Sustainable Horizons

Hydrogen's Contribution to Climate Innovation Clusters

SSN Sustainable Scotland Network

ecci EDINBURGH CENTRE FOR CARBON INNOVATION

eit Climate-KIC

Climate-KIC is supported by the EIT, a body of the European Union

This **Sustainable Horizons** report was developed and produced by SSN and ConnectedClusters in partnership with ECCI and EIT Climate-KIC.

Edinburgh Centre for Climate Innovation

ECCI is the leading low carbon hub for Scotland and beyond. Hosted by the University of Edinburgh, accelerates the move to a zero-carbon society by bringing people together and creating a hub of knowledge and expertise to kick-start new ideas and deliver ground-breaking projects.

Web: **edinburghcentre.org**

EIT Climate-KIC

EIT Climate-KIC is Europe's largest public-private partnership for action on climate change. It was set up in 2010 by the European Institute of Innovation and Technology, an EU body. It has developed a strong foothold in the UK and Ireland since, with centres in Edinburgh, London, Birmingham and Dublin.

ConnectedClusters is an alliance of five city regions – Birmingham, Edinburgh, Frankfurt, London and Valencia – committed to accelerating the impact of climate innovation ecosystems.

ECCI is the official Scottish partner of EIT Climate-KIC.

Web: **www.climate-kic.org**

Sustainable Scotland Network

SSN is Scotland's network for public sector professionals engaged in sustainability and climate action. The Network showcases action taken to reduce emissions and supports deeper commitment and innovation on climate change and sustainability across the public sector. SSN is supported by a secretariat delivered by the Edinburgh Centre for Carbon Innovation and the sustainability charity Sniffer.

Web: **sustainablescotlandnetwork.org**

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Contents

ConnectedClusters

EIT Climate-KIC's ConnectedClusters initiative is an alliance of five city regions – Edinburgh, London, Birmingham, Frankfurt and Valencia – committed to sharing, replicating and scaling what works in developing climate innovation ecosystems for delivering effective climate action.

When business, research, communities and government cluster together to deliver low-carbon innovation, it speeds up the emergence of clean, vibrant places to live and thrive. This is crucial to curbing dangerous climate change. And it drives local economic benefits.

EIT Climate-KIC believe that stimulating these climate innovation clusters should be at the heart of infrastructure delivery, job creation and place-making for governments of all levels.

EIT Climate-KIC's ConnectedClusters project is enabling this shift towards place-based climate innovation by developing new collaborative approaches to technology, procurement, investment and training.

The Edinburgh Centre for Carbon Innovation (ECCI) is the leading low carbon hub for Scotland and beyond.

ECCI is working with public and private sector partners to focus data and city investment on delivering a smart, thriving future.

ECCI is the official Scottish partner of EIT Climate-KIC, Europe's largest climate innovation initiative

https://edinburghcentre.org/projects/connected-clusters

List of Acronyms

ATI	Aerospace Technology Institute
BBC	British Broadcasting Corporation
BEIS	Department for Business, Energy and Industrial Strategy
CAPEX	Capital expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CO_2	Carbon dioxide
DNVGL	Det Norske Veritas Germanischer Lloyd
EMEC	European Marine Energy Centre
ERM	Environmental Resource Management Ltd
EU	European Union
FCHJU	Fuel Cells and Hydrogen Joint Undertaking
GB	Great Britain
GDN	Gas distribution network operator
GHG	Greenhouse Gas Emissions
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
IET	The Institution of Engineering and Technology
IP	Intellectual Property
ITEG	Integrating Tidal Energy into the European Grid
LCITP	Low Carbon Infrastructure Transition Programme
LEP	Local Enterprise Partnership
MW	megawatt
NGN	Northern Gas Networks
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
NTS	National Transmission System
ODE	Offshore Design Engineering Ltd
the Ofgem	Office of Gas and Electricity Markets
OGTC	Oil & Gas Technology Centre
OPEX	operating expenditure
OREC	Offshore Renewable Energy Catapult
PEM	proton exchange membrane
PITCHES	Powering Isolated Territories with Hydrogen Energy Systems
ReFLEX	Responsive Flexibility
SCCS	Scottish Carbon Capture and Storage
SGN	Scottish (Southern) Gas Networks. UK gas distribution
SHFCA	Scottish Hydrogen and Fuel Cell Association
SME	Small and Medium-sized Enterprise
TRL	Technology Readiness Level
UK	United Kingdom
UKRI	UK Research and Innovation
WWU	Wales & West Utilities

Introduction

The Climate Challenge

To deliver the greenhouse gas (GHG) emissions reduction target of net 100% from the 1990 levels by 2050, significant decarbonisation of our current society is essential.

Substantial emissions are associated with the transport sector, and the generation of heat for domestic heating and industrial processes. Consequently, decarbonising these sectors is imperative to achieve the target. The demand for heat in the United Kingdom (UK) in 2019 is mostly met directly by natural gas, and indirectly by gas powered electricity, leading to significant greenhouse gas emissions.

The UK's reliance on natural gas stems from the discovery of methane in the North Sea in the mid 1960's. This was supported by significant conversion of over 40 million gas appliances from Town Gas (composed of 50% hydrogen and about 25% methane) to natural gas. The advantages of natural gas over solid fuels included a much cleaner and convenient source of energy. This resulted in more economically affordable central heating. The IEA report (referenced below) states that in 2016 85% of UK households were heated by natural gas. This widespread adoption of central heating led to an increase in health and quality of life.

However, the emissions from the combustion of natural gas in domestic properties alone resulted in 65.2 $MtCO_2$ equivalent in 2017. This represents a reduction of only 16% from the 1990 level. In addition, the increased reliance on natural gas over all sectors has led to a 25% increase in UK GHG emissions from natural gas since 1990 (Figure 1).

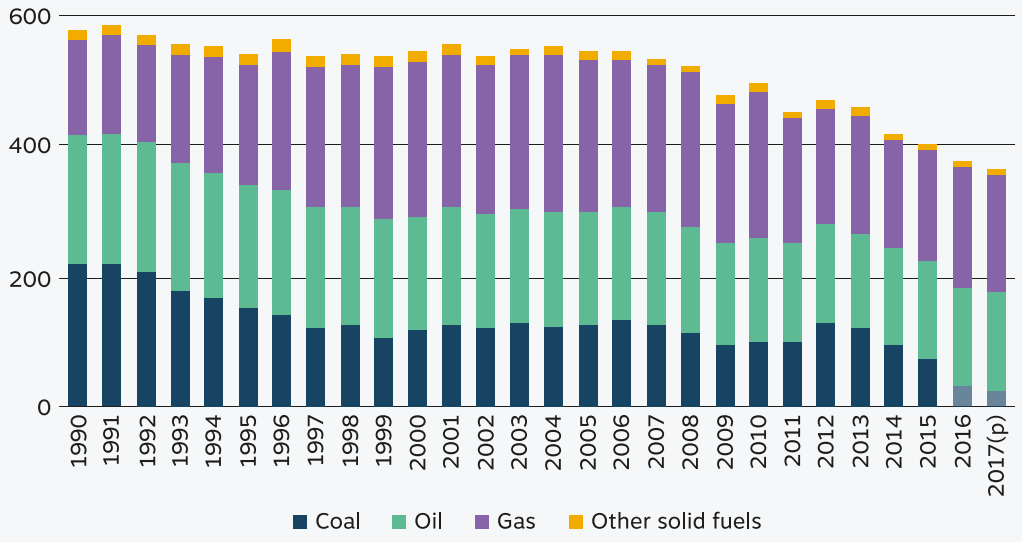


Figure 1: Carbon emissions (vertical axis: $MtCO_2$) by fossil fuels in the UK from 1990 to 2017

Provisional UK GHG emissions national statistics 1990-2017 Excel data tables
Note: (p) 2017 estimates are provisional

IEA. (2019) Energy Policies of IEA Countries - United Kingdom 2019 Review. [ONLINE] Available at: https://webstore.iea.org/download/direct/2784. [Accessed 8 January 2020].

Therefore, reducing the GHG emissions associated with the use of natural gas as an energy vector is paramount. Although Carbon Capture and Storage technology (CCS) is available to capture CO_2 emissions from large point sources (e.g. industry, power generation), such technology is unlikely to be economically attractive to tackle the small and intermittent emissions points represented by domestic heating related emissions which account for 34% of total gas use in the UK (Figure 2).

Reducing the GHG emissions associated with the use of natural gas as an energy vector is paramount

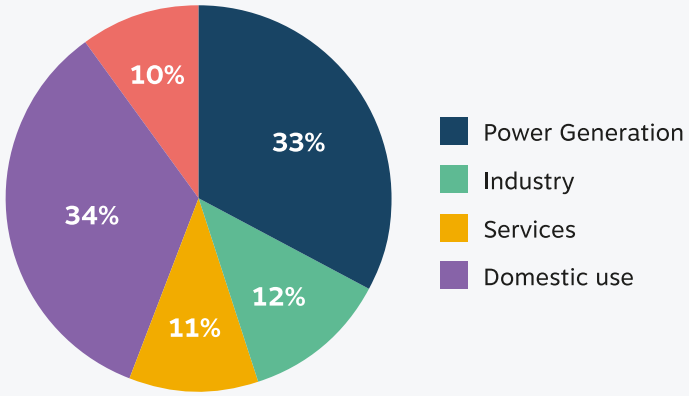


Figure 2: Summary of gas consumption for the UK in 2017
Department for Business, Energy and Industrial Strategy (BEIS), 2018: UK ENERGY IN BRIEF 2018

Hydrogen Benefits

Using Hydrogen as an energy vector has been proposed as part of solutions to decarbonise emissions resulting from natural gas and transport.

In addition, hydrogen can also contribute to increased energy network flexibility, provide inter-seasonal storage and bulk storage, and by use of electrolysis to generate hydrogen, can help reduce curtailment from renewable energy sources (Ball & Weeda, 2015). Hydrogen can be produced commercially at large tonnages, by steam reformation of methane, or at elevated pressures by autothermal reforming. Both of these lead to the co-production of carbon dioxide which needs to be captured and stored, or utilised. This added need for carbon dioxide storage, leads to the hydrogen produced this way to be called 'Blue Hydrogen'. The other projected main source of hydrogen production is the electrolysis of water using electricity. When this electricity is provided by low carbon sources, this hydrogen is called 'Green Hydrogen'. These means of production are not necessarily opposed, and are usually both considered as playing a part in future energy mixes as demonstrated in energy transition roadmaps such as National Grid's Future Energy Scenarios (National Grid, 2019).

The benefits of 'Blue Hydrogen' within a UK energy whole-system are that it is based on the proven and existing upstream value chain for natural gas. It can benefit from the localised entry points of natural gas at gas terminals to achieve large scale production of hydrogen. It is also possible to accommodate seasonal fluctuations and ramp-up rates of production by controlling the importation of natural gas, as is currently done. This would have the benefit of allowing the downstream hydrogen economy to develop and gather experience, giving time for the storage technologies to develop, which are needed to secure the supply of Green Hydrogen from renewable sources. The sale of the Blue Hydrogen would also offer a source of revenue for the CCS operations which are currently slow to commence in the UK, but are seen as essential in the Net Zero transition. This Blue Hydrogen would give time for CCS to be improved and its costs reduced.

The benefits of 'Green Hydrogen' are that it would not be reliant on fossil fuels and as such no carbon dioxide would be produced as a by-product. 'Green hydrogen' generated by offshore electrolysis using renewables has also been suggested as a way to use pipelines to reduce the cost of transporting energy produced to the mainland energy system (D'Amore-Domenech & Leo, 2019). Furthermore, utilisation of green hydrogen has the potential to link renewable energy and energy storage thereby mutually enabling innovative low-carbon configurations.

Innovation Clusters

The lack of large scale deployment of hydrogen as a contemporary clean fuel for domestic heating or transportation use around the world puts it at a disadvantage in comparison to other energy vectors such as electricity, district heating, carbon based gases and liquid bio-fuels (the Institution of Engineering and Technology (IET), 2019).

For this reason it is important to foster innovation and uptake of hydrogen to bridge the gap. One way that this can be achieved is by encouraging 'climate innovation clusters'. Such clusters can be defined as a dynamic mix of start-ups, SMEs, large businesses, research organisations, investors, business angels, community actors and public bodies which are 1) physically close together, 2) committed to co-learning and co-creating innovation on a specific climate-related challenge, and 3) focused on turning ideas into solutions that are positive for the climate and the economy (Bloomfield et al., 2019).

Cluster theory is diverse and no longer particularly novel. It was popularised in 1990 by Michael Porter in 'The Competitive Advantage of Nations' (Gray & Caprotti, 2011).

In this study, we will assess the success of a climate innovation cluster based on the following key features identified from European case studies in the 'ConnectedClusters Landscaping Study' by Bloomfield et al. (2019). We start by presenting and discussing each of those key features, listed below, in the light of existing scientific literature on the topic of clusters and innovations.

Key features of a healthy climate innovation cluster, according to Bloomfield et al. (2019):

Broad partnerships:
Stimulating mutual learning and knowledge exchange between organisations ultimately leads to innovation (Davies, 2013). Partnership between firms within a cluster can lead to high synergies at a managerial and technological level which promote the diffusion of innovation (Daddi, De Giacomo, Testa, & Tessitore, 2012). Clustering allows companies to share risk and uncertainties associated with new technologies (Grandori, 1997) and help them adapt and enhance performance (Martin, Gözübüyük, & Becerra, 2013).

Aim to influence policy:
Cluster policymakers and managers need to understand innovation pathways and cluster dynamics to be able to plan and implement effective policy interventions and management strategies (Arthurs, Cassidy, Charles, & David, 2009). Members of a cluster should actively support the development of accurate and up-to-date indicators for the cluster with the support of government (Arthurs, Cassidy, Charles, & David, 2009).

Stimulate new companies:
The availability of skills, suppliers, etc. makes it easier for new companies and products to be established in the cluster (Porter, 2008). Research institutions are crucial in providing a source of skilled labour and fostering start-ups (Gray & Caprotti, 2011).

Diverse means of funding:
Government funding and venture capital is needed for a healthy cluster to develop. Ability to tap into local, national and international funding streams is therefore of particular importance (Bloomfield et al., 2019).

Promote collaboration alongside competition:
Collaborative research and development is an area that can contribute to the health of an innovation cluster (Liyanage, 1995). Cooperation is an important driver of innovation in clusters, and so is competition (Bengtsson & Sölvell, 2004).

Foster skills development:
Clusters impart a positive impact on skill, knowledge and competencies creation (Daddi et al., 2012; Eisenhardt & Schoonhoven, 1996; Hagedoorn & Duysters, 2002; Powell, Koput, & Smith-doerr, 1996).

Have a public profile and identity:
First impressions are long lasting and the commitments to the cluster's objective are essential to developing the social capital needed for the cluster's success (Sarasini, 2015).

In this report, we highlight how innovation projects incorporating hydrogen in the UK contribute to the key cluster features above.

We then identify key strengths and weaknesses in the current hydrogen innovation landscape in the UK.

Methodology

The assessment conducted in this report was conducted using multiple research methods in order to assess the potential for hydrogen to contribute to climate innovation clusters.

The assessment conducted in this report was conducted using multiple research methods in order to assess the potential for hydrogen to contribute to climate innovation clusters. First, a desk study was performed to identify key hydrogen projects in the UK landscape, and the key features of a 'climate innovation cluster' as highlighted in the introduction. A questionnaire was constructed and interviews with key stakeholders were conducted to gather experts' perspectives and opinions around the benefits which hydrogen technologies and innovation clusters can mutually bring each other. Using the outcomes of the questionnaires and interviews, along with further desk study and in-house expertise we assessed each key project through the lens of the key features required to develop a healthy climate innovation cluster (see Table 1). A similar method proved successful in establishing an understanding of climate innovation clusters around Europe (Bloomfield et al., 2019). For each project we provide a qualitative assessment of each of the key criteria as well as a subjective scoring representation of that assessment. This allows us to establish a heatmap of the hydrogen projects' contribution to innovation within the clusters.

Table 1: Ranking scheme used to quantify the contribution of a project to its associated climate innovation cluster.

Ranking Scheme	Diverges Strongly	Diverges Slightly	Contributes Slightly	Contributes Strongly
Value	**-2**	**-1**	**1**	**2**
Broad partnerships	A single entity from a single sector.	Multiple entities from the same sector.	Multiple entities from multiple sectors (e.g. industry, academia, public bodies, etc.)	Multiple entities from multiple sectors, and of different sizes, all congregating as a formal network.
Aim to influence policy	Project design is within existing policy frameworks. No active lobbying to policy makers is taking place.	Focusing on short term policy changes and derogations. No explicit mention of meeting policy goals or informing them in the aims of the project.	Focused on establishing long term changes in the policy framework, via lobbying and pro-active proposals.	Actively engaged with policy makers at multiple levels. Has dedicated work programs to influence long term policy. Part of a formal network with policy entities.
Stimulate new companies	Each company involved relies on existing resources and skillsets.	Each entity involved develops skillsets and technologies internally, or within other existing entities.	Some of the involved entities actively seek to deploy new learning via new companies. Or actively seeks to stimulate and buy up start-ups.	Project funding available to stimulate growth of new companies. Previous criterion also applies.
Diverse means of funding	Lack of available funding. Entity has to use own funds without any offsetting benefits.	Single source of funding from a single sector.	Funding from a single sector (e.g. government). But can be from various funding schemes within that sector.	Multi-sector investment.

(Table 1 continued)

Ranking Scheme	Diverges Strongly	Diverges Slightly	Contributes Slightly	Contributes Strongly
Value	**-2**	**-1**	**1**	**2**
Promote collaboration alongside competition	No healthy competition. Monopolistic schemes are present. Only focussed on collaboration.	Competition is artificially present through regulations e.g. tendering on procurement. Or no active efforts to share research & development (R&D) efforts.	Active collaboration is present through formalised agreements (Memorandums of Understanding, etc.) Competition is limited to project: competitive arrangements are not aimed to be an enduring regime.	Sharing of R&D efforts through formalised agreement and practical activities. Multiple competing actors involved in innovation efforts and collaborations. Shared Intellectual Property.
Foster skills development	Limited skills development efforts. No formal frameworks for skill development in place. Excessive reliance on existing skills and knowledge.	Skills development is not actively encouraged and is done out of necessity. Efforts are made to record and share those "forced" skill developments.	Skills development and adventurous ideas are encouraged. Formal recording and frameworks are set up to foster skill development across project actors.	Skill development is paramount and is established as a success criteria. Formal skill development frameworks are established encompassing both actors and project partners.
Have a public profile and identity	Project does not aim to develop a public profile. Limited information online and no dedicated webpage.	Public profile is developed out of necessity and sits on the periphery of the project tasks. Not in the project aims.	Public profile and identity development is sought by project participants. Some existing structures might be present to encourage it.	Same as previous criterion with a clear effort to engage with public and forge a new/ unique identity. A formal structure exists to allow it to happen.

Review of Scottish Projects

Map showing location of the three main climate innovation clusters in Scotland in which a strong strand of hydrogen innovation exists

Orkney H_2 Cluster

Introduction

Orkney is situated 10 miles north off the coast of mainland Scotland and is made up of around 70 archipelago islands, 20 of which are inhabited.

The Orkney Islands have an extensive history of innovation in the renewable energy sector having first hosted a wind-turbine as far back as the 1950's.

Today Orkney is a front-runner in UK renewable energy sector innovation, playing host to organisations such as the European Marine Energy Centre (EMEC) and consultancy firm Aquatera. Orkney also permanently hosts employees from Community Energy Scotland and is home to a number of community development trusts with a keen interest in renewable energy generation. However, perhaps most impressively, Orkney generates around 120% of its electricity demand through renewables. In short, the Orkney Islands outperform expectations when it comes to green innovation, especially considering its relatively small population of around 20,000 inhabitants.

When asked about the role that local tradition and culture in Orkney has played in enabling innovation in the energy sector, EMEC Hydrogen Manager, Jon Clipsham who was interviewed for this report informed us that:

"In terms of societal acceptance, it's played a huge role. Orkney's been doing renewable stuff since the '50s with the original wind generator that we had. Through the wave and tidal stuff, the uptake of micro wind generation, and more recently a massive uptake of EVs per capita. Within the culture people are interested in energy."

Windfarm on Orkney © Donna Carpenter/Getty Images

One such manifestation of renewable sector innovation in Orkney is the deployment of green hydrogen technologies. Orkney's 'hydrogen story' has been widely publicised by numerous media agencies including the British Broadcasting Corporation (BBC), the Herald and Forbes and hundreds of visitors from across the world have visited the Orkney Islands to see its hydrogen infrastructure first hand. Orkney even has its very own hydrogen strategy (Orkney Hydrogen Strategy, 2019).

In the words of the Board of Directors of the Orkney Renewable Energy Forum:

"green hydrogen has the potential to play an important role in Orkney's low carbon economy continuing the strong tradition of innovation on our islands. The ability to develop renewable local energy solutions is essential if we are to allow rural areas to fully capitalise on the unique opportunities they possess in order to address the climate emergency."

Surf'n'Turf

Surf'n'Turf is an innovative community project in Orkney, led by Community Energy Scotland, which uses electricity generated from renewable energy, namely an onshore wind turbine and tidal power devices, to split water using a 0.5MW electrolyser located on the island of Eday, making hydrogen gas as a fuel (Figure 3). The hydrogen is then transported on a custom-built trailer by road and sea to the harbour in Kirkwall. There, the hydrogen powers a fuel cell to generate clean electricity on demand. (Surf'n'Turf, 2019).

As was highlighted in the introduction to the Orkney H_2 cluster section of this report, Orkney generates around 120% of its local electricity demand through renewable energy sources. However, due to grid constraints, i.e. a lack of export capacity, many renewable energy sources, most prominently wind turbines, have to be curtailed. This can have significant impacts on the profitability of such assets which is particularly problematic in Orkney due to the fact that 7.3 MW of installed renewable electricity assets throughout the islands are community owned (Community Energy Scotland, 2019).

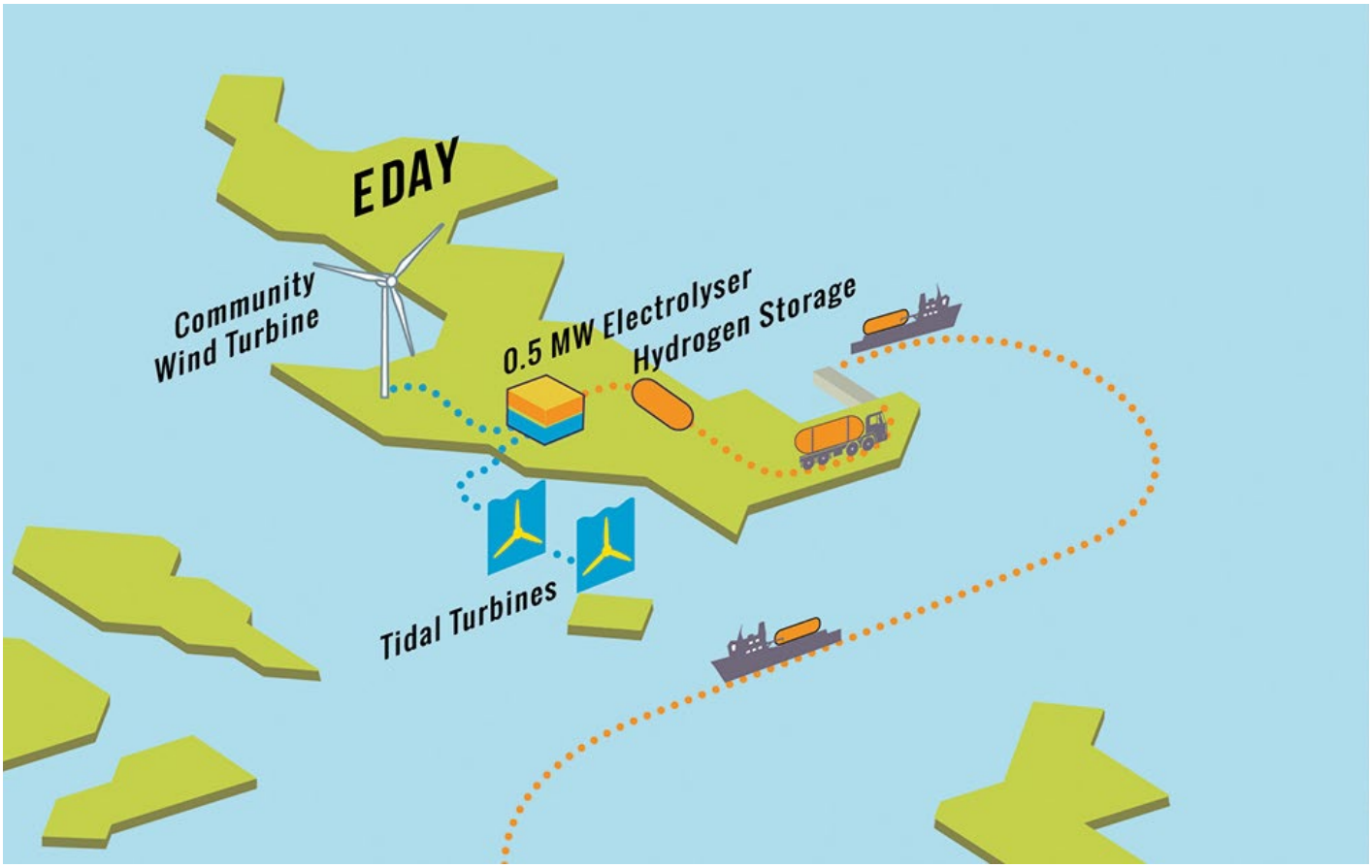


Figure 3: Surf 'n' Turf project

Through incorporating green hydrogen as a clean energy carrier, the innovative Surf'n'Turf project aims to circumvent this curtailment and increase flexibility whilst also creating revenue for the local community. This assessment is echoed by the chairman of Eday Renewable Energy who has stated that he is:

"encouraged by the way that technologies such as Surf'n'Turf and Big Hit [project described below] hold the potential to facilitate curtailment reclamation, which, if successful will create more revenue for local communities"

(Orkney Hydrogen Strategy, 2019)

Broad partnerships:
The Surf'n'Turf project consists of broad partnerships. Partners include: The European Marine Energy Centre (EMEC), Orkney Islands Council, ITM Power, European Union (co-funded), Fuel Cells and Hydrogen Joint Undertaking (FCHJU), The Challenge Fund, Local Energy Scotland, Greener Scotland, Community Energy Scotland and Eday Renewable Energy.

Aim to influence policy:
Surf'n'Turf aims to influence policy by acting as an exemplar demonstration project to provide crucial learning which in turn can be used to inform and thereby potentially influence policy. The Orkney Hydrogen Strategy, 2019, states that: "solutions developed in Orkney will help shape how communities, countries and nations approach energy production, consumption and supply. Projects like BIG HIT and Surf 'n' Turf [prove] that it is achievable to accelerate decarbonisation and lead by example in reaching the Scottish Government net zero carbon emission target by 2045" (Orkney Hydrogen Strategy, 2019).

Furthermore, according to Jon Clipsham, Hydrogen Manager of Surf'n'Turf project partner EMEC, who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout the Scottish Government, and increasingly with the UK Department for Business, Energy and Industrial Strategy (BEIS).

Stimulate new companies:
The Surf'n'Turf project has not directly stimulated new companies. However, it has led to significant investment in follow-up demonstration projects (BIG HIT & PITCHES) aimed at building upon the lessons learned throughout the project. According to the Orkney Islands Council (2019) website, "the project has been instrumental in the initial investment in the infrastructure required in establishing a hydrogen economy in Orkney that is replicable in other locations around the world".

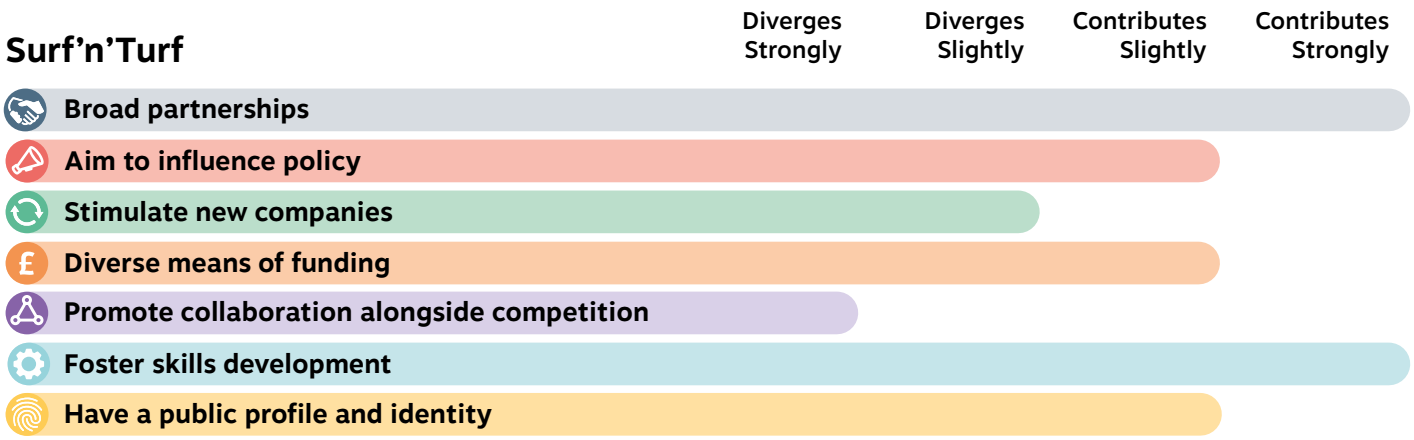
Diverse means of funding:
Surf 'n' Turf is not funded by particularly diverse means. It attracted "£1.46m of support from Local Energy Scotland and the Scottish Government's Local Energy Challenge Fund" (Surf'n'Turf, 2019).

Promote collaboration alongside competition:
As it is apparent from the broad partnerships section of the Surf'n'Turf overview, the project undoubtedly promotes collaboration. In fact, bearing in mind that one of the explicit aims of the project is to support Orkney communities and companies to harness locally-sourced energy, it would appear that collaboration is one of the foundational principles of this project (Community Energy Scotland, 2019).
There is little in the way of competition, although this is unsurprising due to the more demonstrative, as opposed to profit driven, nature of the Surf'n'Turf project.

Foster skills development:
According to the Orkney Islands Council (2019) website: "a hydrogen fuel cell has been situated on Kirkwall pier which has been designed to fulfil training needs for transportation of hydrogen by or at sea. University of the Highlands and Islands Orkney College has designed a hydrogen safety awareness course to provide necessary training on the island as the project will maintain management of shipments of hydrogen as part of the on-going hydrogen economy in Orkney".

Have a public profile and identity:
The Surf'n'Turf project has a website which provides a clear sense with regards to the aims of the project. Additionally, community groups, public bodies and institutions are active partners in the project and have details on their own websites as well. It is also an exemplar within the 'green hydrogen' sector and as such is well-known to academics and industry experts operating in the field. Nevertheless, it is unlikely that the project has a public profile and identity beyond the renewables sector and Orkney itself in a geographic sense.

£1.46m of support from Local Energy Scotland and the Scottish Government's Local Energy Challenge Fund



BIG HIT

Akin to the Surf'n'Turf project, the BIG HIT project involves the generation of renewable electricity which is used by electrolysers to produce hydrogen. However, in addition to the community owned wind turbine, tidal turbines and 0.5 MW electrolyser that were in operation during the Surf'n'Turf project on the island of Eday, BIG HIT also utilises a community wind turbine and 1 MW electrolyser on the island of Shapinsay. Upon production, the hydrogen is stored as high pressure gas in custom-built tube tanks on truck trailers thereafter being transported to mainland Orkney via road and ferry (BIG HIT, 2019).

According to the BIG HIT (2019) website:

"the project uses two proton exchange membrane (PEM) electrolysers. The Shapinsay electrolyser is 1 MW capacity and Eday electrolyser is 0.5 MW capacity, both are located close to the renewable generation assets. The hydrogen acts as an energy-storage medium which can later be converted back into heat and power for buildings and vessels in Kirkwall harbour, as well as the fuel for the operation of zero-emission hydrogen vehicles in and around Kirkwall"

(BIG HIT, 2019)

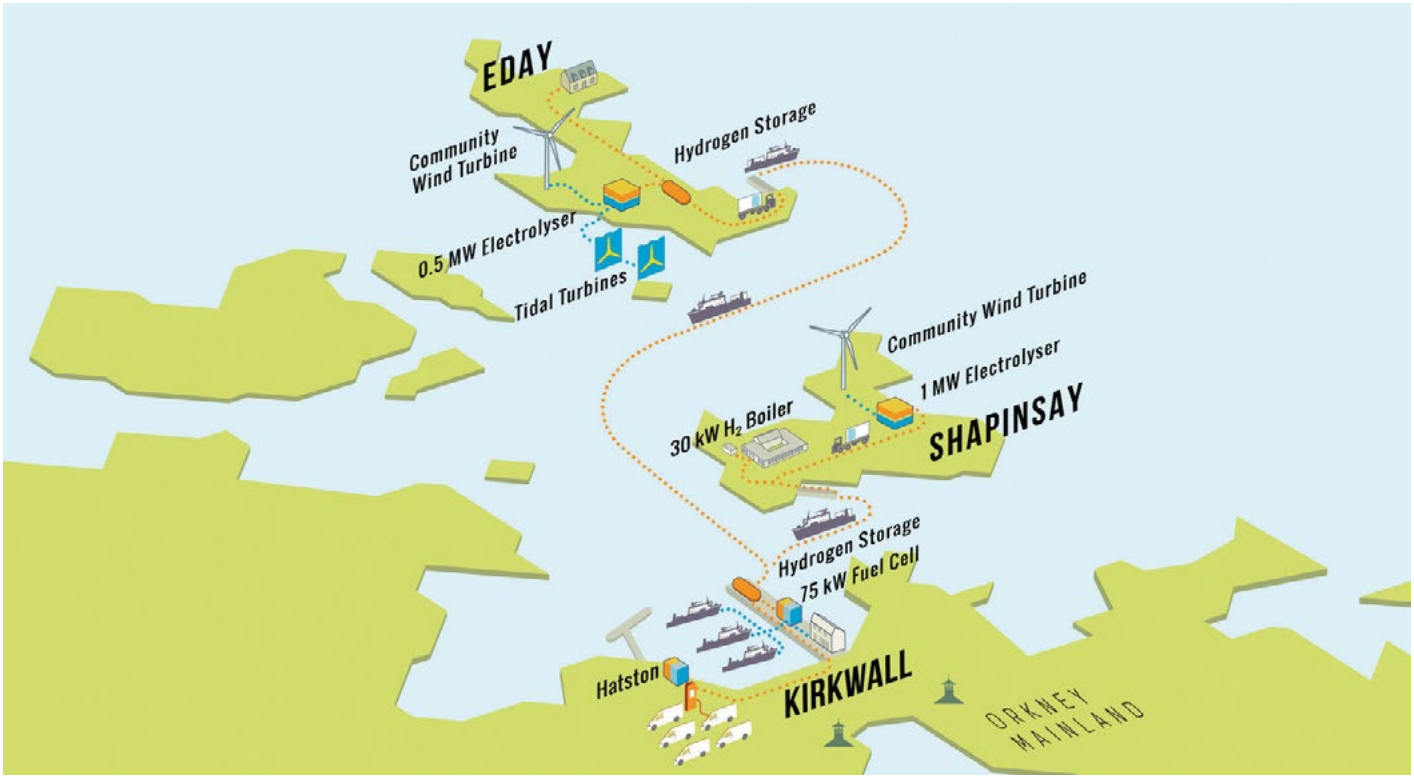


Figure 4: BIG HIT project infographic

Broad partnerships:
The BIG HIT project consists of broad partnerships. Partners include: The Foundation, Calvera, Community Energy Scotland, Technical University of Denmark, EMEC, GIACOMINI, ITM Power, Ministry for Transport and Infrastructure of Malta, Orkney Islands Council, Shapinsay Development Trust, Scottish Hydrogen and Fuel Cell Association (SHFCA) and SymbioFCELL.

Aim to influence policy:
Akin to Surf'n'Turf, BIG HIT aims to influence policy by acting as an exemplar demonstration project, providing crucial learning which can in turn be used to inform and thereby potentially influence policy. For example, the learnings from the project could lead to wider replication and deployment of renewable energy with fuel cell and hydrogen technologies in territories that share similar geographic attributes to that of the Orkney Islands.
According to the BIG HIT (2019) website the project will: "Demonstrate the Orkney Islands of Scotland as a replicable Hydrogen Territory, using curtailed renewable energy generated locally to produce hydrogen which can then be used as a clean energy vector to store and use valuable energy for local applications. BIG HIT will demonstrate use of hydrogen as a flexible local energy store and vector, transporting hydrogen by tube trailer to the Orkney mainland. Here it will be used to demonstrate real end-use applications for hydrogen including auxiliary power and heat for ferries in Kirkwall harbour, fuelling a fleet of hydrogen range-extended light vehicles, and heating for buildings in the Kirkwall area" (BIG HIT, 2019).
Furthermore, according to Jon Clipsham, Hydrogen Manager from BIG HIT project partner EMEC who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout Scottish Government, and increasingly with BEIS.

Stimulate new companies:
The BIG HIT project has not directly stimulated new companies, however it has led to significant investment in a follow-up demonstration project, named PITCHES, aimed at building upon the experience gained throughout both BIG HIT and Surf'n'Turf.

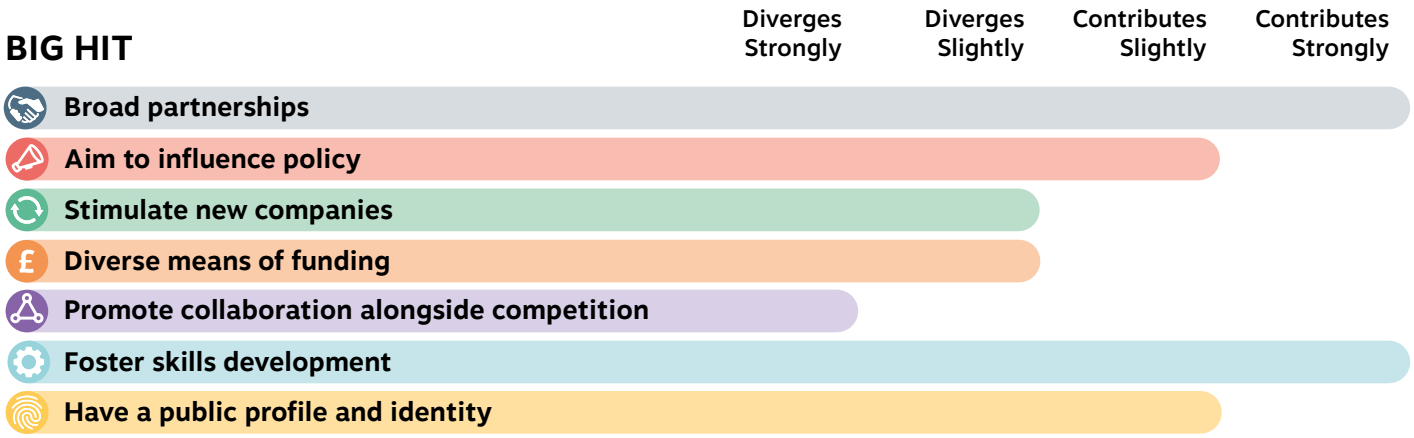
Diverse means of funding:
The BIG HIT project is not funded by diverse means. It received around €7 million in funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement which receives support from the European Union's Horizon 2020 research and innovation programme (EU, 2019).

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the BIG HIT overview, the project undoubtedly promotes collaboration. Given the fact that there are just as many organisations participating in BIG HIT as participated in predecessor Surf'n'Turf, it would appear that collaboration is again one of the foundational principles of this Orkney H_2 project. There is little in the way of competition although this is unsurprising due to the primarily demonstrator, as opposed to profit driven, nature of the BIG HIT project.

Foster skills development:
The BIG HIT project has been able to capitalise and build upon the skills development that was fostered by its predecessor project, Surf'n'Turf including working with the Orkney College who have training and awareness courses running to support people who are operating in the hydrogen space.

Have a public profile and identity:
The BIG HIT project won a UK wide local authority award and has a website which provides clear details about the operation and aims of the project. Additionally, community groups, public bodies and institutions are all active partners in the project and as such have details of the project on their own websites. It is also an exemplar within the 'green hydrogen' sector and is well-known to academics and industry experts operating in the field. Nevertheless, it is unlikely that BIG HIT has a national or international public profile and identity beyond the renewable energy sector and the geographical shores of Orkney.

BIG HIT aims to influence policy by acting as an exemplar demonstration project, providing crucial learning which can in turn be used to inform and thereby potentially influence policy



Powering Isolated Territories with Hydrogen Energy Systems (PITCHES)

The PITCHES project aims to build upon BIG HIT and other Orkney hydrogen projects. Alike its predecessor projects, PITCHES will transport hydrogen from the islands of Eday and Shapinsay to a number of end uses. These include providing electricity to the Kirkwall harbour district, heating local buildings and fuelling a fleet of fuel cell electric vehicles.

According to UK Research and Innovation (UKRI) (2019) the project will also explore:

"the replicability of such systems to isolated, off-grid communities, including in Sub Saharan Africa, by testing configurations of the system, and identifying business models which best suit off-grid communities in developing countries".

Broad partnerships:
The PITCHES project consists of broad partnerships. Partners include: ITM Power (project lead), Overseas Development Institute, Community Energy Malawi, Community Energy Scotland, Shapinsay Development Trust and The European Marine Energy Centre.

Aim to influence policy:
Akin to both Surf'n'Turf and BIG HIT, PITCHES aims to influence policy by acting as an exemplar demonstration project, providing further crucial learning which can in turn be used to inform and thereby potentially influence policy.
For example, according to UKRI (2019), PITCHES will "demonstrate that existing hydrogen technologies can be used to develop a new energy system to meet transport, electricity and heating needs of remote communities, showing that hydrogen based energy systems have the potential to reduce reliance on imported fuels, reduce carbon emissions, and in future as the technology develops, to reduce energy costs".

Furthermore, according to Jon Clipsham, Hydrogen Manager from PITCHES project partner EMEC, who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout Scottish Government, and increasingly with BEIS.

Stimulate new companies:
The PITCHES project has not directly stimulated new companies.

Diverse means of funding:
The PITCHES project is not funded by diverse means having received a £986,570 grant from Innovate UK (UKRI, 2019).

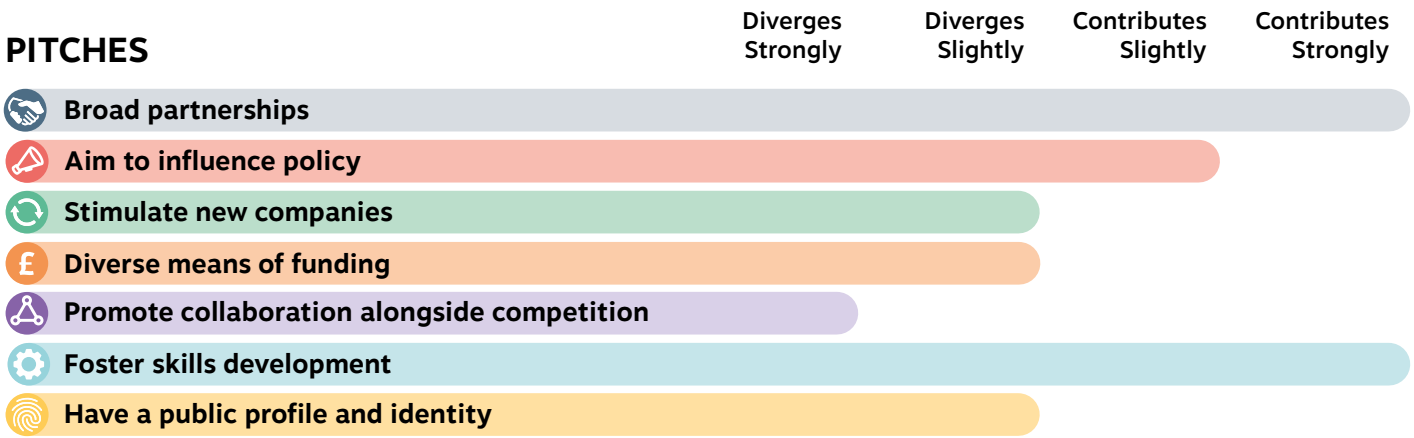
Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the PITCHES overview, the project undoubtedly promotes collaboration. Given the fact that there are just as many organisations participating in PITCHES than as participated in predecessors Surf'n'Turf and BIG HIT, it would appear that collaboration is again one of the foundational principles of this Orkney H_2 project. There is little in the way of competition although this is unsurprising due to the primarily demonstrative, as opposed to profit driven, nature of the BIG HIT project.

Foster skills development:
Due to the participation of 'Community Energy Malawi', PITCHES is helping to disseminate skills far beyond the shores of Orkney to communities in the Global South.
According to the Community Energy Malawi website (2019): "In the developing world, there are many remote communities with little or no grid access – the Energy Africa campaign estimates that 70% of the Sub-Saharan population is without electricity access, and 50% of businesses there view a lack of reliable power as a major barrier to business.

Whilst other energy storage technologies, such as batteries, may be more suitable for the smallest communities, integrated hydrogen systems have potential to support medium sized communities with mini-grids, and also the potential in future to support nascent enterprises and industries through providing local transport fuel".

Have a public profile and identity:
The PITCHES project does not have an independent website providing details of the project. However, community groups, public bodies and institutions are all active partners in the project and have details of the project on their own websites. It too, like its predecessors Surf'n'Turf and BIG HIT, is an exemplar within the 'green hydrogen' sector and as such is well-known to academics and industry experts operating in the field. However, it is unlikely that the project has a public profile and identity beyond that of the hydrogen sector and beyond Orkney, and other project related territories, in a geographic sense.

Kirkwall Harbour © Richard Webb (CC BY-SA 2.0)



Responsive Flexibility (ReFLEX) Project

Unlike the previous projects that have been presented so far in this report, the ReFLEX Orkney project is not primarily centred around hydrogen but is instead an attempt to integrate a number of various innovative low-carbon technologies, hydrogen included, together. ReFlex will demonstrate, for the first time, a Virtual Energy System which will connect local electricity, transport, and heat networks into one controllable, overarching system. The project aims to create a 'smart energy island', demonstrating 'the energy system of the future', which, if successful, could reduce and eventually eliminate the need for fossil fuels (UK GOV, 2019).

According to project partners EMEC (2019), flexible energy balancing technologies are at the heart of the project which aims to deploy:

- **Up to 500 domestic batteries;**
- **Up to 100 business and large-scale batteries;**
- **Up to 200 Vehicle-to-Grid (V2G) chargers;**
- **Up to 600 new electrical vehicles (EVs);**
- **An island community-powered electric bus and e-bike integrated transport system;**
- **Up to 100 flexible heating systems; and**
- **Doosan industrial-scale hydrogen fuel cells**

Broad partnerships:
The ReFLEX project consists of broad partnerships. Partners include: The European Marine Energy Centre, Orkney Islands Council, Aquatera, Solo Energy, Community Energy Scotland, Heriot Watt University and Doosan Babcock.

Aim to influence policy:
At present, our research suggests that the ReFLEX project contributes slightly with regards to influencing policy however, according to Jon Clipsham, Hydrogen Manager at EMEC who was interviewed for this report, "this may well change during the project as the need to adapt the regulatory policies for the electricity market is better understood". This suggests that the project has the potential to inform policy significantly. Furthermore, there is acute interest in the project from central Government: according to the UK Gov, 2019, ReFLEX will contribute to showing "how businesses can develop local energy approaches at scale that will create better outcomes for consumers and promote economic growth for the UK".
UK Energy and Clean Growth minister, Claire Perry, when talking recently in 2019 about "four leading edge demonstrators to jumpstart energy revolution, one of which being ReFLEX" stated that: "these projects backed by Government funding, are set to spark a transformation and change the way we interact with energy for the better part of our modern Industrial Strategy". Furthermore, she stated that, "we're excited to see how these businesses and project partners reveal how innovative technologies, such as energy storage, heat networks and electric vehicles, can set us on the path to a smarter energy future" (UK Gov, 2019).

Stimulate new companies:
The ReFLEX project has yet to stimulate new companies, however, according to Rob Saunders from UKRI, learnings from the demonstration project, such as creation of new business models that incentivise the consumption or storage of energy when generation is high, and encourage uptake of low carbon heating and transport, is expected to drive investment, create high-quality jobs and grow companies with export-potential (UK Gov, 2019). This suggests that in the future the ReFLEX project could well stimulate new companies.

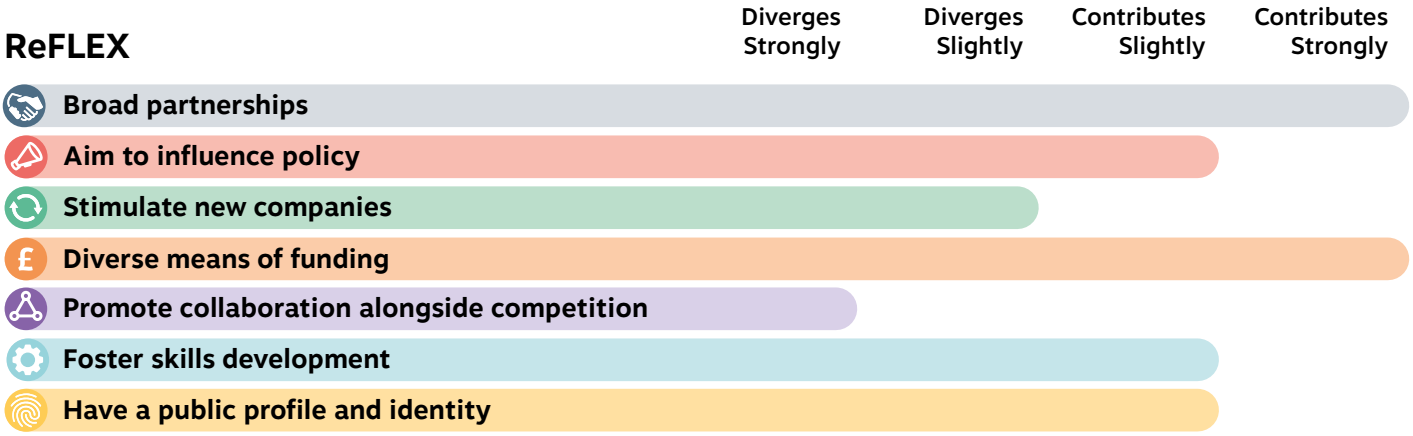
Diverse means of funding:
The ReFLEX project has been funded by diverse means with £14.3 million of funding from the UK Government and the remaining 50% being funded privately by the project partners (EMEC, 2019).

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the ReFLEX overview, the project undoubtedly promotes collaboration with industry, academic and not-for-profit organisations working together as partners. However, there is little in the way of competition although this is unsurprising due to the demonstration, as opposed to profit driven, nature of the ReFLEX project.

Foster skills development:
The ReFLEX project only received funding in April 2019 and is therefore still in the initial stages period. As such, it is yet to foster skills and development, however, if the demonstration proves to be a success then ReFLEX would likely create highly skilled jobs and foster skills development.

Electric coach charging © zssp/Getty Images

Have a public profile and identity:
The ReFLEX project does not have a website to provide details of the project. However, industry, not-for-profit and academic institutions are all active partners in the project and do have details of the project on their own websites. ReFLEX is an exemplar within the balancing sector and as such is well-known to academics and industry experts operating within the field. However, it is unlikely that the project has a public profile and identity beyond that of the sector and beyond Orkney in a geographic sense.



Hydrogen Diesel Injection in a Marine Environment (HyDIME)

HyDIME is a 12-month project that will use green hydrogen as a fuel for a commercial ferry operating between Shapinsay and Kirkwall in Orkney. HyDIME aims to enhance learning in the marine industry by proving the safe integration and use of hydrogen on vessels. HyDIME's goals include the design and physical integration of a hydrogen injection system on a commercial passenger and vehicle ferry which will be the first of its kind worldwide. Furthermore, HyDIME intends to conduct testing and validation studies to address safety concerns, identifying risks and reduction measures. A scale-up plan will also be produced with two main objectives: 1) To assess the economic, environmental, social, and operational impacts of the proposed system and to identify the best approach to scale up hydrogen production and consumption on the Orkney islands. 2) To identify and assess opportunities for replicating the same model for other parts of the UK (HyDIME, 2019).

HyDIME's goals include the design and physical integration of a hydrogen injection system on a commercial passenger and vehicle ferry which will be the first of its kind worldwide

Broad partnerships:
The HyDIME project consists of broad partnerships. Partners include: Ferguson Marine, Orkney Islands Council Ferry Service, Manufacturing Innovations Institute, Ultra Low Emission Mileage Company, Lloyds Register and The European Marine Energy Centre.

Aim to influence policy:
According to Jon Clipsham, the Hydrogen Manager of project partner EMEC, this has become strong throughout the project – HyDIME is proving to be an enabling project for policy makers to focus on. HyDIME is a world-first and therefore learnings from the project are of great value and will inform, and thereby potentially influence, policy decision making.
According to the HyDIME (2019) website, the project "will provide a stepping stone to accelerate and de-risk future hydrogen marine projects and will contribute towards growing the hydrogen economy in the UK".

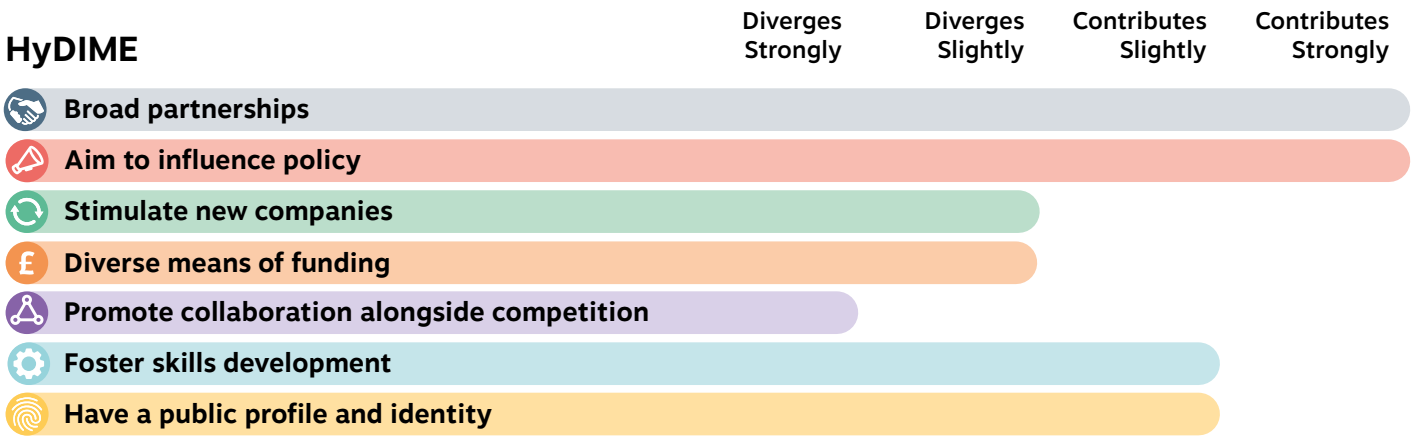
Stimulate new companies:
The HyDIME project has not directly stimulated new companies.

Diverse means of funding:
HyDIME is not funded by diverse means with Innovate UK providing £430,332 funding.

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the HyDIME overview, the project undoubtedly promotes collaboration with industry, not-for-profit and institutional organisations all working together as partners. There is little in the way of competition although this is unsurprising due to the demonstration, as opposed to profit driven, nature of the project.

Foster skills development:
As has already been discussed, the HyDIME project is a world-first. New experience and knowledge acquired during the project should therefore provide learning opportunities that can be disseminated throughout the hydrogen marine sector more broadly. This would likely foster skills development and be useful in refining training programmes.

Have a public profile and identity:
The HyDIME project has its own dedicated website which provides a detailed description of the projects aims. The partner organisations involved also have details of the project on their own individual websites. HyDIME is a world-first and as such is well known by industry and academic actors in the sector. The project has also recently been shortlisted for the 'Outstanding Project' award at the Scottish Green Energy Awards (EMEC, 2019). However, it is unlikely that many people outside the sector, or indeed members of the general public beyond the geographical shores of Orkney, are aware of the project.



HySeas III

The HySeas III project is the final part of a three-part research program. The first two parts of the program investigated a) the potential for hydrogen powered sea vessels (HySeas I), and conducted b) a technical and commercial study to design a hydrogen fuel cell powered vessel (Hyseas II).

According to the HySeas III (2019) website:

"HySeas III builds on the first two parts, highlighted above, by aiming to demonstrate that fuel cells may be successfully integrated with a proven marine hybrid electric drive system (electric propulsion, control gear, batteries, etc), along with the associated hydrogen storage and bunkering arrangements. The project will do this by developing, constructing, testing and validating a full-sized drive train on land".

The HySeas III hydrogen fuel cell powered vessel will be demonstrated in the Orkney islands, operating the Kirkwall to Shapinsay route.

Broad partnerships:
The HySeas III project consists of broad partnerships. Partners include: Ferguson Marine Engineering Limited, Ballard Power Systems Europe A/S, Kongsberg Maritime AS, McPhy Energy SA, Orkney Island Council, DLR Institute of Networked Energy Systems, Interferry European Office and the University of St Andrews.

Aim to influence policy:
The HySeas III project is a world-first and therefore learnings from the project will be of great value and will inform, and thereby potentially influence, policy decision making. According to the HySeas III website, "should this test be successful, Scottish Transport have agreed to fund the building of a roll-on roll-off passenger ferry which will integrate the entire hydrogen/electric drive train which will be subject to extensive monitoring and testing" (HySeas III, 2019).
Furthermore, according to an employee from HySeas III project partner EMEC, who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout Scottish Government, and increasingly with BEIS.

Stimulate new companies:
The HySeas III project has not directly stimulated new companies.

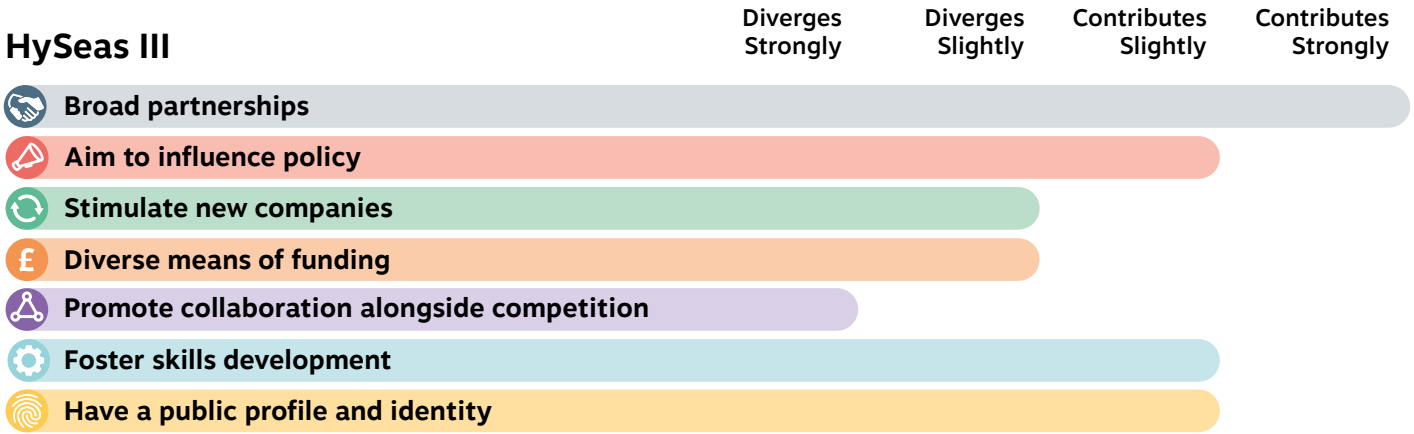
Diverse means of funding:
HySeas III is not funded by diverse means.
It has a total cost of €12,579,610 with the EU contribution totalling €9,276,373. The funder for the remaining proportion of the total cost could not be identified.

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the HySeas III overview, the project undoubtedly promotes collaboration with industry, public sector and academic organisations all working together as partners. There is little in the way of competition although this is unsurprising due to the demonstration, as opposed to profit driven, nature of the project.

Foster skills development:
As has already been discussed, the HySeas III project is a world-first. New experience and knowledge acquired during the project should therefore provide learning opportunities that can be disseminated throughout the hydrogen marine sector more broadly. This would likely foster skills development and be useful in refining training programmes.

Have a public profile and identity:
The HySeas III project won this year's GreenTech Festival Green Awards Innovation of the year. It has its own dedicated website along with being detailed on partner organisations individual websites. HySeas III is a world-first innovation and as such is well known by industry and academic actors within the sector. However, it is nevertheless unlikely that many people outside the sector, or indeed members of the general public beyond the geographical shores of Orkney, are aware of the project.

The HySeas III project is a world-first and therefore learnings from the project will be of great value and will inform, and thereby potentially influence, policy decision making



Integrating Tidal Energy into the European Grid (ITEG)

ITEG is an €11 million EU INTERREG North-West Europe project, in the Orkney Islands, which aims to develop an all-in-one solution for the generation of clean and predictable energy, grid management, and hydrogen production from excess capacity.

According to EU NW Europe (2019):

"(ITEG) will deliver an onshore energy management system at EMEC's Fall of Warness tidal test site, off the northern Orkney island of Eday. This will support the production of hydrogen using an AREVA H2Gen electrolyser, the first to be deployed in the UK, which will be powered by Orbital's next generation 2 MW floating tidal energy converter, the Orbital O_2 2MW".

After the demonstration period, business plans will be drawn-up to construct another turbine at the EMEC Fall of Warness tidal test site, taking the nominal power of the farm to 4 MW. The project partners also intend to develop commercial projects in North West Europe with a target of installing 3 to 5 farms with a total combined capacity of 100 MW within 10 years (University of Gent, 2019).

According to project partners University of Gent website (2019):

"these developments will lead to benefits in line with INTERREG Programme Specific Objective 3: jobs maintained (>1500 jobs), increased capacity of renewable energy production (plus 350 GWh/year) and a reduction in GHG emissions (less 300,000 CO_2 tons/year) which is vital to address global warming".

Broad partnerships:
The ITEG project consists of broad partnerships. Partners include: EMEC, Scotrenewables Tidal Power, AREVA H2Gen, Energy Systems Catapult, Energy Valley/New Energy Coalition, University of Caen Normandy, University of Le Havre Normandy, Ghent University and the Normandy Development Agency.

Aim to influence policy:
The ITEG project is clear in its aim to influence policy. According to EU NW Europe, 2019: "the cost of pre-commercial demonstration for ocean energy is high and investors are reluctant to invest until the technology has been proven in the sea at scale. ITEG sets out to drive down these costs through the development of an integrated hydrogen production solution". Furthermore, according to Jon Clipsham, Hydrogen Manager of ITEG project partner EMEC, who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout Scottish Government, and increasingly with BEIS.

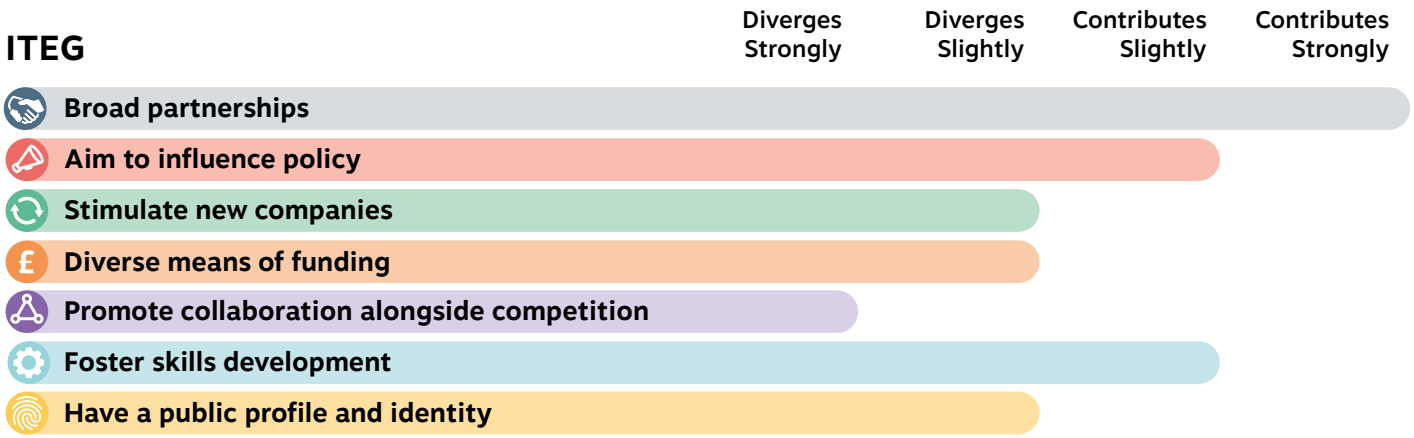
Stimulate new companies:
The ITEG project has not directly stimulated new companies.

Diverse means of funding:
The funder for the remaining proportion of the project costs could not be identified.

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the ITEG overview, the project undoubtedly promotes collaboration with industry, not-for-profit and academic organisations all working together as partners. There is little in the way of competition although this is unsurprising due to the demonstration, as opposed to profit driven, nature of the project.

Foster skills development:
As has already been discussed, the ITEG project is attempting to realise an innovative energy configuration which simultaneously generates predictable and clean energy, improves grid management, and produces green hydrogen from any excess capacity. As such, new experience and knowledge acquired during the project should provide learning opportunities that can be disseminated throughout the sectors involved. This would likely foster skills development and training programmes.

Have a public profile and identity:
The ITEG project does not have a dedicated website to provide details of the project. However, an overview of the project is available on the Interreg NW Europe website and is also detailed on the individual websites of project partners. The ITEG project aims to be an exemplar demonstration project and as such is well known by industry and academic actors in the sector. Nevertheless, it is unlikely that many people outside the sector, or indeed members of the general public beyond the geographical shores of Orkney, and associated project territories, are aware of the project.



HyFlyer

HyFlyer is an innovative aviation project which aims to demonstrate powertrain technology in order to decarbonise medium range small passenger aircraft. The project intends to do this by replacing conventional piston engines in propeller aircraft with electric motors, hydrogen fuel cells and gas storage.

According to EMEC (2019):

"project partners Intelligent Energy will optimise its high-power fuel cell technology for application in aviation whilst EMEC Hydrogen, producers of green hydrogen from renewable energy, will supply the hydrogen required for flight tests and develop a mobile refuelling platform compatible with the plane".

The project will culminate in a 250-300 nautical mile demonstration flight out of an airfield based in Orkney (Fuel Cells Works, 2019).

Broad partnerships:
The HyFlyer project consists of relatively broad partnerships. Partners include: ZeroAvia, Intelligent Energy and EMEC.

Aim to influence policy:
The HyFlyer project aims to provide lessons which will be able to inform, and thereby influence, policy. According to the leader of Orkney Islands Council, James Stockan: "in Orkney we are seeking to be clean, green islands. Transport is our biggest decarbonisation challenge, with our remote and rural setting placing our islanders in the position of producing a significant carbon footprint. Initiatives like this are presenting us with opportunities to reduce this carbon footprint and support Orkney Islands Council's climate emergency declaration. I look forward to the project progressing" (SHFCA, 2019).

Furthermore, according to Jon Clipsham, Hydrogen Manager of HyFlyer project partner EMEC, who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout Scottish Government, and increasingly with BEIS.

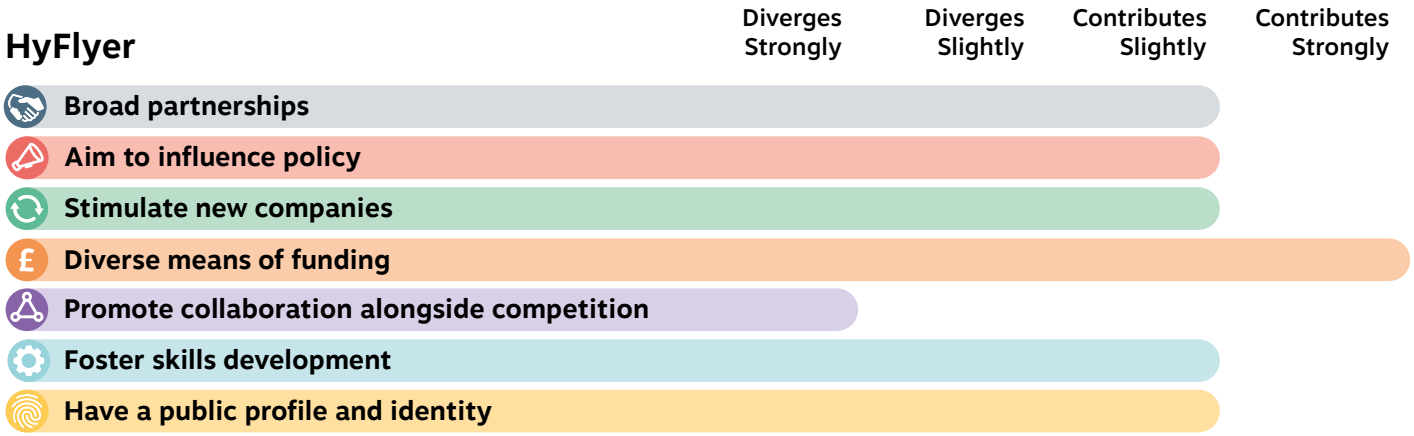
Stimulate new companies:
The HyFlyer project has not directly stimulated new companies. However, it is worth noting that project partner ZeroAvia are a start-up company and are positively impacted by the project whilst sub-contractor Fuel Cell Systems are also benefitting significantly.

Diverse means of funding:
The HyFlyer project is funded by diverse means, including governmental and research institutions, as well as private funds from project partners. This includes a UK Government grant awarded as part of the Aerospace Technology Institute (ATI) programme, supported by the BEIS, the ATI and Innovate UK. The Government's grant is matched by project HyFlyer participants, making the scope of the project in excess of £5m (EMEC, 2019).

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the HyFlyer overview, the project promotes a relatively significant amount of collaboration between industry and not-for-profit organisations working together as partners. There is little in the way of competition although this is unsurprising due to the demonstrator, as opposed to profit driven, nature of the project.

Foster skills development:
As has already been discussed, the HyFlyer project is attempting to realise an innovative configuration of technologies which if successful could enable the wider decarbonisation of medium range small passenger aircraft. As such, new experience and knowledge acquired during the project should provide learning opportunities that can be disseminated. This would likely foster skills development whilst also potentially informing the creation and refinement of specialised hydrogen training programmes.

Have a public profile and identity:
The HyFlyer project does not have a dedicated website to provide details of the project. However, industry and not-for-profit organisations are active partners in the project and do have details on their own individual websites. HyFlyer is aiming to be an exemplar low-carbon demonstration project and as such is well-known by industry and academic actors within the sector. Nevertheless, it is unlikely that HyFlyer has a public profile and identity beyond that of the sector and the geographical shores of Orkney.



HySpirits

The HySpirits project will investigate the development of a thermal fluid heater system to operate with hydrogen as the combustion fuel within the distilling process. This system will remove the need to use fossil fuels such as kerosene and liquid petroleum gas.

HySpirits brings together Edinburgh Napier University, project lead the EMEC and Orkney Distilling Ltd. The university will assess the distillery site and develop the hydrogen system design and specification.

HySpirits was awarded funding after successfully competing in the Industrial Fuel Switching Competition run by BEIS earlier this year, which aims to stimulate early investment in fuel switching processes and technologies.

The competition offers funding for feasibility studies into developing technologies to enable the use of a low-carbon fuel across industrial processes' (Edinburgh Napier University, 2019).

Broad partnerships:
The HySpirits project consists of broad partnerships. Partners include: Edinburgh Napier University, the European Marine Energy Centre (EMEC) and Orkney Distilling Ltd.

Aim to influence policy:
The HySpirits project aims to provide lessons which will be able to inform, and thereby influence, policy.
According to project partners, Edinburgh Napier University (2019): "hydrogen has been identified as an alternative fuel for energy intensive industrial processes, such as distilleries. If the technology and business case detailed in the feasibility study proves viable, this offers a substantial decarbonisation opportunity for the wider industry and The Orkney Distillery could become the world's first hydrogen-fuelled distillery. It is hoped that the findings of this study can be replicated across the sector with the added benefit that the technology will be designed to be retrofitted into existing infrastructure".
Furthermore, according to Jon Clipsham, Hydrogen Manager of HySpirits project partner EMEC, who was interviewed for this report, there is regular engagement between organisations in the Orkney H_2 cluster and people in Holyrood, throughout Scottish Government, and increasingly with BEIS.

Stimulate new companies:
The Hyspirits project has not directly stimulated new companies.

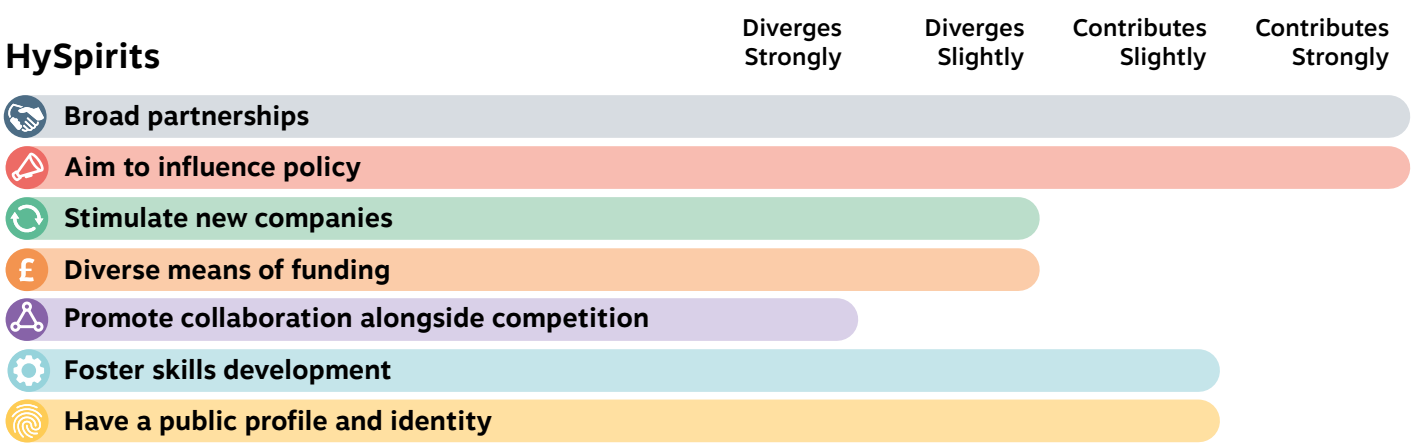
Diverse means of funding:
The HySpirits project is not funded by diverse means. The project was awarded £148,600 by the Department of Business, Energy, and Industrial Strategy (BEIS) to conduct the study (UK Gov, 2019).

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the HySpirits overview, the project represents a significant amount of collaboration between industry, not-for-profit and academic organisations who are working together as partners. There is little in the way of competition although this is unsurprising due to the demonstrator, as opposed to profit driven, nature of the project.

Foster skills development:
As has already been discussed, the HySpirits project is attempting to retrofit existing distillery systems which if successful could enable the wider decarbonisation of the sector. As such, new experience and knowledge acquired during the project should provide learning opportunities that can be disseminated. This would likely foster skills development whilst also potentially informing the creation and refinement of specialised hydrogen training programmes.

Have a public profile and identity:
The HySpirits project has been featured in a number of media outlet publications, at both national and local level, including the BBC and The Orcadian, as well as featuring in industry media publication such as The Spirits Business and Energy Voice. HySpirits does not have its own dedicated website however partner organisations Edinburgh Napier University, EMEC and Orkney Distillery Ltd all feature the project on their own individual websites. It is possible that, due to the media coverage on the project, especially articles from the BBC, HySpirits has a public profile beyond the Orkney Islands and beyond industry and academic circles. However, this is difficult to ascertain for sure.

The project offers a substantial decarbonisation opportunity for the wider industry and The Orkney Distillery could become the world's first hydrogen-fuelled distillery



Hydrogen Offshore Production (HOP)

The HOP project is a collaboration between six diverse project partners hoping to deliver a first of a kind offshore hydrogen supply programme at Flotta Oil Terminal in Orkney. Led by The Oil & Gas Technology Centre (OGTC), the project received a £494,000 grant from the UK government for project delivery via industrial trials (UK Gov, 2019). In short, HOP aims to prove 'the feasibility of several options for decentralised hydrogen generation, storage, and distribution that collectively provide a scalable offshore hydrogen production solution' (Fuel Cell Works, 2019). Furthermore, HOP hopes to demonstrate circular economy principles through re-using and re-purposing oil and gas infrastucture.

Broad partnerships:
The HOP project consists of broad partnerships. Partners include the Oil and Gas Technology Centre (OGTC), EMEC, NOV, Doosan Babcock, Aquatera and Cranfield University.

Aim to influence policy:
The HOP project is, as mentioned, a first of a kind project. As such it aims to provide valuable lessons regarding the feasibility of offshore hydrogen supply which will be able to inform, and thereby influence, policy.

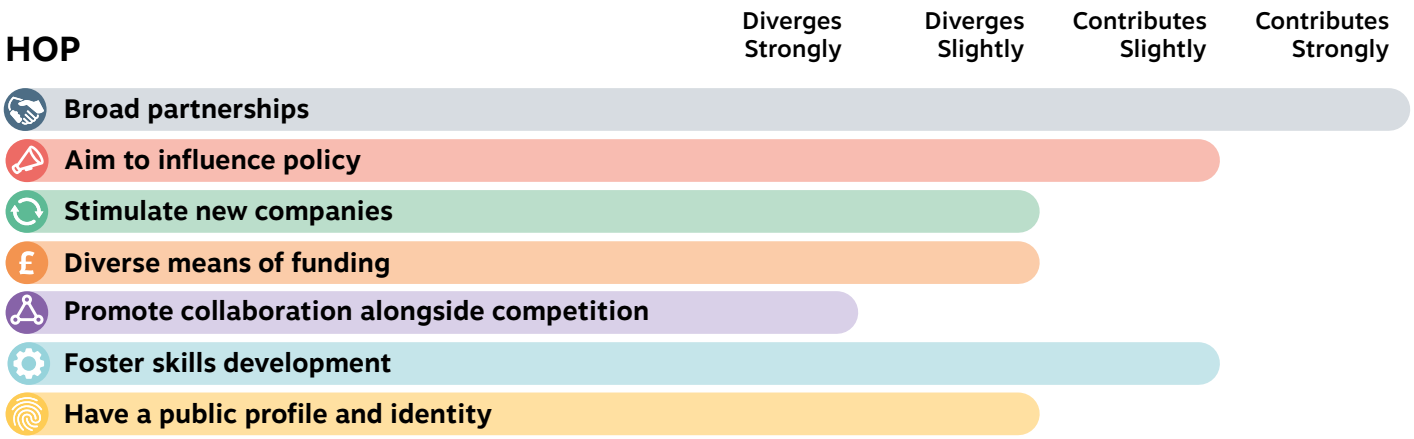
Stimulate new companies:
The Hop project has not directly stimulated new companies. However, it has enabled technology developed by Cranfield to prepare for the next stage of commercialisation and, according to EMEC Hydrogen Manager Jon Clipsham has led to NOV to now look at diversification.

Diverse means of funding:
The HOP project is not funded by diverse means with the entirety of the £494,000 funding coming from a grant from the UK governments £20 million hydrogen supply programme.

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the HOP overview, the project represents a significant amount of collaboration between industry, not-for-profit and academic organisations who are working together as partners. There is little in the way of competition although this is unsurprising due to the demonstrative, as opposed to profit driven, nature of the project.

Foster skills development:
New experience and knowledge acquired during the project should provide learning opportunities that can be disseminated. This would likely foster skills development whilst also potentially informing the creation and refinement of specialised hydrogen training programmes.

Have a public profile and identity:
The HOP project does not have a public profile or identity. It does not have its own dedicated website and information regarding the project is relatively scarce. It is briefly mentioned in one press release from the UK government which has then been disseminated to other media publications within the hydrogen sector and is also presented on the fuel cell works website.


HOP
Diverges Strongly
Diverges Slightly
Contributes Slightly
Contributes Strongly
Broad partnerships
Aim to influence policy
Stimulate new companies
Diverse means of funding
Promote collaboration alongside competition
Foster skills development
Have a public profile and identity

Conclusion

To conclude, our research suggests that the Orkney H_2 cluster is, at present, the most developed H_2 innovation cluster in the UK.

EMEC Hydrogen Manager, Jon Clipsham who was interviewed for this report told us that:

"there are huge opportunities for innovation clusters in this space. The success of the Orkney hydrogen projects is testament of that."

Research undertaken for this report suggests that this observation is accurate. We believe it is noteworthy that, according to Jon, the success of the Orkney H_2 cluster has only been made possible due to what has been happening in the renewable sector over the preceding number of years.

It would appear that the development of the Orkney renewable sector has bred "a culture within the culture" who understand energy, have an interest in de-carbonisation and out of that have developed a mind set in the way that Orkney works, the way energy works, and more recently, how hydrogen as part of that comes into play.

We suggest that this observation should be kept in mind by any actors or institutions who wish to foster low-carbon innovation clusters in the future.

Orkney Cluster Heat Map

	Diverges Strongly	Diverges Slightly	Contributes Slightly	Contributes Strongly
Broad partnerships	0	0	1	9
Aim to influence policy	0	0	8	2
Stimulate new companies	0	9	1	0
Diverse means of funding	0	7	1	2
Promote collaboration alongside competition	10	0	0	0
Foster skills development	0	0	7	3
Have a public profile and identity	0	3	7	0

Broad partnerships

As is evident from the broad partnerships sections of the Orkney H_2 projects that have been presented throughout this report, the Orkney H_2 cluster is constituted by broad partnerships spanning multiple sectors including private and public organisations, industry and not-for-profit organisations, as well as those from academia.

In the words of Jon Clipsham, Hydrogen Manager at EMEC who was interviewed as part of this report:

"as the hydrogen infrastructure has expanded, the number of projects has expanded... from being small and local, to national in Scotland terms, national in UK terms and more recently the scope of what we do is international... stretching through Japan, Australia, the USA."

Aim to influence policy

Research undertaken for this report suggests that the Orkney H_2 cluster does indeed attempt to influence policy.

According to Adele Lidderdale, Hydrogen Project Officer at Orkney City Council:

"local policy has been updated in the 'Orkney Hydrogen Strategy' and the council are in many workshops with Scottish Government to help shape policy".

Furthermore, according to EMEC Hydrogen Manager Jon Clipsham, they are:

"regularly engaging with people in Holyrood, throughout Scottish Government and increasingly with the guys in BEIS across all departments down there".

In addition, a hydrogen technologies group has been set-up down in Whitehall, based in BEIS, which is helping to shape policy and making sure that green hydrogen is not lost on the agenda.

Stimulate new companies

EMEC, whom, as this report has highlighted, are a vital player in the Orkney H_2 cluster, have recently developed a dedicated hydrogen company. However, notably, this is perhaps the only new company that has so far been stimulated by the Orkney H_2 cluster. This is not surprising due to the fact that many of the hydrogen projects currently being undertaken in Orkney are of a demonstrative, as opposed to profit-driven, nature.

If, however, the cluster continues to develop in a similar manner to that suggested by the innovation cluster literature, then it is likely only a matter of time before we begin to see the stimulation of new companies.

A similar analysis was also offered by EMEC Hydrogen Manager, Jon Clipsham who, when interviewed for this report, told us that:

"I think it's certainly a matter of time before you start to see commercial entities spinning out from where we are now."

Diverse means of funding

The Orkney H_2 cluster is funded by diverse means including money received from the EU, UK government, Scottish Government and local government funds. In addition, some of the hydrogen projects in Orkney have been part-funded by the private sector partners of the individual projects, as well as by research councils.

However, EMEC Hydrogen Manager, Jon Clipsham who was interviewed for this report suggested that in the future there will need to be even more diverse means of funding to account for the increasing capital expenditure (CAPEX) and operating expenditure (OPEX) that will be incurred in order to move the Orkney H_2 cluster forwards. He told us that:

"transitioning from single digit million sized projects, up to what is necessary to put a substantial hydrogen use or production assets on the ground will be in the realm of tens of millions and there are not many programs that will provide 100% funding for what is likely to be a purely a commercial entity."

Promote collaboration alongside competition

The Orkney H_2 cluster, on the whole, is very committed to promoting collaboration and is arguably an exemplar of bringing various bodies and organisations together to work towards a common cause.

Adele Lidderdale, Hydrogen Project Officer at Orkney City Council, told us that, quite frankly:

"the projects wouldn't go ahead without commitment to collaboration".

As of yet, there is little in the way of competition however this could change in the future if there was a greater demand for green hydrogen on the islands. This could be driven by, for example, conversion of all Orkney ferries, the introduction of hydrogen planes, and/or an increased number of hydrogen powered road vehicles.

Foster skills development

The Orkney H_2 cluster is undoubtedly fostering skills development. Many of the projects in the cluster are extremely innovative and constituted by new socio-technical configurations which exude rich learning opportunities. These opportunities for learning have in turn been leveraged to further and foster skills development. For example, according to EMEC Hydrogen Manager, Jon Clipsham, who was interviewed for this project:

"right from the outset the Surf 'n' Turf project had a strong training component within it... it worked with the navigation school in Orkney... they've got training and awareness courses running now to support people who are operating in the hydrogen space."

According to Jon:

"we see this as a long-term play, so the STEM [science, technology, engineering and mathematics] role within primary, secondary education is key to this... we've got a team of STEM ambassadors running out of EMEC... it's a long term play as hydrogen technology has moved from concept, through to demonstration, through to on the ground assets, which are going to be necessary if we're going to make this hydrogen transition within an overall energy transition happen."

Have a public profile and identity

According to Adele Lidderdale, Hydrogen Project Officer at Orkney City Council, the Orkney H_2 cluster has had "multiple international media visits and won a number of high profile awards". In addition, research undertaken for this report revealed that a significant number of the H_2 projects being undertaken in Orkney have their own dedicated website and, as exemplars in the sectors, are well known by both industry and academic actors and organisations.

However, despite this, research for this report has still found little conclusive evidence that the Orkney H_2 cluster has a public profile and identity beyond those with a keen interest in green energy technologies. This analysis was also offered by an EMEC employee who was interviewed for this project who told us that the cluster "doesn't have a public profile". We were however informed by the same employee that EMEC are looking at setting up a sub-group within the Orkney renewable energy forum, which covers all the renewable activity running in Orkney and the islands, in part to raise public profile and identity.

Aberdeen Hydrogen Cluster

Introduction

Aberdeen is located on the East coast of Scotland, by the North Sea. It is the third most populated city in Scotland with a population of about 200,000 inhabitants*.

Historically, Aberdeen was a major maritime centre. Over the past 30 years the North Sea oil and gas industry has been one of the major contributors to the city's economy. More recently, Aberdeen has been leading climate innovation in the transportation sector. Indeed, the city boasts a fleet of hydrogen buses. It is also a hub for innovative projects in the region. It offers one of the prime sources of domestic demand for the SGN projects proposing to use the St Fergus Gas Terminal facilities to produce hydrogen.

Aberdeen therefore has experience in climate innovation at multiple levels including: local government level, large industry level, academic level, and public interaction with hydrogen projects. This makes Aberdeen a prime location to stimulate climate innovation in the wider region. In particular with the use of hydrogen as a decarbonisation option.

* www.aberdeencity.gov.uk

King's College, Old Aberdeen © Gannet77/Getty Images

Acorn Hydrogen

The Acorn Hydrogen project seeks to use the industrial site for gas processing facilities at St Fergus, located on the coast about 55 km north of Aberdeen.

Currently the site hosts three gas processing plants (each owned and operated by a separate consortium of hydrocarbon organisations), where about 35% of UK natural gas is imported by pipeline from the UK North Sea, Norway and west of Shetland. The site will continue production from fields west of Shetland during at least the next 30 years. That gas is fed into high pressure Transmission pipelines operated by National Grid.

The Aberdeen Vision project (see below) seeks to convert some of the methane into hydrogen and replace some grid methane with 2% hydrogen – via Transmission pipelines to central Scotland or England, and 20% to 100% hydrogen to Aberdeen in SGN's lower pressure distribution pipelines.

https://sgn.co.uk/

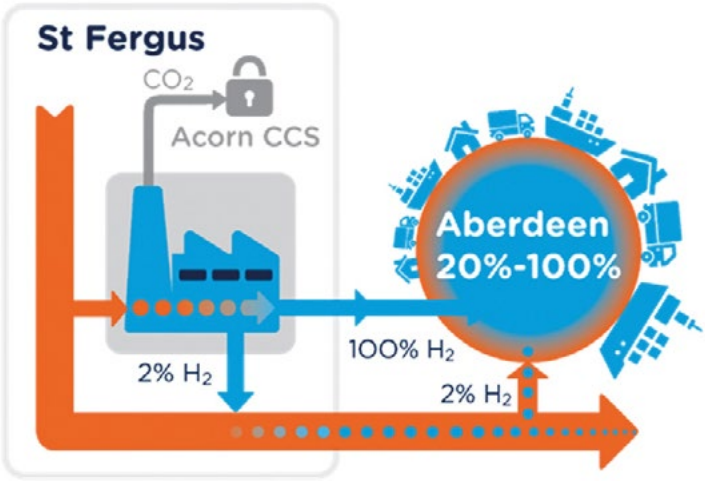


Figure 5: Overview of the Acorn project in conjunction with the Aberdeen Vision Project
© SGN, 2019a

To convert methane to hydrogen uses chemical processes such as Steam Methane Reforming, or Auto Thermal Reformation at higher pressures. These produce CO_2 which needs to be removed to storage.

The Acorn project will remove CO_2 to storage (ACORN, 2019). The CO_2 will initially be captured from the three gas separation units, and importantly their compressor machinery at about 0.2-0.4 Mt CO_2/yr. A redundant offshore pipe which formerly brought gas onshore will be repurposed to take CO_2 offshore, to store in the depleted Goldeneye gas field or Captain sandstone reservoir.

Broad partnerships:
Partnerships for the Acorn project are built around the emergence of the small and medium-sized enterprise (SME) Pale Blue Dot, west of Aberdeen, as the catalyst and actor. Pale Blue Dot have created the CO_2 commercial project. Now in 2019, Pale Blue Dot and SGN together are promoting hydrogen development.

Aim to influence policy:
Acorn needs to influence policy to make an operational Carbon Capture and Storage (CCS) system. There needs to be full permission to store offshore. Liability against long duration (1,000 – 10,000 years) needs to be agreed with Scottish and UK governments. And payments for CO_2 stored need to be agreed with confidence.

Stimulate new companies:
Acorn has stimulated Pale Blue Dot, as a group of three ex-oil executives and has grown to an SME employing several tens of people during busy contracts. Most of the partnerships for subcontracts use hydrocarbon companies in Aberdeen or part of that North Sea cluster.

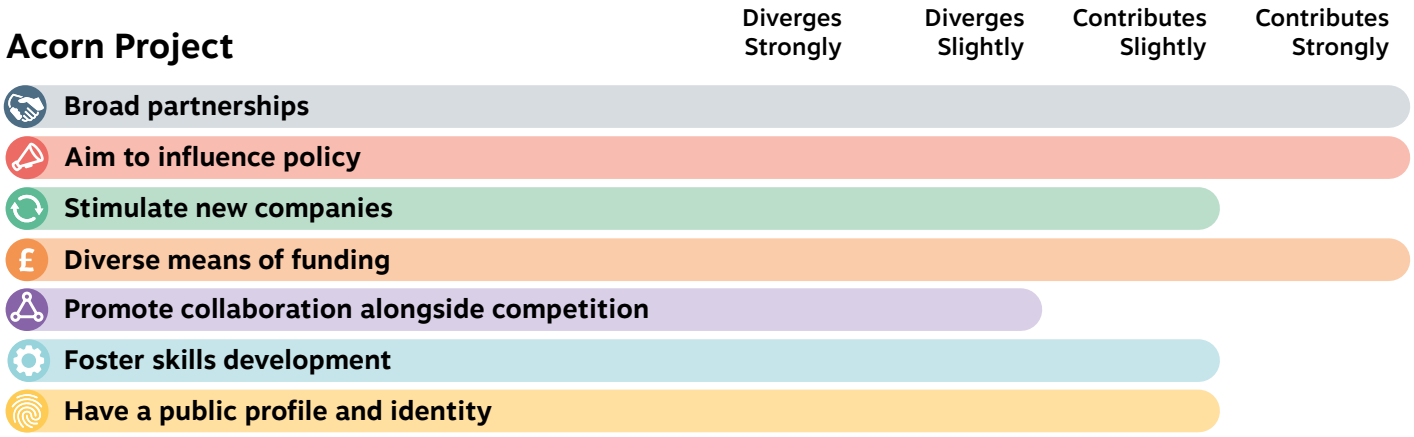
Diverse means of funding:
Acorn has used multiple funding methods, as and when available. These include: consultancy work on other projects and investing in the projects on CO_2, direct grants from BEIS, the European Accelerating CCS Technologies funds x2. And through the impact of policy work undertaken by Scottish Carbon Capture and Storage (Edinburgh) in Europe – 4 tranches of funding from Project of Common Interest.

Promote collaboration alongside competition:
The Acorn project opens up CO_2 removal services for all industries in Scotland. The Central Scotland industries will be connected by re-purposing of the Feeder 10 onshore pipeline from St Fergus to Grangemouth. If Acorn is not constructed, then "Blue" hydrogen from chemical splitting of methane will not be viable as the CO_2 cannot be removed. Then hydrogen cannot be commercially produced. The early emergence of hydrogen at scale at low cost in Scotland will be delayed by decades if Acorn fails to be built. One cluster depends on another.

Foster skills development:
Acorn skills are adapted from hydrocarbon analysis. The North Sea hydrocarbon cluster is essential to develop commercial CO_2 appraisal and storage.

Have a public profile and identity:
Acorn has specifically allocated significant funds to achieve it public and professional profile. That is by website, press releases, technical documents and technical publications.

Acorn Project



Aberdeen Vision Project (SGN, 2019a)

Aberdeen Vision seeks to show the commercial viability of introducing 2% hydrogen into the gas National Transmission System (NTS). While the initiative begins at St Fergus Gas Terminal and will fully include Aberdeenshire, it will also drive impact in areas outside Scotland via the national network systems. The venture also seeks to provide a rationale for the development of a new 100% hydrogen pipeline from St Fergus to Aberdeen, which would originally provide the network with a gas mixture of up to 20 percent hydrogen, rising to 100 percent after a full hydrogen conversion. The new pipeline will promote hydrogen distribution to Aberdeen, where the most advanced and widespread use of hydrogen in transportation in the UK can be found.

Broad partnerships:
The project collaborators are SGN and National Grid, in partnership with Pale Blue Dot Energy, Environmental Resource Management (ERM) and Det Norske Veritas Germanischer Lloyd (DNVGL). As such the official partnership of the project is industry focused.

Aim to influence policy:
This project clearly aims to address long term issues to reduce carbon emissions and help the UK in achieving the UK's net zero GHG reduction target.

Stimulate new companies:
The evaluation of the commercial viability of hydrogen networks and marketability of hydrogen and its end uses can provide valuable insights into the commercial opportunities and contribute to articulating market growth strategies.

Diverse means of funding:
The means of funding are from the Ofgem's Network Innovation Allowance fund. Hence there is no diversity in funding sources.

Promote collaboration alongside competition:
This project clearly indicates potential benefits for many other ongoing hydrogen projects in other clusters such as H21 (NGN, 2019), H100 (SGN, 2019c) and HyNet (HyNet, 2019) (all discussed subsequently), as well as the understanding developed by the NTS operators for applications elsewhere. This cross-project collaboration is particularly strong with the Acorn CCS project. Competition development is not a main project driver, although there is consideration of market growth strategies.

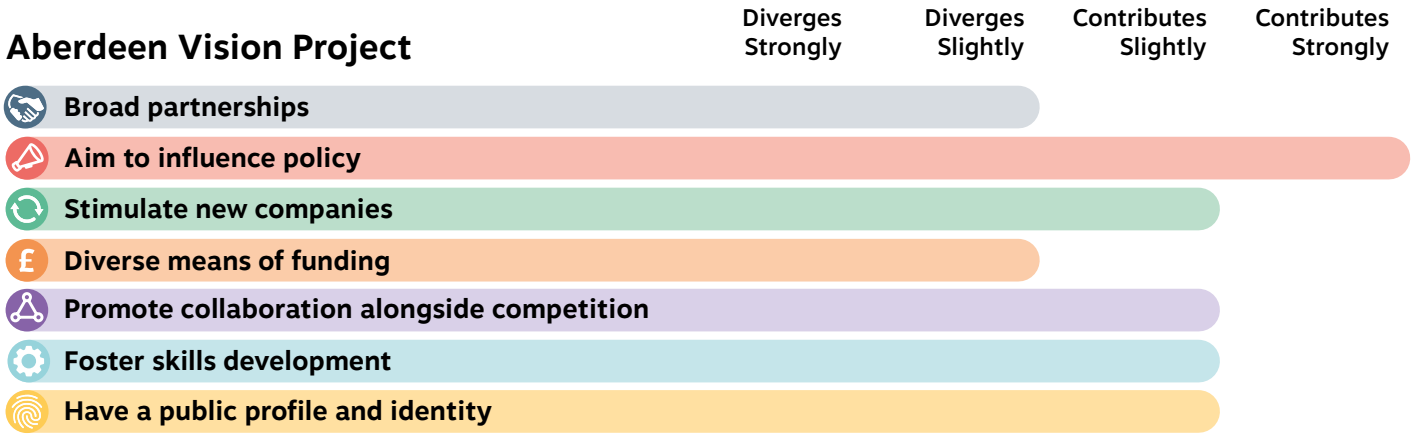
Foster skills development:
There is a clear aim to foster skill and knowledge development in the following areas:

- the analysis of hydrogen production at St Fergus using Steam Methane Reforming,
- the injection of 2% hydrogen in the NTS,
- ascertain technical issues related to all materials,
- examine the Acorn CCS proposal and its overall feasibility,
- the construction of a hydrogen pipeline from St Fergus to Aberdeen and the creation of a commercially viable network and transport hub in Aberdeen,
- assess the impact on the end-users in terms of perception and cost.

Yet, no skills pipeline will be put in place to channel knowledge to key end users and stakeholders.

Have a public profile and identity:
A webpage on the SGN website is available, although it has not been updated to include the learnings from the end of the project which was due to terminate in June 2019.

Aberdeen Vision Project



The Hydrogen Hub

The Hydrogen Hub project is the latest attempt by Aberdeen city to develop plans to become a centre of excellence for green hydrogen technology. According to Opportunities North East (2019):

"a tender process has been launched as Aberdeen bids to build on its reputation as a centre of excellence for hydrogen and fuel cell technologies. As part of the tender, potential locations for a hydrogen hub will be identified in addition to outlining the strategic, economic, financial and commercial objectives whilst determining the opportunities to seek private investment in the hydrogen market... The study aims to develop a business case which will explore the development of a sustainable and commercial supply of hydrogen in the city, which can then be adopted by other Scottish cities in future years".

Meanwhile, H2Aberdeen and Invest Aberdeen are continuing to work with the Department of International Trade to promote the hydrogen sector in Aberdeen as one of eight energy investment opportunities within the UK on a global platform (Aberdeen City Council, 2019).

Broad partnerships:
The Hydrogen Hub project consists of reasonably broad partnerships with Aberdeen City Council and Opportunities North East and Scottish Enterprise working together on the project.

Aim to influence policy:
The Hydrogen Hub aims to develop a viable business case for the commercial supply of hydrogen in the city which could be adopted by other Scottish cities. If successful the project could inform, and influence, policy decision-making. According to Councillor Douglas Lumsden: "the Aberdeen City Region Hydrogen Strategy and Action Plan 2015-2025 maps out the steps for a hydrogen economy in the region... Aberdeen City Council and our partners believe in a cleaner, greener more sustainable future, and our commitment to pioneering technology is something the world can profit from" (Aberdeen City Council, 2019).

Stimulate new companies:
The Hydrogen Hub project is yet to directly stimulate new companies; however, this is unsurprising due to the fact that the project is early in its development.

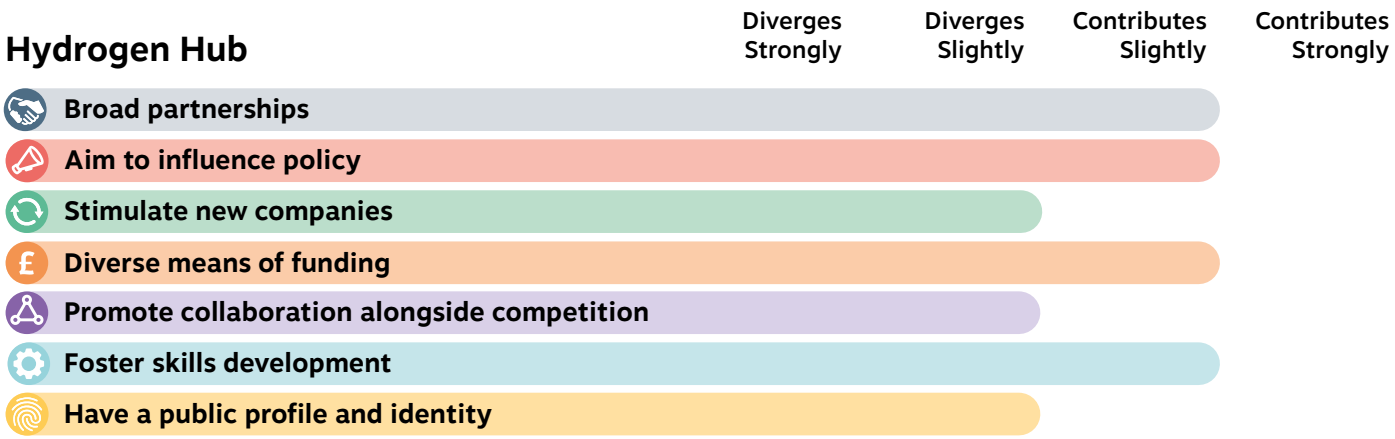
Diverse means of funding:
The £100k study is jointly funded by Aberdeen City Council and Opportunity North East and Scottish Enterprise thereby demonstrating a reasonable amount of funding diversity.

Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the Hydrogen Hub project overview, the project promotes some collaboration, with both public and private sector organisations working together as partners. There is not much in the way of competition as of yet, however, given the overall aim of the project i.e. the development of a business case which will explore the development of a sustainable and commercial supply of hydrogen in the city, we expect that the project may drive competition in the not so distant future.

Foster skills development:
According to Trevor Garlick, Opportunity North East's Oil, Gas and Energy Sector Board Chairman: "hydrogen presents regional and global opportunities for North East Scotland's existing infrastructure and skills base, and an opportunity to build on our regional competitive advantage to deliver energy transition. For example, two retrofitted diesel/hydrogen transit vans have been gifted to North East Scotland College by the City Council as learning vehicles for the development of a technical training course" (Aberdeen City Council, 2019).

Have a public profile and identity:
The Hydrogen Hub project does not have a dedicated website to provide details of the project. The project is however featured on the partner organisations individual websites in the form of news articles. Nevertheless, it is unlikely that the project has a public profile and identity beyond the sector.

Hydrogen Hub



Dolphyn ERM Project (IET, 2019)

The Deepwater Offshore Local Hydrogen Production (Dolphyn) undertaking will explore the large-scale retrofit supply of hydrogen from deep-water offshore floating wind turbines. The project aims to use the considerable resource of UK offshore wind to operate electrolysers in order to generate hydrogen from the seawater surrounding the wind turbines. Sizeable 10MW turbines comprising of desalinization capabilities and PEM electrolysers can inject pressurised hydrogen to a subsea manifold with other turbines' lines via a single flexible riser. The gas can then be sent back to shore. 1.5 million homes could be heated using the hydrogen produced by the capacity of 4GW from a 20-by-20 array.

Broad partnerships:
The project is led by a partnership between Environmental Resource Management (ERM), the Tractebel unit of French energy company Engie, and the offshore specialist Offshore Design Engineering Limited (ODE). This partnership is composed of industry partners.

Aim to influence policy:
No clear aim to influence policy could be gathered from an online search. The project clearly seeks to demonstrate the technological feasibility of producing hydrogen offshore. This might influence policy by demonstrating technical feasibility.

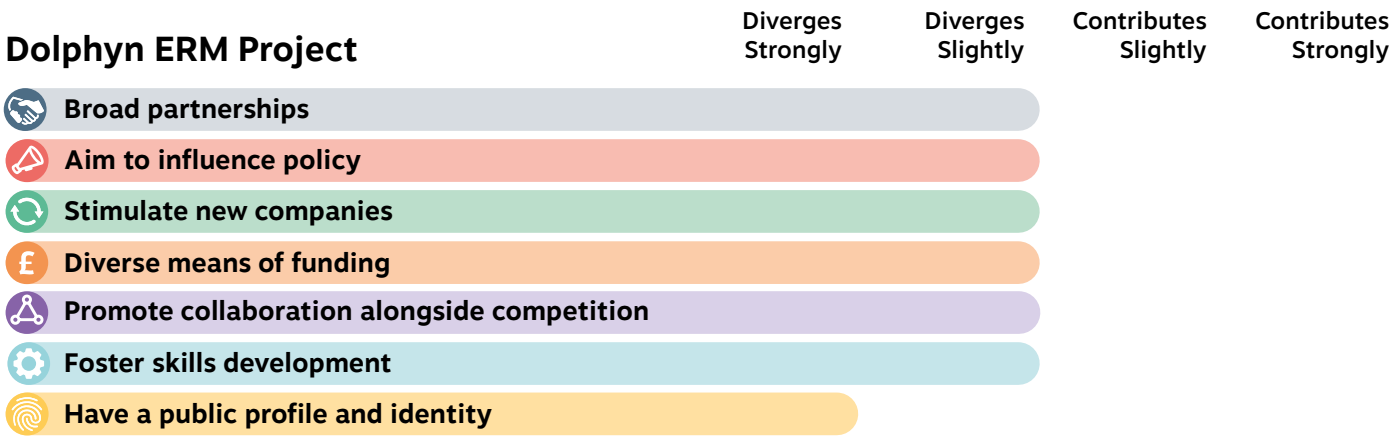
Stimulate new companies:
No clear evidence of an aim to stimulate new companies as part of the project could be found. The project findings however, could de-risk the offshore hydrogen production from renewable wind resource by increasing its Technology Readiness Level.

Diverse means of funding:
All the £427,600 were awarded by the UK Government as part of the Government's £20m Hydrogen Supply Programme (Gov, 2019).

Promote collaboration alongside competition:
The project appears to be focussing on collaboration and knowledge development.

Foster skills development:
The project will clearly contribute to the development of skill and knowledge in the area of offshore hydrogen production from renewables. No clear training program capable of creating and promoting skills was identified however.

Have a public profile and identity:
The project has generated a few articles in online specialised press. No project website seems to exist.



Aberdeen Hydrogen Bus Project

The Aberdeen Bus project is the world's largest demonstration of hydrogen fuel cell buses. The project, which is funded by High Vlo City and HyTransit (both of whom are supported by the FCHJU), has backing from both public and private sector organisations from the UK and Europe.

According to H2 Aberdeen (2019) the Aberdeen Bus project includes:

- **Production of hydrogen from a 1 MW electrolyser - supplied by Hydrogenics**
- **Establishing a state-of-the-art hydrogen refuelling station, Scotland's first commercial-scale hydrogen production and bus refuelling station that will include hydrogen production through electrolysis**
- **Deployment of a fleet of 10 hydrogen buses, to be operated by First Group and Stagecoach.**
- **The development of a hydrogen safe maintenance facility, within an existing maintenance depot for an operational fleet.**

In their first year of operation, Aberdeen Bus Projects' hydrogen fuelled vehicles travelled 250,000 miles and carried in excess of 440,000 passengers. Not only do the tailpipes of the buses produce no harmful emissions, they have also been found to be four times more efficient than their diesel counterparts. This had led Aberdeen council to look into the possibility of expanding the fleet.

A hydrogen bus © Bill Harrison (CC BY-SA 2.0)

Broad partnerships:
The Aberdeen Bus Project consists of broad partnerships. Partners include: Aberdeen City Council (project lead) BOC Group (owner and operator of the hydrogen refuelling station), Van Hool (bus fleet provider), First (route operator), Stagecoach (route operator), Scottish and Southern Energy Power Distribution (control system and network monitor) and SGN (working with Scottish and Southern Energy Power Distribution on grid-balancing). Other partners in the High V.LO-City and HyTransit projects are: De Lijn, Riviera Trasporti, Rigione Liguria, University of Genoa (DITEN), Solvay, Dantherm, Planet, PitPoint, Finanza Innovazione e Trasporti (FIT) Consulting, HyER, WaterstofNet, Element Energy.

Aim to influence policy:
The Aberdeen Bus Project is the largest demonstration of hydrogen fuelled buses in the world. Learnings from the project are of great value and will inform, and thereby potentially influence, policy decision making offering a route to decarbonisation in the sector.

Stimulate new companies:
The Aberdeen Bus Project has not directly stimulated new companies.

Diverse means of funding:
The Aberdeen Bus Project is funded by diverse means. According to the Aberdeen City Council (2019): "The Aberdeen Hydrogen Bus Project has been co-funded by Scottish, UK and European partners: the UK's innovation agency, Innovate UK (£2.4million); Scottish Government (£1.7million); Scottish Enterprise (£1.7million); Fuel Cells and Hydrogen Joint Undertaking (FCHJU) through the High V.LO-City and HyTransit projects (£8.3million); Aberdeen City Council (£2million); First (£1million); Stagecoach (£1million); Scottish Hydro Electric Power Distribution £750,000; and Scotland Gas Network £200,000. BOC Group has invested £1million in the hydrogen production and refuelling station".

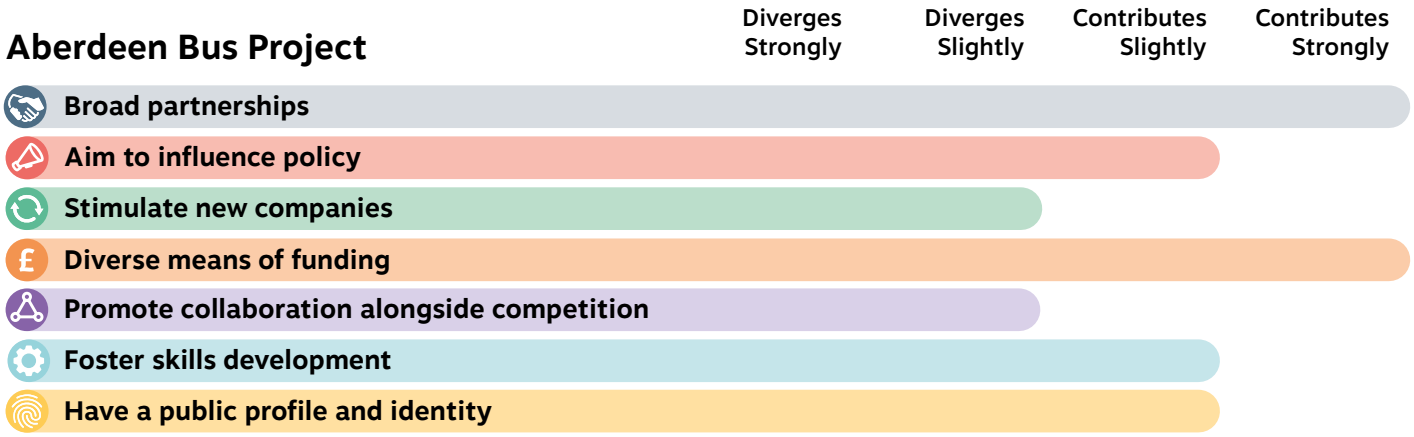
Promote collaboration alongside competition:
As is apparent from the broad partnerships section of the Aberdeen Bus Project overview, the project undoubtedly promotes collaboration with both public and private sector organisations working together as partners. There is not much in the way of competition as of yet, however, given the success to date of the project, and the consequent consideration by Aberdeen Council to expand the size of the fleet, we expect that there may be competition for value chain roles in the not so distant future.

Foster skills development:
According to Councillor Barney Crockett, Aberdeen City Council's lead member for hydrogen: "by working with this clean, renewable fuel we are securing our position as a world-leading energy city which will continue to not only attract significant investment, but also present exciting new research, development and employment opportunities" (Aberdeen City Council, 2019).
Furthermore, according to Dr Hamish Nichol, former BOC Group Innovation Manager for hydrogen: "the result of a successful public-private partnership project, BOC's hydrogen refuelling station at Kittybrewster provides a clear demonstration of the viability of hydrogen as a carbon-free, zero emission fuel and redefines the benchmark for other refuelling stations to follow. We are very proud of the station's 99.99% availability which clearly defines the station as World Class" (Aberdeen City Council, 2019).

Have a public profile and identity:
The Aberdeen Bus Project does not have a dedicated website to provide details of the project. However, public and private sector organisations whom are active partners in the project do have details on their own individual websites. The Aberdeen Bus Project is the largest demonstration of hydrogen fuelled buses in the world and is an exemplar low-carbon demonstration project, as such it is well-known by industry and academic actors within the sector. Nevertheless, it is unlikely that the project has a public profile and identity beyond that of the sector.

In their first year of operation, Aberdeen Bus Projects' hydrogen fuelled vehicles have travelled 250,000 miles and carried in excess of 440,000 passengers

Aberdeen Bus Project



Conclusion

The Aberdeen Cluster boasts a vibrant palette of innovative hydrogen projects. These projects are dominated by relatively broad partnerships which contribute to the cluster dynamic. The Aberdeen Cluster projects tend to share a common goal in influencing policy at a local, national and European level. This is reflected by the breadth of funding in projects such as the Aberdeen Bus Project or Acorn Hydrogen. These are also the two flagship projects of this cluster. They both have a strong public profile (for example the Acorn project has been recognised by the EU as a Project of Common Interest). This public identity seems to have made it harder for projects such as Dolphyn ERM and the Aberdeen Vision Project to develop a strong public identity independently. The skill set in terms of handling innovation projects by the local government has also grown over the years, making Aberdeen a strong contender for future innovation in the hydrogen space. It is crucial to keep that innovation dynamic going to prevent local skills to be lost to other regional clusters. This is particularly true since it appears that most projects do not have a clear framework to maintain the skill set developed through training programs.

Aberdeen Cluster Heat Map

	Diverges Strongly	Diverges Slightly	Contributes Slightly	Contributes Strongly
Broad partnerships	0	2	1	2
Aim to influence policy	0	1	2	2
Stimulate new companies	0	3	2	0
Diverse means of funding	0	2	1	2
Promote collaboration alongside competition		4	1	0
Foster skills development	0	1	4	0
Have a public profile and identity	1	1	3	0

Fife Hydrogen Cluster

Introduction

Fife is a council area of Scotland located between the Firth of Forth and the Firth of Tay with inland boundaries to Perth and Kinross and Clackmannanshire.

Fife has a population of around 360,000 people, with 160,000 households and 21 towns and villages. Fife has a strong history of innovation, as the birthplace of the famous economist Adam Smith, and with the presence of St Andrews University, the third oldest in the English speaking world. (Cargill, 2019)

Fife's industry is strongly linked to energy, with mining activity for over 100 years ending in the late 1980s, a dock with Oil and Gas activity since 1973, and from 2005 the growing presence of renewable energy sources, in particular wind turbines. Similarly to Aberdeen, Fife Council has been a driving force in promoting innovative projects seeking to decarbonise the region. Amongst these are an anaerobic digestion plant with a gas district heat scheme from landfill gas. A fleet of electric, and hybrid hydrogen low carbon vehicles. (Cargill, 2019)

Industry is also playing a key role in promoting climate innovation in Fife. As described in this section, industry projects are considering the development and use of hydrogen as a way of scaling up decarbonisation efforts in the region and maximising the benefits from renewable energy investments.

Fife Council has been a driving force in promoting innovative projects seeking to decarbonise the region

Fife Coast at Buckhaven © Richard Law (CC BY-SA 2.0)

HyGen 100 (IET, 2019)

HyGen is a feasibility study investigating how hydrogen production and storage could be developed at three sites in Scotland: Levenmouth in Fife, Aberdeen and Machrihanish in Campbelltown. Although not specifically focused on the Fife region HyGen still considers it. The focus of the project is to assess how 100% hydrogen could be deployed at each site, along with avenues for scaling up the development to the surrounding area. The re-use and building of existing and new infrastructure will be considered respectively. Investigation in the most suitable production and storage technologies will be considered on a site specific basis, along with a commercial assessment. This project is knowingly investigating three different sites with unique opportunities and challenges specific to each. The future use of the infrastructure for heat and transport will also be considered as part of the assessment.

Broad partnerships:
The partnership of actors involved in HyGen could not easily be found online. The project lead is SGN.

Aim to influence policy:
No specific project aim or work package was identified as aiming to influence policy. The project seems more focused on the local hydrogen generation and storage options.

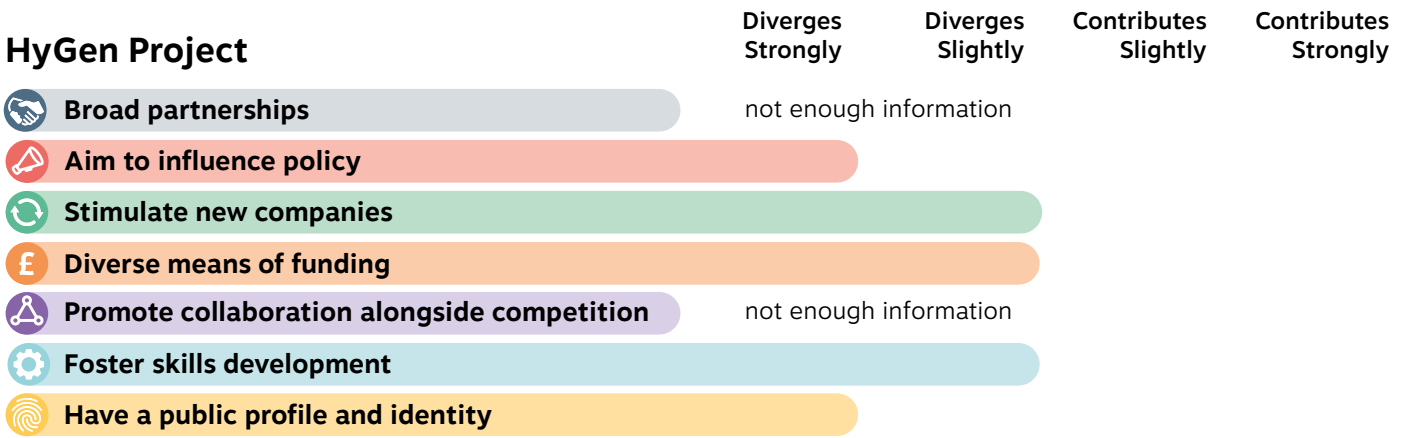
Stimulate new companies:
No information was available, although the focus placed on local sites might hint to promoting local growth.

Diverse means of funding:
A single source of funding could be identified from SGN presentations publically available online: the Low Carbon Infrastructure Transition Programme (LCITP).

Promote collaboration alongside competition:
Not enough information is available to express a view on that point.

Foster skills development:
It is unclear how skill development is being fostered as part of this project since little information could be gathered. Learning in site assessment for a hydrogen supply chain will be developed as part of this project.

Have a public profile and identity:
The project does not seem to have developed a public profile and identity. Communication to the wider public is limited. Little information can be gathered online aside from SGN presentations. No dedicated website exists.



Hydrogen 100 (SGN, 2019c)

H100 is a feasibility on the decarbonisation of gas of up to 300 homes in Scotland. According to SGN's website the two sites considered for H100 are Machrihanish in Argyll, and Levenmouth in Fife. Since Fife is developing more of a cluster dynamic than Machrihanish the project is discussed in this section, although the final decision on the site selection has not been made.

H100 aims to demonstrate the safe, secure and reliable distribution of pure hydrogen. The projects seeks to deliver what it calls the "H2 road to social proof" which consists in identifying the socio-economic and technical barriers associated with the conversion of 300 domestic houses to hydrogen and overcoming those barriers by developing an evidence base which satisfies all the customers and stakeholders. H100 is led by SGN, one of the Gas Distribution Network Operators, operating in Scotland, Southern England, and parts of Northern Ireland. H100 will investigate all the characteristics of gas distribution that may be affected by a change from natural gas to hydrogen.

Broad partnerships:
SGN is the only gas distribution network operator involved in the project. Technical and industry specialists are involved in delivering the various work packages of the project. Academic partners are also involved. No government body is involved as part of the project team. H100 constitutes a reasonably broad partnership.

Aim to influence policy:
H100 seeks to demonstrate the safe, secure and reliable distribution of 100% hydrogen to domestic customers. This aim is to provide an evidence base for policy makers.

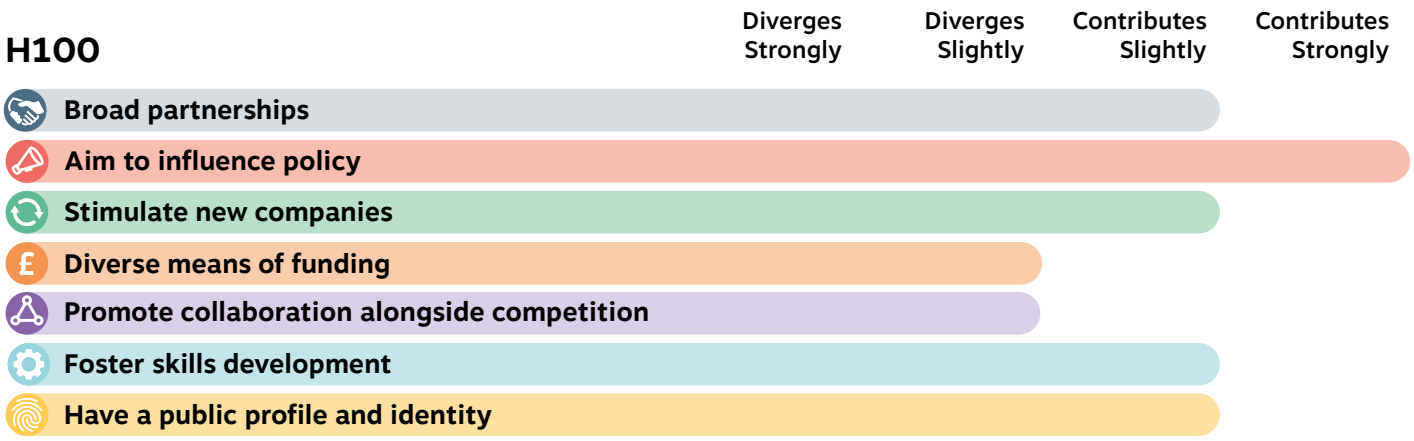
Stimulate new companies:
No clear incentive to stimulate new companies was identified. Although for the project to come to fruition a whole value chain will have to be developed and as such H100 is likely to promote the development of these value chain roles.

Diverse means of funding:
The project is only funded by the Ofgem's Network Innovation Allowance fund.

Promote collaboration alongside competition:
The initial phase of H100 is led by SGN who assigned each work package to organisations with the relevant expertise. This led to the formation of an informal network where skills and knowledge can be shared through collaboration. Since H100 is primarily focused on building an evidence base limited competition exists. Competition is likely to develop in the later stages of the project (or subsequent projects) aimed at the construction and operation of the required supply chain.

Foster skills development:
H100 investigates multiple technical aspects of distributing hydrogen through polyethylene pipes. It creates knowledge and a skill base in testing of safety aspects of hydrogen. It also contributes to the skill development of project managers and leaders in delivering innovative projects under the UK government incentives to decarbonise heat.

Have a public profile and identity:
So far H100 has only had limited exposure to the end-use consumers since the demonstration site has not been selected. It however has a full work package dedicated to stakeholder engagement. As part of this programme consumer engagement is being considered further along the timeline of the project. The project has no dedicated website at the moment, although a dedicated page exists on SGN's website.



Project Methilltoune (IET, 2019; SGN, 2019d)

Project Methilltoune is a feasibility study into the deliverability of an innovative hydrogen production demonstrator in Levenmouth in Fife. The project considers a hydrogen distribution network with storage facilities to provide domestic properties with hydrogen for heating and cooking. The project will synergise with H100 to deliver the entire supply chain required to deliver 100% hydrogen to domestic homes by the early 2020s. This project will aim to ensure the reliable production of hydrogen for public use, to move towards decarbonising heat.

Broad partnerships:
The partnership is led by SGN and includes Arup, Kiwa Gastec and the Offshore Renewable Energy Catapult (OREC). OREC uses unique facilities and research and engineering capabilities to bring together industry and academia and drive innovation in renewable energy. As such this partnership can be considered relatively broad.

Aim to influence policy:
A clear statement of willingness to demonstrate that renewable electricity produced by offshore wind can generate a secure and reliable supply of green hydrogen is made in a news statement on the SGN website (SGN, 2019d). Although this is not specifically targeted to policy makers, it will contribute to the evidence based needed to drive policy decisions supporting hydrogen production from renewables.

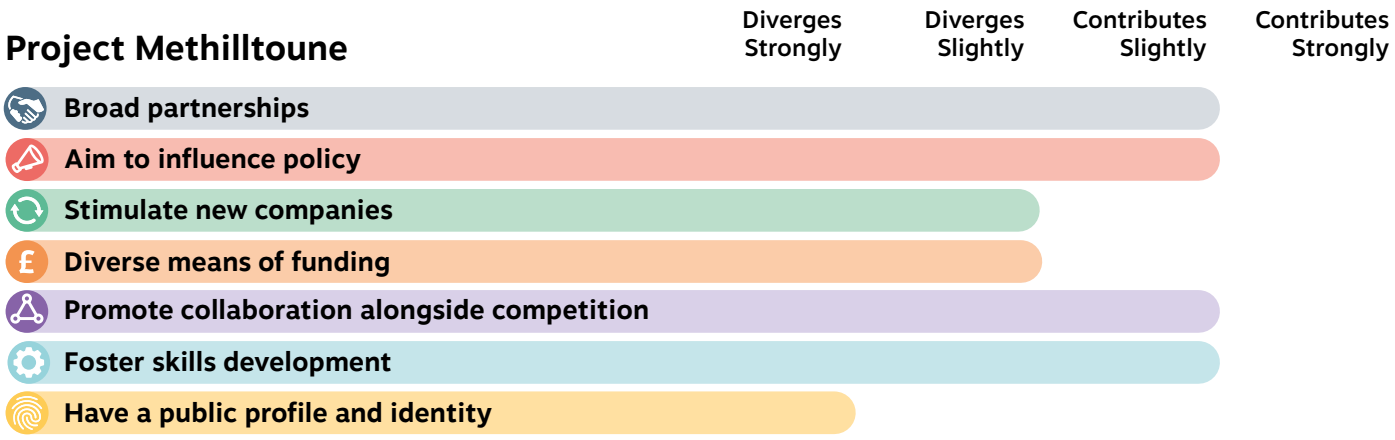
Stimulate new companies:
No specific details could be found, yet, as for H100 this project is likely to inform and de-risk the value chain of hydrogen for domestic use, promoting future developments in that area.

Diverse means of funding:
Single source of funding from BEIS as part of their Hydrogen Supply Competition.

Promote collaboration alongside competition:
The partners involved in the project will work collaboratively, along with stakeholders at a local level to deliver the project. Inter-project collaboration could occur between H100 and this project as they each address a complementary part of the supply chain (IET, 2019).

Foster skills development:
Experience in using offshore renewables to produce 'Green hydrogen' in a reliable way at a community level will be gained. Such knowledge could benefit other communities with offshore renewables.

Have a public profile and identity:
No dedicated project page or website could be found.



East Neuk Project (SGN, 2019b)

The East Neuk Power to Hydrogen project is led by SGN in collaboration with Scottish Power Energy Networks (SPEN), and in partnership with E4Tech. The project is a feasibility study exploring how excess constrained electrical energy in the East Neuk of Fife could be converted to hydrogen. The project will focus on how local energy generation, distribution and efficiency, could be maximised by assessing gas and electricity networks in the East Neuk of Fife. The project will contribute to developing a whole systems approach and business case for the use of renewables for generating hydrogen.

Broad partnerships:
The partnership consists of three industry actors and as such can be considered relatively narrow. However, if the project includes a strong stakeholder engagement program it could include a much wider range of actors.

Aim to influence policy:
The aim of the project does not appear to be focussed at influencing national policy.

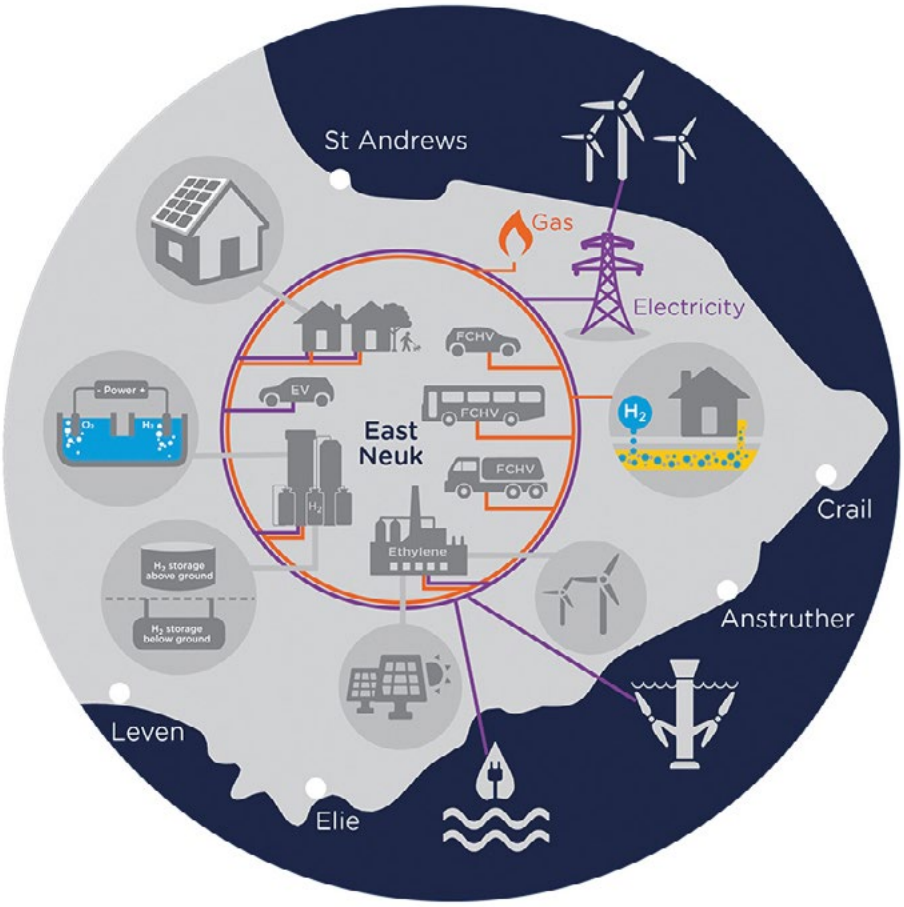


Figure 6: East Neuk of Fife Power to Hydrogen Vision

Stimulate new companies:
The project is likely to provide valuable insight in market growth opportunities in the region of East Neuk in terms of power to hydrogen. This has a strong potential to stimulate the growth of existing companies and possibly new ones if the opportunities identified are large enough.

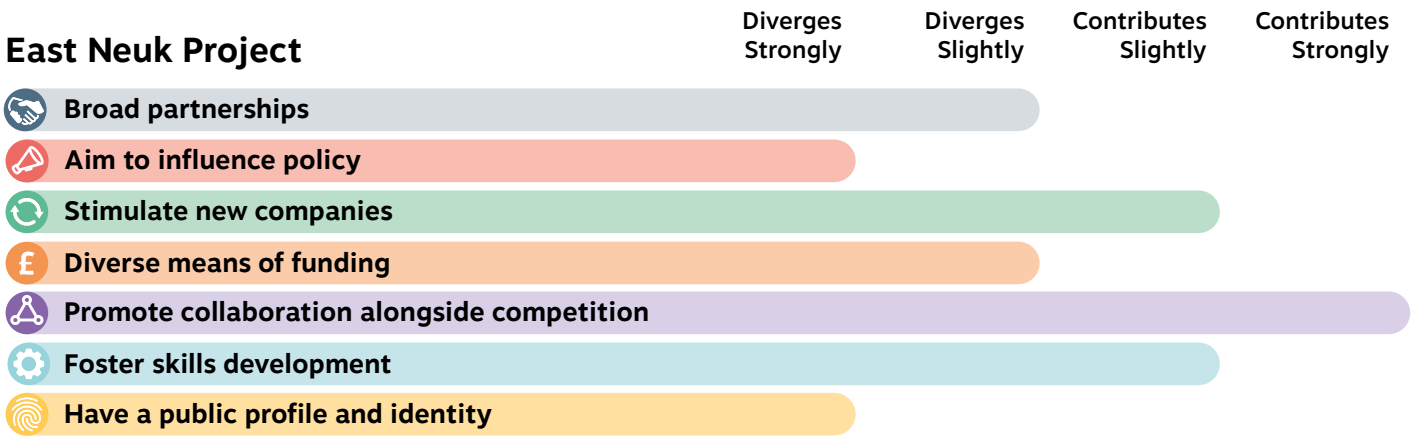
Diverse means of funding:
The project is funded by a single source, the Ofgem's Network Innovation Allowance fund.

Promote collaboration alongside competition:
The project will investigate business models around the opportunities identified. These business models are likely to incorporate some evaluation of competition and how a project could be developed in a profitable venture in a competitive environment. The project actors are primarily a collaborating force, even though they seek to understand potential for competitive opportunities.

Foster skills development:
The development of whole systems thinking and compatible business cases applied to a practical problem in a target area will be developed. These skills are likely to be important in driving local climate innovation in the hydrogen space.

Have a public profile and identity:
The project has a web page on the SGN website, but wider public profile and identity does not seem to be actively promoted.

East Neuk Project



Levenmouth Community Energy Project (BrightGreenHydrogen, 2018)

Levenmouth is a location on Fife's southern coast which encompasses three towns – Leven, Buckhaven and Methil. Bright Green Hydrogen, located in Methil Docks Business Park, operates the project from The Hydrogen Office. Located on one of the largest former coal export docks in Europe, the initiative highlights the transition from historic conventional energy to modern green energy by showcasing sustainable power supply and transportation alternatives. To address the intermittency of renewables, this project was created to explore the use of hydrogen energy storage. The project offers a robust green energy approach that addresses the supply and demand limitations of the local network and proposes that it will provide a roadmap for other businesses to decarbonize further locations in both the electricity and transport industries through the use of a smart microgrid. This was achieved by introducing state-of-the-art technologies and first-time integrated designs.

The initiative highlights the transition from historic conventional energy to modern green energy by showcasing sustainable power supply and transportation alternatives

Broad partnerships:
In 2014, the principle project partners consisting of Bright Green Hydrogen, Fife Council and Toshiba formed a consortium of organisations and were successful in their bid to Local Energy Scotland Challenge Fund.

Aim to influence policy:
The project aimed to demonstrate the use of hydrogen energy storage to tackle renewable energy intermittency. No specific claim appears to have been made with a clear policy influencing target as part of the project.

Stimulate new companies:
The project had a clear aim of providing blueprints for other companies in the energy and transport sectors to decarbonise specific sites using a smart microgrid. In that sense the project did contribute to stimulate company growth, if not specifically new companies.

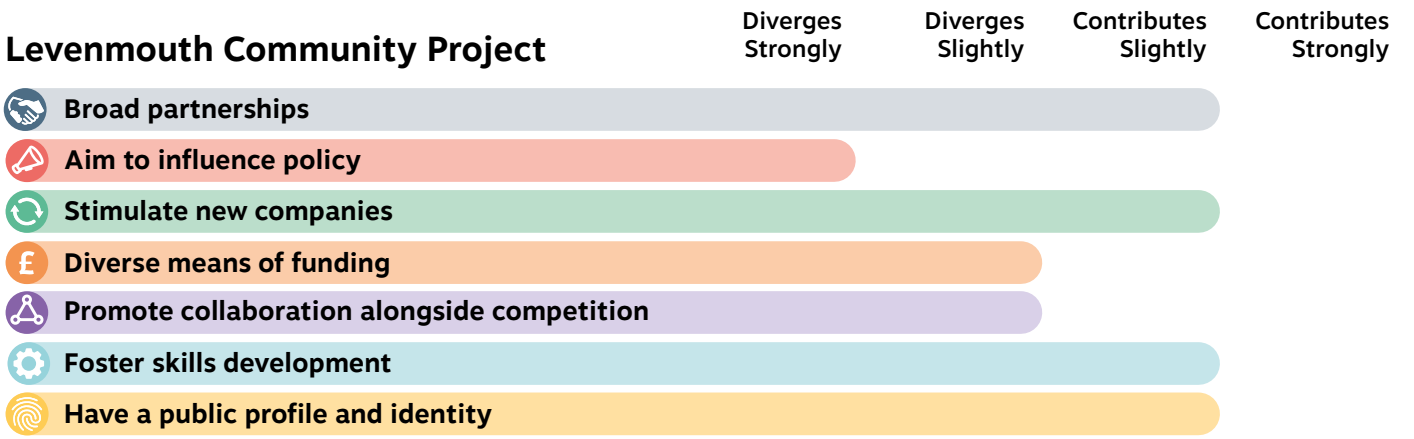
Diverse means of funding:
A grant of £4.4 million was awarded to the project through the Scottish Government, in that sense the funding was not diverse.

Promote collaboration alongside competition:
The project focus was clearly on collaboration. At this early stage the focus was placed on knowledge building and experience. Future large scale projects and developments are more likely to lead to market maturity and opportunity resulting in competition.

Foster skills development:
This particular project led to skill development across sectors in local energy industry, large manufacturer Toshiba and the local government. The knowledge and skill development from this project has underpinned the promotion of climate innovation and hydrogen in the region of Fife.

Have a public profile and identity:
The development of a fleet of hybrid hydrogen vehicles for the local council has contributed to the public being exposed and aware of the project. The project consortium also included two local actors Bright Green Hydrogen and the Fife Council which resulted in a stronger involvement of individuals local to the project site.

Levenmouth Community Project



Conclusion

There is a strong collaborative strand to the hydrogen innovation projects being undertaken in Fife, Scotland. In this cluster the local government has been instrumental in the development of hydrogen technology for climate innovation. Often, Fife Council, acted as an initiator, actor and end-user of the innovation projects. These projects allowed the actors involved to develop the required skills and knowledge to initiate more ambitious projects in partnership with large industry and governmental actors. Another key aspect of the initial projects developed in Fife was for the region to develop a 'hydrogen identity' through public facing interactions, such as the development of a hydrogen hybrid vehicle fleet. It should be noted that currently there appears to be a lack of formal training framework to deliver the skills developed in the cluster.

Other regions in Southern/Central Scotland are also seeing hydrogen innovation and development such as the Hydrogen Buses in Dundee and Machrihanish in Argyll being one of two sites considered for the H100 project, the other being Levenmouth, Fife. This clearly shows that the initiation phase of the Fife Cluster has started and that knowledge, interest and experience is reaching other regions in Southern and Central Scotland.

Fife Cluster Heat Map

	Diverges Strongly	Diverges Slightly	Contributes Slightly	Contributes Strongly
Broad partnerships	0	1	3	0
Aim to influence policy	3	0	1	1
Stimulate new companies	0	2	3	0
Diverse means of funding	0	5	0	0
Promote collaboration alongside competition	0	2	1	1
Foster skills development	0	1	4	0
Have a public profile and identity	3	0	2	0

Review of English Projects

Map showing location of the main English innovation clusters driving hydrogen innovation

Introduction

Climate innovation clusters are also found in England.

These clusters are primarily developed around industrial clusters. The reason behind this is that industry provides large demand at single points which is easier to predict than spread out domestic demand. This allows upscaling of hydrogen technologies and regulatory and business models whilst also delivering significant decarbonisation.

This section presents three key projects leading the development of hydrogen in climate innovation clusters in England. These projects bring together companies, regional leaders, and academic institutions into developing innovative, sustainable and multi-vector energy systems.

The North West Energy and Hydrogen Cluster is one such collaboration of institutions aiming to deliver the UK's first low carbon industrial Cluster by 2030 (North West Business Leadership Team, 2019).

Green fields in Weardale, County Durham © HPuschmann/Getty Images

HyDeploy & HyDeploy$_2$ (HyDeploy, 2019)

Being the first live domestic application of hydrogen, HyDeploy seeks to show that mixing up to 20% of the amount of hydrogen with natural gas is a secure and environmentally friendly substitute to the gas we are currently utilising. The project will prove how consumers do not need to modify their cooking or heating appliances to use the new hydrogen and natural gas mixture, which ensures less disruption and cost to them. It will also evidence initial conclusions that when using the hydrogen blend, consumers do not notice any difference. The first phase of the project will take place on the private gas network of the Keele University campus in Staffordshire. Following the completion of this initial phase the demonstration will move to a larger public network in the North East of England, followed by another large demonstration in the North West. This will ensure the hydrogen and natural gas blend is evaluated across a range of conditions and customers. (HyDeploy, 2019)

Broad partnerships:
The partnership includes gas distribution operators (Cadent and NGN), a university, a government body (HSE), an electrolyser manufacturer (ITM Power), energy development and implementation company (Progressive Energy). Extensive engagement and collaboration with other blending programmes in the EU (e.g. Engie's project in Dunkirk).

Aim to influence policy:
A clear statement is made on the project website that HyDeploy is designed around helping the UK to reach the Government's net zero target for 2050. The project aims to influence the safety, blending, and billing regulations via evidencing and demonstration of hydrogen technology. Engagement with stakeholders, particularly in regard to emerging government policy on low carbon heat.

Stimulate new companies:
No specific plans to support start-ups was identified despite a very strong sense that the practical demonstration from this project could significantly contribute to the expansion and de-risking of hydrogen projects in the UK.

Diverse means of funding:
Only funded via the Ofgem's Network Innovation Competition fund.

Promote collaboration alongside competition:
The project is strongly emphasising collaboration between parties, both in its aims and in its project partners. No strong competitive strand was identified in the project.

Foster skills development:
The fostering of skill development is likely to take place due to the strong involvement of an academic institution. In addition, findings from the Exemption process and technical work are to be shared via publications. A technical workshop is also planned for early 2019. (HyDeploy, 2018)

Have a public profile and identity:
Has a website and news page, along with contact details. Public Annual Gas Safe check offering. Customer engagement plan, dedicated customer liaison officer who developed a public profile and identity on the site. Project presented at COP24. Public press statements were released on the granting of the Exemption.

© kamisoka/Getty Images

HyDeploy seeks to show that mixing up to 20% of the amount of hydrogen with natural gas is a secure and environmentally friendly substitute to the gas we are currently utilising

HyDeploy

	Diverges Strongly	Diverges Slightly	Contributes Slightly	Contributes Strongly
Broad partnerships			●	
Aim to influence policy				●
Stimulate new companies			●	
Diverse means of funding		●		
Promote collaboration alongside competition		●		
Foster skills development				●
Have a public profile and identity				●

HyNET (HyNet, 2019)

HyNet is a hydrogen energy and Carbon Capture, Usage and Storage (CCUS) project. HyNet's objective is to reduce carbon emission levels from industry, homes and transport and foster economic growth in North West England (HyNet, 2019). It will explore two parts of the UK commonly known as the estuaries of Mersey and Humber. The project aims to investigate the possibility of blending around 20% hydrogen into the natural gas supplied locally. The study considers the conversion of large industries in the area as well as the possibility of increasing the blended amount of hydrogen (IET, 2019).

Merseyside was recognized as possessing stronger initial opportunities because there was a strong degree of industrial engagement, the businesses were less geographically dispersed (Figure 7). Furthermore, the diminishing output from the oil and gas fields of Liverpool Bay provided the opportunity to store the CO_2 produced by the hydrogen production from autothermal reforming of natural gas in a timely fashion. A significant advantage of the area was the degree of industrial demand, which ensures that the high fluctuations in the space heat demand can be balanced by line back in the blended hydrogen network. It eliminates the onerous construction of salt caverns that would otherwise be required. The availability of a hydrogen source in the region expands opportunities to include transportation and power generation over and above what was considered in the original design (IET, 2019).

Broad partnerships:
Involvement of cross sector industry (from chemicals, glass and oil refining to food, paper and automotive), consultancy, university, Local Enterprise Partnerships (LEPs) and government bodies (HyNet, 2019).

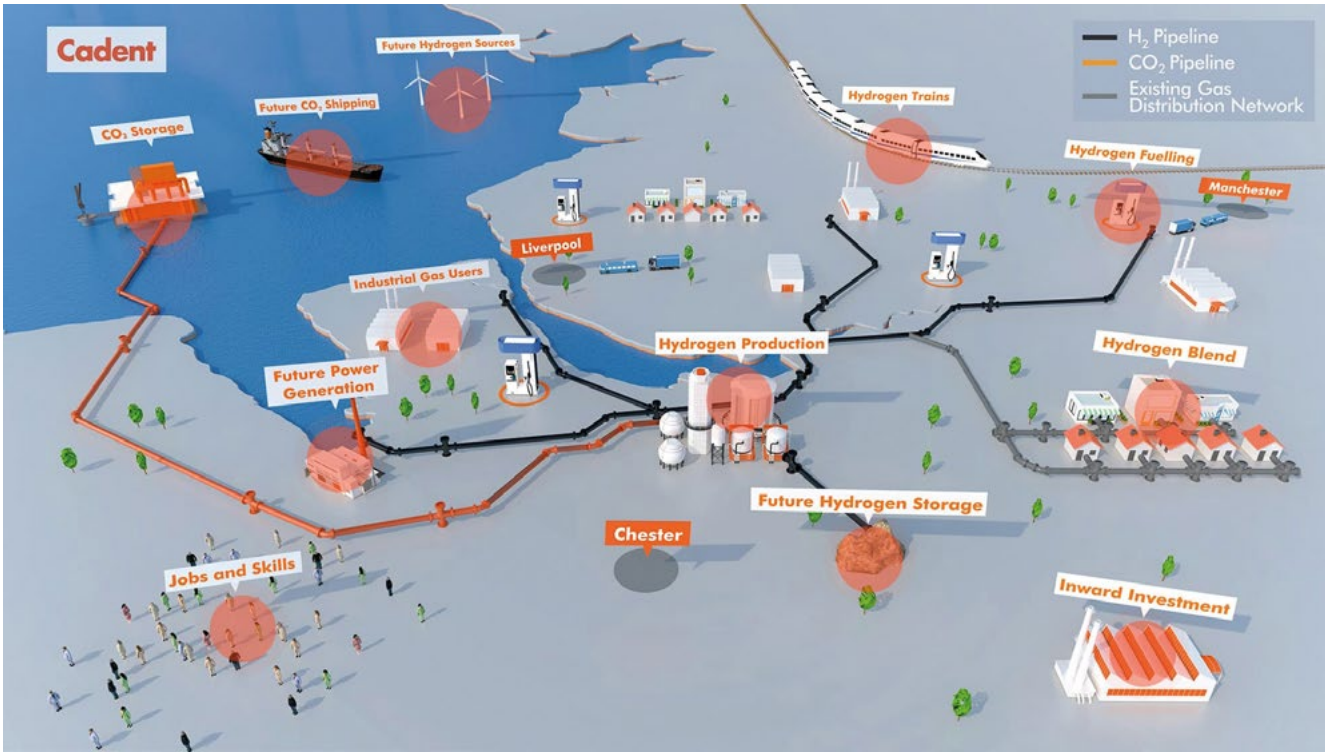


Figure 7: The HyNet NW Project vision

Aim to influence policy:
A clear statement is made on the HyNet website: "Technical, cost and practical evidence to inform government heat and carbon capture policy" (HyNet, 2019). Dedicated CCUS Advisory Group business models were developed to form the basis for Government's consultation. This shows active consultation with Government to seek a funding and socialisation mechanism to support the development of hydrogen as part of the next Price Control period. Funds are from government (Network Innovation Allowance).

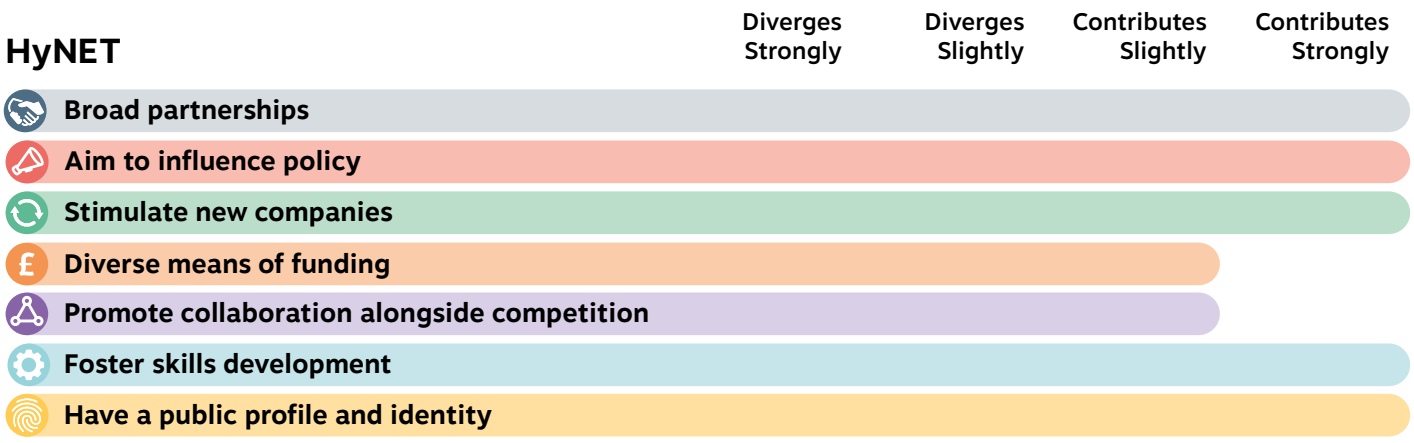
Stimulate new companies:
Involvement of the Local Enterprise Partnership (LEP) Network in the project is an essential driving force to drive local growth of companies (LEP Network, 2019).

Diverse means of funding:
The current work undertaken is funded under several Network Innovation Allowances from the government regulator the Ofgem (IET, 2019). The funding model proposed for the demonstration phase is reliant on Government funding and socialisation across the wider Great Britain (GB) gas customer base. (Cadent gas, 2018)

Promote collaboration alongside competition:
New business models and policy framework are being developed to ensure competition whilst promoting collaboration in innovation.

Foster skills development:
The focus and philosophy of the project is focussed on using existing technologies, rather than relying on unproven ones. This is likely to lead to limited skill development in low TRL technologies, but will provide significant experience in network scale integration of current technologies and the associated scale-ups. The project philosophy states that: "the skilled local supply chain, which is ready to service the HyNet Project and to sell the resulting expertise and intellectual property (IP) on a global basis." (Cadent gas, 2018).

Have a public profile and identity:
It currently seems that no dedicated engagement with the general public and future domestic customers has been undertaken. A website exists which provides a clear sense for the project direction however, and public bodies are active partners in the project.



H21 Programme (H21 Leeds City Gate, H21 NIC, H21 North Of England)(NGN, 2019)

H21 is a series of ground breaking projects in the gas industry, led by Northern Gas Networks, intent on showing that the current British gas network can be repurposed to transport 100% hydrogen to reach the 2050 goal. In 2016, Northern Gas Networks, the gas distributer for the North of England, completed the H21 Leeds City Gate feasibility study (NGN, 2019).

Building on a model of the city of Leeds, it was first proposed that decarbonizing UK gas distribution networks by switching them from natural gas to 100% hydrogen is technically possible and economically viable. Before the promise that the hydrogen gas network can be fully achieved, the vital safety-based data for such a transition, both upstream and downstream of the meter, must be given. Only then can a meaningful government policy decision on heat decarbonisation be made.

In 2017, a Network Innovation Competition bid was successfully submitted to the Ofgem as an initial move towards gathering this vital evidence. This bid led to the H21 NIC project aimed at gathering the safety evidence required for the UK gas network conversion in two phases: Phase 1a and Phase 1b, and subsequently Phase 2.

Focused on the North of England, is the H21 North of England project, a technical study outlining a conceptual design to convert the North of England gas networks to hydrogen between 2028 and 2035. This work also underpins the safety case for heat decarbonisation through the use of hydrogen. (NGN, 2019)

Broad partnerships:
An extensive partnership between organisations, including various industry sector representatives, governmental organisations, consultancies and expert laboratories, and academic partners.

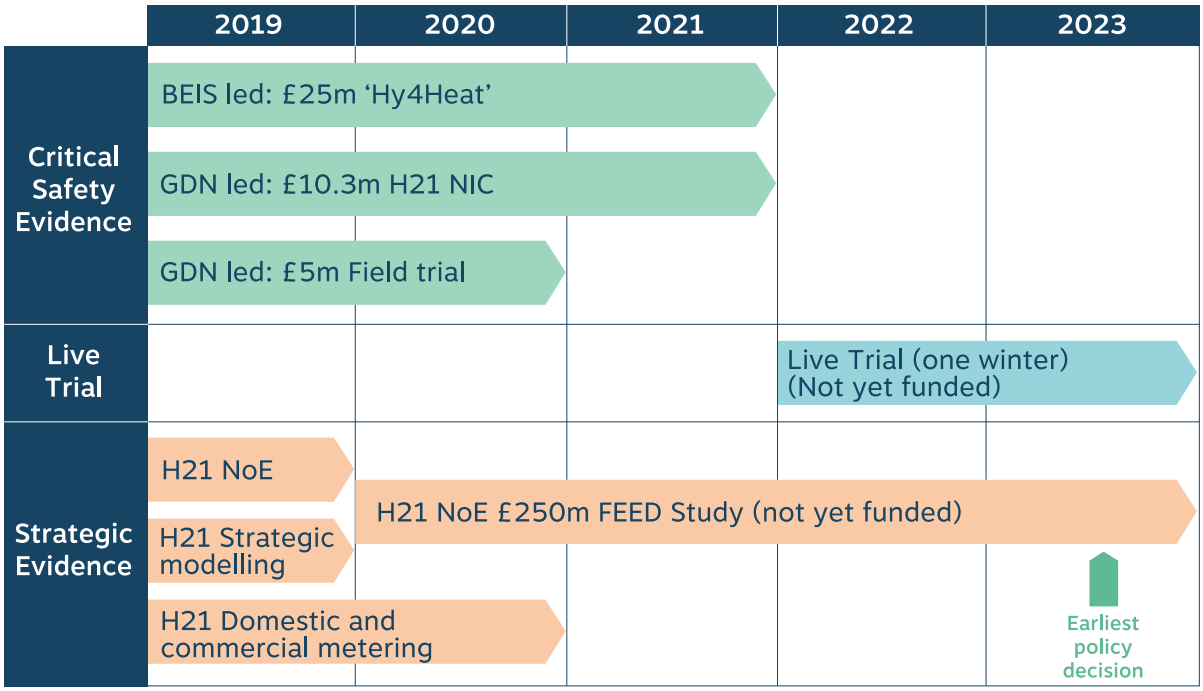


Figure 8: H21 Programme and related projects timeline

Aim to influence policy:
The project contains a strong strand aiming to inform and influence policy (NGN, Equinor, & Cadent gas, 2018). H21 NIC projects are aimed to evidence hydrogen as an alternative as safe as current natural gas. A 'H21 Roadmap' can help achieve the necessary policy decision required for the development of hydrogen in the UK. The H21 projects aim to provide the 'critical' and 'strategic' evidence base required to allow the UK government to make a first credible policy decision regarding a hydrogen transition around the year 2023 at the earliest.

Stimulate new companies:
H21 North of England clearly considers a wide mix of companies for its electrolyser technology. For example, well-established electrolyser manufacturers, new entrants in that market, and small companies with competitive technologies.

Diverse means of funding:
The Ofgem Network Innovation Competition funding along with £1 Million from UK networks to carry out the H21 NIC project aimed at quantifying safety evidence of 100% hydrogen networks. Further Network Innovation Allowance funding has also been secured as part of the H21 programme (NGN, WWU, Kiwa, & Amec Foster Wheeler, 2016). H21 North of England is based on a 50/50 funding mechanism between industry and the government.

Promote collaboration alongside competition:
The range of project partners involved, in particular the UK GDNs, shows that competing companies are working together to innovate and develop the evidence base to support their joint business transition from natural gas to hydrogen. With the core of the funding coming from the Ofgem it also ensures that competition is upheld via tendering for example.

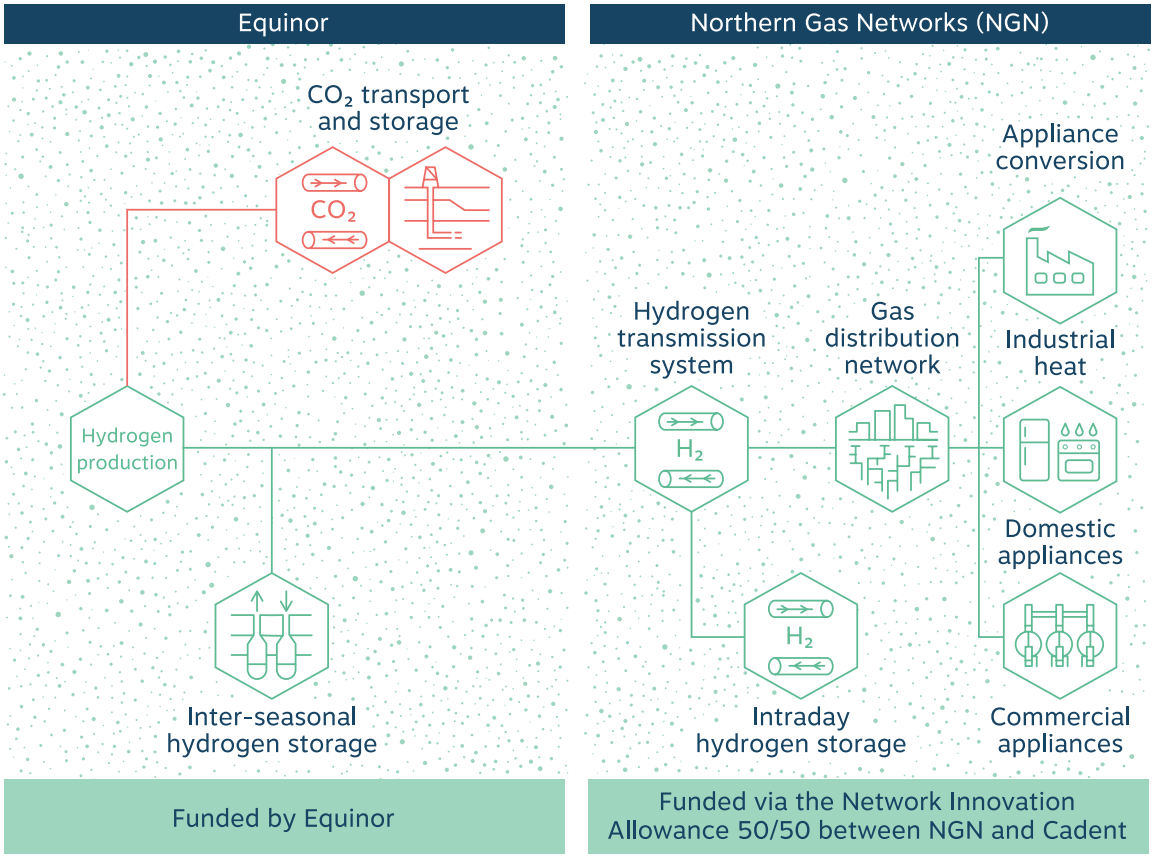


Figure 9: Funding arrangements between NGN and Equinor

Foster skills development:
The core aim of these projects is to develop the required skill base for the hydrogen transition. Technical skills are being developed through experimental programmes. Skills in developing commercially innovative business plans and policy plans are also being stimulated by such a large project.

Have a public profile and identity:
A project website is available.

The Humber Bridge near Hull, East Riding of Yorkshire

Table 3: Summary of the H21 Projects' funding and partnerships

Project	Start Year	Funding (Fund)	Funding (M£)	Partners
H21 Leeds City Gate	2016	Network Innovation Allowance	£0.266	Wales & West Utilities, Kiwa Gastec, Amec Foster Wheeler
H21 Keighley and Spadeadam	2017	Network Innovation Allowance	£0.357	NGN, HSL
H21 NIC – Phase 1	2018	Network Innovation Competition	£10.3	All UK GDNS, DNV-GL, HSE Laboratories
H21 Social Science Research	2018	H21 NIC	Not Found	Leeds Beckett University
H21 North of England	2018	Network Innovation Allowance / Equinor	Not Found	Equinor, Cadent
H21 Phase 2/ H21 Field Trials	2018	Network Innovation Allowance	£0.778	All UK GDNs
H21 Domestic and Commercial Metering	2017	Network Innovation Allowance	£0.360	NGN, Cadent
H21 Strategic Modelling – Major Urban Centres	2017	Network Innovation Allowance	£0.440	NGN, Cadent, SGN, WWU

Conclusion

The two main climate innovation clusters in the UK which contain a strong emphasis on hydrogen for heating are located in Yorkshire and Humberside and the North West of England.

The H21 programme is strongly focussed on delivering a hydrogen transition to industrial and domestic heat demand. However, the project programme appears to lack a proper framework to channel new skills and knowledge. Skills appear to remain within the H21 project partners, whilst knowledge is shared mainly via comprehensive final reports. One way to inject developed skills would be to strongly integrate the learning within academic institutions locally. This would ensure a qualified workforce is trained throughout the duration of the H21 programme.

The North West of England appears to have a formal Hydrogen network in place called the North West Hydrogen Alliance. This approach is likely to be hugely beneficial in ensuring a formal platform exists to allow knowledge exchange and cooperation across sectors and projects in the area. This is likely to strongly benefit the HyNet and HyDeploy initiative.

No heatmap is provided for the clusters discussed in this section since only the leading projects have been reviewed and as such a heatmap of the clusters might not be representative of all the hydrogen project initiatives in the clusters. We only investigated the key flagship projects in England, as such the North West of England cluster heat map would only incorporate the metrics from HyNet and HyDeploy. Similarly the Yorkshire and the Humber cluster would be limited to the H21 programme.

Review of Standalone Projects

Introduction

In addition to the clustering of innovative projects which is occurring across the UK it is also apparent that some projects aim to develop a more generic approach which is not cluster specific.

This section presents two projects addressing two very different aspects of hydrogen technologies. They each support innovation and development of clusters by the learning they provide and the partnerships they involve whilst not being geographically tied to a specific cluster.

In that respect it is not surprising that one of these two projects is led by an academic institution which aims to deliver UK wide benefits through developing a more fundamental understanding of hydrogen storage.

Hy4Heat (Hy4Heat, 2019)

Planned for spring 2021, Hy4Heat may comprise commercial and industrial appliances (including certification), hydrogen gas meters, domestic demonstrations and expanding HyDeploy's safety assessments. The investigations conducted under Hy4Heat will contribute to the decisions on whether to advance to a community trial involving hydrogen (IET, 2019). Contractors are appointed to deliver a number of work packages aimed at developing the technical feasibility, safety and convenience, of converting the existing low-pressure gas network to 100% hydrogen.

Broad partnerships:
In Hy4Heat the role of BEIS is predominant. For this project the government forms an integral part of the project team. The rest of the team is formed of technical and industry specialists. Academic institutions are also involved in delivering various work packages of the project. This is a very broad partnership.

Aim to influence policy:
The aim to influence policy is clearly stated on the Hy4Heat website: "Our mission is to establish if it is technically possible, safe and convenient to replace natural gas (methane) with hydrogen in residential and commercial buildings and gas appliances. This will enable the government to determine whether to proceed to community trial."

Stimulate new companies:
No specific parts of the programme have been identified as being targeted at stimulating new companies.

Diverse means of funding:
The project is funded by BEIS.

Promote collaboration alongside competition:
The Hy4Heat findings will be critical to progressing large scale demonstrator projects and industrial cluster projects such as HyDeploy2 and H21. Some of the aims of Hy4Heat, such as developing a hydrogen quality standard or appliance certification are achieved via collaboration whilst being key in establishing a benchmark against which competition can develop.

Foster skills development:
The work packages aimed at delivering domestic and industrial hydrogen appliances foster significant skills development in design, testing, retrofitting and conversion, as well as safety evaluation.

Have a public profile and identity:
Hy4Heat has a dedicated website presenting the project in simple terms, along with news and updates. Work packages 8 and 9 are focused on the community trial preparation. A showroom to demonstrate the appliances to the public is proposed and engagement with local authorities is being undertaken.

HyStorPor (UKRI, 2019)

HyStorPor is a research project into the feasibility of using porous rocks to store hydrogen in large quantities between summer and winter. This kind of storage would contribute to the energy security of the UK, by ensuring higher energy demand in the winter can be met without having to over-build power plants or wind farms, or import energy.

The storage type that HyStorPor proposes to investigate is currently poorly understood. This project will include, experiments, modelling and stakeholder engagement, to evaluate the technical and social feasibility of storing vast quantities of hydrogen in the subsurface. This technology is likely to synergise well with a cluster approach where hydrogen can be produced in bulk and easily transported to the storage site.

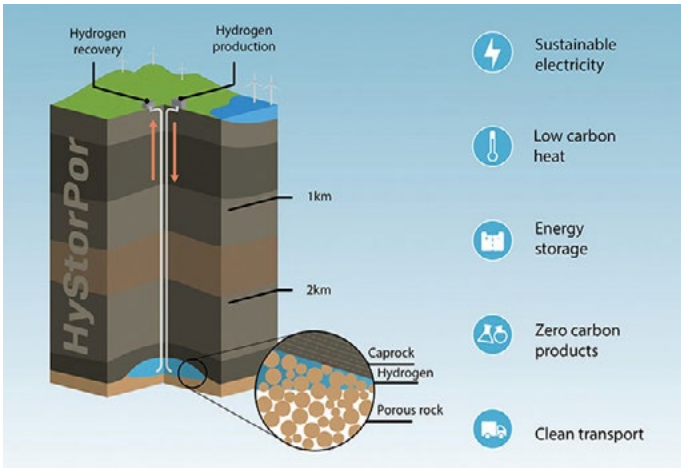


Figure 10: HyStorPor hydrogen storage in deep underground porous rocks

Infographic created for the HyStorPor project (https://blogs.ed.ac.uk/hystorpor). © 2019 The University of Edinburgh

Broad partnerships:
The project is led by the University of Edinburgh in partnership with Pale Blue Dot, the Scottish Hydrogen & Fuel Cell Association (SHFCA) and SGN. This is a partnership which involves industry and academia. No project member from the government or civil associations is part of the project team.

Aim to influence policy:
The project does not aim to directly influence policy. The focus is primarily on investigating technical feasibility and social perception.

Stimulate new companies:
The project will not lead to new companies. The learning however could increase the TRL of hydrogen storage in porous rock and move the technology closer to commercialisation and demonstration projects.

Diverse means of funding:
The funding was awarded by the Engineering and Physical Sciences Research Council of the UK.

Promote collaboration alongside competition:
The academic nature of the project places an emphasis on collaboration and shared learning rather than competition.

Foster skills development:
As the project is led by a university, the findings will be made public through publications and integrated to student projects and teaching material.

Have a public profile and identity:
An entire workstream will engage civil society with the research. A strong effort will be done to understand the public perception and use that understanding to improve communication with the public on the topic of hydrogen storage.

Conclusion

The key findings of this report on the integration of hydrogen technologies in innovation climate clusters are summarised here:

01 The Orkney cluster is the only UK hydrogen cluster which can be argued to be past its initiation phase and into its growth phase.

02 Hydrogen is being strongly considered as part of a decarbonisation option well suited to promote and contribute to the development of innovation climate clusters in the UK.

03 Funding routes are starting to expand but have historically been mostly limited to Government funding (UK, devolved and local) and EU funding. Future cost socialisation mechanisms are being proposed and discussed as part of future price controls.

04 Currently most clusters are in the initiation stage and there is a lot of learning needed with respect to hydrogen. As such the current emphasis is on collaboration to share knowledge and lessons learned.

05 The development of new companies seems not to be applicable to the initiation phase of innovation cluster development. One way a future project can contribute to stimulating companies and growth is by dedicating workstreams to identify and articulate market growth strategies in a specific cluster. It can do so by identifying the gaps in the supply chain where indigenous companies could have been beneficial.

06 The scale of the actors and the opportunities which arise from their commitment to the cluster is key. If the opportunities are not large enough, setting up new companies will not be deemed worthwhile for a single project or a small opportunity.

07 A key weakness of the ongoing cluster initiation strategy from the point of view of hydrogen is that no definite skill development pipeline exists in the current clusters. Most experience and knowledge trickles down within companies or organisations. In the current framework where large actors are involved in multiple projects in different clusters the consequence is limited. However, it might create an additional barrier to new entrants at the 'growth' stage of the cluster. It could also result in a shortage in skilled workforce as the cluster grows.

08 Another consequence of the lack of skill development pipeline is the reliance on current knowledge holders. This is not always sustainable, since some knowledge holders might leave the sector or geographic location due to a lack of continuous demand for their skills (i.e. limited number of projects).

09 There is usually a genuine effort for projects to develop a positive and active public profile and identity. Although this might be project specific, especially when a secondary project is designed to inform another project that already has a well-established public profile. There is also a time dimension in the development of a public profile of a project or endeavour. Communication with the public can, in some instances, be planned in the project early on but actually be delivered during the lifespan of the project rather than at its inception. This approach has been criticised, but it allows project teams to communicate when more certainty is available.

10 The role of demand is key in the establishment of robust climate innovation cluster. This is why large industry actors signalling a willingness to shift to hydrogen is crucial to stimulate projects and the cluster as a whole.

11 The view of regional development by industry, local government, and grassroots organisations can be very diverse. It can sometimes be conflicting and sometimes synergising. This is why a broad partnership is key in developing hydrogen as part of a climate innovation cluster.

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