Therefore, its demand is relatively consistent in all scenarios.
- For the case where Spain exports hydrogen via pipeline or ship, Tees Valley's opportunity is significantly reduced.



Range of excess H2 demand for the low, base, and high scenarios that could be captured by Tees Valley for EU countries in 2030.

23.6 Techno-economic Modelling

The aim of the techno-economic analysis is to determine which technology option is the most cost-effective for the specific scenarios of interest to the Tees Valley. The technology options considered are:

- compressed gas hydrogen (CH_2)
- liquid hydrogen (LH_2)
- ammonia (NH_3)
- liquid organic hydrogen carriers (LOHC)
- methanol

For each of these technology options, road, rail, and sea distribution is analysed. Pipeline distribution is out of scope, as this study focuses on meeting hydrogen demand that cannot be supplied via pipeline.

Each technology has relative strengths and weakness that make them well suited to certain applications and contexts. The purpose of the techno-economic assessment is to contextualise these results, by providing clear recommendations about which technology is the most cost effective for each market.

A sensitivity analysis has been conducted to identify the key cost drivers and explore special cases where some technologies perform better than others.

A generic hydrogen distribution chain contains the following functions:

- **Hydrogen production:** has not been modelled in detail. Instead, hydrogen prices have been assumed based on public data from major hydrogen production projects (such as Gigastack and HyNet).
- **Preparation:** The preparation facility is required to increase the volumetric energy density of the ambient hydrogen to reasonable levels ready for transport. Each carrier has a different preparation step, e.g., compression for CH_2, liquefication for LH_2, hydrogenation for LOHC, and the Haber- Bosch process for NH_3.
- **Distribution:** by road, rail and sea has been modelled. Distribution by pipeline is beyond scope.
- **Withdrawal:** refers to the conversion step from carrier form back to gaseous hydrogen. Similar to the preparation facility, the withdrawal step varies for each technology: further compression for CH_2, regasification for LH_2, cracking for ammonia, and dehydrogenation for LOHC.
- **Purification:** When supplying to the mobility sector, a high level of purity is required (99.99%). In this case, an additional purification step is when dealing with ammonia of LOHC. This is modelled as a pressure swing absorption (PSA) step here.
- **Compressed gas buffer storage:** Electrolysers are able to ramp up/down with the variable renewable energy input to provide a variable supply of hydrogen. Downstream, most preparation facilities (e.g., liquefaction plants, Haber-Bosch, and LOHC hydrogenation facilities) are not able to ramp up/down in this way cost-effectively. Therefore, compressed gas buffer storage is installed between the electrolyser and preparation facility to allow for a near constant stream of hydrogen input.

A 'hub and spoke' model has been assumed for this study. Here, the hydrogen is received at the port/rail/road terminal and delivered to a centralised withdrawal facility (the hub), to maximise economies of scale. This also allows electricity to be purchased wholesale.

The resultant compressed hydrogen gas is then distributed to the specific end use site, such as an industrial plant or hydrogen refuelling station (the spokes). This aspect has not been modelled in the main results (as it is the same for all carriers). However, the costs of this are illustrated in a separate "last mile" section in the sensitivity analysis.

The model therefore considers bulk hub-to-hub distribution from Tees to the epicentre of the import cluster:

- For road, the distance between Teesside and the epicentre of the destination cluster has been considered.
- For rail, we considered the distance from Teesside's freight terminal to the main freight terminal at the destination.
- Port to port distance has been assumed for distribution by ship.

23.7 Overview of Technology Options

A full overview of the relative advantages and disadvantages of each technology option can be found in the downloadable documents. The key points are summarised below.

Compressed gas (CH_2): is the most common distribution method in current low carbon hydrogen projects at modest scales (e.g., hydrogen mobility projects). For larger scale applications (e.g., at refineries), pipelines are usually preferred. The hydrogen is first compressed to the specified pressure, and then stored and transported at ambient temperatures. Standard pressures usually seen in industry are 350 bar and 500 bar, corresponding to common tube trailer specs. Compressed gas hydrogen benefits from high technology readiness level (TRL9), low energy requirements, and minimal losses. There are drawbacks to CG H_2, including high CAPEX compressors and logistical issues derived from low volumetric and gravimetric densities.

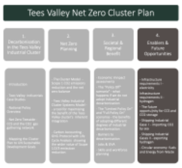
Liquid hydrogen (LH_2): Liquifying hydrogen increases its volumetric energy density, allowing more hydrogen to be transported per vessel. This is particularly important for long-distance or high-volume distribution, as it significantly reduces operating costs associated with vessel operation (per unit of fuel). Gaseous hydrogen is liquefied by cooling to below −253°C in a liquefaction plant at the production site (involving a series of compressors), a process that requires considerable energy using current technology. The LH_2 is then transported in super-insulated, cryogenic vessels for distribution by road, rail, or ship (only one liquid hydrogen ship exists today, making it low Technology Readiness Level). Specialist infrastructure is thus required to store and transport LH_2 at such low temperatures. On delivery, hydrogen can be evaporated and released at the correct pressure (depending on the application) via a cryo-pump. For applications requiring liquid hydrogen (e.g., Daimler trucks using liquid hydrogen storage tanks), this step is not necessary. A key advantage of liquid hydrogen is its high output purity, making it a suitable option for the fuel cell EV transport sector.

Ammonia (NH_3): During ammonia synthesis, hydrogen is reacted with nitrogen, separated from air, in the Haber-Bosch to process to produce ammonia. This is a very mature process, producing approximately 176 million tonnes of NH3 annually. There is extensive experience of NH3 production on Teesside at the CF Fertilisers plant. Ammonia is stored and transported as a liquid. Liquification is achieved either by compressing the gas to 17 bar or cooling to −33^{o}C. There is already a mature infrastructure for ammonia distribution that has been developed by the fertilizer industry. After distribution, by road, rail or sea, hydrogen can be released in an ammonia decomposition unit, or "cracker". This process requires significant heat input (9 $kWh.kg^{-1}$) and releases low pressure and low purity hydrogen. This heat input can come from burning a fraction (c. 20%) of the hydrogen output stream. This stage of the supply chain has the lowest Technology Readiness Level. Purification can be achieved by a pressure swing adsorption (PSA) unit.

Liquid Organic Hydrogen Carriers (LOHCs): LOHCs are oil-like liquids that are reacted with hydrogen. A de-hydrogenation reactor, which requires heat, is needed to release hydrogen at point of use. This is a process that requires significant amounts of heat (14.5 $kWh.kg^{-1}$). As with ammonia cracking, this heat can come from combusting a fraction of the delivered hydrogen (35-45%), or from an external source. Given the end use site is generally energy deficient (hence the need to import hydrogen in LOHC form), the former is considered more likely. The unloaded LOHC material needs to be transported back to hydrogenation plant. LOHCs can be stored at ambient temperature and pressure in existing oil infrastructure, including oil tanker ships, meaning the distribution infrastructure is highly mature and inexpensive. Currently only small scale LOHC plants have been demonstrated (c. TRL 7), with commercialisation expected to occur in mid to late 2020s.

23.8 Results for distribution to SWIC

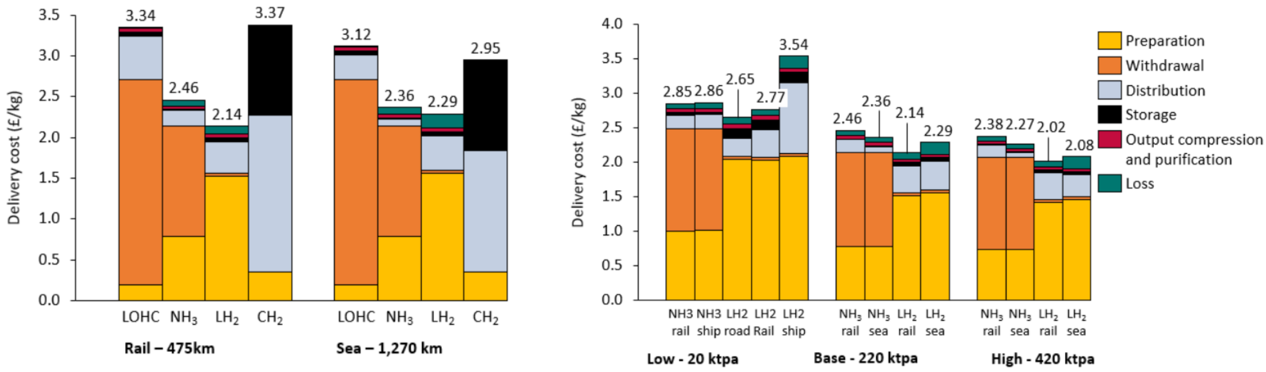
For this executive summary, results for distribution from Tees to SWIC are presented as a base case. SWIC was chosen as it is the cluster with the most significant excess demand in the base case, as it has very limited local supply which fails to meet demand even if hydrogen is adopted to a minimal extent. The other distribution targets are described in the downloadable documents.



The base case considered in the techno-economic modelling is hydrogen distribution to satisfy industrial, power, or domestic heating demands. High purity hydrogen demand from the transport sector has not been considered in the base case, as the UK demand analysis indicated that local hydrogen supply is greater than surface transport demand for all clusters. It has been assumed that this high purity hydrogen demand will be met by local supply, as it is the highest value sector and so will be targeted first by the domestic supply projects.

The base electricity price is an average of DESNZ's price predictions between 2030 and 2040. It has been assumed that a fraction of the delivered hydrogen is combusted to provide heat for the withdrawal plant, requiring the whole supply chain to be oversized. The hydrogen price determines the cost added by combusting a fraction of the delivered hydrogen to provide heat for the withdrawal plant.

The cost drivers highlighted here are applicable to all domestic and international demand centres. The small capacity of road trailers results in a logistically unfeasible number of deliveries at larger scales. As such, distribution by road has only been included in scenarios with an excess demand of <50 KTPA, with rail and sea being the focus of analysis.



(Left). Delivery cost of hydrogen from Tees to SWIC in a base case (220ktpa) showing all carriers. (Right). Delivery cost of hydrogen from Tees to SWIC considering promising delivery options across the excess demand spectrum.

Hydrogen distribution will add £2–£3.50/kgH_2 to the delivered cost of hydrogen when distributing from Tees to SWIC in the base case.

The Figure shows that LOHC is a high-cost distribution option across all modes of transport. This is a consequence of the costly withdrawal (dehydrogenation) process which is energy intensive and requires high CAPEX facilities. CH_2 is also a costly option, with the major components being storage and distribution, as high-pressure tanks are expensive and numerous deliveries are required due to the low volumetric energy density of CH_2.

The techno economic analysis suggests that liquid hydrogen and ammonia are the most cost-effective options (both rail and sea) in the base case. It is challenging to determine the most cost-effective option between these technologies, due to the uncertainty in the underlying assumptions (there are novel technologies present in each supply chain).

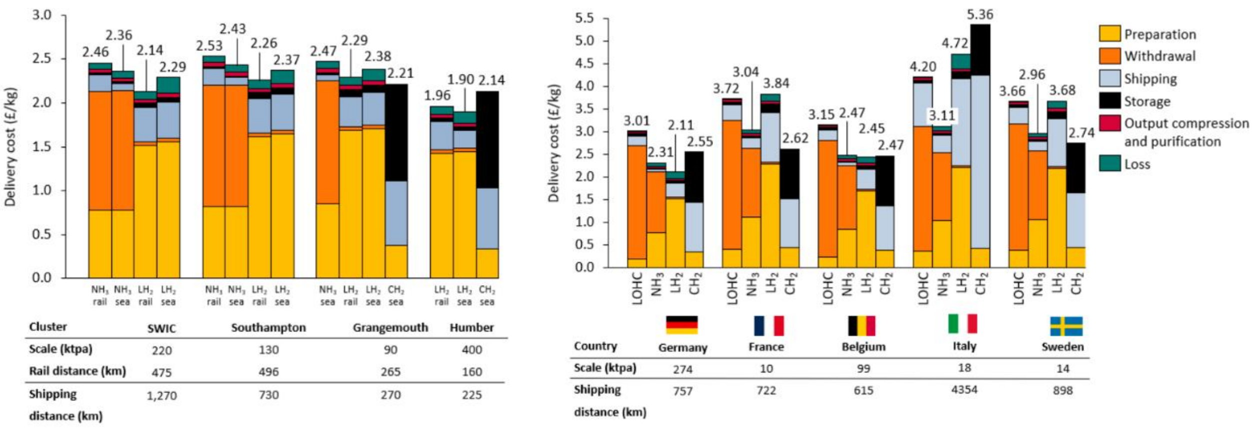
All four carriers have electricity requirements across their supply chains, but the reliance on electricity varies depending on the carrier. Liquefaction has very high energy demands and thus renders the final cost of LH_2 very exposed to fluctuations in electricity prices. If cheap electricity is available in Teesside, LH_2 becomes a very attractive option. Ammonia would also benefit if low-cost electricity in Teesside can be sourced.

23.9 Summary of Results for All Demand Centres

Results show that liquid hydrogen and ammonia are well suited to applications with long distribution distances and significant demand, such as SWIC and Southampton. This is because liquefaction, ammonia cracking, and liquid hydrogen ships benefit strongly from economies of scale, and liquid hydrogen and ammonia ships have high volumetric energy densities, allowing large amounts of hydrogen to be transported per delivery. Rail is more promising for smaller scales, with shipping costs increasing more rapidly with decreased scale.

Shorter distances and smaller scales (such as Grangemouth) suit compressed gas shipping, as the low volumetric energy density of CH_2 is less problematic over shorter distances.

LOHC represents the highest cost carrier in all cases within the UK.



Delivery costs of hydrogen from Tess to major UK industrial clusters considering only low-cost delivery options (left hand Figure) and to international demand centres considering all carriers by sea (right hand Figure). Base demand has been used throughout.

The results from the modelling have high uncertainty, as these supply chains have not yet been developed and require the use of novel technologies. Our sensitivity analysis shows that small changes, for example in electricity pricing at the input facility, can alter the priority order of carriers. Therefore, it is challenging to conclusively state which carrier option is the most favourable for hydrogen distribution from Tees Valley to European markets.

23.10 Techno-economic Modelling Conclusions

The following conclusions were drawn by Element Energy:

- Liquid hydrogen should be considered in scenarios where low-cost electricity at the production site can be sourced and when transporting large amounts of hydrogen. Liquefaction plants benefit from scale to bring down the CAPEX of the plant and achieve lower energy consumption per kg H2.
  - It should be noted that only one small liquid hydrogen demonstration ship exists today (TRL7), making it challenging to source ships pre-2030. However, projects at the 100 tH2/day[13] scale are set to come online in the mid-2020s, meaning liquid hydrogen supply

[13] Hydrogen liquefaction: a review of the fundamental physics, engineering practice and future opportunities - Energy & Environmental Science (RSC Publishing)

chains could be near-commercial maturity by 2030, should these projects come to fruition.

- Ammonia is well suited to scenarios involving long-range, large-scale distribution, because of its high volumetric energy density. This makes it a popular candidate for projects looking to ship to Europe from places such as Australia and Saudi Arabia.
  - Ammonia also benefits from scenarios where the input hydrogen price is low, as there are large losses associated with the cracking step when hydrogen is itself used as a fuel for the process, or when low-cost heat can be used at the import terminal to crack the ammonia back to hydrogen.
- Compressed gas shipping should be considered when transporting over shorter distances at smaller scales, to mitigate its volumetric energy density disadvantages. In addition, the costs of storage are high (and requires significant space), meaning linkages to salt caverns may be required.
- LOHC is less competitive than the other carriers in our modelling for near-term scenarios. However, scaling benefits and technological improvements to the low TRL hydrogenation and dehydrogenation facilities in the long-term might enable it to be competitive.

For the international market:

- Germany has the largest excess demand, therefore LH_2 could be the most attractive option as it benefits greatly from economies of scale.
- France and Sweden both have significant shipping distances and low scales of excess demand. This results in CH_2 being the lowest cost option with NH_3 marginally more expensive.
- Belgium has a slightly increased scale, so LH_2 becomes the cheapest option; however, all three carriers have a similar cost.
- Italy has a far greater distribution distance than any other demand centre considered in this report and therefore NH_3 is the best carrier in this instance as it has a low shipping cost.

23.11 Methanol-H2 Supply Chain with Closed Loop CO2

Element Energy proposed methanol as a potential supply chain for export of hydrogen from the Cluster:

- Methanol synthesis => Methanol Storage => Distribution (by sea) => Steam Reforming with CO2 capture => Purification => End Use.
- CO2 from steam reforming is liquified and returned to cluster for storage.

Each supply chain step is close to commercial maturity with the process (or a process very similar) being conducted at commercial scale today, with the exceptions:

- CO_2 shipping is relatively novel although there are advanced plans for projects to begin shipping at bulk scale such as Northern Lights.
- Methanol reforming without CCS is currently conducted at commercial scale. Though plans for plants planning to conduct methanol steam reforming plants with carbon capture are limited there are advanced plans to conduct carbon capture at commercial scale on methane reforming plants in the UK industrial clusters this decade.

The methanol supply chain model mirrors existing plans to use methanol as a hydrogen carrier, to deliver hydrogen onboard ships as a decarbonisation solution for the maritime sector in projects

such as HyMethShip. Methanol can offer the following advantages as a hydrogen carrier:

- Low-cost distribution and storage, as it is a liquid under ambient conditions with high hydrogen density.
- Lower flammability and toxicity risks than other technology such as hydrogen (liquid or compressed gas and ammonia).

The key risk to the supply chain is the need to capture and return CO_2. As well as being a less mature process this will increase the heat requirement on the methanol reforming plant which will increase the supply chain losses (for a self- sufficient supply chain), driving up costs.

Cost analysis of the methanol supply chain showed it can be cost competitive with the other promising carriers for longer distances and large scales, liquid hydrogen, and ammonia in the near term. The most expensive component of the methanol supply chain was the withdrawal step (similar to the cases of ammonia and LOHC), methanol steam reforming with carbon capture. However, in the future there is greater scope for technology innovations to lead to increased future cost reductions for other technologies as most of the methanol supply chain components are closer to commercial maturity.

Overall methanol was shown to be a cost-competitive technology at large scale and long shipping distances, however there are the following key risks:

- Carbon capture on the methanol steam reforming plant, could increase the withdrawal heat requirement significantly resulting in higher supply chain losses, for a self-sufficient supply chain.
- CO_2 shipping requiring additional infrastructure, and potentially increasing supply chain emissions as carbon capture rates are not typically 100%. There was also found to be limited cost benefits to sharing CO_2 infrastructure.

24 Circular Economy Fuels and Energy from Waste

24.1 Underlying Report

Title	Tees Valley Industrial Decarbonisation Cluster Plan - Task 17 Comparison of Circular Economy Fuels and Energy from Waste Projects
Author	Fraser Nash Consultancy
Filename	Task 15 Circular Economy & Energy from Waste.pdf
Location	https://teesvalley-ca.gov.uk/business/wp-content/uploads/sites/3/2023/10/Task-15-Circular-Economy-Energy-from-Waste.pdf

24.2 Description

The Tees Valley is already a centre for circular economy industries and energy recovery from waste. Two prime examples of this are:

- Suez Recycling and Recovery energy from waste operations at Haverton Hill (3x plants) and Wilton 11 (2x plants) treating waste from the North East and North West of England respectively.
- Greenery's biodiesel production which sources waste oils, including Used Cooking Oil (UCO) from around the world.

There are more Energy from Waste plants and circular economy fuels project that are developing new operations in the Tees Valley. These include:

- Energy from Waste: Tees Valley ERF; Redcar Energy Centre; Graythorpe EfW.
- Circular Economy Fuels: alfanar's Lighthouse Green Fuels (SAF); Circular Fuels Ltd (rDME); Biofuels International Group (SAF).

To help understand the impact that these existing and new industries will have on the industrial cluster, we tasked Frazer Nash Consultancy (FNC) with carrying out a study comparing EfW and circular economy fuels projects. The intention is not to find a preference to one or the other, but to understand better how they will work in the decarbonised industrial cluster.

24.3 Summary

The FNC report provides a review of how waste is used and is planned to be used in the Tees Valley Industrial Cluster to generate energy, fuel and chemicals. The comparative benefits of using waste in Circular Economy Chemicals including "renewable fuels" and Energy from Waste Projects are also discussed.

In relation to how our economies will adapt in the future and looking beyond carbon emissions, it is likely that those organisations that are identified with and generate sustainable revenues by producing regenerative and restorative outcomes will be more commercially viable than those that don't.

In future, it is expected that organisations will have to demonstrate how they are transitioning beyond carbon emissions and creating regenerative outcomes on a regular and progressive basis. The regenerative outcomes will be context specific, develop and change over time and will always have a positive impact on the local, regional, and national economy. Creating greater value of those regenerative outcomes will rely upon adopting a whole systems (holistic) approach that envisages a network of interdependent relationships across actors and stakeholders that collaborate across the Industrial Cluster.

In addition, and as influenced by Government policy, members of the industrial cluster can continually show evidence of how their products and services are adapting towards a carbon neutral society that looks beyond carbon emissions. This can be achieved through actors and stakeholders planning to work with the future, more circular, economy by adopting and applying circular economy principles within their own context.

These principles can be assimilated and embedded in individual business strategies and shown as evidence that the organisation is continually adapting, and the organisation is looking beyond carbon emissions. For example, future procurement strategies are likely to insist on evidencing the existence and the integrity of circular economy practices from the supply chain. These types of practices can evolve at an organisation, network of organisations, at a cluster, or at a sector level.

The study provides a review of how waste streams are being used and planned to be used in the industrial cluster to generate chemicals, fuels and energy, and the comparative benefits of these projects. Waste in this context is considered to be any substance or object which the holder discards or intends or is required to discard. This study is needed to understand the comparative benefits of using waste to generate chemicals, fuels and energy (with carbon capture and storage).

24.4 High Level Circular Economy framework

As a general rule, anything that grows the economy, and incentivises regenerative and/or restorative outcomes, reduces consumption compared to alternatives. and could be considered as something that has circular economy value. The economy will adapt and move away from a take-make-waste society to become more circular towards sustainability and in so doing move beyond carbon emissions. Circular economy behaviour can be incentivised within and across organisations and industries/sectors but in general organisations that are working towards the circular economy are identified with the following principles (within the context of the Tees Valley Industrial Cluster):

- Placing the organisation within the context of the value it creates across the local, regional and national economy as part of the Tees Valley industrial cluster. As opposed to working as a solitary organisation.
- Enabling regenerative and restorative outcomes, continually improving the wellbeing and welfare of employees and the environment within and around the industrial cluster as well as directly or indirectly supporting Power CCUS, Hydrogen and Industrial Carbon Capture (ICC). (As opposed to those organisations that provide less regenerative and restorative outcomes compared with others).
- Rely upon collaboration and diversification, creating multiple and diverse value streams that are exploited through a range of cluster actors and stakeholders.
- Distributing value, for example proving enabling platforms for other businesses to thrive and operate that place them in an advantageous position in remaining competitive.

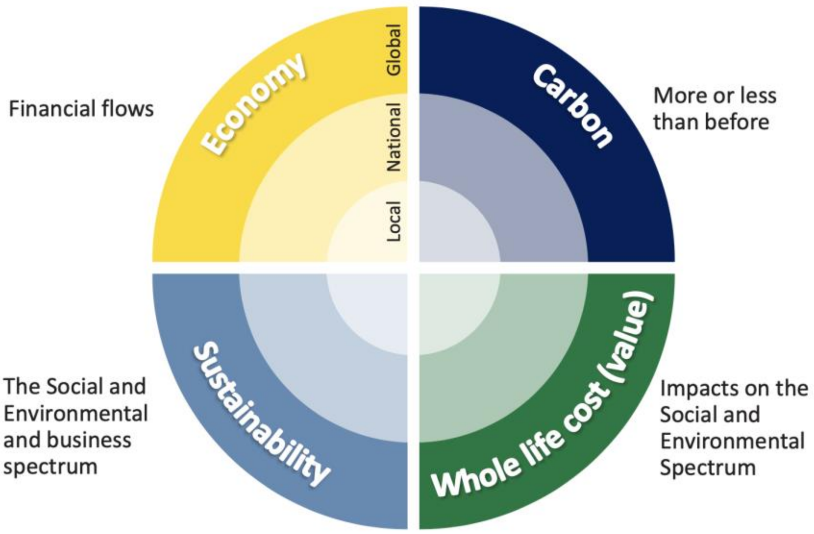
These concepts apply across the whole of Scope 1 – 3 emissions as organisations should be cognisant of their impact on all three areas either directly or indirectly. Continuous business change activities should strive to have a regenerative and restorative impact, directly or indirectly on all scope 1-3 emissions. In this context this is not interpreted as a means for compliance but as a means to exceed compliance thus informing a competitive advantage.

For example, some business propositions may be more 'circular economic' than others. These business changes are embedded in the identity of the organisation and evidenced in business development plans that ultimately directly or indirectly embrace shared and longer-term business goals.

Using the principles described above we can consider the organisations or group of organisation's commitment (or readiness) to working towards the circular economy across two dimensions.

24.5 Progress towards Circular Economy and Impact

Cognisance of organisation's (or group of organisations) progress to move towards the circular economy and impact can be mapped out at a high level using the range shown in the figure below.. The meanings of the ranges are also described below:



Circular Economy Value Impact

Economy: The impact the organisation/s have on the local, regional and national economy. This is associated with financial flows (not value extraction) incoming, going within and across the cluster and provides visibility of economic fluidity which is an indicator of economic growth of the cluster.

Carbon: The status of the reduction of or increase in carbon impact that each organisation contributes towards. Organisations should already be committing to the reduction of carbon.

Whole life cost (value) of the asset infrastructure. This is one of the areas where key drivers for circular economy value can come from. Conventional asset investment has been based upon 'whole life cost' and upon a 'take-make-waste' linear economy approach. This needs to change where members of the cluster should move towards 'whole life value' where that value is tied into externalities. For example, it's not what the assets are, it's what the assets enable in terms of the benefits customers gain from the product and services that the cluster produces. In simple terms, the assets that are invested in and managed by the cluster enable benefits for the cluster's customers from Power CCUS (Carbon Capture, Utilisation and Storage), Hydrogen and Industrial Carbon Capture (ICC).

If the cluster didn't enable those benefits for its customers, then those benefits would be created by another cluster somewhere else or overseas. Therefore, the impacts or dependency on those assets (externalities that the assets enable) to create that value needs to be captured at a high level and interpreted on a social and environmental spectrum. An example of that could comprise:

a) A continuous stream and broad range of sustainable employment opportunities working from apprenticeships upwards across a wide range of professions particularly around the manufacturing sector. This would support the upgrading and remanufacturing of assets, extending asset life and immediately reducing the carbon footprint of the cluster.

b) Establishing ways and means of re-purposing existing assets or for example redesigning new assets that enable the cluster to effectively and efficiently work across the Power CCUS, Hydrogen and Industrial Carbon Capture (ICC) sectors. This presents new problems to be solved, will need a continuous demand for advanced research, new skills and technologies, new types of businesses and services, new partnerships and changes in business operating models.

c) Achieving the transition to beyond carbon emissions where the cluster has established a resilient and diverse network of actors and stakeholders where competencies and capabilities continually evolve to support transition from carbon dependent industries to non-carbon dependent industries, including exports of the technologies and capabilities to make that happen overseas.

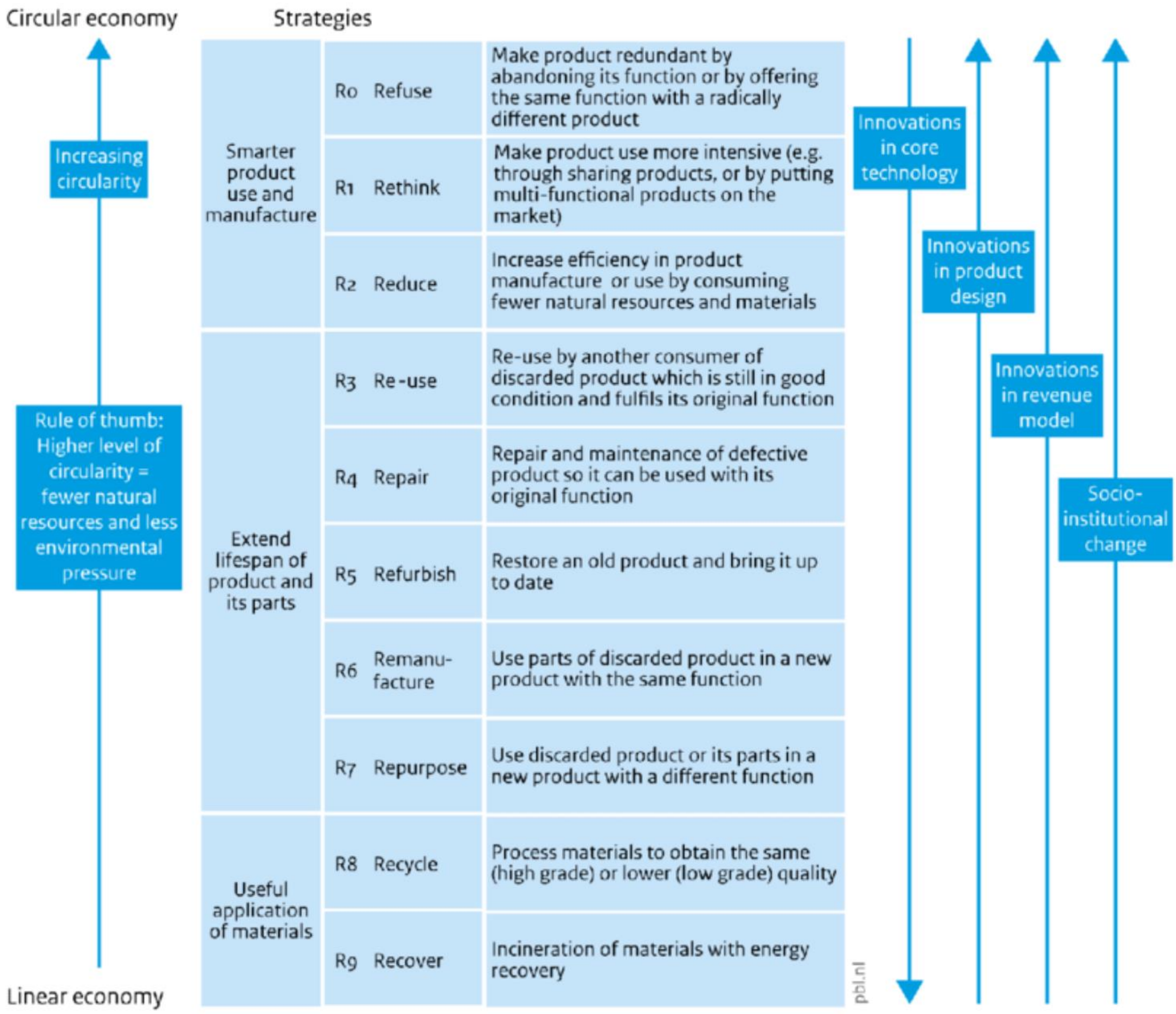
Some of these value streams already exist, but the value of them is not being articulated effectively.

Sustainability and Resilience refers to the sustainability and resilience of the organisation (and/or network of organisations) itself in providing those externalities. The cluster and members of it should never get into a state of fragility such that it is no longer able to provide the social, economic and environmental outcomes on a sustainable basis. The continuity and growth of the cluster sets a precedence and the route to achieve that will be based upon the evolving diversity of businesses, policies, standard practices and communication protocols, behaviours and transparency.

24.6 Organisation's increasing position on the circularity scale

This is applicable to the infrastructure (assets) the organisation relies upon which are described in the Institute of Asset Management's *'How Asset Management can Enable the Circular Economy'*; and the products and services the cluster produces for other members of the cluster.

An example of a circularity scale is shown below. A specific 'Tees Valley Cluster chemicals circularity scale' could be developed and regularly updated for the industrial cluster and used as a baseline to indicate the value of circular economy transformation from an organisational and cluster perspective.



For example, it could be applied at three interdependent levels:

a) The infrastructure (assets) the organisation relies upon. Evidence is required in the organisation's asset management strategies and plans to move up the circularity scale by extending the life of the asset, converting, upgrading and investing in assets as part of the beyond carbon future, growing the local economy because of the reliance upon remanufacturing etc. This captures circular economy activity that the organisation is investing in from an asset perspective and is the response to new infrastructure requirements or enhancements needed to support of grow the cluster industries.

b) The products and services the cluster produces for other members of the cluster. This is within a value- add or transformative context ; for example, waste from one member of the cluster to then be used as a feedstock for another member. In this context this could be seen as a 'closed-loop' activity within the cluster which would enter the scale at one level and move up or down depending upon value of the transformative activity. This includes direct and indirect organisations that make that happen as well as whether that product or service relies upon Carbon Capture or not. This captures circular economy transformation activity (value of the capability, technology and the service) and circular products and services internally within the boundary of the cluster.

c) The products and services the cluster produces that rely upon imports of raw materials / feedstocks into the cluster. This includes an understanding of the value-add or transformative context for exports of the cluster whether that product or service relies upon Carbon Capture or not. This captures circular economy value that the cluster creates and exports. This can be combined with b) to understand internal and external interdependencies at a cluster and cluster member level.

FNC's study takes a very limited view of the wider deployment of the high-level circular economy framework described here. The framework would have to be developed further within the context of the Tees Valley Industrial Cluster and used as a governance platform to strategically develop, plan, invest in and monitor future circular economy value.

It is important to note that this requires a governance and reporting structure that the cluster works under that upholds the integrity of, for example, common reporting structures and accountabilities. We appreciate that this structure may not exist, therefore the availability of information is limited to open-source information or the information the organisation is prepared to offer. This project forms the basis of what that governance structure may comprise in the future.

24.7 Future of waste

All of these processes considered in the study relied on one key thing – waste. They all take waste from various different sources and compositions and utilise it for the production of new products or heat/electricity. They all do it with varying levels of efficiency, but they all rely on the waste produced from other industries in society. It is worthwhile to consider how the waste we produce will impact the future viability of these plants which means they may need to adapt their operational principles or face being unviable. This is particularly important for EfW processes as they already operate on the limit of circularity and any further decrease in their efficiency would challenge the overall justification for their use.

24.8 Carbon Performance

24.8.1 Waste Feedstocks

The use of waste feedstocks within processes to produce electricity/ fuels/ chemicals pose significant environmental benefits in aiding the decarbonisation of the Tees Valley and wider UK. Waste used within these processes alter their intended fate which is typically disposal within landfills.

Disposal of waste within landfills poses a significant emissions dilemma due to the various greenhouse gases being emitted as a result of the waste decomposition. Methane gas release from decomposing waste is a significant issue as it has 28 times greater global warming potential than carbon dioxide. As well as methane the decomposition of waste emits carbon dioxide, water vapour and other organic compounds which can contribute to climate change.

The use of waste materials as feedstock for processes provides an indirect environmental benefit as the incineration of the waste avoids disposal.

Biogenic feedstocks are derived from renewable sources, such as plants, crops, or agricultural waste, and are typically produced through photosynthesis. As a result, they have a lower carbon footprint than traditional fossil-based feedstocks because they capture and store carbon from the atmosphere during their growth cycle. The carbon absorbed by the biogenic feedstock will counterbalance the emissions associated with the production/ combustion/ use of the products resulting in a low/zero life cycle emission associated with the product.

24.8.2 Carbon Capture & Storage

CCS is a technology that has a potential to play an important role in aiding the decarbonisation of the cluster and the whole UK. CCS captures carbon dioxide emissions from industrial processes and power generation and stores them underground, preventing their release into the atmosphere.

CCS can reduce greenhouse gas emissions and mitigate climate change by allowing industries to continue using fossil fuels/ waste feedstocks while reducing their carbon footprint. The captured carbon dioxide can then be stored in deep geological formations, such as depleted oil and gas reservoirs or saline aquifers, where it can be securely stored for centuries.

The use of CCS has the potential, if capturing CO2 from the atmosphere by being applied to, for example, biomass combustion processes, to reduce net emissions over time – "negative emissions."

Processes

The use of processes to produce electricity/ fuels/ chemicals from non-conventional sources are growing and incorporating circular economic methodologies. This section provides an introduction into the typical carbon performance of these alternative processes verses conventional processes that traditionally are used to produce the electricity/ fuels/ chemicals. The three comparisons that have been made include:

- Waste to fuel vs fossil feedstock to fuel.
- Energy from waste vs energy from natural gas.
- Waste to chemical vs crude oil to chemical.

24.8.3 Waste to Fuel vs Fossil Fuel to Fuel

The use of waste to produce fuels such as sustainable aviation fuel are a good alternative compared to fossil based routes. Taking the gasification process as an example to demonstrate a comparison of potential emissions, both processes have similar characteristics.

Comparing gasification processes for producing jet fuel from waste and from fossil feedstocks both will have similar process routes which result in Scope 1 emissions being emitted as part of the process. However, sustainable aviation fuel produced from waste materials typically has lower life cycle carbon emissions compared to aviation fuel produced from fossil feedstocks. This is because waste-based aviation fuel made from renewable/ recycled feedstocks, such as agricultural residues, municipal waste, or used cooking oil, which emit less carbon during their production and processing than crude oil extraction and refining

Aviation fuel produced from waste materials can offer a more sustainable alternative, as it can reduce waste and emissions associated with waste disposal. The use of crude oil results in higher life cycle carbon emissions which include the extraction, refining and transportation of the fuel.

Energy from Waste vs Energy from Fossil Fuel

Energy from waste process routes are becoming more common within industry where it is seen as an alternative process to producing electricity from fossil fuels. The two process pathways have similar characteristics in producing electricity. However, both electricity production techniques have a different carbon emissions profile due to the different source of energy input.

Energy from waste involves incinerating waste materials, such as municipal solid waste or biomass, to generate energy. This process produces carbon emissions, as well as other air pollutants such as nitrogen oxides, sulphur dioxide, and particulate matter. The incineration of the waste will contribute to the processes Scope 1 emissions. These are direct emissions as a result of operation.

The use of waste materials as a feedstock for this process poses an indirect environmental benefit due to the incineration of the waste avoiding the alternative fate of the waste, which could include landfill.

Burning natural gas involves methane emissions and also releases carbon dioxide as well as nitrous oxides but emits fewer pollutants than other fossil fuels like coal, which makes it a popular choice for electricity generation. The burning of natural gas will contribute to the processes Scope 1 emissions.

Both processes will have Scope 2 emissions associated as utilities including electricity and cooling water will be required. Some processes may use their own generated electricity to aid the operations of the plant; this would reduce Scope 2 emissions.

The scope 3 emissions associated with the production's techniques may vary between process types. A key difference will be the downstream emissions associated with each feedstock. Using natural gas as a feedstock will pose downstream emissions associated with the extraction, processing, transportation. For waste as a feedstock this will only consider the emissions associated with the purchasing of the waste, and transportation to site.

Overall, the carbon emissions associated with energy production from waste versus natural gas depend on a variety of factors, such as the type and amount of waste being burned, the efficiency of the energy generation process, and the emissions control technology used. However, in general, energy from waste has the potential have lower life cycle carbon emissions than natural gas.

24.8.4 Waste-to-Chemical vs Crude Oil to Chemical

As a way of increasing circularity , and maximising the potential of the products, waste to chemicals (in particular plastics) is becoming more common. The life cycle carbon emissions associated with producing plastic from waste materials and crude oil differ significantly.

Producing plastic from waste materials typically results in lower carbon emissions than producing plastic from crude oil. This is because waste-based plastics use recycled or renewable feedstocks, such as plastic waste or plant-based materials, that emit fewer greenhouse gases during their production and processing than crude oil extraction and refining.

The production of plastic from crude oil is a carbon-intensive process, starting with the extraction of crude oil from the ground, followed by refining and polymerization to produce plastic. This process results in significant greenhouse gas emissions, contributing to climate change.

Waste-based plastics can offer a more sustainable alternative, as they can reduce waste and emissions associated with waste disposal and provide a closed-loop system that recycles plastic waste. This makes it a potentially attractive option for reducing the carbon footprint of plastic production and waste management.