Department for Energy Security & Net Zero

Evaluation of the Industrial Fuel Switching and Hydrogen Supply Innovation Programmes

Impact evaluation report

June 2025

Acknowledgements

This independent report was produced for the Department for Energy Security and Net Zero by CAG Consultants, supported by Winning Moves.

We are grateful to all participants who agreed to be interviewed in research for this report.

Glossary

Term / acronym	Description
BEIS	Department of Business, Energy and Industrial Strategy
Biomass	Defined by the UK Government as “any material of biological origin (including biodegradable fraction of products, wastes and residues from biological origin).[1]
‘Blue’ hydrogen	‘Blue’ hydrogen is derived from natural gas, generally through a process of steam methane reforming. This can be low carbon hydrogen provided that CO2 emissions can be captured by Carbon Capture, Usage and Storage (CCUS)
CCUS	Carbon Capture, Usage and Storage
CHP	Combined Heat and Power
Cluster Sequencing process	The UK Government’s process for deploying CCUS in two industrial clusters by the mid-2020s, and a further two clusters by 2030.
COP26	The 2021 United Nations climate change conference
COVID	The COVID-19 pandemic
DESNZ	The Department for Energy Security and Net Zero
EIP	Energy Innovation Programme – part of SICE (see below)
EQ	Evaluation question

[1] BEIS, *Biomass policy statement*, November 2021. Available at: https://assets.publishing.service.gov.uk/media/6183a2f4d3bf7f55fd843da1/biomass-policy-statement.pdf [Accessed 7 December 2023]

FEED	Front End Engineering Design – detailed engineering study which comes after a conceptual design or feasibility study. It focuses the technical requirements as well as rough investment cost for a project.
Fuel Switching	Switching from fossil fuels to lower carbon fuel sources including biomass, electricity or hydrogen
Green Distilleries programme	An innovation programme focused on fuel switching for distilleries
‘Green’ hydrogen	‘Green’ hydrogen is generated from water by electrolysis or by gasifying biomass.
HS	Low Carbon Hydrogen Supply programme
HS2	Low Carbon Hydrogen Supply 2 Programme – successor programme to HS
ICCUS Board	Industrial and Carbon Capture, Utilisation and Storage Board – now known as the Hydrogen Industry Carbon Capture, Utilisation and Storage (HICCUS) board
IETF	Industrial Energy Transformation Fund
IFS	Industrial Fuel Switching programme
IFS2	Industrial Fuel Switching 2 programme – successor programme to IFS
IHA	Industrial Hydrogen Accelerator
Johnson Matthey process	A specific industrial process which involves a type of steam reforming to produce ‘blue’ hydrogen
Low carbon hydrogen	Low carbon hydrogen includes both ‘blue’ and ‘green’ hydrogen (see above)

KPI	Key performance indicators
KTN	Knowledge Transfer Network
Lots	The funding allocations for Phase 1 the Hydrogen Supply competition was split into four 'lots'. These were separate funding pots for different types of hydrogen supply technologies: Low Carbon Hydrogen (Lot 1), "Zero" Carbon Hydrogen (Lot 2), Hydrogen Imports (Lot 3) and Hydrogen Storage (Lot 4).
MW	Mega Watt
NDA	Non-Disclosure Agreement
NZHF	Net Zero Hydrogen Fund
NZIP	Net Zero Innovation Portfolio
PEM electrolysers	Polymer electrolyte membrane electrolysers
Pre-FEED study	A technical study that was preparatory to a full FEED study
SBRI	Small Business Research Initiative
SICE	Science and Innovation for Climate and Energy - a directorate within DESNZ
TRL	Technology Readiness Level
UKRI	United Kingdom Research Institute
'Zero' Carbon Hydrogen	Synonymous with 'Green' hydrogen

Contents

Executive Summary

The Department for Energy Security and Net Zero (referenced as 'the Department' in this report)[2] commissioned CAG Consultants, Winning Moves and Verco to undertake the evaluation of both the Industrial Fuel Switching (IFS) and Low Carbon Hydrogen Supply (HS) innovation programmes.

This report presents findings from the impact evaluation of the programmes. Another report focusing on the processes of the two programmes has been published alongside this report.

About the programmes

Both the IFS and the HS programmes formed part of the government's Energy Innovation Programme (EIP). The schemes were run by the Department, offering 100% funding for projects in the form of pre-commercial procurement funding through the Small Business Research Initiative (SBRI).

Industrial Fuel Switching programme

The £21 million IFS competition aimed to stimulate early investment in and development of fuel switching processes and technologies, so that a range of technologies are available by 2030 and beyond. The competition was split into three phases: a market engagement study during 2018 (Phase 1, £200k); feasibility studies during 2019 (Phase 2, £2 million); and four demonstration studies during 2020-22 (Phase 3, £18.4 million). The Phase 3 projects demonstrated the use of hydrogen, biomass and electrical heating across a range of industry sectors.

Low Carbon Hydrogen Supply programme

The £33 million Low Carbon Hydrogen Supply programme sought to develop, demonstrate and reduce the cost of low carbon bulk hydrogen solutions (production, storage and supply), and was aimed at innovations involving pre-commercial technologies with a medium level of maturity. Phase 1 of the HS programme funded 13 feasibility studies during 2019 across four lots (Low Carbon hydrogen, 'Zero' Carbon hydrogen, hydrogen imports and hydrogen storage). Phase 2 funded five demonstration projects from 2020-2022, including three 'zero' carbon and two 'low carbon' hydrogen technologies.

The UK Government is now running successor versions of both programmes. This evaluation focused only on the first iterations of each.

[2] Note that at that the Department for Business, Energy and Industrial Strategy (BEIS) commissioned this evaluation. DESNZ took over management of the evaluation after a departmental restructure in February 2023.

Findings

The findings are structured around main areas that the programmes were expected to have a short-term impact, as identified in the evaluation's theory of change.

Impact on industry awareness, engagement, and confidence

Both programmes demonstrated evidence of boosting industry awareness, engagement and confidence, even if in the IFS programme's case, this impact was restricted primarily to a small number of sectors.

The **IFS programme**:

- raised awareness in sectors like glass, cement, and lime through collaborations and demonstrations
- demonstrated fuel switching at different scales, reducing perceived risks while highlighting remaining challenges to deployment, such as affordable hydrogen supply

However some stakeholders remained unaware of the programme, and for other sectors not directly involved in the programme, its influence was less significant than other initiatives. The programme's impact on investor confidence was more mixed, with evidence suggesting that larger demonstrations and a clearer government direction might boost investor confidence further.

The **HS programme**:

- significantly impacted the hydrogen industry in the UK - it fostered hydrogen supply awareness, influenced media, and supported various production technologies
- focused on advancing hydrogen supply projects through research, trials, and testing, establishing a project pipeline and boosting industry confidence - it enhanced understanding of hydrogen production in supply chains, identified cost-saving opportunities, and highlighted economic viability as a key challenge over technical feasibility

However some stakeholders were sceptical about future progress due to a lack of clarity on investments in hydrogen plants.

Impact on UK investment and activity

Government backing for both IFS and HS instilled business confidence in exploring hydrogen production and fuel switching primarily by demonstrating governmental dedication to these domains.

The **IFS programme:**

- showcased the practical utilisation of hydrogen and biofuels in industrial environments
- facilitated the establishment of testing infrastructures

- bolstered proficiency in the fuel-switching supply chain, igniting innovation even outside the IFS programme, for example through enabling firms involved in the programme to expand their expertise in using hydrogen on industrial sites, ranging from the design and manufacture of hydrogen burners to engineering and consulting expertise on hydrogen combustion, transport and storage
- spurred more innovation in other government-funded projects
- started influencing the private sector's investment, for example the programme played a significant role in influencing and building confidence for Encirc's proposed £100 million investment in a multi-fuel glass furnace in the Northwest

However, the influence of the programme on innovation and investment was limited by two factors. Firstly by the small number and scale of project; in this respect, the programme was not designed to have large-scale influence. Secondly, external factors such as inadequate electricity grid connections, lack of hydrogen infrastructure, fuel price volatility, supply chain expertise deficits, and long investment timescales in industrial sites were also cited as barriers to progress in innovation and investment in industrial fuel switching.

The HS programme:

- stimulated private-sector funding in additional technology studies and subsequent stages of hydrogen-related projects
- de-risked follow-on innovation investments, and
- played a crucial role in partnership-building and credibility development

Despite evidence of the programme influencing innovation investment, interview evidence suggested investors remained hesitant to invest in hydrogen technology deployment. This hesitancy is attributed to several factors: the need for ongoing government support, challenges such as commercial and technical issues, water access, supply chain limitations, and insufficient Carbon Capture, Utilization, and Storage (CCUS) infrastructure.

Impact on UK programmes and policy debate

The IFS and HS programmes played a pivotal role in shaping their successor programmes.

The **IFS programme**:

- played a pivotal role in influencing several broader governmental strategies, programmes, and initiatives
- directly informed the Industrial Decarbonisation Strategy[3]
- played a significant role in shaping many aspects of the Industrial Energy Transformation Fund, and
- was instrumental in the establishment of the Industrial Hydrogen Accelerator

[3] HM Government (2021), Industrial Decarbonisation Strategy, March 2021. Available at: https://www.gov.uk/government/publications/industrial-decarbonisation-strategy [Accessed 31 May 2024]

The **HS programme**:

- helped shape governmental policies, including the Low Carbon Hydrogen Standard and the Hydrogen Business Model
- highlighted regulatory considerations tied to hydrogen production, transportation, and usage

However, the sharing of knowledge and learning from the programmes' design and implementation was not as systematic as some staff within the Department felt it could have been; this potentially limited the extent to which the IFS and HS programmes informed programmes and policies.

International impact

Both IFS and HS boosted the UK's global reputation in hydrogen and fuel switching. The programmes fostered global awareness, serving as inspirations for other countries.

However, although IFS and HS helped to position the UK as an early leader in this domain, industry insiders pointed out that there has subsequently been significant investments in this field in the US and EU.

Evidence of IFS and HS programme contribution to outcomes

Table 1 Summary of evidence of IFS programme contribution to outcomes identified in programme theory

Outcomes identified in IFS programme theory Strength of evidence (* - ***)	Summary of evidence of IFS programme contribution towards outcome
Outcome 8. Evidence and learning about feasibility of IFS is generated, validated and widely shared ***	Considerable evidence, from interviews and media monitoring, of dissemination by IFS projects including reports, webinars, advice services, site visits, videos, conference presentations, social media and so on. Dissemination by Glass Futures and HyNet raised awareness and stimulated activity in sectors not included in IFS (e.g. ceramics, metals, food).
Outcome 9. Raised awareness, confidence, reduced perception of risk and increased appetite within industry, investors, and Government around fuel switching	Evidence of raised awareness in the glass, cement, and lime sectors about fuel switching through collaborations and demonstrations, though some stakeholders remained unaware and its impact varied across sectors. Programme reduced perceived risks associated with deployment, challenges like affordable hydrogen supply

Outcomes identified in IFS programme theory Strength of evidence (* - ***)	Summary of evidence of IFS programme contribution towards outcome
***	persist, but its influence on investor confidence was mixed.
Outcome 10. Further innovation / deployment programmes supported by Government/ private sector ***	Government support for IFS increased business confidence in fuel switching by showcasing its commitment, evidenced through the practical use of hydrogen, development of testing infrastructures, and fostering innovation within and beyond the programme.
Outcome 11. Development of IFS and related policy and programmes ***	Clear evidence of IFS programme influencing a wide range of government strategies, programmes, and initiatives, including the Industrial Decarbonisation Strategy, the IETF, and the establishment of the IHA. It significantly shaped the IFS successor programme, demonstrating its pivotal role in policy and strategy development.
Outcome 12. Widespread uptake of IFS *	Too early to see widespread take-up of industrial fuel switching on a significant scale. Constrained by poor economics of switching to hydrogen or electricity and by the lack of infrastructure for hydrogen supply, transport and storage. Some stakeholders reported that biomass use was closer to being economic for some industries. One example of uptake: proposed £100 million investment by Encirc/Diageo in a new multi-fuel (potentially hydrogen-fired) glass furnace, partly catalysed by Encirc's involvement in IFS programme amongst other factors.
Outcome 13. IFS supply chain development, including skills and finance **	Evidence of IFS contributing to supply chain development, primarily through up-skilling project partners and increasing capacity in 'catalyst' organisations (e.g. Progressive Energy, Glass Futures), together with direct and indirect contribution to additional testing facilities.

Outcomes identified in IFS programme theory Strength of evidence (* - ***)	Summary of evidence of IFS programme contribution towards outcome
Outcome 14. Decarbonisation of industry *	Too early to see evidence of the decarbonisation of industry on a significant scale.
Outcome 15. Jobs, growth, business growth, competitiveness and export potential **	Evidence of small-scale job creation and business growth, including export potential, from interviews with project leads/ partners and wider stakeholders.

Table 2 Summary of evidence of HS programme contribution to outcomes identified in programme theory

Outcomes identified in HS programme theory Strength of evidence (* - ***)	Summary of evidence of HS programme contribution towards outcome
Outcome 6. Evidence and learning about feasibility of IFS is generated, validated and widely shared ***	Considerable evidence, from interviews and media monitoring, of dissemination by HS projects, particularly Gigastack and Acorn Hydrogen. Dissemination included site visits, conference presentation, public reports and updates. Some commercial constraints on sharing in-depth cost data but more detailed cost, performance and risk information was shared potential investors (e.g. by Dolphyn and HyNet HPP1).
Outcome 7. Raised awareness, confidence, reduced perception of risk and increased appetite within industry, investors, and Government around hydrogen supply	Evidence that the HS programme significantly enhanced the UK hydrogen industry's awareness, engagement, and confidence by fostering hydrogen supply awareness, influencing media, supporting production technologies, and advancing hydrogen supply projects through research, trials, and testing.

Outcomes identified in HS programme theory **Strength of evidence (* - ***)**	**Summary of evidence of HS programme contribution towards outcome**
***	
Outcome 8. Further innovation / deployment programmes supported by Government/ private sector ***	Government support for the HS programme boosted business confidence in hydrogen production by showcasing commitment, stimulating private investment, and fostering partnerships.
Outcome 9. Development of HS and related policy and programmes ***	The HS programme significantly shaped its successor programme, and influenced government policy through the Low Carbon Hydrogen Standard and the Hydrogen Business Model, and through bringing attention to regulatory aspects of hydrogen production, transportation, and usage.
Outcome 10. Widespread supply and demand for hydrogen across multiple sectors *	Too early to see widespread supply and demand for hydrogen across multiple sectors. Some signs of potential within Track 1 clusters, subject to government support for hydrogen infrastructure (supply, storage and transport) and support for operational costs via the proposed Hydrogen Business Model.
Outcome 11. HS supply chain development, including finance **	Evidence of HS contributing to supply chain development, primarily through upskilling project partners, engaging with potential investors and supply chain companies, and increasing the capacity of 'catalyst' organisations (e.g. Progressive Energy, Storegga).
Outcome 12. Decarbonisation of industry, transport, heating & other sectors at least cost *	Too early to see evidence of decarbonisation of multiple sectors based on widespread supply and demand for hydrogen.

Outcomes identified in HS programme theory Strength of evidence (* - ***)	Summary of evidence of HS programme contribution towards outcome
Outcome 13. Jobs, growth, business growth, competitiveness and export potential **	Evidence of small-scale job creation and business growth, including export potential, from interviews with project leads, project partners. and wider stakeholders. Considerable scope for growth if hydrogen economy takes off (e.g. in Track 1 cluster areas), subject to government support.

Lessons for future programmes

Key lessons for future programmes were as follows:

- despite the Government's commitment to Net Zero, there is still a need for stronger signals about the long-term direction of travel of Government policy, to support potential investor decisions about major investments in industrial fuel switching and hydrogen supply
- resolving remaining regulatory issues for hydrogen (e.g. regulation of offshore hydrogen pipelines, decisions about hydrogen use in the gas NTS) is likely to be critical to the success of future innovation and deployment projects for hydrogen supply
- wider deployment of hydrogen supply and industrial fuel switching is likely to be dependent on Government support for infrastructure development in relation to both hydrogen and CCUS, with CCUS being important both for process emissions from the cement and lime industry and for 'blue' hydrogen production processes
- hydrogen transport and storage infrastructure should be considered as potential priorities for future innovation support – consideration could be given to hydrogen access for industries outside the Track-1 and Track 2 cluster areas
- when new technology areas arise, policy makers should consider early innovation programmes - the early timing of IFS and HS showed that early support led to practical learning by policy-makers and industry at an early stage, contributing to the UK's international competitive position in this area
- more systematic knowledge sharing mechanisms should be developed for future innovation programmes, both with industry and within Government
- innovation programmes should be managed in a flexible way that takes into account the inevitable uncertainties in implementation

- when assessing applications for major demonstration projects within innovation programmes, applicants’ project management capabilities should be assessed, as well as their technical capabilities
- innovation programmes should consider how to encourage and support the development of ‘catalyst’ organisations whose business model involves making advice and knowledge available to other businesses, as the catalyst organisations can help to spark subsequent activity
- future innovation programmes should require projects to produce a consistent – and ‘analysable’ – set of data on key outputs (e.g. providing updated calculations/models for the levelised cost of electricity / hydrogen) in order to support future impact evaluations of government programmes
- in designing future innovation and deployment programmes for industrial fuel switching and hydrogen supply development, policy makers should consider the overall policy landscape so that new programmes continue to complement rather than duplicate other policy initiatives (e.g. the Cluster Sequencing programme, IETS, NZHF programmes)

Note that the process evaluation of the two programmes highlighted more detailed lessons about the design and implementation of the programmes. These can be found in the process evaluation report, published alongside this impact evaluation report.

Chapter 1: Introduction

This report presents findings from the second and final wave of fieldwork and analysis from the evaluation of the reformed Industrial Fuel Switching and Low Carbon Hydrogen Supply innovation programmes.

The Department for Energy Security and Net Zero (referenced 'the Department')[4] commissioned CAG Consultants, Winning Moves and Verco to undertake an evaluation of both the Industrial Fuel Switching (IFS) and Low Carbon Hydrogen Supply (HS) innovation programmes under the Department's Energy Innovation Programme (EIP).

This report focuses primarily on 'impact' evaluation findings (i.e. the effects produced by the two programmes, either directly or indirectly). The fieldwork and analysis to inform this report was completed around a year after most of the programmes' projects were completed. As such, the observed effects are primarily the outputs and short to medium-term outcomes from the programmes, rather than their longer-term impacts.

A process evaluation report – *Evaluation of the Industrial Fuel Switching and Hydrogen Supply Innovation programmes: process evaluation report* - has been published alongside this report.

Overview of the programmes

Both the HS and IFS programmes formed part of the Department's Energy Innovation Programme (EIP). The schemes offered 100% funding for projects in the form of pre-commercial procurement funding through the Small Business Research Initiative (SBRI).

Note that the UK Government is now running successor versions of both programmes. This evaluation focused only on the first iterations of each.

Industrial Fuel Switching Programme

Switching industrial processes from carbon-intensive to low carbon fuels was highlighted in the Clean Growth Strategy (2017) as being necessary for industry to reach net zero by 2050. The IFS competition aimed to stimulate early investment in and development of fuel switching processes and technologies, so that a range of technologies are available by 2030 and beyond. The competition was split into three phases:

- Phase 1 (£200,000) a market engagement and assessment study
- Phase 2 (£2 million) feasibility studies
- Phase 3 (£18.4 million) demonstration projects

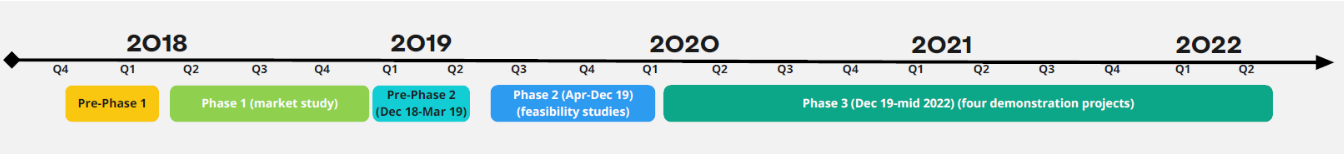
[4] Note that at that the Department for Business, Energy and Industrial Strategy (BEIS) commissioned this evaluation. DESNZ took over management of the evaluation after a departmental restructure in February 2023.

The Department procured Element Energy to carry out the Phase 1 market engagement and assessment study, undertaken in 2018. The aim of this study was to understand the technical and economic potential for industry to switch to low carbon fuels (including electrification, hydrogen and bioenergy/waste) with current and future technologies, and the key barriers to realising this potential. The final report from the market engagement study suggested that 30% of industrial energy demand can be switched to a low carbon fuel, around 45% when also including combined heat and power.

Phase 2 consisted of seven feasibility studies (chosen from 13 applications), conducted in 2019, to assess specific fuel switching technologies to enable the use of a low carbon fuel for a particular industrial process or across an entire site.

Phase 3 commenced in December 2019 and consisted of four demonstration projects (from nine applications), that aimed to implement and test their proposed fuel switching solutions. These projects reached completion during summer 2022, as shown in the timeline below.

Figure 1: Timeline for the IFS programme



The following projects were selected for demonstration funding:

- **HyNet Northwest Industrial fuel switching** - led by Progressive Energy Ltd – practical demonstration and experimental development of direct-firing, boiler, and refinery technologies at NSG Pilkington's Greengate Works (glass manufacturer), Unilever's Port Sunlight plant (personal care, home care, and beauty products), and Essar Oil's Stanlow Refinery (contract value: £5.24 million)
- **State-of-the-art fuel mix for UK cement production to test the path for net zero** - led by the Mineral Products Association – physical trials to switch energy input from fossil fuels to cleaner fuels at two cement manufacturing sites involving hydrogen and biomass (Hanson site) and electrical heating (plasma) with biomass (Tarmac site) (contract value: £3.2 million)
- **Hydrogen alternatives to natural gas for calcium lime manufacturing** - led by British Lime Association (within Mineral Products Association) – demonstration of using up to 50% hydrogen in full-scale calcium lime manufacturing kiln plus prototype system for using hydrogen as an alternative to natural gas in firing lime kilns (contract value: £2.82 million)
- **Alternative fuel switching technologies for the glass sector** - led by Glass Futures Ltd – biodiesel trial on a full-scale commercial line and large lab-scale hydrogen demonstration for the UK glass sector, leading to proposals for decarbonisation of the sector (contract value: £7.12 million)

A key requirement from the demonstration phase was that, once successfully implemented, the fuel switching solution must be demonstrated and disseminated to organisations with similar opportunities for utilising the technology – to help promote further confidence in future deployment. The programme was also expected to support further innovation and deployment programmes and help develop policy in relation to industrial decarbonisation. All projects were completed by summer 2022.

Low Carbon Hydrogen Supply Programme

Low carbon hydrogen could play an important role in decarbonising industry, power, heat and transport. However, for the market to grow, potential users (in any application) need to be confident in the supply of sufficient amounts of low carbon hydrogen at a competitive price.

To this end, the £33 million Low Carbon Hydrogen Supply programme sought to develop, demonstrate and reduce the cost of low carbon bulk hydrogen solutions (production, storage and supply), and was aimed in particular at innovations at a technology readiness level (TRL)[5] of 4 to 7.

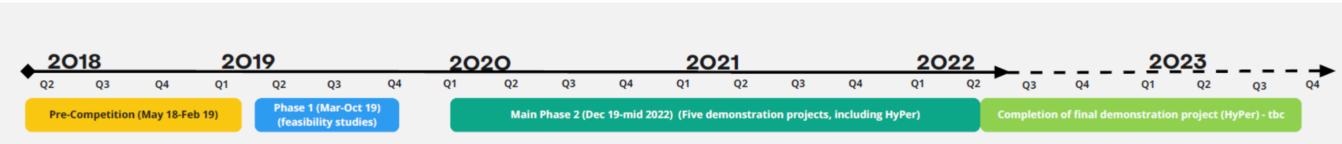
Phase 1 (£1.7 million) funded 13 feasibility studies (from 43 applications) looking into the development of low carbon bulk hydrogen supply solutions across four lots:

- Lot 1 – Low Carbon Hydrogen (6 successful 'blue' hydrogen projects - £2.4m total)
- Lot 2 – "Zero" Carbon Hydrogen (5 successful 'green' hydrogen projects - £2.0m total)
- Lot 3 – Hydrogen Imports (no applications received)
- Lot 4 – Hydrogen Storage (2 successful projects - £0.5m total)

It ran from March to December 2019.

Phase 2 (£28 million) began in December 2019 with most projects completing in mid-2022. It supported projects that aimed to design, implement and demonstrate a technology or process for enabling the bulk supply of hydrogen. It has funded five projects in total (from 12 applications), all of which took part in Phase 1. Four of these projects were complete at the time of writing, with the final project due to be finished in 2023, as shown in Figure 2.

Figure 2: Timeline for the HS programme



The HS programme was anticipated to generate, validate and widely share evidence and learning about the feasibility of low carbon hydrogen supply technologies. The programme was expected to increase industry awareness, appetite and confidence in hydrogen supply technologies and to support the development of further innovation and deployment programmes, as well as the development of policy in relation to low carbon hydrogen supply.

[5] Technology Readiness Levels (TRL) serve as a metric system for evaluating the development stage of a specific technology. Each technology project is measured against the criteria for each readiness level, allowing it to be categorized with a TRL score that reflects its current stage of advancement.

The following projects were selected for Phase 2 demonstration funding:

- **Dolyphn** - led by Environmental Resources Management Limited (ERM) – detailed design of 2 MW prototype system for the production of 'green' hydrogen at scale from offshore floating wind in deep water locations plus pre-Front End Engineering Design (FEED) for 10 MW commercial demonstrator (contract value: £3.12 million)
- **Gigastack** – led by ITM Power Trading Ltd (ITM) – demonstration of the delivery of bulk, low-cost and zero-carbon 'green' hydrogen through ITM Power's gigawatt scale polymer electrolyte membrane (PEM) electrolysers, involving trial of 150kW electrolyser stack, FEED study for 100MW electrolyser system and trialling of systems for large scale production of electrolysers (contract value: £7.5 million)
- **HyNet low carbon hydrogen plant (Hydrogen Production Plant 1 – HPP1)** - led by Progressive Energy Ltd – project development and detailed engineering design (FEED study) for a 'shovel ready' 100,000 Nm3 per hour 'blue' hydrogen production facility for the HyNet Cluster, using Johnson Matthey's low carbon hydrogen technology with carbon capture and storage (contract value: £7.48 million)
- **Bulk Hydrogen Production by Sorbent Enhanced Steam Reforming (HyPer)** - led by Cranfield University – detailed design and build of a 1.5 MW pilot plant for sorption enhanced steam reforming of 'blue' hydrogen, offering potential cost and performance savings compared to existing technologies (contract value: £7.44 million)
- **Acorn Hydrogen Project** - led by Pale Blue Dot Energy (PBDE), now known as 'Storegga' – evaluation and development of an advanced reforming process, comprising a pre-FEED assessment of low carbon hydrogen technologies and FEED-level study of Johnson Matthey's low carbon hydrogen technology advanced reforming package, to deliver energy and cost-efficient process for 'blue' hydrogen production from North Sea Gas with carbon capture and storage (contract value: £2.7 million)

The IFS and HS programmes complemented the Department's Cluster Sequencing process which was designed to support the development of Carbon Capture Usage and Storage (CCUS) infrastructure in areas with a high concentration of energy intensive industry. In October 2021, the HyNet cluster in NW England and the East Coast cluster in NE England were identified as 'Track-1' clusters receiving support for CCUS deployment during the 2020s. At the time of this research, the Acorn cluster in Scotland had 'Reserve' status. Both the Acorn cluster and the Viking cluster in Humberside were being considered as potential 'Track-2' clusters that may receive support for CCUS deployment during the 2030s. A separate evaluation of the CCUS Track-1 cluster sequencing programme has been published by the Department[6].

[6] https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-track-1-cluster-sequencing-evaluation

Chapter 2: Evaluation approach and methodology

This Chapter outlines the approach to this impact evaluation, the evidence sources that this report draws from, and the limitations of the research.

The core aims of the impact evaluation were to establish to what extent and how[7] the programmes (and their component funded projects) produced the impacts and outcomes intended in business cases and applications. These included wider goals such as improving understanding & reducing uncertainty / risk amongst stakeholders, stimulating further investment, innovation and deployment, and contributing to future/wider impacts.

Further detail on the approach and the methods used is set out in the appendices.

Evidence sources

The impact evaluation drew upon a combination of:

- **in-depth and semi-structured interviews** with key stakeholders across both HS and IFS, including representatives of demonstration and feasibility leads, representatives of the programme team, unsuccessful applicants, and the wider supply chain and industries linked to the programmes. Interviewing comprised 67 interviews in Wave 1 (conducted in 2022) and 122 interviews in Wave 2 (conducted in 2023). Interviews explored a wide range of questions (relevant to the respondent group) around programme processes and influence, project delivery experiences, and project outputs and outcomes
- **a review of secondary data from overarching programme and project documentation**, including SICE KPI returns, project closure and feasibility reports, programme business cases and documentation on management / governance, techno-economic data on the levelised cost of electricity / hydrogen (LCOE/LCOH), and published policy statements. Collectively these sources provided evidence on achievement of intended outcomes, including per project impacts and wider programme influence. The evaluation also included media monitoring (via web scraping) to determine awareness and perceptions of the programme, including internationally, as well as the effectiveness of dissemination activities

[7] And if not, why not.

Analysis

Data were combined into an analytical framework to perform analyses covering learning, feedback and insights from Phases 1, 2 and 3 of the programmes. The data were analysed through several approaches:

- **general case-level analysis and synthesis** (using multiple data sources) for each demonstration project, in addition to programme-wide, thematic analysis and synthesis. The case-level approach supported a more holistic assessment against the project theories of change (ToCs) and a stronger basis for aggregating findings to the programme level. The thematic analysis drew together programme-wide findings against each evaluation question. A coding framework was developed for all interview groups. Each interview transcript was coded against the relevant coding framework, with the coded data being organised by topic and by participant. Analysis was conducted thematically, structured around key evaluation question themes
- **contribution analysis** - a step-by-step theory-based approach for inferring causality, by seeking to identify an intervention's contributions to expected outcomes and impacts, as well as alternative explanations or contributions. For this evaluation, contribution analysis was key to understanding the programmes' impacts, alongside the light touch economic evaluation (see below). The approach was designed to help revise and/or confirm the programme theories of change (rather than uncover a hitherto implicit or inexplicit theory of change)[8]
- **light-touch economic evaluation** of the extent to which and how the programmes have addressed the barriers and market failures indicated in the business cases. It also estimated the costs and benefits of the two programmes and thus value-for-money at the programme level. Due to the challenge of placing a value on benefits beyond the timing of the evaluation (e.g. decarbonisation of industry, jobs growth and export growth, supply chain development), the evaluation did not include a full CBA; therefore cost effectiveness analysis was undertaken at three broad levels – outputs, energy costs and commercial scalability – and the types and scale of impacts were assessed for employment and supply chain effects, knowledge spillovers, monetised carbon savings, and additional investment
- **a series of project-level case studies** providing case-based insights on key themes, highlighting transferable learning from the IFS and HS programmes for relevant programmes, policies and industrial sectors

The evaluation also includes a process-based case-study, to be published alongside the final evaluation, focused on generating insights into the effectiveness of knowledge sharing at programme-level between the IFS and HS programmes and wider policy and programme development within the Department.

[8] The final programme theories and contribution stories for this evaluation are set out in Appendix C.

Chapter 3: Overview of project and programme impact

This chapter presents an overview of how the projects and the overall programmes performed against the outcomes and impacts they were anticipated to achieve, as outlined in the evaluation's programme theory of change (Appendix C).

Industrial Fuel Switching programme

This section starts by summarising IFS project-level outputs and then provides an overview of IFS programme-level outcomes and impacts.

Have IFS projects delivered planned outputs?

The delivery schedule for IFS was extended in response to the challenges of COVID, as explained in the process report. Within the extended timescale, the four IFS demonstration projects delivered their planned outputs.

All of the IFS demonstration projects involved physical demonstrations and trials, in addition to desk-work and modelling. In general, the demonstrations generated successful results although two elements of the trials had some limitations:

- While the MPA project was successful overall, there were technical problems with a trial on one of the cement production sites leading to curtailment of the trial involving use of biomass and an electric plasma torch.
- The BLA trial was undertaken as planned, but the findings were less positive than anticipated, with hydrogen use being found to be technically feasible at 20% by volume but not 50% by volume.

A summary of IFS demonstration project characteristics and outcomes is presented in Appendix E.

How have IFS projects advanced IFS/HS solutions, including TRL increase?

All IFS projects showed Technology Readiness Level (TRL) progress, notably more than the HS programme. Three projects reported substantial progress: BLA from TRL 3 to 6, MPA to TRL 7, and Glass Futures to TRL 9. HyNet Northwest advanced from TRL 7 to 9. This was possible due to demonstrations on full-scale industrial sites, supplemented by desk research and pilot demonstrations. Projects in the IFS programme's feasibility phase did not report TRL progress.

Did IFS projects showcase cost, performance, and carbon savings? Were advancements over current technology evident?

All projects explored novel industrial fuel switching. Each found technical feasibility, but full-scale hydrogen switching was not economically viable without government aid at the time of the research. HyNet's trials at NSK Pilkington and Unilever's Port Sunlight were successful, but highlighted various challenges and costs. Glass Futures found biofuels could replace natural gas, saving 70-80% carbon, while hydrogen was feasible but not economical. MPA and BLA, focusing on cement and lime respectively, faced challenges with hydrogen's economic viability and the emission reduction in their processes. Full decarbonisation would require CCUS systems for these industries.

Have IFS projects successfully generated, validated and widely shared evidence and learning about the feasibility of IFS/HS, and how?

While most IFS project results were not externally validated, they were cross-checked by projects' partner organisation and sometimes externally verified if under the UK ETS scheme. Validation credibility was higher for projects executed on commercial sites. Dissemination was key, with HyNet, Glass Futures, and MPA notably active in sharing findings. For example, Glass Futures emphasised knowledge-sharing services to members, while MPA widely publicised their cement project.

Have IFS projects contributed towards capacity building?

The Glass Futures initiative established a 350kW test bed at Liberty Steel's Rotherham site for pilot-scale testing in various industries, including glass, metals, and ceramics. Glass Futures and Progressive Energy noted enhanced capabilities in industrial fuel switching due to IFS project insights. These organisations facilitated further demonstration activity by industry. All projects witnessed growth in hydrogen knowledge and practices, both organisationally and site-wise, ensuring compliance with regulations like COMAH[9], 2015. Networking was crucial in the Hynet NW and Glass Futures projects, leading to more demonstrations and investment impacts. Jobs supported by projects are detailed in the value for money chapter.

What are the reasons for any differing levels of achievement between IFS projects, including for any under-achievement against expectations / intentions?

Overall, the four IFS projects met expectations, providing significant learnings even when facing technical challenges. Factors affecting achievements included:

- organisational nature of the lead organisations – all the IFS projects were led by coordinating bodies or trade organisations that shared findings and sought government funding. This enabled them to act as catalysts for further industrial fuel switching
- emissions scale – the cement and lime sectors needed CCUS or equivalent for full decarbonisation due to process emissions

[9] Control of Major Accident Hazard Regulations, 2015.

- cluster status - being part of or near a Track-1 cluster, like HyNet, influenced confidence in accessing hydrogen supplies, fostering interest in fuel switching
- policy and infrastructure - IFS projects depended on future government funding and infrastructure, especially hydrogen supply, storage, and transport. Truck-based transport posed challenges due to hydrogen's low density

How did the IFS programme perform overall?

Overall the IFS programme achieved the outcomes that were expected during the programme’s lifespan, and made some contribution to two longer term goals.

- programme outcomes were found to be influenced by a wide range of external factors **(e.g. corporate commitments to Net Zero by industrial firms and their customers, government policy/support (short and long term) and prices for low carbon and existing fuels).** Interview and project output evidence showed that COVID risks were well managed by the Department and the IFS projects.
- the evaluation found that the **rationale for the programme was still valid**, with no evidence found of duplication with trials in other countries
- despite shorter industrial trials, owing to hydrogen supply constraints and higher than anticipated hydrogen prices (because of COVID and related factors**), programme activities were successfully completed**. There were some operational constraints on the use of specific fuels in certain industrial processes, but Departmental staff and project participants highlighted that that was to be expected in an innovation programme of this type
- projects involved in the programme reported that the **additionality of the Department’s funding was high**, as detailed in chapter 8, and that the IFS programme delivered innovation on industrial fuel switching sooner, or on a greater scale, than would have happened without the Department’s support
- there was evidence from interviews and media monitoring, of **dissemination by IFS projects** including reports, webinars, advice services, site visits, videos, conference presentations, social media and so on, as detailed in chapter 4. Dissemination by Glass Futures and HyNet raised awareness and stimulated activity in sectors not included in IFS (e.g. ceramics, metals, food)
- there was evidence of a **general increase in awareness of and engagement** with IFS within certain industry sectors (e.g. glass, ceramics, metals, distilleries), particularly in relation to Government funding programmes and switching to hydrogen, as detailed in chapter 4. Many factors influenced this but interviews showed that IFS played a role in demonstrating that hydrogen could be used safely on industrial sites and that use of hydrogen and biofuels was technically feasible (up to certain limits) in a range of production processes. There was some, more limited evidence of lessons being shared outside the UK, primarily via international companies and international trade bodies.as well as online.

- there was evidence of **increased public sector and private sector investment in trialling industrial fuel switching** (e.g. second IFS, IETF, IDC, academic programmes), as detailed in chapter 5. Interview evidence showed that IFS contributed by helping to build business cases, build partnerships, build expertise, identify issues requiring research and (in some sectors) stimulating lobbying for government funding
- **learning from IFS fed into the design of the Department's and UKRI's successor policies and programmes**, including IFS2, IETF, IDC, hydrogen business model support, zero carbon hydrogen standard, as detailed in chapter 6. However, this could have been greater if dissemination within the Department had been planned more proactively
- there was some evidence of **IFS contributing to supply chain development**, primarily through up-skilling project partners and increasing capacity in 'catalyst' organisations (e.g. Progressive Energy, Glass Futures), together with direct and indirect contribution to additional testing facilities, as detailed in chapter 8. And there was evidence of small-scale job creation and business growth, including export potential (see chapter 7), from interviews with project leads, project partners and wider stakeholders
- **as expected, it was too early to see widespread take-up of industrial fuel switching or decarbonisation of industry on a significant scale.** Widespread take-up of industrial fuel switching was constrained by the poor economics of switching to hydrogen or electricity and by the current lack of infrastructure for hydrogen supply, transport and storage. One industry stakeholder gave an example, for one specific industry, that the price of hydrogen would have to be comparable with the price of gas (or at most double the gas price) for switching to hydrogen to be economic. For comparison, the future hydrogen costs forecast by HS projects are outlined in chapter 8. Some industry stakeholders reported that biomass use was closer to being economic for some industries

IFS programme impacts are explored in more detail in chapters 4-8, and summarised against the programme theory of change in Appendix C, while further details on IFS project outcomes are presented in Appendix E.

Hydrogen Supply programme

Again, this section starts by summarising HS project-level outputs and then provides an overview of HS programme-level outcomes and impacts.

Have HS projects delivered planned outputs?

The delivery schedule for HS was extended in response to the challenges of COVID, as explained in the process report. Within the extended timescale, four out of the five HS demonstration projects (Dolphyn, Gigastack, HyNet HPP1 and Acorn Hydrogen) delivered their planned outputs. Additional activities were also undertaken, some of them funded by the Department and others by the project partners:

- Dolphyn focused HS-funded activities on the design of a 10MW commercial-scale demonstrator project, with agreement from the Department, because the progress meant that a 2MW prototype was not needed
- HyNet HPP1 partners funded and undertook further engineering work beyond the HS-funded FEED study for a ‘generic’ LCH plant. The additional work focused on issues specific to the proposed plant at the Essar refinery site
- Acorn Hydrogen partners funded and undertook parallel studies on alternative reformer technologies, in parallel with the HS-funded FEED study of a LCH plant, to improve the robustness of their future investment decisions

The HyPer project was significantly delayed, for reasons explained in the process report, and was still underway at the time of the evaluation research. However, the project was expected to reach completion and already showed signs of disseminating learning.

A summary of HS demonstration project characteristics and outcomes is presented in Appendix E.

How have HS projects advanced IFS/HS solutions, including TRL increase?

Gigastack and HyNet HPP1 progressed from TRL 6 to 7, while Dolphyn moved from TRL 4 to 5 with certain elements reaching TRL 7. HyPer's assessment was pending at the time of this research. HS feasibility projects did not report TRLs. Acorn Hydrogen did not report TRL progress, focusing instead on alternative technologies. They prioritised providing evidence for diverse technology options, influenced by the Scottish cluster's 'reserve' status and national gas grid uncertainties. Conversely, Gigastack and HyNet HPP1 aimed for swifter implementation in Track-1 clusters.

Did HS projects showcase cost, performance, and carbon savings? Were advancements over current technology evident?

Evidence suggests that HS projects feature technologies advancing the current state of the art for producing blue or green hydrogen. These projects anticipate carbon savings by replacing fossil fuels with hydrogen. Verco reviewed the final reports, revealing:

- Dolphyn – developed by ERM, it aims to produce green hydrogen from offshore wind. It targets a hydrogen price of £6.15/kg, expecting cost reductions to £1.50/kg by 2040
- Gigastack – this project designs an electrolyser system powered by offshore wind to supply renewable hydrogen. The LCOH is projected to decrease to £2.80/kg by 2030
- HyNet HPP1 –this project focuses on fuel switching and Carbon Capture and Storage. It aims for 3 TWh of low carbon hydrogen production by 2025, expanding to 30 TWh by 2030
- Acorn Hydrogen – planning to produce hydrogen from North Sea Gas, it expects a significant reduction in LCOH over time
- HyPer – a new method with potential performance and cost savings, it anticipates 20-30% cost reductions compared to existing blue hydrogen production methods

Several project representatives highlighted uncertainties in capital cost estimates due to supply chain issues and inflation, suggesting possible increased costs in the final construction.

Have HS projects successfully generated, validated and widely shared evidence and learning about the feasibility of IFS/HS, and how?

There was evidence of HS demonstration projects generating knowledge and validating it, both through internal quality processes within project partners and through third-party validation. Two projects that had worked closely with potential private-sector investors mentioned that their findings had been subject to due diligence processes undertaken on behalf of potential commercial investors.

All HS projects disseminated findings to partners and the Department, with Gigastack and Acorn being particularly active, referencing stakeholder events, conferences, and communications campaigns. Dolphyn engaged in supply chain events, conference presentations, and industry group networking. Their engagement with potential investors was intensive, targeting over 50 companies, with increasing information shared as investor selection narrowed.

HyNet's outreach included a major webinar with 500 attendees and regular communication through the HyNet cluster. The HyPer project actively disseminated information online and through networks, discussing potential commercialization. Johnson Matthey promoted their LCH technology in the UK and globally.

While some data remained confidential, a demonstration project lead felt the Department could have sought more project dissemination, highlighting the balance between industry discretion and government-desired knowledge transfer.

Have HS projects contributed towards capacity building?

On a small-scale, the HS projects were reported to have upskilled individuals and organisations, developing hydrogen expertise within project lead and partner organisations. This expertise could then contribute to these organisations pursuing further opportunities within the UK and internationally.

Some partner organisations were reported to have grown during the HS programme. For example, Progressive Energy was reported to have grown from 14 to 40 people, influenced by this and other funding programmes. Some of the new staff were making a transition to hydrogen from the fossil fuel industry. Networking and partnership were pivotal in projects, with firms like Dolphyn and Gigastack engaging potential suppliers.

What are the reasons for any differing levels of achievement between HS projects, including for any under-achievement against expectations / intentions?

All of the projects except for HyPer delivered or over-delivered against expectations. Several factors were identified as affecting levels of achievement and speed of progress post-project:

- **Level of project management and financial management skills** - slow initial progress with HyPer was attributed to the lead organisation's lack of experience in major capital projects. To address this, they established a project office and enhanced their project and financial management skills
- **Nature of demonstration project** - HyPer's delays were also due to its construction-focused nature, differing from the mainly desk-based FEED studies in other projects. Construction was notably affected by supply chain issues and cost increases related to COVID and EU Exit
- **Level of technology development** – projects with technologies already in advanced stages at the HS programme's onset (like HyNet HPP1) were naturally closer to commercialisation than those with experimental technologies (like Dolphyn)
- **Cluster status** – Gigastack and HyNet benefited from being in Track-1 industrial clusters, offering additional funding and a customer base. Conversely, the 'Reserve' status of the Scottish cluster introduced uncertainty for Acorn Hydrogen
- **Policy and regulatory uncertainty** – completed HS projects were reliant on future Government funding avenues such as the Hydrogen Business Model (HBM) and Net Zero Hydrogen Fund. Delays in the HBM launch hindered subsequent activities. Regulatory concerns about offshore hydrogen pipelines and hydrogen content in the NTS affected Dolphyn and Acorn Hydrogen respectively

How did the HS programme perform overall?

Overall the HS programme achieved the outcomes that were expected during the programme lifespan, and made some contribution to two of the longer term goals:

- there was evidence of **many drivers for rising hydrogen awareness within industry**, including government and industry commitment to Net Zero (and hydrogen’s role within this), and numerous hydrogen programmes and initiatives - but contribution analysis identified that the HS programme played a notable and multi-faceted role in driving awareness, alongside these other drivers. Interviews and project outputs indicated that COVID risks were well managed
- the evaluation evidence indicated that the **rationale for the HS programme was still valid**. No direct evidence was found of HS duplicating earlier trials in the UK or other countries, although international activity was difficult to assess given the major increase in hydrogen-related activity since the start of the programme
- **four HS projects delivered successfully, to a revised timetable that was adjusted to take account of COVID.** However, the HyPer project was delayed because of COVID-related supply chain and cost issues, together with project management issues. Reporting and knowledge-sharing worked well for completed projects
- interviewees reported that the **additionality of the Department’s funding was high**, as detailed in chapter 8, and that the HS programme delivered innovation on hydrogen supply sooner, or on a greater scale, than would have happened without the Department’s support

- there was **considerable evidence of dissemination by HS projects**, particularly Gigastack and Acorn Hydrogen, as detailed in chapter 4. Dissemination included site visits, conference presentation, public reports and updates. There were some commercial constraints on sharing in-depth cost data but more detailed cost, performance and risk information was shared with potential investors (e.g. by Dolphyn and HyNet HPP1)
- there was evidence **of industry awareness of hydrogen opportunities growing strongly during the HS programme**, linked to a number of external factors including Government and corporate commitments. Evidence indicated that HS projects fed into and influenced media debate on hydrogen issues, particularly within the UK, as explained in chapter 4. The projects progressed towards commerciality to different degrees, as detailed further in Appendix E. The completed demonstration projects provided more robust evidence of feasibility and costs for HS technologies
- investment monitoring showed a **dramatic increase in the level of innovation investment in hydrogen supply during the HS programme**, in the UK and internationally, linked to a number of external factors. Interview evidence shows that HS contributed by helping to stimulate co-funding of additional activities, de-risk follow-on investments, support wider investment decisions, build partnerships and build capacity and knowledge, as detailed in chapter 5
- there was considerable interview evidence of **learning from HS feeding into the design of the Department's successor policies and programmes**, including HS2, IHA, hydrogen business model support and zero carbon hydrogen standard, although this could have been greater if dissemination within the Department had been planned more proactively. This is detailed in chapter 6
- there was some **evidence of HS contributing to supply chain development**, primarily through upskilling project partners, engaging with potential investors and supply chain companies, and increasing the capacity of 'catalyst' organisations (e.g. Progressive Energy, Storegga), as detailed in chapter 8. And there was evidence of **small-scale job creation and business growth, including export potential**, from interviews with project leads, project partners. and wider stakeholders, as detailed in chapter 7. They reported that there was considerable scope for growth if the hydrogen economy takes off, but this is dependent on government support for infrastructure development and operating cost support via the Hydrogen Business Model or a similar mechanism
- as expected, **it was too early to see evidence of widespread supply and demand for hydrogen across multiple sectors**, or widespread decarbonisation of industry, transport, heating and other sectors. Widespread supply and demand for hydrogen were constrained by lack of infrastructure (including storage and transport) and by the poor economics of industrial fuel switching to hydrogen without a support mechanism such as the proposed Hydrogen Business Model, as detailed in chapter 8. There was evidence that these constraints are likely to be overcome first in the Track-1 cluster areas, where there is a realistic prospect of government-supported hydrogen infrastructure development and commercial interest in industrial fuel switching (subject to introduction of the Hydrogen Business Model)

HS programme impacts are explored in more detail in chapters 4-8, and summarised against the programme theory of change in Appendix C, while further details on HS project outcomes are presented in Appendix E.

Chapter 4: Impact on industry awareness, engagement and confidence

This chapter assesses the contribution the programmes made to awareness, engagement and confidence levels in relation to industrial fuel switching and hydrogen supply. It begins by setting out how industry awareness, engagement and confidence evolved throughout the programmes' lifetimes. It then summarises what the programme and projects did in terms of dissemination and explores how IFS/HS contributed to observed changes in awareness, engagement and confidence.

How industry awareness, engagement and confidence in hydrogen supply and industrial fuel switching changed during the programme

Awareness of and engagement with hydrogen supply and industrial fuel switching rose during the lifetime of the programmes in the following three ways. These changes are not necessarily attributable to the IFS and HS programmes but the IFS and HS contribution is considered later in this chapter:

- **rising awareness of hydrogen supply** - media mentions of hydrogen and its supply rose between 2016 to 2021, levelling out at levels 3-4 times higher than before 2020. This rise in awareness was also highlighted by stakeholders who identified an enhanced recognition of hydrogen's role in decarbonisation. Moreover, they had observed an increased strategic importance being attached to hydrogen supply by firms previously seen as oil and gas or chemical-sector companies, which are now active within the hydrogen supply sector
- **increase in industrial fuel switching awareness and engagement** - there was a discernible increase in the industry awareness and discussions about fuel switching during the programme period, although media mentions of 'fuel switching' were considerably lower than for hydrogen supply and related primarily to the IFS programme and its successor. Industry interest was particularly evident regarding hydrogen as an alternative fuel. Engagement in fuel switching increased during the IFS programme, as indicated by the growing number of participants in government innovation meetings. Many firms began recognising the need to transition from fossil fuels, with a significant focus on the feasibility of hydrogen fuel switching.
- within the Department, however, **there was a perspective that enthusiasm for industrial fuel switching within industry had fallen off slightly since 2020**, partly due to COVID and partly due to uncertainties linked to increasing gas, electricity and hydrogen prices and to safety concerns around hydrogen. This might also reflect some firms and sectors deepening their appreciation of the challenges involved in identifying appropriate decarbonisation routes.

Various external factors influenced the industry's awareness and engagement. For hydrogen supply, these included international activities like the UN Climate Change Conferences, Net Zero targets, UK's hydrogen strategy, and policies from other countries - especially significant commitments from the US. Factors influencing industrial fuel switching included cost considerations, the government's industrial decarbonisation strategy, corporate Net Zero targets, carbon prices, and significant changes in fossil fuel prices, among others.

Industrial firms saw hydrogen supply and associated fuel switching as more viable within the designated Track-1 CCUS clusters. The UK's cluster approach gained international attention, being seen as crucial in facilitating industry access to hydrogen and CCUS infrastructure. As highlighted below, the IFS and HS programmes were also instrumental in bolstering industry awareness and engagement concerning industrial fuel switching and hydrogen supply.

Programme knowledge dissemination activities

The dissemination methods and activities used to share knowledge from the two programmes are set out below. The next section explores whether and how these activities contributed to the observed changes in industry awareness, confidence and engagement highlighted above.

IFS projects

Knowledge dissemination activities by IFS projects included:

- presentation of findings at COP26 and other industry events (e.g. Glass Futures)
- advertising workshops around environment and impacts of work (e.g. HyNet)
- organising site visits for industry stakeholders (e.g. HyNet and MPA)
- YouTube videos and associated social media activity for dissemination
- posts by project partners about their involvement (e.g. Tarmac, MPA), and
- stakeholder engagement activity (e.g. engaging with project suppliers, partners and customers)

HS projects

Knowledge dissemination activities by HS projects included:

- promotion at events such as COP26 and other business conferences
- site visits (e.g. Gigastack, HyNet HPP1)
- publicly available newsletters and dissemination documents, and
- disseminating findings to stakeholders via private newsletters and other mechanisms (e.g. Gigastack, Acorn, Dolphyn)

Department-level dissemination

In addition to project-level dissemination, the Department undertook some knowledge dissemination at programme-level.

- publishing final project reports on the gov.uk website
- running and attending meetings and events ((including two webinars and a stall at COP26)
- social media, press, and communications activity
- sharing information via Innovate UK's 'Knowledge Transfer Network' (KTN), and
- holding ad hoc conversations with industry

Some industry stakeholders commented that the Department could have been more demanding in the dissemination activities that it required from grantees.

How the IFS programme contributed to changes in industry awareness, engagement and confidence

This section considers first how the IFS programme contributed to industry awareness and engagement, and then how it contributed to perceptions of risk and investor confidence.

IFS contribution to industry awareness and engagement

The IFS programme contributed to industry awareness and engagement in several ways:

- the IFS programme significantly increased industry awareness and engagement in industrial fuel switching within those industries involved in the IFS programme (e.g. glass, cement, lime). This was achieved in a number of ways including: firms being involved as project partners, projects' own dissemination activities, dissemination via trade associations and information being shared within geographical networks (particularly the HyNet cluster)
- HyNet and Glass Futures were particularly effective in engaging industry using tangible examples, demonstration sites and site visit, taking technology from the lab to real-world applications.
- the success of the IFS programme led to increased engagement for later funding rounds from successor programmes, with Glass Futures in particular benefiting from and catalysing cross-sector research activities
- IFS projects that were part of or close to the HyNet Track-1 cluster engaged firms with fuel switching more readily both because hydrogen supply was a more realistic possibility within this industrial cluster and because there was a readily available network of local firms with experience of demonstration projects. The IFS programme both influenced and drew insights from the Cluster Sequencing programme

However, while there were successful dissemination efforts from the IFS programme globally, some stakeholders – and sectors - remained unaware of its activities, suggesting that its impact might be less than other government initiatives.

IFS contribution to perceptions of risk and uncertainty

The IFS programme helped to reduce perceptions of risk and uncertainty in several ways:

- the IFS programme successfully reduced perceptions of risk in industrial fuel switching by demonstrating the use of hydrogen and biofuels at a ‘pilot’ or industrial scale. This was particularly beneficial for smaller firms that couldn't take the risk of conducting trials independently
- demonstrations and trials conducted by the IFS provided crucial insights regarding the cost, safety, effectiveness, and reliability of fuel-switching options. These included handling and storing hydrogen, design specifications for burners, and the effects of different fuels on product quality and capital equipment
- the safe handling of hydrogen emerged as a significant industry concern. Successful trials alleviated some of these concerns by showing that hydrogen with a purity level of 98% was safer and more manageable because its flame was visible
- knowledge from the IFS projects was transferred to sectors beyond the direct participants, with other industries showing interest in understanding the safety and handling of these alternative fuels

  We’ve had discussions with other industries – the cement, the brick and food industry – about our experiences of firing these fuels and wanting to understand [..] fundamental things, like safety, and, “How did you deal with these fuels?” rather than what the impact on our process was. So it’s about all the bits around the edges, so that they feel confident about having those fuels on their sites. (Project partner, IFS)

While many IFS projects did not face quality issues due to fuel switching, there were still challenges identified, like quality issues in lime production with high hydrogen usage and concerns about accessing a reliable and affordable hydrogen supply, especially for firms outside major industrial clusters.

IFS contribution to investor confidence

The contribution of the IFS programme to investor confidence was highlighted in the following ways:

- impacts arising directly from participation in IFS - some project partners and project leads provided evidence that the IFS programme had improved investor confidence. One UK-based company, for example, specifically cited its involvement in the IFS programme as helping build confidence in fuel switching for its international parent organisation
- dissemination activity – there was media evidence of an increasing number of organisations within the HyNet cluster making plans for future use of hydrogen. This

appeared to be linked to dissemination activity by the HyNet cluster and by Glass Futures, amongst other factors, indicating that public awareness and perception were influenced, in part, by IFS related activities

- demonstration effects - some respondents felt that the demonstrations from the IFS programme reduced perceived risks, thereby contributing to industry confidence

However, the evidence also highlighted some points of contention and limitations:

- need for larger demonstrations – some stakeholders expressed the view that more extensive demonstrations of certain solutions (e.g. hydrogen use in lime kilns) would be required to significantly improve investor confidence
- demonstration technologies not universally influential - the MPA project had trialled options that were not readily available at present (i.e. hydrogen and plasma) while switching to biomass, which was more achievable, had been known about for a long time. The implication was that while some projects under IFS were pioneering, others were not as groundbreaking in terms of generating investor confidence
- relative importance - some respondents felt that other factors, like the proposed Hydrogen Business Model and the Cluster Sequencing Programme, played a more pivotal role in shaping industry confidence than the IFS programme

In summary, while the IFS programme did contribute to boosting investor confidence through tangible projects, media coverage, and its role in larger industry initiatives, its impact was mixed, with some stakeholders feeling that other factors were more influential.

How the Hydrogen Supply programme contributed to raising industry awareness, engagement and confidence

HS contribution to industry awareness and engagement

The HS programme contributed to industry awareness and engagement, to the extent this might be expected given the relatively small number of projects and the relatively low levels of investment compared to billions of investment announced worldwide[10]. The contribution happened in the following ways:

- kick-starting awareness - the HS programme was cited as the first UK-Government-supported programme concerning hydrogen supply, which initiated or "kick-started" awareness of hydrogen supply issues in the country
- media influence and engagement - evidence from media monitoring and web-scraping indicated that HS projects influenced and played a role in specialist media debates. The HS programme's dissemination activity garnered significant interest, especially within industry and public bodies. A keyword web search identified 181 articles referencing HyPer, 133 referencing HyNet, 53 referencing Acorn and more than 30 referencing

[10] See 'Hydrogen Insights 2023' published by the Hydrogen Council: https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf

Gigastack and Dolphyn respectively, but some of these articles (particularly for the HyNet cluster) may reference wider activities than those funded by the HS project.

- growth of associations - an example of the programme's tangible impact on awareness and engagement is the growth of the Scottish Hydrogen and Fuel Cell association, which increased its membership from 40 in 2014 to nearly 400 in 2023. This growth was attributed, in part, to dissemination from the Acorn project
- stimulating academic research - there was evidence that HS projects had spurred additional university research programmes. Project leads provided evidence suggesting that such research initiatives might not have commenced without the HS programme
- practical impact on stakeholder activities - wider stakeholders had utilised findings from HS reports for practical tasks like scouting potential hydrogen production sites around Scotland's coast
- diverse technological coverage - by funding various technologies, the HS programme had emphasised that there isn't a single solution to hydrogen production. This broad scope, collaborative approach, and openness of the programme (including publishing free-access results) were highlighted positively by stakeholders
- driving collaboration and openness - the programme's consortium-based approach and the publishing of its findings were praised for driving collaboration and knowledge dissemination, which, in turn, boosted awareness and engagement
- making hydrogen supply realistic - the HyNet HS project gave companies in its cluster the motivation to consider hydrogen fuel switching because it presented hydrogen supply as a feasible option in the near future. This project also bolstered HyNet's position in its bid to become a 'Track-1' cluster due to its potential supply of blue hydrogen
- demonstrating government commitment - the existence of government funding programmes, like HS, bolstered the interest and confidence of industries around hydrogen by showcasing the government's commitment
- potentially setting a new path - the Dolphyn project was highlighted as potentially pivotal in indicating a direction for the hydrogen economy, especially centred on green hydrogen. Stakeholders expressed that the success of this project could make the Government's target for green hydrogen more attainable.

In summary, the HS programme played a multifaceted role in enhancing industry awareness and engagement with hydrogen supply, from sparking initial interest and influencing media debates to stimulating academic research and demonstrating government commitment.

HS contribution to perceptions of risk and uncertainty

The HS programme's contribution to perceptions of risk and uncertainty can be summarised as follows:

- project development and pipeline creation - the HS programme (and its successor, the HS2 programme), played a key role in fostering a pipeline of projects that were then taken up by the Net Zero Hydrogen Fund. This development helped in providing an initial structure for projects and giving the industry a sense of confidence

- knowledge enhancement - the HS programme provided firms in the hydrogen supply chains with a deeper understanding of hydrogen production. This was evident in how Johnson Matthey's reformer technology (involved in two HS projects) saw reduced uncertainties and an advancement in the company's comprehension of the technology
- cost estimation and savings:
    - the HS programme aided in the identification of possible cost savings for hydrogen production in certain projects like Dolphyn and HyPer
    - for the Acorn project, the programme assisted in discerning the most cost-effective route
    - in the case of Gigastack, the HS programme concluded with higher but more accurate cost estimates - these more reliable estimates were regarded as leading to a reduction in risk associated with cost unpredictability

Despite these improvements in costs, or at least reductions in cost uncertainty, the constraints on hydrogen development seem to be more on the economic viability side than technical feasibility. Stakeholders emphasised the need for the Hydrogen Business Model, as it would make hydrogen use more economically viable by making its cost comparable to natural gas.

In summary, the HS programme substantially reduced uncertainties related to hydrogen production and costs. By laying the groundwork for projects, enhancing knowledge, and providing more reliable cost estimates, the programme paved the way for more stable future ventures in the hydrogen sector, thus mitigating perceptions of risk and uncertainty.

HS contribution to investor confidence

The HS programme's contribution to perceptions of risk and uncertainty regarding hydrogen technologies can be analysed as follows:

- increased confidence in hydrogen technologies - respondents indicated that the HS programme, in combination with the IFS programme, had increased confidence in hydrogen technologies
- interest from financial institutions – programme management staff highlighted financial institutions were actively interested in the findings from HS, an indication of its credibility and relevance. Financial institutions, being risk-averse by nature, generally base their decisions on a comprehensive analysis of available data. Their active interest implies that the HS programme had helped to lower perceived risks associated with hydrogen technologies
- increased private investment interest – similarly Dolphyn reported greater interest from private investors upon completion to the HS project. Dolphyn reported that companies that had been indifferent to the project before the programme, even when offered the technology for free, expressed a willingness to invest tens of millions of pounds post-

programme, suggesting that the HS programme effectively reduced perceived uncertainties about the technology's viability

- remaining scepticism - despite the positive shifts in perceptions, there remained certain reservations. Some stakeholders, including energy-intensive industry representatives, were sceptical about the tangible results, noting the lack of actual investment and construction of hydrogen plants. This suggests that while the HS programme addressed some uncertainties, others, such as the practical aspects of hydrogen production and use, remain
- challenges with transport and storage - several stakeholders mentioned lingering uncertainties about how to transport and store hydrogen in the UK. This implies that the HS programme had limited impact on resolving these specific challenges, and they persist as major areas of concern.

In summary, the HS programme significantly contributed to reducing perceptions of risk and uncertainty related to the feasibility and reliability of hydrogen technologies. It garnered interest from both financial institutions and private investors, showcasing the technology's viability. However, it was not without its limitations, as tangible investments in hydrogen plants were yet to materialise, and concerns regarding transport and storage remained unresolved.

Wider factors influencing industry awareness, engagement and confidence

Media monitoring and qualitative research indicated that industry awareness and engagement with fuel switching and hydrogen supply were influenced by many factors external to the IFS and HS programmes.

The main external factors reported to have influenced awareness and engagement of industrial fuel switching were: the Government's overarching industrial decarbonisation strategy; corporate Net Zero targets and industry commitments to climate change objectives; carbon prices; fossil fuel price changes; other UK Government hydrogen industrial fuel switching initiatives; and supply chain pressures and consumer awareness of climate change and decarbonisation

The main external factors reported to have influenced awareness and engagement of hydrogen supply were: international agreements; Net Zero targets; UK Government policies and UK Government support programmes for hydrogen supply; hydrogen strategies and policies in other countries, including Europe and the US; and dissemination activities undertaken by hydrogen conferences, Hydrogen UK, the Scottish Hydrogen and Fuel Cell Association and university knowledge exchange programmes.

Qualitative interview evidence indicated that industrial firms regarded hydrogen supply, and associated hydrogen fuel switching, as more viable within the Track-1 clusters. The UK's cluster approach had also attracted the attention of international stakeholders interviewed in relation to IFS. They saw clusters as important in facilitating industry access to hydrogen and CCUS infrastructure.

Chapter 5: Impact on investment and activity in the UK

The opening section of this Chapter sets out how research, development and innovation and investment activity in IFS and HS changed over the lifetime of the programmes, irrespective of cause. The sections that follow then examine the contribution each programme made to these changes in investment activity.

How investment and activity in the UK changed during the programme

This section sets out how research, development and innovation and investment activity in IFS and HS changed over the lifetime of the programmes, irrespective of cause. The sections after then examine the contribution each programme made to this change.

Industrial fuel switching

There was evidence that innovation investment and activity in industrial fuel switching increased over the duration of the programme.

By the end of the programme, numerous public-sector programmes were funding research, innovation and early deployment of industrial fuel switching (including the second IFS programme, the Industrial Energy Transformation Fund, the UKRI's Industrial Decarbonisation Challenge funding programme and a number of academic programmes (e.g. the Gas Turbine Research Centre, the Hydrogen Centre). A review of funding databases and related online materials showed a considerable rise in IFS spending between 2017/18 to 2022/23, from a very low base. The funding estimates presented in the table below should be interpreted as minimum figures: they do not include the second IFS programme and also exclude two major investments identified by qualitative research which do not yet appear in industry databases.

Table 3: Change in fuel switching activity - from industry databases

	2017	2018	2022	2023 (Jan to Aug)
Funding of fuel switching projects	None identified	None identified	£10.8 million	£11.7 million
Private sector % (share of fuel switching projects)	None identified	None identified	None identified	32%
Patents granted	None reported	None reported	10	6
Industrial energy consumption from biomass and waste	1,162,000 tonnes of oil equivalent	1,452,000 tonnes of oil equivalent	1,806,000 tonnes of oil equivalent	Data not yet available
Biomass and waste % (share of total industrial energy consumption)	4.83%	6.39%	8.21%	Data not yet available
Industrial energy consumption from electricity	7,964,000 tonnes of oil equivalent	7,998,000 tonnes of oil equivalent	7,318,000 tonnes of oil equivalent	Data not yet available
Electricity % (share of total industrial energy consumption)	33.09%	35.21%	33.24%	Data not yet available
Total industrial energy consumption	24,071,000 tonnes of oil equivalent	22,716,000 tonnes of oil equivalent	22,012,000 tonnes of oil equivalent	Data not yet available

Sources: Relevant projects from the Gateway to Research, Crunchbase, EU Cordis database, DESNZ/BEIS listings (Net Zero Hydrogen Fund, the Industrial Energy Transformation Fund, Hydrogen Grid R&D, Clean Steel Fund and UKRI's Industrial Decarbonisation Challenge Fund). The analysis excluded projects in the first and second IFS programmes and those that did not specify project details and recipients. The source for industrial energy statistics was the Digest of UK Energy Statistics (aggregate energy balance for UK, presented in gross calorific values).

As shown in the table above, there was evidence of increased innovation activity through 16 patents being granted for industrial fuel switching during 2022 and 2023 (to date), compared to no patents being granted in these areas during 2017 and 2018. Energy statistics showed an increase in industrial consumption of biomass and waste fuels, probably attributable to switching from fossil fuels, but electricity consumption reduced rather than increased between 2018 and 2022 (when measured in terms of energy content)[11].

Furthermore, qualitative interview evidence pinpointed two major new plants that were not included in the funding statistics set out above: a proposed £100 million investment by Encirc and Diageo, involving a new multi-fuel glass furnace in the North West capable of being hydrogen-fired and of producing 400 tonnes of glass per day[12]; and a £54 million investment in a new industrial testing facility by Glass Futures, funded largely by public sector bodies including UKRI and Liverpool City Region[13].

Hydrogen supply

There was a significant increase in the level of innovation investment in hydrogen supply by both public and private sectors during the lifetime of the HS programme.

New Government programmes relating to hydrogen supply and usage included the second HS programme (£60 million), the Industrial Hydrogen Accelerator (£26 million), the Scottish Government's Hydrogen innovation scheme, UKRI innovation support and a number of other programmes. Deployment funding had also been allocated, notably the Net Zero Hydrogen Fund (up to £240 million). The evaluation also found evidence of major private sector investment in hydrogen-related projects by partners involved in HS projects (e.g. a chemicals company, an oil and gas company).

A review of funding databases and related online material showed an increase in funding for hydrogen supply from £8 million in 2017 to £125 million in 2022, as shown in the table below. This excludes some of the private sector investments flagged above and may be an underestimate. The increases in UK funding took place in the context of massive levels of investment internationally, with the Hydrogen Council indicating in May 2023 that there were 1,040 hydrogen projects worldwide requiring US$320 billion in investment, up from US$240 billion in the previous year[14].

[11] The Energy Trends quarterly report published by BEIS/DESNZ suggests that the reduction in electricity consumption by industry may relate partly to changes in industrial production levels. https://www.gov.uk/government/statistics/electricity-section-5-energy-trends
[12] https://www.encirc360.com/2022/12/12/encirc-and-diageo-announce-hydrogen-powered-furnace-to-change-the-face-of-uk-glass-manufacturing-industry/ This proposed new plant is not yet included in funding databases.
[13] https://www.liverpoolcityregion-ca.gov.uk/delivery-underway-of-54-million-glass-futures-development-in-st-helens/ This is plant is not yet included in funding databases.
[14] https://hydrogencouncil.com/en/hydrogen-insights-2023/

Table 4: Change in hydrogen supply activity - from industry databases

	2017	2018	2022	2023 (Jan to Aug)
Funding of hydrogen supply projects	£8.0 million	£6.5 million	£125.0 million[15]	£27.0 million
Private sector %	None identified	None identified	None identified	22%
Patents granted (hydrogen-related technologies)	None reported	None reported	14	3

Sources: Gateway to Research, Crunchbase, IEA database, BEIS listings of hydrogen projects (including the Net Zero Hydrogen Fund, NZIP (Accelerating Carbon Capture and Storage Technologies (ACT) 3), Hydrogen BECCS Innovation Programme plus hydrogen projects funded by the UKRI's Industrial Decarbonisation Challenge Fund). These figures excluded projects in the first and second HS programmes and those that did not specify project details and recipients.

There was an increase in the number of patents granted for hydrogen-related technologies, from none in 2017/2018 to 17 in 2022/2023 (to date), as shown in the table above. 2023 KPI returns for the HS programme highlighted that 4 patent applications were made by HS Phase projects, with 2 being granted and 1 published at that time. In terms of actual production of hydrogen, no update was available on the UK Hydrogen Strategy figure of 27 TWh per year[16]. The levelised cost of hydrogen was estimated by the Department to be £59/MWh (for steam reformation with carbon capture).

How the IFS programme contributed to changes in investment and activity

Along with the external influencing factors on industry engagement, outlined at the end of the previous chapter, there was evidence that the IFS programme was successful in contributing to increases in innovation activity relating to industrial fuel switching. Four main mechanisms for IFS influence were identified:

- helping to build business cases
- building partnerships

[15] The 2022 figure includes over £90 million for projects focusing on hydrogen for transportation.
[16] UK Hydrogen Strategy 2021.

- building expertise and capacity
- identifying issues requiring research

IFS influence on investment: helping to build business cases

The IFS programme played a significant role in influencing and building confidence for Encirc's proposed £100 million investment in a multi-fuel glass furnace in the Northwest[17]. The programme, along with other factors like UKRI and the Liverpool City Region's investment in Glass Futures, and UKRI's wider Industrial Decarbonisation Challenge, were essential contributors to the decision for this major investment.

The investment is seen as a significant step towards decarbonisation. It remains uncertain whether the investment will be fully funded by private investors or if it will receive some public-sector funding.

> *So, even though this project [i.e. Encirc trial within the Glass Futures project] was started before I joined, I am familiar with the success of it. And it was very much heralded amongst our organisation as being a stepping stone, or a trampoline maybe even more so, towards decarbonisation because it got us quite excited. (Project partner, IFS)*

IFS influence on investment: building partnerships

The IFS programme played a significant role in fostering partnerships and consortium building, acting as a catalyst for further activities and bids.

Six firms within the HyNet cluster – from a wide range of sectors–- were involved in three feasibility projects funded by the second IFS programme, also led by Progressive Energy. Three of these firms (Essity, Kellog's and Novelis) were awarded demonstration funding in the second IFS programme, worth just over £10 million in total, with at least some of these projects being implemented in partnership with Progressive Energy.

Two Glass Futures projects were also awarded demonstration funding in the second IFS programme, worth £12 million in total. An additional £6 million was awarded to the British Ceramic Confederation for a project that includes use of hydrogen pilot kiln hosted by Glass Futures. These activities were influenced to some degree by partnerships developed during the IFS programme.

Several organisations involved in the IFS competition also took forward bids to the IETF, the CCUS innovation competitions, and the Industrial Hydrogen Accelerator. Evidence from Departmental staff interviews suggested that some IETF projects built on Glass Futures' IFS partnership work. Follow-on projects within the IETF by partners involved in the IFS lime and cement projects tended to focus on CCUS technologies rather than industrial fuel switching,

[17] https://www.encirc360.com/2022/12/12/encirc-and-diageo-announce-hydrogen-powered-furnace-to-change-the-face-of-uk-glass-manufacturing-industry/)

because of the importance of CCUS for capturing process emissions from lime and cement production. These IETF projects were therefore less clearly linked to the IFS programme.

Both Hynet and Acorn were successful in winning Government funding from a range of sources, including the Cluster Sequencing programme and Industrial Decarbonisation Challenge Fund, but it is not clear how far these activities were influenced by IFS.

IFS influence on investment: building capacity and expertise

The IFS programme significantly influenced and catalysed future innovation in the area of industrial fuel switching by helping to develop the capacity and expertise of project partners.

This was achieved by:

- enabling IFS firms and their supply chains to expand their expertise in using hydrogen on industrial sites, ranging from the design and manufacture of hydrogen burners to engineering and consulting expertise on hydrogen combustion, transport and storage,
- IFS and supply chain firms using their increased expertise to generate business activity within and beyond the UK
- contributing to a major enhancement in the capacity and capability of Glass Futures, both directly through facility support and indirectly by bolstering its establishment and credibility, leading to further funding opportunities. This included funding for a new building, at a cost of £54 million, which will provide additional testing facilities for industrial fuel switching across a range of industries, and
- enhancing the reputation and capacity of Progressive Energy, allowing them to more credibly engage with industry and foster new partnerships

IFS influence on investment: identifying issues for research

IFS also contributed to follow-on activity by identifying issues that required further investigation. Follow-on work was also undertaken to investigate further risks and issues of concern, beyond the sectors and locations involved in the IFS programme. For example, further work was required to understand how the higher temperature at which hydrogen burns would affect different industrial processes.

> *We wanted to know if the radiation from the flame, will [..] actually affect the steel differently than natural gas. Because the work [had been] done on the combustion, on the flame, but not on how it affects the furnace, or the steel [...] But we've funded that because we know we need to get extra resource to help our clients who are short of resource. So, that's what I mean. A lot of it can be traced back to that initial piece of work.* (Wider stakeholder)

Limits to IFS influence on investment

Despite IFS influence on innovation investment and activity in industrial fuel switching, interview evidence indicated the scale of IFS influence was limited by the number and scale of projects involved.

With only four demonstration projects, there were gaps in terms of the technologies and industrial sectors covered. In this respect, the programme was not designed to have a broad scope of influence.

Full-scale deployment of industrial fuel switching, and associated investment, was reported to be happening slowly, being dependent on government subsidies. Deployment of IFS technologies was also reported to be constrained by a number of external factors, including:

- lack of electricity grid connections
- lack of hydrogen infrastructure
- volatility in fuel prices
- lack of expertise and capacity in the supply chain
- the long time-scale for investment in industrial sites

Commercial switch-over to hydrogen was also reported to be heavily dependent on the Hydrogen Business Model.

While there was strong evidence of IFS influence on innovation investment within the UK, it is possible that there may have been more progress in other countries such as the US, which offers considerable government subsidy, a less strict regulatory regime and a government-led Industrial Decarbonisation Plan.

How the HS programme contributed to changes in investment and activity

There was evidence that the HS programme stimulated innovation activity relating to hydrogen supply, contributing to the dramatic upsurge in hydrogen-related innovation investment and activity in the UK during the lifespan of the programme, alongside the external factors highlighted at the end of the previous Chapter.

The main mechanisms for HS influence were identified as follows:

- stimulating co-funding of additional activities
- de-risking follow-on investments
- supporting wider investment decisions
- building partnerships
- building capacity and knowledge

HS influence on investment: stimulating co-funding of additional activities

The Acorn project stimulated private-sector funding of an additional technology study that was undertaken in parallel with the main HS project. This additional study cost slightly more than £1 million and complemented the main project activity.

> *"It doesn't only enable Acorn Hydrogen to progress and support that, but it creates some space for the other parts of the project to move forward as well. Everything helps from a wider Acorn and Scottish Cluster perspective. It creates some space to focus on the transportation and storage or the shipping module as well. While the funds might be directed specifically to Acorn Hydrogen, I think it has a wider impact as well" (Project partner, HS)*

HS influence on investment: de-risking follow-on investments

The HS programme de-risked follow-on investments in HS projects, enabling investment in the next stage of that innovation project. This contributed to the growth in hydrogen investments in the UK in recent years.

Evidence from Departmental funding announcements and project/partner interviews showed that most of the demonstration projects funded by HS were making progress towards implementation at the time of writing:

- HyNet's HPP1 project had submitted a planning application and expected to reach deployment and was on the project negotiation list for Track-1 Cluster funding. In parallel with HPP1, funding had been obtained for other elements of HyNet cluster activities through the Net Zero Hydrogen Fund and the Industrial Decarbonisation Challenge Fund
- Gigastack obtained HS2 funding for a 'Gigatest' £8 million demonstration project, building on the FEED study undertaken with HS support. The demonstration project should enable the project to reach TRL 8 or 9. There was also some evidence from Departmental stakeholders of Gigastack raising private investment on the back of the project.
- Dolphyn obtained HS2 funding for a £8.6 million project involving offshore demonstration trials and development of a commercial scale demonstrator by 2025. Subject to feasibility, they were engaging with private investors potentially interested in funding demonstration and roll-out of the technology
- Acorn Hydrogen moved closer to a Final Investment Decision through the HS project but recent funding awards have related to other elements of Acorn cluster activity (e.g. offshore and onshore net zero infrastructure, funded via the Industrial Decarbonisation Challenge Fund). Next steps with the HS project were subject to external dependencies including the 'Reserve' status of the Scottish cluster, the proposed Hydrogen Business Model and CO2 funding support mechanism, as well as future policy on gas network blending and heat

At the time of writing, both Gigastack and Dolphyn had withdrawn from the competition for the first round of Hydrogen Business Model funding. This occurred after the research period so the reasons for their withdrawal were not explored by this research.

Given the delays in implementation of HyPer, follow-on plans for the HyPer project were not yet known. But there was evidence of HS feasibility studies leading to further activity funded through other funding streams (e.g. HS2 and/or the Net Zero Hydrogen Fund).

The evaluation was unable to identify evidence of the cost of future trials being reduced through HS learning, although expected reductions in the levelised cost of hydrogen were reported (see chapter 8). However, two project partners noted in interview that their project had highlighted impacts and pitfalls of the technologies being trialled, with the implication that these could be avoided in future demonstration projects.

HS influence on investment: supporting wider investment decisions

In addition to supporting direct follow-on investment in HS innovation projects, the HS programme supported wider strategic investment decisions relating to hydrogen supply, by reducing perceived risk and increasing credibility.

One firm involved in hydrogen supply, for example, reported that HS came at just the right time to influence their corporate commitment to hydrogen. They cited the HS competition as helping to build internal support for hydrogen initiatives because 100% funding reduced the risk involved. For this company, HS was effectively a stepping-stone on the path from hydrogen being a niche interest to a major part of their overall growth strategy. A company representative stated that they had recently invested around £100 million in hydrogen-related capability within the UK, including green hydrogen and fuel-cell-related facilities. Departmental stakeholders commented that this firm had recently raised export guarantee credit and that the project had likely added to their credibility as a potential exporter of this technology.

There was also evidence of HS contributing to the development of the HyNet and Acorn clusters. Although both clusters are complex and involve a large number of players and multiple funding sources, having a credible source of blue hydrogen in the medium term was seen as an important part of the jigsaw. The HS projects were reported by wider stakeholders to have contributed to the credibility of cluster activities, helping to bring on board major players and investors, which then built credibility further.

> *I believe that the business case for the HyNet cluster was supported under HySupply 1. [..] that's very significant so that cluster is one of the two biggest hydrogen zones in the UK for real hope for any kind of rollout. That's a big contribution to the domestic picture. (IFS/HS programme management staff)*

Furthermore, the existence of HS within the HyNet cluster was also reported to have supported the success of IETF applications from firms within the cluster, because they could demonstrate potential access to hydrogen within a five-year timeframe.

HS influence on investment: building partnerships

There was strong evidence that HS contributed to the development of partnerships, with one project partner estimating that they had built or strengthened at least 15-20 relationships through their involvement in the Acorn Hydrogen project. Acorn was reported to have acted as a catalyst for other blue hydrogen projects across Scotland, with Storegga being actively involved in four out of 13 proposed blue hydrogen hubs. Some partnerships from HS were successful in the second HS programme, building on the links they had made during HS.

Partnerships were described as important not just in catalysing projects but in providing third-party credibility for emerging HS concepts.

> *"As much as anything, it was bringing some of the groups together. We talk about HyNet. It meant that our senior leadership could go and talk to the folk at Progressive Energy and understand their vision, and it wasn't just me banging a drum. You've then got some external [reference] points." (Wider stakeholder)*

The involvement of major players (e.g. oil and gas companies) in these partnerships was reported as being important in building momentum and credibility.

HS influence on investment: building capacity and knowledge

HS helped to develop capacity and knowledge within the firms involved in delivery. Some firms used this expertise and capacity to apply successfully to the second HS programme. There was also evidence of learning from the HS programme being used to support wider activities, including export activities within and beyond the UK.

Furthermore, there was also evidence that engineering and consultancy partners involved in the HS demonstration projects had applied the knowledge and expertise gained in the HS projects in future projects, supporting the spread and application of the knowledge from the programmes.

Constraints on HS development

Despite this evidence of HS influence on innovation investment and activity, HS project partners reported that many investors were still reticent to invest in deployment of hydrogen technologies.

The viability of HS investment was dependent on further government support (e.g. through further innovation/deployment funding and/or the Hydrogen Business Model). Further constraints were cited to be:

- commercial and technical issues (hence the need for the HBM)
- access to water
- supply chain capacity, including electrolyser manufacture
- lack of CCUS infrastructure (for blue hydrogen)

A view was also expressed that the UK should try to speed up the deployment of hydrogen technologies, to avoid being overtaken by activity in other countries offering larger-scale funding.

Impact on domestic UK capability

The IFS and HS programmes contributed to increased domestic UK capability on industrial fuel switching and hydrogen supply. In particular, there was evidence of:

- partner firms involved in the IFS and HS programmes developing capabilities which they then used in their business offers, both within and beyond the UK
- facilities being developed to test industrial fuel solutions at pilot-scale, either directly funded by the IFS programme (e.g. Glass Futures' 350 kW test bed) or indirectly catalysed by the programme (e.g. Glass Futures new facility, co-funded by UKRI and the Liverpool City Region)
- projects engaging with potential investors and supply chain companies (e.g. by running supplier days or developing supplier packs)
- HS and IFS supporting the growth and development of 'catalyst' organisations (e.g. Glass Futures, Progressive Energy, Storegga), often linked to a cluster initiative; these organisations played a catalytic role in engaging other companies in IFS and/or HS within the relevant cluster

Furthermore, the Glass Futures test bed facility, funded by the IFS programme, is now used for further demonstration testing, including testing by private companies.

Chapter 6: Impact on UK programmes and policy debate

This chapter assesses the impact of the programmes on other programmes and policies within the UK.

Influence on the successor IFS and HS programmes

Since the completion of the IFS and HS programmes, the Government has launched second versions of each programme, both broadly modelled on the first iterations. Both programmes have included two phases: a feasibility phase and a demonstration phase. The second IFS programme was allotted £55m of funding and was launched in 2021. The second HS programme was also launched in 2021 with around £60m of funding available across two streams.

The influence of the IFS and HS programmes on the second IFS and HS programmes was significant, leading to improvements in programme design, the introduction of technology-specific lots, and the successful justification for increased funding and support for the subsequent phase.

The influence can be categorised in three main ways:

- streamlined business case – the first iterations of the IFS and HS programmes served as a critical component in making the business case for funding for the second versions. The initial programmes' success provided evidence of the respective sectors' interest and the potential for strong project outcomes, which helped secure support and resources for the second programmes
- justification for scale – furthermore, the success and outcomes of the first programmes played a pivotal role in justifying the scale and scope of the second, NZIP programmes. The HS programme, for example, had an initial budget of c£60 million, a response to the success and demand generated by the HS programme, suggesting the positive outcomes and interest generated by the first programme influenced the allocation of a larger budget for the second

  "I think it would probably be difficult to justify the amount of projects that we've funded through this programme, without that initial round to show, "Okay, this programme does work well. There is interest from the sector. We can generate strong outputs from these projects" (Wider policy and programme staff)

- programme design - the experience gained from the first programmes informed the design and approach of the second versions
  - lessons learned from the initial IFS programme, including the need for diversifying hydrogen suppliers, improve application quality, address supply chain disruptions, and remove the market engagement phase, were applied to fine-tune

the structure and execution of the second IFS programme. The design of the second HS programme was also fine-tuned based on the experience of the first

  - the second IFS programme also introduced technology-specific lots, a departure from the open approach of IFS1. This change allowed for a more targeted focus on particular technologies, such as hydrogen, based on the success and interest generated by the first IFS projects. This shift in approach aimed to maximise the impact of the second programme
  - the second IFS programme did not include a market engagement study phase as government understanding of industry engagement with fuel switching was deemed to have advanced significantly since the first programme

Influence on wider strategy, programmes and regulations

The interviews highlighted a wide range of other strategies, policies, programmes and regulations that the IFS and HS programmes have helped to influence.

Strategy

At a strategy level, the programmes were reported as having had at least some influence on:

- the UK Hydrogen Strategy (2021), partly through enabling 'a cacophony of feedback from industry' from organisations involved with projects in the IFS and HS programmes that wanted government to make hydrogen a priority
- the Industrial Decarbonisation Strategy (2021) – insights from the programmes were said to have been used to outline pathways for fuel switching and decarbonisation in the industrial sector, influencing broader government policies in this area

  The learnings from the Fuel Switching competition, the Hydrogen Supply competition, were informative to the development of that strategy (Wider policy and programme staff)

No specific examples were provided of how these programmes had influenced these strategies.

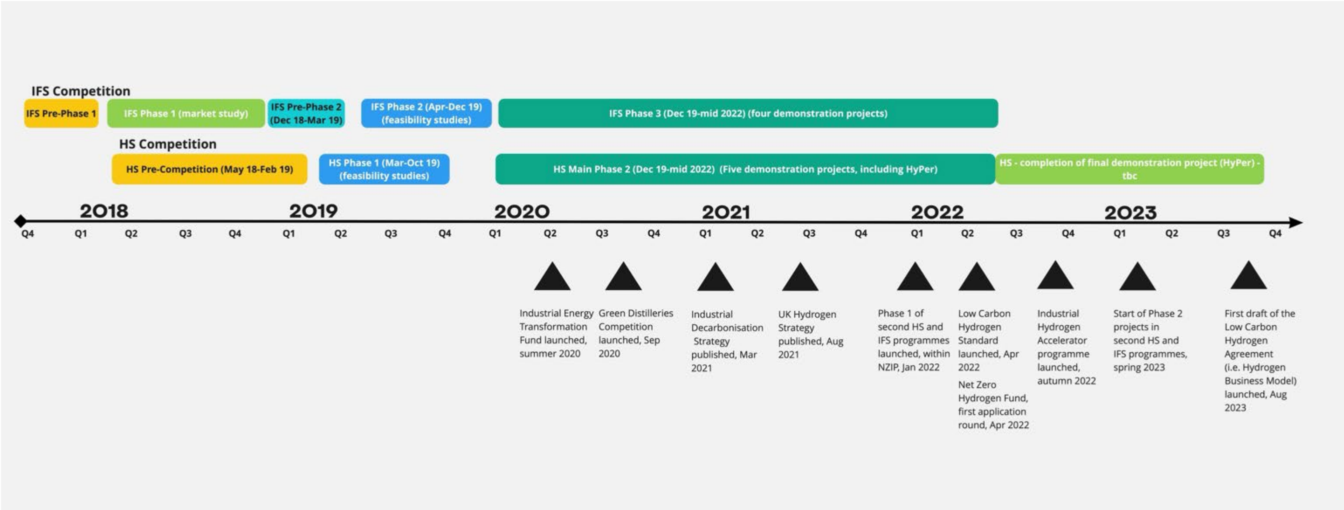


Figure 3 Timeline of IFS and HS programmes and related programmes and policies

Programmes

Key programmes influenced by the IFS and HS programmes are outlined below.

Industrial Energy Transformation Fund (IETF)

The influence of the IFS programme on the IETF had previously been highlighted in the process evaluation report. The IFS programme had regular interactions with the IETF team during the design phases of the IETF. Examples of influence included the ability to speak directly to organisations involved in IFS and HS, insights into technology balance, using information on project costs to inform budget-setting, gathering insights on barriers and challenges, and incorporating modifications of terms and conditions.

Furthermore, the design of the IETF took into account the IFS programme in terms of:

- complementarity - there was a recognition of the need for complementarity between the IFS and IETF programmes (e.g. IFS operates at TRL levels 4-7, while IETF typically focuses on TRLs 8-9). While both programmes had their own aims and objectives, there was an effort to ensure the IETF was designed so that it would complement the IFS programme and support projects, sites and technologies that had been through the IFS programme, enabling them to move on to a more advanced stage of progression. Indeed, Departmental staff highlighted that organisations and site that received support from the IFS programme were also involved in the IETF, demonstrating the interconnectedness of the two programmes.
- eligibility requirements - the IETF included eligibility requirements that explicitly considered projects that might have received funding from various SICE or NZIP funds, including the IFS programme

The HS programme was also identified as having provided evidence for the hydrogen policy teams within the IETF.

Industrial Hydrogen Accelerator (IHA)

The IFS programme was highlighted in interviews as instrumental in the creation of the IHA, emerging as a result of the perceived success of the IFS programme. The IFS programme's influence on the IHA was evident in the creation of the IHA, its focus on hydrogen, substantial financial commitment, and the incorporation of lessons learned from IFS. The IHA was regarded as representing a strategic effort to accelerate the adoption of hydrogen in industrial processes, building upon the foundation laid by the IFS programme.

Low Carbon Hydrogen Standard

The HS programme's influence on the Low Carbon Hydrogen Standard was regarded as substantial. The programme helped to support cross-departmental collaboration, and the incorporation of critical emissions-related insights into the standard's design, ultimately contributing to the wider acceptance of low carbon hydrogen in the UK and Europe.

In particular, staff tasked with designing the standard felt that having access to insights on applied hydrogen production practice ensured that the standard was informed by existing industry experience. The insights gained from the HS programme, particularly related to fugitive emissions and upstream emissions, therefore played a crucial role in shaping the Low Carbon Hydrogen Standard. These insights helped identify key areas of concern from an emissions perspective and informed the development of the standard's specifications.

> *I think massively influential, because those are the only programmes that we had at the beginning on hydrogen production. And, essentially, that was the main insight into what we could see from hydrogen projects on the ground, from the UK, what's up and coming (Wider programme and policy staff)*

Hydrogen Business Model (HBM)

The HS programme was regarded as important in influencing and enabling the development of the HBM. The HS programme was perceived to have had an impact on shifting the debate and expectations around hydrogen supply, particularly in terms of the timescale for volume deployment, laying the ground for – for example in terms of accelerating technology development, fostering partnerships and supporting the hydrogen production supply chain - the HBM. There were also specific examples of the project leads of three of the HS demonstration projects directly feeding into the design of the HBM, including sitting on the working groups for the HBM.

Net Zero Hydrogen Fund (NZHF)

The design of the NZHF was also influenced by the HS programme. The HS programme was described as setting the ‘blueprint’ for the design of the NZHF. The NZHF borrowed from HS the programme’s delivery model when designing its fund, mirroring the structure, incorporating similar communications and engagement practices, and applying lessons learned from the HS programme.

The HS programme also helped inform the NZHF's decision to set an eligibility requirement that projects must prove their core production technology is at TRL 7 or above. This alignment was based on discussions with HS colleagues, who indicated that HS funding covered projects at TRL levels 4-7. This decision allowed NZHF to signal that they were picking up where HS funding ended (i.e. TRL level 8 and above), ensuring a smooth transition in technology readiness levels.

> *I know lots of teams in our hydrogen production side have spoken to the HySupply teams, when we were designing the fund. When we were thinking of which TRL level to pitch the fund at and how to design the fund (Wider stakeholder)*

Green Distilleries Competition

The IFS programme was also cited as having directly influenced the design of the Green Distilleries Competition, an initiative focused on promoting fuel switching and decarbonisation within the distillery sector, mirroring the success of the IFS programme in other industries.

Other

Other examples of the IFS and HS programmes having influenced wider policy, programmes or regulatory process included influence on:

- industrial electrification policy (potential revenue funding for electrification projects)
- the UKRI’s Industrial Decarbonisation Challenge Fund, and
- the Environment Agency’s regulatory approach to providing approvals for hydrogen production plants

Knowledge-sharing challenges

Whilst the programmes have been influential, however, the sharing of knowledge and learning from the programme design and implementation was not as systematic as some staff within the Department felt it could have been, as highlighted in the process evaluation report. This potentially limited the extent to which the IFS and HS programmes informed programmes and policies, suggesting they could have been more influential with more systematic knowledge-sharing.

Chapter 7: Impact on international reputation

This chapter examines the impact of the IFS and HS programmes on the UK's international reputation, as well as their global influence on the awareness and engagement with fuel switching and hydrogen supply.

Impact on UK visibility and reputation

A consistent theme in the interviews was the belief that the two programmes have had a positive impact on the UK's reputation in relation to fuel switching and hydrogen innovation production. Research participants frequently mentioned that the programmes reflected well on the UK, both internally and externally.

In particular, the presence of multinational companies participating in these programmes had drawn international attention and interest in the UK's capabilities and expertise in hydrogen supply and fuel switching.

Furthermore, the fact that the UK Government had allocated funding to support these programmes was regarded as a positive signal, especially alongside the UK Government's wider policy support, financial commitment and openness to international collaboration. One interviewee, for example, highlighted the significance of "consistent policy" and "legally binding support mechanisms," stating that these factors contributed to a positive view of the UK.

Additionally, a respondent mentioned that public funding through the HS and IFS programmes demonstrated the UK Government's willingness to support innovation, which could attract international investments.

> *"These international companies that were involved … could see how the government would support innovation in the UK and therefore there's more chance of them investing in the UK" (Demonstration project lead, IFS)*

Impact on the UK's leadership position

The UK was generally seen as a global player, with many believing that the UK is one of the leading countries in Europe in terms of innovation and funding in the fields of hydrogen supply and fuel switching. This recognition was in part attributed to the funding and support provided by the UK government for the IFS and HS programmes.

Many individual project participants felt that what they had been doing in the UK as part of the IFS or HS programmes had been more advanced than other sites they operated, or were aware of, internationally. This had helped to establish the UK as a leader in the minds of international stakeholders.

> *"Certainly I remember at the latter stages of [HS] being involved in a couple of working groups with the US and Canada. And their view was that, 'Wow. You guys, what you have been doing in the UK, particularly through this HS programme, is way beyond what we have been looking at here in North America.'" (Demonstration project lead, HS)*

Interviewees expressed the importance of maintaining the UK's leadership position in the context of fuel switching and hydrogen innovation. They saw the HS and IFS programmes as having been instrumental in preserving the UK's reputation and competitiveness.

Nonetheless, a counter view was that the UK's reputation may have peaked more recently, and others, such as the USA and the EU, have caught up or surpassed the UK in terms of funding and innovation in hydrogen supply and fuel switching. This suggests that the UK's leadership position may have diminished somewhat despite the existence of programmes like IFS and HS. The view was that conditions in the United States and other countries had become more favourable for innovation and investment (compared with the UK) because of new laws and policies, such as the Inflation Reduction Act.

> *"I think the challenge we now have in the UK is we have a certain number of companies that are active in this area but they have a lot of exciting opportunities in place, like the USA, where there's a lot of funding now" (Sector stakeholder, HS)*

Impact on international awareness and engagement

The interview evidence highlighted the findings from the programmes and their projects had been shared internationally, contributing to global awareness and engagement.

Public funding of the programmes was thought to have allowed the results and findings of these programmes to be shared more widely than if they were privately funded, contributing to the UK's reputation, even if (a) confidentiality issues related to project results may have limited the direct dissemination of findings to international parties, (b) respondents mentioned challenges in disseminating knowledge and suggested the need for better platforms for sharing information globally.

Respondents highlighted several different avenues through which the programmes had had an influence on international awareness and engagement:

- international companies involved in the programmes had shared the findings and knowledge they gained with their global counterparts – there were examples of large international players in the lime and heavy materials industry, for example, respectively, disseminating the findings across their global operations
- some companies expressed interest in applying the knowledge gained in the UK programmes to their global operations – for instance, an interviewee from a global company mentioned that the findings from its UK IFS project could influence their operations in various regions

- companies and other organisations involved with the programme reported approaches from organisations in other countries - either directly or at conferences – conversations included queries on specific elements of projects, overall project solutions, opportunities for investment and further work, and even one about business acquisition
- government-level interactions had been a channel for sharing information internationally – government interviewees provided examples of sharing details about projects within the programmes with other governments, leading to international interest
- there were mentions of the programmes attracting interest from other governments more spontaneously – for instance the IFS was thought to have inspired the Netherlands to explore creating a similar initiative, while a similar programme in Germany was closely following the HS programme, suggesting international interest and influence

Chapter 8: Value for money and unintended outcomes

This section considers the overall value for money of the IFS and HS programmes in turn. The analysis draws primarily on the interviews, but also from reports and studies produced by the projects and a survey of the projects seeking details of economic impacts.

Overview

Neither programme had measurable value for money outputs to enable more detailed assessment of cost effectiveness. Nonetheless, available evidence suggests that both programmes were cost-effective. For example, they both delivered what they had been commissioned to do for the agreed funding, levels of additionality appear to have been high, and there was measurable achievement in that both programmes made a contribution towards addressing the market failures they were designed for, in particular helping to overcome information market failures.

Industrial Fuel Switching programme

Cost effectiveness analysis

There were four demonstration projects supported at a total cost of £18.38m, these ranged from £2.82m for the British Lime Association project to £7.12m, for Glass Futures, the most expensive project.

For the programme as a whole, including the feasibility phase, 13 projects reported they had fully met their objectives, with 2 saying they had met most of them. Two further projects reported that some of the project objectives had been met and 8 reported that none had been met.

The demonstration projects delivered broadly what they had been funded to do, with some minor changes to planned activities owing to hydrogen supplies being more expensive than anticipated and to technical outcomes being different from expectations (see project chapter). There was no evidence reported from the interviews in terms of wastefulness or inefficiency in the project delivery. The programme thus passes the first test of cost effectiveness.

In terms of achievements, all the projects demonstrated they could achieve carbon savings, even if they were not able to wholly decarbonise the process. The BLA project, for example, only demonstrated 30% savings on carbon emissions with the industry recognising that the remaining 70% would also need to be addressed in order for the sector to stay fully competitive. But even where projects were not able to achieve full decarbonisation there were valuable learnings. For example, although one project reported that they were not able to successfully burn high levels of hydrogen (50%), that finding generated information that was not available before.

In terms of advancing the wider programme objectives, the Business Case for the IFS programme identified the following market failures:

- **unpriced or under-priced negative externalities** – carbon prices do not reflect the true cost to society of releasing pollutants and GHGs into the atmosphere, therefore industries release these at a higher level than it would if these costs were fully priced in.
- **information failure** – as fuel switching technologies are new, firms are unsure if and how these technologies will work in practice and firms do not know the true carbon savings from installing these technologies. Furthermore, there are positive spillover effects from demonstrating new technologies.

The programme did not directly reduce carbon emissions or address the under-pricing of carbon emissions, so did not address the first of these market failures. But there was strong evidence that it acted on the second of these market failures, as reported in the awareness raising and engagement section above. Information sharing and awareness raising extended to sectors not directly involved in the IFS programme. For example one stakeholder reported that *"I think, it's definitely raised awareness across all sectors, really, particularly, food"* (*IFS demonstration project*). Some of the information sharing and awareness raising impacts of the IFS programme were ongoing, through the increase in domestic capability in the UK, as outlined above.

Specific barriers to further deployment of fuel switching technologies were identified in the Business Case for the IFS programme as:

- **limited access to finance for cost-effective low carbon investments** - this was noted as applying to both internal and external finance
- **uncertainty over the future use of hydrogen as fuel** – there was significant uncertainty over whether investment in hydrogen technologies would result in a positive return on investment, or the potential rate of return.
- **unstable and uncertain carbon and energy prices** - carbon abatement costs were noted to be highly sensitive to changes in the price of electricity and gas for heating. This uncertainty was reported to deter potential investors in fuel switching technologies as it made returns to investment more difficult to determine

There was no clear evidence that the IFS programme played a role in lowering these barriers. However, the programme did confirm the importance of these barriers. In particular, it was clear from project lead interviews that scale up of hydrogen-related technologies would be dependent on there being a consistent and reliable supply of hydrogen. So, ultimately, the successful adoption of industrial fuel switching to hydrogen, consistent with the longer term goals set out in the theory of change, is dependent on the success of the Hydrogen Supply initiative. This dependence does not apply to switching to biomass fuels, which formed part of IFS project activities[18].

The cost effectiveness of fuel switching depends not just on the supply of alternative fuels (e.g. hydrogen, biofuels or electricity) but also on the cost. Projects reported that the cost of hydrogen needs to be significantly reduced to make hydrogen use viable. It was also reported that the cost of hydrogen impacted the ability to do more trials with a reported increase in the cost of hydrogen of 300% during the programme, for reasons explained in the process report.

There thus needs to be more certainty to encourage investment. As the BLA report concluded, "*transferring the UK lime sector to 100% hydrogen firing [..] could require new investment between £60 and £120 million, highlighting the need for a stable and predictable policy environment."* The Government's 'Hydrogen Strategy Update to the Market: August 2023'[19] set out proposed policy responses to address these types of concern, including a proposed Hydrogen Business Model linking the cost of low carbon hydrogen to the cost of natural gas.

There was some evidence about the steps projects on the programme had taken toward commercialisation. 2023 KPI returns showed that one project had reported taking 'considerable steps' towards commercialisation, two reporting taking 'some steps' towards commercialisation, while the other reported it had taken no steps towards commercialisation.

Levels of additionality from the programme were high. Project partners reported no duplication from the programme activities. All project partners were clear that they would not have been developing these technologies without the programme support. Most were in agreement that government funding was necessary, though one of the wider stakeholders thought the projects should not be 100% government funded and that the companies should pay for part of the research as they were gaining a benefit from it. A wider stakeholder also commented that additionality might be less strong for projects involving switching to biofuels rather than hydrogen.

When examining potential benefits from the IFS programme, we looked at four factors:

- employment and supply chain impacts
- knowledge spillovers
- monetized carbon savings
- additional investment

Employment and supply chain impacts

2023 KPI returns reported that the cumulative number of FTEs delivering IFS projects across the programme was 31.

[18] The IFS programme did not aim to exclude fuel switching to electricity but, as explained in the process report, the successful demonstration projects happened to involve only small elements of electrification.

[19] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1179651/hydrogen-strategy-update-to-the-market-august-2023.pdf

Data provided to the evaluation team by two of the projects indicated that one project had employed five people during the project phase and another had employed eight. The types of jobs supported during the project phase included project manager, software engineer, computer modeller, environmental engineer, safety specialist (both site and hydrogen supplier) and site technical engineer. These were posts funded by, and for the duration of, the programme.

The evaluation team also sought data about future jobs that may be created through a wider roll out of the IFS technologies. The projects responded that industrial fuel switching has potential to safeguard existing industrial jobs, or enable transition to new roles, but is not expected to create significant numbers of net additional jobs. For example, all jobs in the lime industry are considered at risk if the industry does not decarbonise as it will no longer be competitive.

> *It is more about maintaining jobs than growing them. (Demonstration project IFS)*

> *Retention of jobs, I think that's more long-term. If we don't use hydrogen, we'd end up just importing it, because the carbon costs would be too high in the UK. (Demonstration project IFS)*

It was expected that there would also be some displacement of jobs from the natural gas industry, as part of the transition from a fossil-fuel economy to a low or zero carbon economy.

> *"Maybe where we are today many of the people on the project, like myself, are coming from an oil and gas background. We're transitioning ourselves towards… I've been working for four and a half years on carbon capture and storage projects and I'm no different to many of the other people who are working on Acorn. It's happening now, that retention. The skills that we have developed on the projects we've worked on before, albeit oil and gas related, are perfectly transferable to energy transition projects. It's not only something in 5 or 10 years' time, it's a journey that we're already on." (Project partner HS)*

As noted in the investment section above, there were reportedly firms in the supply chain that achieved significant growth in business as a result of their participation in the project. These included a burner manufacturer making hydrogen-ready burners and an engineering company that was reported to have gained additional work as a result of being involved in an IFS trial. As reported in the investment section, there was also some growth in activity amongst project partners. *"Glass Futures grew from a one-man band to 45 people. [They] built a team with a diverse background, younger workers, female scientists." (IFS/HS programme management staff)*

Supply chain constraints were reported in that 'grey' hydrogen was difficult to source, with the projects noting that it was impossible to source 'green' hydrogen at the quantities required. In addition to absolute constraints, we also asked whether supply chain needs could be met from within the UK. Items reported as having to be imported as they were not available in the UK included a plasma torch used in the BLA project and lime-specific technical support.

There was consensus from stakeholders that scaling up the technology would require a large and reliable supply of green hydrogen that is not currently available. They reported that there was a need for new infrastructure to support the transport and storage of hydrogen. But evidence collected by the evaluation suggested that goods and services needed to scale up the technology could be sourced in the UK.

Shortage of skills workers was flagged as a critical factor for future development of industrial fuel switching.

> *[..] what else is required to make this project successful? So, if you haven't got your gas fitters, if you haven't got staff training, if you haven't got your permitted people competent in looking at hydrogen, you can't get your whole project through. So, you've actually got to look wider. So, it is knowledge sharing, or upskilling, but it's putting those additional resources into the normal operation of a site. (Wider stakeholder)*

Business relationships

The programme was successful in helping to establish business relationships. 145 new business relationships were reported as having been established through the programme's 2023 KPI returns. 44 of these were described as being 'formal relationships', 101 were 'informal', and 80 were classed as being completely 'new' relationships.

Knowledge spillovers

As noted in the projects chapter, there was evidence that the projects delivered on the formal dissemination activities they were contracted to undertake. Outside of the formal dissemination programmes, there was informal awareness raising of the work of the projects. As noted in the 'awareness and engagement section', partner organisations like Glass Futures and Progressive Energy undertook a great deal of knowledge exchange activity.

Knowledge was also reported to have grown within the project partners as well. One project partner reported that the project had changed the way their business thought about Research and Development. Without doing the fuel switching and smaller projects, they would not be doing as much as they are now. Another project partner has suggested that the learnings from the programme are being applied elsewhere in their organisation.

> *Some of the partners had a very low level of knowledge, but hopefully, by the time they finished, they had a much better understanding of what is required to go to fuel switching. (Wider stakeholder)*

Monetised carbon savings

There was very little in the published technical reports that gave data on carbon savings and related project costs, and we have recommended that future programmes require the production of more consistent and transparent data from projects about key outputs to support future impact evaluations.

HyNet stated that switching to low carbon hydrogen could result in major CO2 savings. Examples given were:

- decarbonising steam supply from boilers in the UK might save 5 MtCO2 annually
- converting around 50 glass-making sites in the UK to hydrogen could reduce emissions by approximately 1.2 MtCO2 annually

MPA calculated a “Cost of CO2 Avoided (CAC)” of 1559 €/tCO2, based on hydrogen comprising 40% of the thermal input to the main burner compared to a reference based on 100% coal. This was noted as many times higher than would be expected from CCUS technologies where the expected range was 55 to 170 €/tCO2

Glass Futures reported that the total investment requirement for fuel switching was estimated at around £500 million by 2040, with a positive NPV expected around 2060. This represents the "break-even" point, with initial costs outweighed by long-term savings. It also stated that biofuels offer greater value for money but there remains an economic barrier.

Additional investment

Two of the four IFS demonstration projects reported in their 2023 KPI returns that they have received follow-on funding, equating to £144m. £103m of this was from public sources, £2m from the private sector and a further £2m from unspecified sources.

Furthermore, Chapter 5 presents strong evidence that activities undertaken by the IFS programme and its partners helped to catalyse a number of proposed investments relating to innovation and early deployment of industrial fuel switching, from both the public and private sector. These included:

- Encirc and Diageo’s proposed £100 million investment in a multi-fired glass furnace in the Northwest (capable of being hydrogen-fired)
- Glass Futures’ new testing facilities, funded by UKRI and Liverpool City Region at a cost of £54 million

In addition, IFS helped to catalyse Essity, Kellog’s and Novelis demonstration projects in the IFS2 programme, which were 100% funded by the Department at a value of £27 million.

There was also more interest from other sectors such as distillery and ceramics in undertaking innovation work on fuel switching, which informed bids to the Department-funded Green Distilleries and IFS programmes.

> *I think maybe other those other sectors, there’s maybe been an acceleration of some of the thinking around the research that’s needed. (Wider stakeholder)*

> *Glass Futures has encouraged other foundation industries such as Ceramics and Steel to look at fuel switching (Wider stakeholder)*

Through initiatives in the Northwest, led by Glass Futures and HyNet and combined with wider HyNet cluster initiatives, the programme was reported to have had a wider impact on innovation investment in fuel switching than the IFS projects themselves.

> *So that's where the programme has a wider impact. It's done what it said it was going to do, in terms of those projects. They would've had a certain impact on their own but the connection with other things is enabling a lot more so the impact is broader than you might think, you know. (Wider stakeholder)*

There has been some growth in wider investment in the technologies to support industrial fuel switching because the market is recognising the future growth opportunities. In this regard the political and institutional frameworks were probably the key driver. But the demonstration projects may have had some influence in showing what is possible, or in bringing forward investment, through the mechanisms outlined in the 'investment' section above.

> *[there was] direct investment from [the] private sector in low carbon glass and decarbonising boilers, not necessarily linked to programme but going on at same time.* (*IFS/HS programme management staff*)

> *I think it's expedited… If anything, what it's done is it's brought forward private spending that might have sat on the shelf for longer. (Wider stakeholder)*

The IFS programme contributed to the current appetite for innovation investment in fuel switching, particularly around potential industrial use of hydrogen, but several industry stakeholders commented that it was too early to say whether IFS will have an impact on the longer term goal of widespread deployment of industrial fuel switching. There are still considerable barriers to wider deployment in terms of concerns about the volatility of fuel prices, the economic viability of switching to more expensive fuels (particularly hydrogen and electricity) and the lack of required infrastructure (for hydrogen supply, storage and transport and for electricity grid connections).

Conclusion

To summarise the overall assessment of value for money, the IFS programme made a contribution to overcoming market failures and – given its size – played a considerable role in catalysing further innovation activity relating to industrial fuel switching, beyond the IFS projects themselves. But, in the absence of government funding for infrastructure for alternative fuels (particularly hydrogen and electricity), and operating cost support for hydrogen use through the proposed Hydrogen Business Model, widespread take-up of industrial fuel switching remains unviable at present, except possibly for biofuels. Further government support is needed to support wider roll-out of industrial fuel switching at scale.

Hydrogen Supply programme

Cost effectiveness analysis

Hydrogen Supply was a £33m programme. Phase 1 cost £1.7m. In the demonstration phase five projects were funded at a cost of £28.24m. Three projects received around £7.5m each and the other two around £3m each. In addition, programme KPI analysis highlighted that one HS Phase 2 project received an additional £3m of private investment.

As experimental projects, there were no tangible measurable outputs in terms of what was expected per £m of funding. For the programme as a whole including the feasibility phase 19 out of 28 projects reported they had fully met their objectives. One project reported that some of the project objectives had been met, while 7 reported that none had been met. For one project, achievement of project objectives was reported as ‘not applicable’.

One project, (HyPer), was considerably delayed and was still underway at the time of this research. The process report details the management issues encountered on this project. There was no extra cost to the Government and the project is expected to deliver its objectives in due course. Another project (HyNet) had a modest increase in cost due to the technical design rework deemed necessary by a change in the site selected.

With these exceptions, the projects delivered what they were funded to do in terms of demonstrating alternative technologies to enable increased production and reduced costs of hydrogen. With the exception of the HyPer project, the HS projects primarily involved desk research (e.g. FEED studies) with limited trial and testing of technologies.

> *Programme was not about demonstrating you could reduce costs but demonstrating that these things could be done (IFS/HS programme management staff)*

Nevertheless the projects were able to demonstrate that the chosen technologies could reduce cost of hydrogen production, if not yet to the levels where it would be commercially viable. One project (HyPer) reported that they would be able to produce hydrogen 20%-30% cheaper than existing technologies.

Beyond demonstrating technological capability, the programme should look to make progress towards the commercialisation of hydrogen supply. The Business Case for the Hydrogen Supply programme identified a number of market failures that justified intervention:

- **imperfect information** - firms are unsure as to the feasibility and potential of hydrogen
- **co-ordination failure** - the gas industry is a heavily fragmented market and there is a perceived lack of certainty about Government’s strategic direction on heat decarbonisation
- **unvalued benefits of knowledge spillovers** - these wider benefits are unlikely to be taken into account by private investors in their decisions, as they may not be the ones benefitting from the spillovers

- **unpriced negative externalities** – the true cost to society of releasing pollutants and GHGs into the atmosphere are not fully reflected in the price of energy, resulting in less incentive for private investment into low carbon technologies (i.e. hydrogen for heat) and associated research, development, and demonstrations (RD&D) than would be socially optimal

The programme made progress on the first two of these points. In particular, at the end of the programme there was better information and far greater awareness and understanding of the role that hydrogen is likely to play in decarbonising the economy. Evidence presented in the 'awareness and engagement' section above indicates that the programme played a role in this, though there were also wider market moves in this direction.

There was also more direct evidence about the steps projects on the programme had taken toward commercialisation. 2023 KPI returns showed that four patents had been applied for by HS Phase 2 projects, with 2 being granted and 1 published. All five of HS demonstration projects also indicated in the KPI returns that they had taken some steps towards commercialisation.

There was also some evidence of knowledge spillovers, the third point, as discussed further below. The programme does not impact directly on the fourth point relating to negative externalities.

The Business Case for the HS programme also identified a number of market barriers to development of hydrogen supply, namely:

- **regulatory barriers** – the gas network is heavily regulated and will require a strategic decision by government to move away from natural gas
- **high upfront capital costs** - the high cost of hydrogen production and technologies required to adapt the network poses a barrier to greater diffusion in the market
- **uncertain consumer demand** – industry demand for hydrogen is uncertain. This is due a current lack of evidence on industries attitudes towards hydrogen

Feedback from stakeholders involved with the programme confirmed the extent to which the latter two were major barriers but the programme has helped to provide further understanding of what might be done to address these barriers. It also became clear that it is not just the capital costs that are an issue but also the operational expenditure.

> *Because what is really evident within all the work we have been doing, not just on blue hydrogen but also on green hydrogen, is that the capital cost of the equipment is actually a really small component of the overall levelised cost of hydrogen. (Demonstration project lead)*

Levels of additionality for the programme were high. Public funding was not seen as substituting for private investment.

> *We got the funding through [the Department], we weren't able to get it through the private sector (Demonstration project lead)*

> *I certainly don't think there has been any crowding out of private sector money. I think if anything it's encouraged private sector money into the sector. [In terms of] duplication, again, nothing obvious from my understanding of the projects. (Wider stakeholder)*

Project partners did not say that the activity would not have happened in the absence of the programme but HS funding was reported to accelerate it. One partner noted it would have been two or three years slower without it.

> *I think they would have happened, but I think we are about two, probably three, years further ahead of where Scotland would have been if we hadn't had the HS Phase 1 and HS Phase 2 funding (Demonstration project lead)*

Although difficult to measure in any meaningful way it was reported that there were cumulative benefits from HS funding in parallel with public investment in industrial clusters such as HyNet. To the extent that these cumulative effects have occurred, this would add further to the value for money of the programme.

Five types of potential benefit from the HS programme are explored below:

- employment and supply chain impacts
- potential market for hydrogen
- knowledge spillovers
- monetized carbon savings
- additional investment

Employment and supply chain impacts

Employment

2023 KPI returns reported that the cumulative number of FTEs delivering HS projects across Phases 1 and 1 was 59.

As part of the research, the evaluation team undertook a short survey of projects asking for details on employment and other economic issues. Two projects responded. Each of the two projects that responded said that they employed 20 full-time equivalent workers during the project phase, either directly or through contractors. For one project the jobs were predominantly technical and engineering roles, while for the other the posts were more varied (including a design engineer; construction worker; academic; project manager; and financial/contract/procurement staff). A third project published a report stating that the project had employed 100 people directly and would support an additional 180 jobs in total.

One project reported that technicians, operators and welders have been particularly hard to find and one reported difficulty in finding economists. Given the short-term nature of the demonstration phase, the projects continued to pursue recruitment of necessary skills rather than train up workers.

More generally the industry was seen as attractive for potential employees. One consultee noted that a lot of high-quality highly skilled people were coming into the hydrogen industry because that is where they want to work. One consultee felt that the programme had an impact in developing skills for the hydrogen industry.

> *[HS] had an accelerating effect on developing engineering skills in looking at hydrogen (IFS/HS programme management staff)*

Supply Chain

The principal expenditures incurred by the projects were in design and construction of the hydrogen plant. Other costs included legal, planning and utilities.

One project reported that well-manufactured vessels and pipework has been challenging to source and that pipework, vessel metals and compressors had to be imported as they could not be sourced in the UK. More generally it was reported that there had been a real issue with supply chains due to COVID and also that EU Exit had pushed up costs of imports.

One project noted that the hydrogen industry could tap into the existing oil gas and offshore industries as a rich source of supply chain potential. This would also provide opportunities to transition away from fossil fuel industries, mitigating some of the downside economic impacts of the move away from fossil fuels.

> *All of that supply chain, that's in mostly the UK for the oil and gas sector or the offshore wind sector, we've had really good gradual drip feeding of people saying, "Hey we've read this, by the way we manufacture this for the oil and gas industry proven for 50 years. We'd love to move into low carbon do you mind putting us on your supply database so that when it goes out to tender, we get an option to bid into it." So that has been great. (Demonstration project lead)*

It was reported that the programme had a positive impact in developing skills and capacity in the supply chain.

> *So Acorn Hydrogen has helped to put, through the wider efforts of the team- It has [..] helped to really build that presence and that capability of the supply chain within Scotland (Demonstration project lead)*

But there were concerns that there were still likely to be capacity constraints in scaling up the hydrogen supply industry.

> *The biggest challenge in the big picture is that the engineering industry does not have the resources it needs to deliver what government wants to deliver, and I am not sure that it will. (Demonstration project lead)*

Business relationships

The programme generated a large number of business relationships. 215 new business relationships were reported as having been established through the programme's 2023 KPI returns. 115 of these were described as being ‘formal relationships’, 100 were ‘informal’, and 206 were categorised as being completely ‘new’ relationships.

Potential Market

The future market for hydrogen, and the number of associated jobs it may support, are potentially of substantial scale. Estimates of the potential market vary. For example, the UK Hydrogen Strategy[20] states that:

> *“Analysis suggests that in 2030 the UK hydrogen economy could be worth £900m and support over 9,000 jobs. Around a quarter of these jobs could be driven by British supply chain exports.*
>
> *By 2050, under a high hydrogen scenario, the hydrogen economy could be worth up to £13 billion and support up to 100,000 jobs, with exports growing in relative importance.”*

The Scottish Hydrogen Assessment report[21], focussing just on the market in Scotland, states that:

> *“In the most ambitious scenario, establishing Scotland as an exporter of green energy to Europe could result in a £25 bn contribution to Gross Value Added (GVA) with over 300,000 jobs by 2045. This would be achieved by unlocking Scotland’s vast offshore wind potential, but would be dependent on Scotland producing green hydrogen that is competitive in a European market.*
>
> *Supporting a domestic hydrogen market is likely to support anywhere between 70,000 to 175,000 jobs (£5-16 bn GVA) and is very dependent on the extent of the penetration of hydrogen in the energy system.”*

Knowledge spillovers

Knowledge sharing was reported as quite good during the programme and has continued post-programme. As noted in the project chapter, a number of formal dissemination channels were established. And, as noted in the awareness and engagement section above, there has been a noticeable shift in attitude about hydrogen over the programme period, although it is difficult to be specific about the contribution of the HS programme to this. Ways in which the HS programme contributed to reducing risk and uncertainty, including firming up estimated costs, are also documented in the ‘risk and uncertainty’ section above.

One project lead highlighted the importance of knowledge shared by HS representatives within the Hydrogen Business Model working groups in the Department. As explained further in the policy influence section above, this allowed insights from the HS programme to inform policy

[20] UK hydrogen strategy (2021), https://www.gov.uk/government/publications/uk-hydrogen-strategy
[21] Scottish hydrogen: assessment report (2020), https://www.gov.scot/publications/scottish-hydrogen-assessment-report/

development. This interviewee commented that the Hydrogen Business Model will have a big influence on whether or not future hydrogen projects are implemented.

One consultee wanted to differentiate knowledge transfer from education. There was evidence that both have occurred as a result of the programme.

> *We run a lot more educational activities around hydrogen, so there are a lot more courses that we provide which are related to hydrogen. Then we have a lot of hydrogen related research projects on production, storage, end use and systems, so in the academic world there's a lot more active research on hydrogen. Then there's a lot more collaboration with industry on hydrogen. We're seeing, yes, a lot more activity in this space. (Wider stakeholder)*

New structures have also been established to support development of hydrogen in a more strategic way, both within academic institutions and within businesses.

> *One of the things that Cranfield has done since HyPer is that we made hydrogen a strategic priority and we formed this hydrogen research network within the university. We've got a strategy committee. There have been lots of top-level commitments towards hydrogen research in the university that would not have happened without it. (Demonstration project lead)*

Whilst not documented in evaluation evidence, there will also be some more informal knowledge spillovers as people move between jobs.

> *People don't breach NDAs but knowledge is porous, it spills out and people move around jobs (Demonstration project lead)*

Monetised carbon savings

Capital costs were reported to be rising fast at the time of this research. But both capital and operational costs were reported to be important for future hydrogen supply.

Estimated LCOH costs were published in the final reports of three projects, Acorn Hydrogen Gigastack and Dolphyn. The costs put forward by Acorn Hydrogen were reported to be *"broadly consistent with the range of hydrogen costs developed by [the Department] in the Hydrogen Strategy".*

Table 5: Acorn Hydrogen - predicted LCOH

	Now	Future (2040s)
Cost per kg of hydrogen	£6.15/kg	£1.5/kg
Cost per kWh of hydrogen	5.4-8.4 p/kWh	2.6-4.2 p/kWh

Source: Acorn Hydrogen

Significant savings in the costs of generating green hydrogen were predicted by the final report of the Gigastack project. Gigastack reported that the Levelised Cost of Hydrogen (LCOH) was calculated at £7.93/kg of hydrogen in the base case and between £5.11 - 5.44 /kg of hydrogen in the low-cost case. This cost was predicted to fall by around 47% to £2.80 /kg of hydrogen by 2030, as future plants were deployed using ITM's electrolyser stack technology[22].

The ERM Dolphyn report provided a figure that was "slightly higher" than industry benchmark and stating that, after government support, the LCOH would be in the range of interest for potential offtakes (quoting "a hydrogen target price of £6.15 for the Aberdeen Hydrogen Hub). It also estimated that by 2040, hydrogen at a price of around £1.50/kg would be available for bulk-scale production from ERM Dolphyn projects.

Some project leads mentioned that supply chain constraints and inflationary pressures at the time of the evaluation research might lead to changes in capital cost estimates for hydrogen supply plant. So there is an inflation risk on these figures. However, some elements of inflation risk may also apply to capital investments in other fuels.

Additional investment

As highlighted above, one HS Phase 2 project received £3m of private investment for the project itself. Furthermore, KPI returns showed that four of the five demonstration projects have informed related projects that have received further funding, with a total of £91 million follow-on funding received (as reported in the 2023 KPI returns). £12m of this follow-on funding was public sources, £2m was reported as being private funding, and the source of the remaining £77m of follow-on funding was unspecified.

The HyNet cluster and Acorn were in receipt of multiple forms of support, so attributing any additional investment to any one programme was problematic. But the industrial clusters were reported to be a source of major investment activity. As set out in the investment section above, HS and cluster investment appeared to be mutually supportive.

> *"A lot of the investments that are happening in the clusters, particularly the Northeast and Northwest clusters, are happening because they know that the companies in the UK will be able to switch to hydrogen." (IFS/HS programme management staff)*

Some projects also demonstrated evidence of additional innovation investment in terms on contribution in kind to related parallel projects.

> *As part of the valuation, we had to go through this process. So, in terms of contribution in kind, ERM have put in about the same across all the phases, they've put in about the same as [the Department] put in. So, including current phase that's about £12m that ERM has put in. (Demonstration project lead)*

And some projects have been able to identify direct innovation investment because of the programme. In other cases, Government funding gave private partners more freedom as to

[22] Gigastack Phase 2: Pioneering UK Renewable Hydrogen – Public Report for the Department

where they invested in other related parts to the development of hydrogen supply system (e.g. storage, transport).

> *We've got at least a £1 million that we can identify, to say it's come on the back of HyPer. (Demonstration project lead)*

> *We are going way above that in terms of what we are now funding through the Acorn Development Agreement with Storegga, Shell, Harbour and North Sea Midstream partners, in terms of that dual FEED. (Demonstration project lead)*

As noted in the 'investment confidence' section above, the programme was seen as having an important role in getting potential investors interested. Some projects also reported a lot of international interest in their project, with the potential for exports going forward.

> *"But when you talk about projects, risk is usually about capital, and about investment. So, that funding early doors, and endorsement from the government, we're told, is really helpful to keep investors interested, and get them over that financial investment decision-making process. So, we're convinced that that's really helping those projects to get investors involved, and retain them." (Wider stakeholder)*

However, Final Investment Decisions in hydrogen production plants were reported to be dependent on further government support, for example via the Hydrogen Business Model.

> *I would say we haven't unlocked anything additional as of yet. However, long term, we will consider an application to the next hydrogen allocation round in the hydrogen business model. (Project partner HS)*

For the most part, project partners reported that they were looking at future investment but were still cautious at this stage. For example, one of them noted, *"The project's not yet at a stage where they're investing in specific technology. [We're] working with technology providers looking at which technologies might work, but not investing in any yet." (Project partner, HS)*

To summarise the overall assessment of value for money, the HS programme made a considerable contribution to overcoming market failures and to progressing projects towards viability, as expected for an innovation programme. But hydrogen supply cannot currently compete on price with other fuels. Further government support is needed to support final investment in hydrogen production plants if the longer-term goal of widespread demand and supply for hydrogen market is to become a reality. Such support is in the process of implementation through the Hydrogen Business Model.

Unintended outcomes

Common unintended outcomes

Unintended outcomes common to both programmes included:

- funding competition and capacity issues - multiple interviewees mentioned that the funding competitions led to challenges in terms of programme capacity. There were more projects seeking funding than available funds, which limited the number of projects that could be supported. The competitions may have therefore missed out on funding some potentially valuable projects, although we also note that it is not atypical for applications to programmes of this nature to be oversubscribed
- duplication of effort - while interviewees did not provide concrete examples, there were mentions of potential duplication of effort with other national or international programmes. It was suggested that there might have been cases where projects were working on similar goals, leading to inefficient use of resources. However, the evaluation did not find any direct evidence of such duplication, and it was difficult to assess whether similar activities had been undertaken in other countries

Hydrogen Supply Innovation Programme

For the HS programme specifically, two unintended outcomes were identified:

- supply chain challenges: one interviewee highlighted the challenges of moving and delivering hydrogen effectively. Initially, there was a misconception that hydrogen transportation would be simple, but it turned out to be more complicated, involving factors like flow rate and pressure, which led to the need for specific infrastructure
- Low Carbon Hydrogen Standard influence (see above) - the establishment of a Low Carbon Hydrogen Standard was considered as a positive unintended consequence, influencing the acceptance of blue hydrogen in the European Union, particularly in Germany. This standard helped bridge the gap between green and blue hydrogen

Chapter 9: Wider findings

This final findings Chapter presents findings from the impact evaluation that do not directly relate to the impact evaluation questions.

All respondents to the evaluation were asked if they had any further comments pertaining to the IFS and HS programmes, funded projects, or hydrogen supply and fuel switching more widely. The following section summarises responses to this question, and respondent views provided throughout interviews, that do not fit easily within previous chapters, but nonetheless provide useful wider insight into stakeholder views and perceptions:

Continued funding

Common across respondent groups was a reiteration of the importance of continued Government funding for HS / IFS activity. There was a particular emphasis on focusing future funding on progression of projects from research to demonstration. Project team representatives noted that gaps between funding programmes and projects can mean project teams are disbanded; key personnel / expertise are sometimes lost to other activities, or even other organisations entirely.

Multiple respondents felt that more organisations would be looking more at hydrogen projects, but that the landscape – in terms of energy policy, support mechanisms and priorities – is very crowded and potentially confusing, with ‘a lot to get your head around’[23].

Views on wider development of hydrogen supply and switching in the UK

A number of respondents addressed the wider question of whether and how hydrogen production could be progressed in the UK. Comments and suggestions included the following:

- regional opportunities - respondents noted regional disparities in hydrogen production opportunities. Scotland, with lower demand compared to England, might have the potential to export hydrogen, for example. Existing industrial clusters and infrastructure were seen as immediate opportunities
- industry focus - some participants recommended focusing on industries heavily reliant on natural gas, where electrification is challenging, such as heavy-duty transport and aviation. Interest in electrolysers is growing, although concerns about rare metal usage persist

[23] It should be noted that one programme participant felt there should be more investment from wider stakeholders, and development of UK hydrogen should not be reliant on Government funding.

- types of hydrogen - opinions varied on the feasibility of green hydrogen, with some deeming it not yet scalable. However, increased renewable energy production and geopolitical factors like the Ukraine conflict could make green hydrogen more viable. "Turquoise hydrogen" from pyrolysis of natural gas was also highlighted as an opportunity
- grid network investment - respondents stressed the need for greater investment in the grid network to facilitate hydrogen distribution
- information sharing - stakeholders suggested that the government should improve information provision by formalising and increasing the volume of information sharing Forums for industry updates and more accessible information were proposed.
- regional regulatory challenges - sharing best practice on gaining permits was regarded as challenging as different countries within the UK have differing regulations
- crowded programme and policy landscape - many organisations are interested in hydrogen, but there was a concern that the complex energy policy landscape can be confusing, and that uncertainty about policy directions can lead to inertia in decision-making
- long-term costs - respondents noted that long-term operational expenditure (OPEX) is poorly understood and underreported in funding applications
- infrastructure challenges - building major infrastructure in the UK was perceived as challenging due to factors like labour costs, productivity, and regulatory restrictions
- public communication - to garner greater public support for hydrogen infrastructure, a communications campaign was suggested to explain the ongoing focus on hydrogen and its complementary role alongside renewables

Programme design and delivery

Respondents were overwhelmingly positive about the HS / IFS programmes in terms of their focus and the progress they enabled. However, a number of respondents suggested improvements to the design and delivery of future HS / IFS programmes (or those like them). Their suggestions encompassed various aspects:

- reducing administrative burden - respondents, particularly from smaller and less experienced organisations, recommended streamlining administrative tasks, especially in areas like monitoring and reporting. However, specific areas needing simplification were not identified
- flexible programme timescales - several respondents across different groups suggested making programme timescales more flexible, especially regarding deadlines for hydrogen production. They acknowledged the need for timely delivery but noted that rigid deadlines might discourage ambitious projects that require longer timelines
- rolling funding allocation - project representatives advocated for a rolling allocation system rather than fixed windows, which would reduce pressure on applicant teams and

allow more time for project design and planning. Additionally, there was a call for longer notice before funding windows open

- stakeholder input on programme design - respondents proposed that potential participant organisations should have the opportunity to contribute to the design and scope of future funding programs. They emphasised the importance of programme designers responding to industry requests regarding programme timescales
- funding award decision transparency - some respondents, particularly those from feasibility and unsuccessful applicant groups, questioned the transparency of funding award decisions. They raised concerns about whether their solutions had been fully understood and scored correctly. Additionally, there were concerns that information requirements during the feasibility funding application stage were too advanced, potentially conflicting with the aims of that stage. To address these issues, one respondent suggested preliminary discussions and coaching for interested parties to improve the quality of applications and project outcomes

Chapter 10: Conclusions

This chapter sets out the key themes from the evaluation research and lessons for future programmes.

Key themes

The evaluation found that the IFS and HS programmes played an important catalytic role within the early stages of UK activity on hydrogen supply and industrial fuel switching, both within industry and within government. Their influence on innovation was enhanced by the early timing of the programmes relative to the wider framework provided by the UK Hydrogen Strategy and Net Zero Strategy.

The timing of Departmental support catalysed greater engagement around industrial fuel switching, at a time when companies were becoming more committed to Net Zero and becoming aware that they needed to switch away from fossil fuels in future. The IFS programme provided practical evidence of hydrogen and biofuels being used on industrial sites and supported the development of testing facilities and increased skills/capacity in the fuel-switching supply chain, sparking innovation and demonstration activity beyond the sectors involved in the IFS programme itself. This contributed to higher levels of innovation activity on industrial fuel switching in other Government-funded programmes and had some early impacts on private sector activity.

Similarly, Departmental support for HS catalysed early activity on hydrogen supply, being the first major hydrogen-related innovation programme in the UK. As well as supporting the progress of the specific projects within the HS programme, this early timing allowed HS to influence thinking and policy development in Government and raise regulatory issues associated with the production, transport and use of hydrogen. Learning from HS had a catalytic effect on some important elements of Government policy, including the low carbon hydrogen standard and the Hydrogen Business Model.

The support that Government provided to both the IFS and HS programmes helped to generate confidence for businesses to pursue hydrogen production and fuel switching, by showing that Government was committed to these areas.

Furthermore, both programmes provided Government with access to invaluable, practical examples of how the technologies worked in practice, highlighting the realities of how they worked on the ground and highlighting practical challenges (e.g. in terms of regulatory issues). They were an invaluable reference point for programme and policy design, as well as giving unique insight to industry, and providing examples that enhanced the UK’s reputation at home and abroad.

While the IFS and HS programmes were conceived and developed at a time when there was relatively little activity in the UK on industrial fuel switching and hydrogen supply, the policy and support landscape in this area has evolved and become more complex during the lifetimes of the programmes. While this brought challenges in terms of industry capacity and potential confusion between funding schemes during the later stages of the programme, the evaluation found evidence of cumulative benefits from the interrelationships between IFS and HS and other programmes. For example, support from the industrial clusters programme enhanced the future feasibility of IFS and HS demonstration projects while HS contributed to the viability of clusters by progressing potential near-term hydrogen supply. IFS and HS also provided early-stage funding for projects that progressed onto other funding programmes such as IETF and NZHF.

The reach of IFS was enhanced by the involvement of 'catalyst' organisations such as Glass Futures and Progressive Energy, whose business was to generate more innovation and demonstration activity in a range of industrial sectors. Again, there was synergy with cluster activity because clusters encouraged information sharing and site visits within geographic networks of industries. Catalyst organisations such as Progressive Energy and Storegga played a similar role in the HS programme, feeding into geographic networks in both the Northwest and Scotland, but the involvement of major players such as oil and gas companies was also important for the credibility of HS projects in the eyes of investors.

Despite the success of IFS and HS influence on innovation and demonstration activity, the market for the deployment of IFS and HS technologies remains in its infancy. Industrial fuel switching is still uneconomic in many instances, particularly for fuel switching to hydrogen. There has yet to be widespread take-up of industrial fuel switching or major investment in a hydrogen-production plant. Evaluation evidence highlighted the need for further government support and a clear, sustained policy framework to give the private sector the confidence to invest in deployment. Areas where further support was needed included funding for innovation and deployment, urgent resolution of regulatory issues, support for development of infrastructure for hydrogen transport, storage and CCUS, and support for hydrogen users' operating costs through a mechanism such as the proposed Hydrogen Business Model which is now being implemented.

While IFS and HS helped to enhance the UK's reputation as a leader in this area in the early stages of the programme, industry stakeholders commented on the scale of funding currently being offered by the US and EU. There was a view that the UK needed to increase deployment funding to avoid falling behind in the hydrogen economy race.

Learning for future programmes

Key lessons for future programmes were as follows:

- despite the Government's commitment to Net Zero, there is still a need for stronger signals about the long-term direction of travel of Government policy, to support potential investor decisions about major investments in industrial fuel switching and hydrogen supply.

- resolving remaining regulatory issues for hydrogen (e.g. regulation of offshore hydrogen pipelines, decisions about hydrogen use in the gas NTS) is likely to be critical to the success of future innovation and deployment projects for hydrogen supply
- wider deployment of hydrogen supply and industrial fuel switching is likely to be dependent on Government support for infrastructure development in relation to both hydrogen and CCUS, with CCUS being important both for process emissions from the cement and lime industry and for 'blue' hydrogen production processes
- hydrogen transport and storage infrastructure should be considered as potential priorities for future innovation support – consideration could be given to hydrogen access for industries outside the Track-1 and Track 2 cluster areas
- when new technology areas arise, policy makers should consider early innovation programmes - the early timing of IFS and HS showed that early support led to practical learning by policy-makers and industry at an early stage, contributing to the UK's international competitive position in this area
- more systematic knowledge sharing mechanisms should be developed for future innovation programmes, both with industry and within Government
- innovation programmes should be managed in a flexible way that takes into account the inevitable uncertainties in implementation
- when assessing applications for major demonstration projects within innovation programmes, applicants' project management capabilities should be assessed, as well as their technical capabilities
- innovation programmes should consider how to encourage and support the development of 'catalyst' organisations whose business model involves making advice and knowledge available to other businesses, as the catalyst organisations can help to spark subsequent activity
- future innovation programmes should require projects to produce a consistent – and 'analysable' – set of data on key outputs (e.g. providing updated calculations/models for the levelised cost of electricity / hydrogen) in order to support future impact evaluations of government programmes
- in designing future innovation and deployment programmes for industrial fuel switching and hydrogen supply development, policy makers should consider the overall policy landscape so that new programmes continue to complement rather than duplicate other policy initiatives (e.g. the Cluster Sequencing programme, IETS, NZHF programmes).

Note that the process evaluation of the two programmes highlighted more detailed lessons about the design and implementation of the programmes. These can be found in the process evaluation report, published alongside this impact evaluation report.

Appendix A: Evaluation questions

The evaluation sought to answer six overarching questions, each with their own sub-questions. This report focuses on the 'impact'-related questions (EQs 1 to 4). A separate process evaluation report focused on 'process' questions (i.e. EQs 5 and 6).

EQ1: To what extent and how (and if not, why not) have the projects produced the intended outputs in the programme business cases and individual grant applications?

- To what extent have the projects demonstrated the further development of IFS/HS solutions (e.g. increased TRL, amongst other measures)?
- Have projects demonstrated cost, performance and carbon savings from their solutions? Have they demonstrated actual (or potential for) improvements upon the current state of the art?
- Have projects successfully generated, validated and widely shared evidence and learning about the feasibility of IFS/HS, and how?
- Have projects contributed towards capacity building (skills, new jobs, growth and retention of expertise, partnerships), and how?
- What are the reasons for any differing levels of achievement (between projects), including for any under-achievement against expectations / intentions?

EQ2: To what extent and how (and if not, why not) have the programmes contributed to improving understanding & reducing uncertainty / risk amongst stakeholders?

- [IFS only] Has the programme improved cross-sector awareness of the potential IFS options available
- Have the programmes altered perceptions of IFS/HS as a credible and viable pathway to achieving future decarbonisation at scale? Have they improved understanding and/or reduced risks and uncertainty as to:
    - The flexibility, safety, effectiveness, and reliability of IFS options?
    - The ability to reliably supply low carbon Hydrogen, at volume, and / or at a sufficiently low price?
- Have the programmes provided an evidence base to give sufficient confidence to industry to make informed and timely decisions about future investments?
- Have the programmes influenced other government and publicly-funded programmes and initiatives, or UK policy development more widely?
- Have the programmes contributed to the debate (current thinking, evidence and expectations) about the timing, scale, likelihood or cost of future deployment of IFS/HS at scale?

EQ3: To what extent and how (and if not, why not) have the programmes contributed to stimulating further investment, innovation and deployment?

- Have the projects leveraged matched or follow-on funding or investment?
- Have the projects made progress towards commercialisation after the end of programme funding?
- Have the programmes contributed to stimulating wider investment in RD&I (industry, supply chain, academic) in the UK?
- Have the programmes resulted in other projects (i.e. outside of the programmes) engaging in activities to develop/deploy IFS/HS technology at scale? in the UK?
- Have the programmes contributed to the development of domestic UK capability that can service UK and international IFS/HS demand?
- Have the programmes increased the international visibility and reputation of the UK in relation to IFS/HS capabilities and expertise?

EQ4. To what extent and how (and if not, why not) have programmes contributed towards intended future/wider impacts?

- Have the programmes contributed towards the UK's decarbonisation goal of Net Zero emissions by 2050?
- Have the programmes contributed to establishing the UK as an international leader for IFS/HS innovation?
- Have there been any unintended outcomes (positive or negative)? For example:
    - Has government activity crowded out private sector activity that may have happened anyway (deadweight)?
    - Has there been any duplication of effort with other national or international programmes (substitution)?
    - Have any projects demonstrated that the development of the technology or solution in question is not feasible?
    - Has there been any wider social or environmental multiplier effects?
- Does the success or otherwise of the Hydrogen Supply programme have any implications for the success of the Industrial Fuel Switching programme?
- Do the IFS/HS programmes represent value for money (i.e. does the present value of expected future benefits outweigh the costs)? Is there evidence to suggest that certain types of intervention or project achieved greater value for money?
- Have other government or industry initiatives influenced the achievements and impacts of these programmes?
- Is additional evidence, effort or support needed to achieve anticipated impacts?

EQ5. What insights can be gained to inform the delivery processes of future programmes?

- Were the programme launches, calls and associated communications successful in reaching target audiences? Why / not?
- Did programmes receive a sufficient number and range of high-quality applications across the different phases? Why/not?
- Was the application and assessment process efficient and effective? Why / not?
- What were the drivers and barriers to (a) programme application and (b) programme participation (both in relation to programme design / processes and internal company processes)?
- Was the approach to risk management during projects effective? Why / not? For example:
    - Were all project risks identified at the feasibility stage?
    - How agile were programmes in responding to new risks as they emerged?
- Was the programme management / monitoring efficient and effective? Why / not?
- Did programmes sufficiently engage with relevant industry stakeholders at the appropriate stages? Why/not?
- Were sufficient mechanisms put in place to share progress and insights from the programmes to inform ongoing policy and industry development and other related funding programmes?
- To what extent were applicants and beneficiaries satisfied with programme processes?

EQ6. To what extent has design of the programmes effectively supported intended achievements?

- To what extent do the portfolio of projects within the IFS/HS theme act as a coherent and appropriate approach to supporting the development of deployment pathways for IFS/HS? For example:
    - Were there any important gaps (e.g. in technology or TRL)– both within the portfolio, and in relation to other UK or international efforts?
    - Were there any duplications, both within the portfolio, and in relation to other UK or international efforts?
    - Was there sufficient diversification of risk within the portfolio?
    - Were there opportunities for the IFS/HS programmes to inform one another?
- What have been the advantages and disadvantages of the different approaches to phasing programme funding, for both IFS and HS programmes?

- Have the aims and intentions for a) the projects and b) the programmes evolved over time? How / why?
- Were opportunities for learning across the programmes and projects (and beyond – e.g. across the Department's policy teams and other programmes) maximised?
- Can lessons be learned for future Industrial Fuel Switching and Hydrogen Supply innovation support in terms of e.g. scale, scope, targeting of future departmental programmes?
- Have programmes identified areas for future investment and effort to focus on the future/not?

Appendix B: Additional Technical Methodology

This appendix includes additional methodological material.

Evaluation aims and objectives

Aims

Evaluation of the two programmes aims to support policy development in several key areas:

- future innovation funding and state support, including identifying areas that may need additional support and the kind and size of effective state engagement in the areas of industrial decarbonisation and hydrogen supply
- the pathway to net zero, including understanding the options, cost and support requirements for decarbonising high-energy industrial production and, separately, hydrogen supply
- decisions on effective regulatory frameworks for, separately, industrial energy use and hydrogen supply

In addition, the evaluation aims to:

- provide accountability for spending on innovation, identifying value for money achieved
- improve innovation delivery through improvements to commissioning and management processes
- generate descriptions of projects that provide case-related insights into mechanisms, barriers and drivers, as well as provide material for communicating effectively about the projects

Objectives

To do this, the objectives of the evaluation are to:

- identify the overall benefits and impacts of the two programmes, at a programme level
- assess the extent to which, how, and if not, why not, the programmes achieved their objectives – this will also include identifying whether the relevant policy teams' needs have been met by the programmes
- assess the cost effectiveness of the programmes, and understand issues associated with value for money
- understand how effective and efficient the programmes' implementation has been – this will include assessing the effectiveness and efficiency of project management, procurement structures and internal governance

- provide case-based insights on key themes, highlighting transferable learning from the IFS and HS programmes for relevant programmes, policies and industrial sectors

Evaluation approach

Overall approach

The evaluation had four main analytic strands:

- a process evaluation to assess how the programmes were designed and delivered and how design and delivery can be improved
- a contribution analysis approach to assess the extent to which, and how, and if not, why not, each (and both) of the programmes produced the outputs and outcomes envisaged. - this is the central tool for the impact evaluation
- an economic evaluation to review the extent to which and how the programmes have addressed the barriers and market failures indicated in the business cases (and set out in the scoping study report), and give a high-level estimate of the costs and benefits of each of the programmes
- case studies to provide case-based insights on key themes, highlighting transferable learning from the IFS for HS programmes for relevant programmes, policies and industrial sectors

The evaluation was theory-based, developing and employing a theory of change for each programme. Project-level theories of change were developed to strengthen the theoretical underpinning for the evaluation. The theoretical framework was integral to the contribution analysis and also supported the other strands to a greater or lesser extent, particularly the case studies. Equally, the findings from the other strands (process, economic and case studies) also informed theoretical framework updates, thereby strengthening the evidence available for the contribution analysis.

Phases

The evaluation had three main phases, outlined below.

Inception phase (Jan 21-Jan 22)

The inception phase of the evaluation was delayed as a result of the delays in completing the IFS and HS programmes.

The key activity completed during this phase was:

- familiarisation with programmes and projects – involving the review of key programme literature and five scoping calls with programme management personnel
- establishment of the baseline and context for the programmes – involving a short review of published literature and the development of baseline estimates of the status of IFS and HS innovation at the programmes' outset

- scoping calls with the leads from the nine demonstration projects
- a review and revision of the programme-level theory of change
- consultation on the programme theory with a panel of Department-endorsed stakeholders
- contribution analysis (steps 1-4) - to develop the initial contribution stories to be tested in Wave 2 of the evaluation
- the development of project-level theories of change for each demonstration project
- process mapping - summary maps and documents outlining key programme processes
- case study approach - identification of the approach to undertaking the case studies, including shortlisting of potential case study themes
- evaluation question mapping – a review of the original evaluation questions and a mapping of these against the evidence sources that will be used to help answer them
- evaluation plan – setting out the approach to conducting the evaluation as a whole
- sampling framework development - development of sampling frame, including identification of gaps in sample contact details for Wave 1 fieldwork
- research instrument development - development of discussion guides and associated research instruments for Wave 1

Wave 1 (Jan 22-Sep 22)

Focusing primarily on process findings, Wave 1 produced the key evidence for the process evaluation report. Key activity was:

- in-depth and semi-structured interviews with a range of key stakeholders (Jan-Apr 22)
- secondary data collection and analysis (Jan-May 22)
- analysis and synthesis of evidence (Apr-Jul 22)
- reporting (including a process evaluation report, a slide deck (May-Oct 22))

The findings from Wave 1 research are the focus of this report.

Wave 2 (Oct 22-Nov 23)

Focusing primarily on impact findings, Wave 2 involved:

- Wave 2 set-up, including evaluation plan update, theory update and development of research instruments (Oct-Dec 22)
- in-depth and semi-structured interviews with a range of key stakeholders (Jan-May 23)
- secondary data collection and analysis, incl. KPI returns review, techno-economic modelling and the completion of a review of feasibility studies and final demonstration phase reports (Jun-Sep 23)
- analysis and synthesis of evidence (May-Sep 23)

- reporting (including a final evaluation report, case study reports, and slide deck (Jul-Nov 23)

Evidence sources

Qualitative interviews

Mode and composition

The ‘depth’ interviews consisted of qualitative video or telephone interviews conducted by senior members of the evaluation team, based around detailed discussion guides. These were developed based around the key evaluation questions and sub-questions, and signed off by the Department. The interviews were either:

- depth interviews - 60-90 minute conversations, reserved for programme management staff and demonstration phase project leads and partners. Whilst interviews were focused on key questions and potential additional prompts, conversations were designed to be responsive and flexible, with attention paid to probing answers to collect detailed information beyond surface-level answers, or
- semi-structured interviews – c.45 minute conversations with feasibility leads and wider stakeholders. These interviews comprised a combination of closed and structured open-ended questions, providing a greater depth of insight than a standard survey, whilst retaining a consistent, standard set of closed questions on some aspects. Priority questions were agreed to limit the length of interviews where necessary

Sampling

Wave 2 interviews were undertaken for both programmes from January to May 2023.

- In Wave 1, 67 interviews (with 66 respondents) were conducted in total across different respondent groups
- In Wave 2, 122 interviews (with 121 respondents) were conducted in total across different respondent groups, involving 47 depth interviews and 75 semi-structured interviews

sets out the sample composition for both Waves.

Table 6: Sample composition for Wave 1 and Wave 2 fieldwork

Group	Description / purpose	Interview type	Sample population	Interviews completed (Wave 1)	Interviews completed (Wave 2)
Demonstration phase project leads	The project lead for each of the IFS Phase 3 projects and the HS Phase 2 projects.	Depth	9 (5 HS, 4 IFS)	9 (5 HS, 4 IFS)	9 (5 HS, 4 IFS)
Demonstration phase project partners	Key subcontracted partners for each of the IFS Phase 3 projects and the HS Phase 2 projects.	Semi-structured	Not known	11[24] (8 HS, 3 IFS)	10 (5 HS, 5 IFS)
Feasibility study participants	Project leads for each of the IFS Phase 2 projects and the HS Phase 1 projects that did not proceed to the demonstration phases.	Semi-structured	13 (8 HS, 5 IFS)	11 (7 HS, 4 IFS)	9 (6 HS, 3 IFS)
IFS Phase 1 project lead	Project lead for the IFS Phase 1 market engagement study	Semi-structured	1	1	0
Unsuccessful applicants	Leads for projects who had unsuccessfully applied for the feasibility phases (IFS Phase 2 and HS Phase 1).	Semi-structured	35	10 (10 HS)	7 (7 HS)

[24] Securing demonstration phase project partners was reliant on demonstration phase project leads nominating appropriate partners to interview. As some projects felt that their project partners were not involved in programme process, they declined to nominate partners, meaning interview numbers were lower than anticipated.

Group	Description / purpose	Interview type	Sample population	Interviews completed (Wave 1)	Interviews completed (Wave 2)
	Interviews explored views on their experiences of the programme process and activity subsequent to their application (informing the counterfactual / contribution stories).		(29 HS, 6 IFS)		
Supply chain	Hydrogen sector organisations involved in the design and / or delivery of projects.	Semi-structured	Not known	Not interviewed in Wave 1	9
Energy Intensive Industries[25]	Organisations with high energy consumption, potentially best suited to be early adopters in switching to hydrogen.	Semi-structured	Not known	Not interviewed in Wave 1	8
Wider NZIP programme participants[26]	Representatives of projects that had been awarded funding through other / successor NZIP programmes.	Semi-structured	Not known	Not interviewed in Wave 1	32
IFS/HS programme management staff	Programme owners and managers for each programme, plus other key staff involved in programme management	Depth	Not known	11	8

[25] Identified through wider lists of potentially relevant organisations e.g. those with CCAs.
[26] Added due to limited populations resulting from snowball sampling approaches for other groups e.g. supply chain and EIIs.

Group	Description / purpose	Interview type	Sample population	Interviews completed (Wave 1)	Interviews completed (Wave 2)
Wider department policy and programme staff	Staff from programmes and policies connected to industrial fuel switching and hydrogen supply	Depth	Not known	9	7
Wider stakeholders	Wider stakeholders with interests in and awareness of industrial fuel switching and hydrogen supply, such as sector bodies and other key industry representatives	Depth	Not known	7	23

Sample selection was purposive:

- we obtained contact lists from BEIS for project participants (successful and unsuccessful), programme managers, wider policy and programme staff, wider NZIP programme participants and a small number of wider stakeholders
- we used 'snowball' sampling to generate further contacts for project partners, supply chain representatives, energy intensive industry representatives, some policy and programme staff, and some wider stakeholders – this involved asking certain interviewees to nominate other potential interviewees that would be useful to participate in the research

Secondary data

To supplement and triangulate the data collected from the qualitative interviews, the evaluation utilised a range of existing data sources:

- a review of SICE KPI returns, providing project-level quantitative data on impacts and outcomes against programme metrics / targets
- a review of programme documentation, such as programme business cases and existing documents on programme risk management and governance
- a review of project outputs, including reporting at feasibility stages and (for demonstration projects) at project closure. These provided evidence of project delivery and achievements / outcomes against programme metrics / targets
- a review of available techno-economic data providing updated calculations/models for the levelised cost of electricity / hydrogen (LCOE/LCOH) based on the outputs of their projects[27]
- published policy statements, to capture references to IFS and HS innovation and evidence policy influence
- media monitoring (via web scraping) to determine awareness and perceptions of the programme, including internationally, as well as the effectiveness of dissemination activities

Media monitoring

In Wave 2, media monitoring (via web scraping) was used. This was primarily to support the contribution analysis (evidencing wider awareness, perceptions and influence of the programmes), but was also used to provide supplementary evidence on:

- the effectiveness of project dissemination of results and learnings from their HS / IFS funded activities
- the extent to which the programmes increased the international visibility and reputation of the UK in relation to IFS/HS capabilities, expertise and innovation

[27] Note that this activity was more limited in scope than originally intended due to the limited and variable evidence and data available for each project.

The media monitoring sought to identify useful evidence for the evaluation via a series of work elements:

- general media monitoring searches using the BuzzSumo platform, searching for media mentions of specific terms in both UK and worldwide media over the past five years to examine trends in general mainstream media coverage
- Google Trends analysis to examine the same in terms of search term usage
- searching and scraping of a range of general and sector specific websites, including general media, Social Media, and sector body websites, which identified more than 30,000 individual search results of potential relevance for subsequent processing and analysis (articles and tweets)
- supplementary desk-based research to examine individual projects funded under the HS/IFS programmes to:
    - understand the dissemination activities of individual projects
    - consider the potential influence of project dissemination activities over observed outcomes and subsequent activity, and
    - explore whether individual projects, technologies or the companies involved were mentioned in or became involved in subsequent policies

A comprehensive list of the sources scraped, searches conducted and sources identified is set out in Appendix D of this report.

Analysis

General

This comprised case-level analysis and synthesis (using multiple data sources) for each demonstration project, in addition to programme-wide, thematic analysis and synthesis. The case-level approach supported a more holistic assessment against the project ToCs and a stronger basis for aggregating findings to the programme level. The thematic analysis drew together programme-wide findings against each evaluation question.

A coding framework was developed all interview groups. Each interview transcript was coded against the relevant coding framework, with the coded data being organised by topic and by participant. Analysis was conducted thematically, structured around key evaluation question themes.

Contribution analysis

Contribution analysis is a step-by-step theory-based approach for inferring causality in evaluations, by seeking to identify an intervention’s contributions to expected outcomes and impacts, as well as alternative explanations or contributions. For this evaluation, contribution analysis was key to understanding the programmes’ impacts, alongside the modest economic evaluation (see below).

The approach was designed to help revise and/or confirm the programme theories of change (rather than uncover a hitherto implicit or inexplicit theory of change). The final programme theories and contribution stories for this evaluation are set out in Appendix C.

Economic evaluation

To inform the impact and economic evaluations, a baseline study was undertaken to explore (public and private) investment in HS / IFS technologies, including development of new technology. The research drew upon a number of sources, both within Government and more widely, to plot, on a per programme basis, trends for these key metrics before and across the programme timescales.

Analysis for the final evaluation included light-touch economic evaluation of the extent to which and how the programmes have addressed the barriers and market failures indicated in the business cases. It also estimated the costs and benefits of the two programmes and thus represent value-for-money.

Value for Money analysis was conducted at the programme level. Due to the challenge of placing a value on benefits beyond the timing of the evaluation (e.g. decarbonisation of industry, jobs growth and export growth, supply chain development), the evaluation did not include a full CBA; therefore cost effectiveness analysis was undertaken at three broad levels – outputs, energy costs and commercial scalability – and the types and scale of impacts were assessed for employment and supply chain effects, knowledge spillovers, monetised carbon savings, and additional investment.

Analysis of impact and economic outcomes included review and aggregated reporting of the per project KPI returns submitted as part of standard reporting to SICE. These returns provided project-level quantitative data on impacts and outcomes against programme metrics / targets. This fed into the impact and economic evaluations. Outcomes of interest included project achievement of reductions in energy demand and costs, increased energy system flexibility, progress in terms of follow on funding and commercialisation, and COVID effects on project performance. The data were aggregated to the programme (HS and IFS) level, with steps taken to minimise double-counting across multiple submissions for the same project.

Case studies

The case studies provided case-based insights on key themes, highlighting transferable learning from the IFS and HS programmes for relevant programmes, policies and industrial sectors. In particular, the case studies:

- used findings from particular cases to provide a more narratively engaging, case-based set of findings on key themes than the report is able to - they use cases to help ground the findings within real-life examples, illustrating and brining to life areas of thematic interest
- provide a digest of learning around key themes from the evaluation - they are outward-facing, designed to be used by stakeholders such as programme managers, policy

developers and relevant industrial stakeholders, with the focus on highlighting the transferable learning from the key themes for other relevant programmes, policies and initiatives.

Limitations of this research

The following are key limitations that should be noted by the reader when interpreting the findings of this report:

- Add one re: challenges in speaking with orgs not involved in the programme??
- There were **only a limited number of unsuccessful Phase 2 IFS applicants (six) and all of those either were non-contactable or declined to be interviewed**. There was therefore no direct feedback from this group about topic such as barriers to participation or the application and assessment process for the IFS programme
- **A number of respondents had difficulty recalling details of programme activities**, particularly activity which occurred early in the programmes, such as the launches for the initial phases. Care was taken during analysis to distinguish comments relating to IFS2/HS2 from comments about the earlier IFS/HS programmes. Furthermore, there were other respondents who were not in post from the beginning of the programmes. Nonetheless, there was a sufficient range of respondents who could provide considered responses about early programme processes to give us confidence in the findings
- The scope of the planned techno-economic modelling work had to be reduced because of much more limited project-level information on levelised costs than anticipated at the project outset
- **Media monitoring activity was subject to several key limitations** that were considered in interpreting the usefulness and meaning of the results to the evaluation:
    - The relatively small number of IFS1 and HS1 projects, and specialist nature of the topic, means general media monitoring activities (such as general social media listening via off-the-shelf platforms) were of limited use to the evaluation compared to targeted secondary research. Therefore the decision was taken to supplement the core media monitoring with more traditional desk research to examine project dissemination activities and references to the projects and technologies in subsequent policies and programmes.
    - The significant volume of media activity relating to hydrogen and fuel switching precluded detailed analysis and human inspection of each individual article identified, so processing involved identifying articles for more detailed examination using a combination of keyword searching and use of AI (large language models) to assist in the process.
    - A range of specialist media sources (e.g. sector body websites) were referenced to improve the relevance of web-scraping activities. However, search functions available for individual websites vary in their functionality and effectiveness in identifying relevant articles for review. Search results for a number of sites

included content in a range of different formats, including video, and in different webpage layouts, making it challenging to scrape all content of potential relevance from identified sources. This meant some articles on individual websites could not be scraped and returned a blank result[28].

- General media monitoring services are better suited to identifying recent trends in citizen social media activity than they are to identifying coverage and growing interest and awareness in specialist media. The specific interest in industrial use in this evaluation contract meant it was difficult to isolate relevant articles from the wider 'noise', such as content relating to hydrogen in transportation applications and domestic settings (e.g. hydrogen ready boilers), and gas to oil fuel-switching. The results do provide, however, a means of understanding general trends, and a means of identifying specific case-level evidence of relevance to the evaluation in some instances.

[28] Furthermore, some results and articles did not include date stamps, preventing easy determining of when the article was published. This was only the case for approximately 10% of the scraped content, excluding tweets, so was not considered to have a significant impact on the analysis.

Appendix C: Programme Theories of Change

Theories of change for each programme were reviewed post-analysis with an assessment added on the extent to which anticipated outcomes and impacts were achieved.

Figure 4: IFS programme level theory of change, with summary assessment

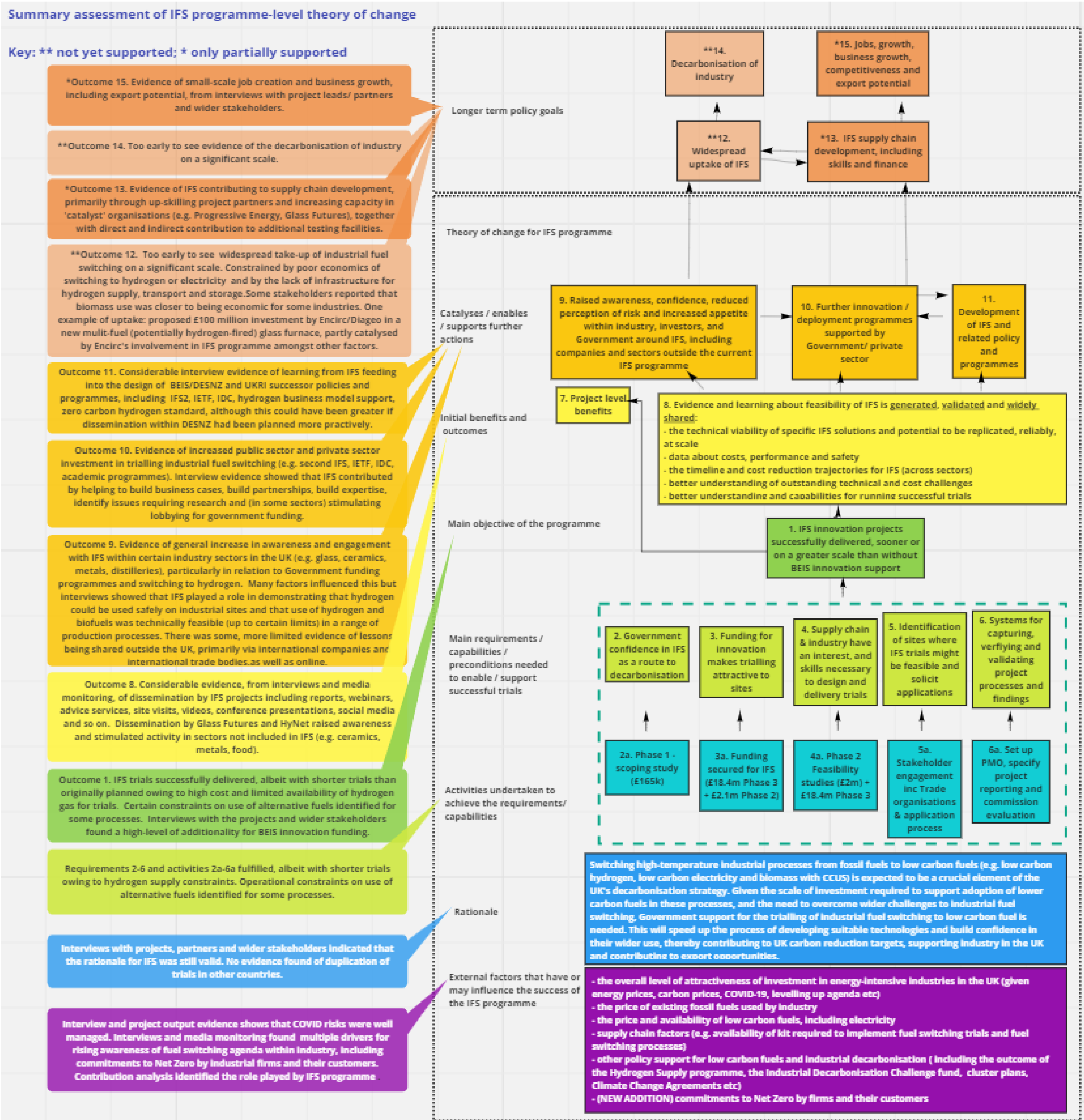
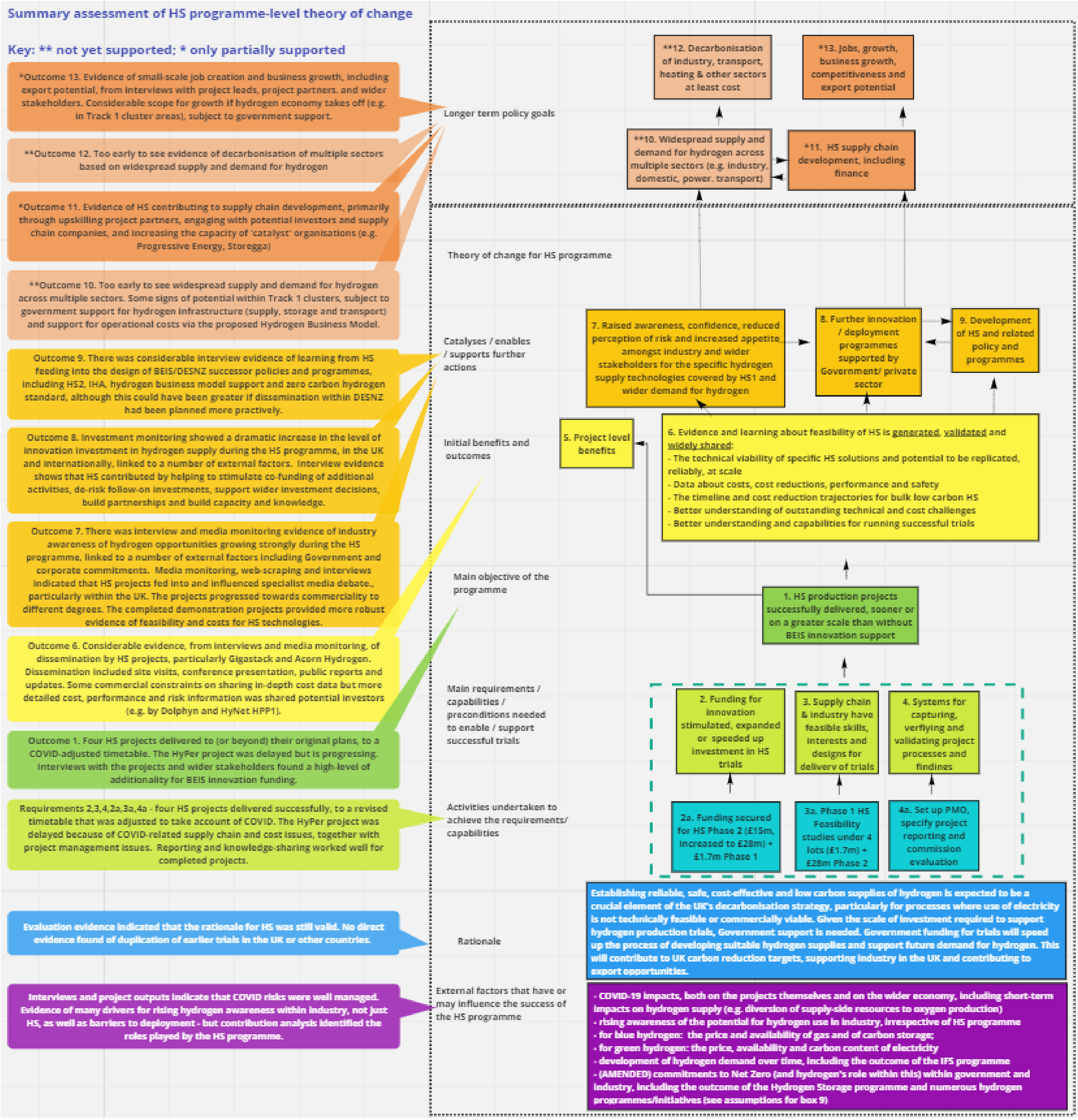


Figure 5: HS programme level theory of change, with summary assessment



Appendix D: Media Monitoring Sources

The table below summarises the main websites referenced in the web-scraping exercise with colour coding to indicate the outcome. Rows highlighted in green were scraped successfully – using either automated or semi-automated approaches. Those in red were either of limited use or could not be scraped due to content being locked behind a paywall, or other technical obstacles such as website content being. Rows in grey are sites for which the searches returned no results, or few results which were manually inspected and deemed to be irrelevant for use in the analysis.

The websites searched were selected during early scoping work to identify a range of general and specialist media sources that might provide evidence of intended outcomes, evidence of the influence of the HS and IFS programmes on intended outcomes or evidence suggesting alternative explanations for observed outcomes.

Source	Website URL
ABMEC (The British Mining Trade Association)	https://abmec.org.uk
ABPI (Association of the British Pharmaceutical Industry)	https://www.abpi.org.uk
ALFED (aluminium manufacturing)	https://alfed.org.uk
Bank of England	https://www.bankofengland.co.uk
BBC	
BCCF (The British Calcium Carbonate Federation)	https://calcium-carbonate.org.uk
BCP (British Coatings Federation)	https://coatings.org.uk/
BLA (British Lime Association)	https://www.mpalime.org
Bloomberg	
BPF (British Plastics Federation)	https://www.bpf.co.uk
Brick Development Association	https://www.brick.org.uk/
British Glass	http://www.britglass.org.uk/
British Pump Manufacturers Association	https://www.bpma.org.uk/

British Stainless Steel Association	https://bssa.org.uk
CBM (Confederation of British Metal Forming)	https://thecbm.co.uk
CEPI (Confederation of European Paper Industries)	https://www.cepi.org
Channel 4 News Online	https://www.channel4.com
CIA (Chemical Industries Association - CIABATA)	https://www.cia.org.uk
City AM	
Clean Energy Ministerial	https://www.cleanenergyministerial.org
Clean Technica	https://cleantechnica.com/
CNBC	https://www.cnbc.com
CNN	https://edition.cnn.com/
CONF - Confederation of Forest Industries (UK) Ltd	https://www.confor.org.uk
CPI (Confederation of Paper Industries)	https://www.paper.org.uk/
ECRA (European Cement Research Academy)	https://ecra-online.org
Energy Observer	https://www.energy-observer.org/
Energy Voice	https://www.energyvoice.com/
ePure (European Renewable Ethanol)	https://www.epure.org
EUA (Energy & Utilities Alliance)	https://eua.org.uk/
EuLA (European Lime Association)	https://www.eula.eu/
EURATEX (The European Apparel and Textile Confederation)	https://euratex.eu
Euro Mines (European Association of Mining Industries, Metal Ores & Industrial Minerals)	
Euronext	https://www.euronext.com

European Chambers of Commerce	https://www.eurochambres.eu
European Investment Bank	https://european-union.europa.eu
FETA (Federation of Environmental Trade Association)	https://www.feta.co.uk/
Financial Times	
Food and Drink Federation	https://www.fdf.org.uk/
Forbes	https://www.forbes.com/
Fortune	
Funds Europe	
Gasworld	https://www.gasworld.com/
GCCA (Global Cement and Concrete Association)	https://gccassociation.org/
Greentech media news	https://www.greentechmedia.com/
H2 View	https://www.h2-view.com/
Hydrogen East	https://hydrogeneast.uk/
Hydrogen UK	https://hydrogen-uk.org/
International Energy Agency	https://www.iea.org
International Flame Research Foundation	https://ifrf.net
International Lime Association (ILA)	https://www.internationallime.org
London Stock Exchange	https://www.londonstockexchange.com
Make UK (a division of which is UK Steel)	https://www.makeuk.org/about/uk-steel
Mineral Products Association	https://www.mineralproducts.org
MTA (The Manufacturing Technologies Association)	https://www.mta.org.uk/
Nasdaq	https://www.nasdaq.com

National Association of British and Irish Millers	https://www.ukflourmillers.org/
Natural Gas World	https://www.naturalgasworld.com/
Offshore	https://www.offshore-mag.com/
Power Engineering International	https://www.powerengineeringint.com
Power Technology	https://www.power-technology.com/
Recharge (Global News and Intelligence from Energy Transition)	https://www.rechargenews.com/
Renewable Energy Magazine	https://www.renewableenergymagazine.com
Reuters	
S & P 500	https://www.spglobal.com
Scotch Whisky Association	https://www.scotch-whisky.org.uk
Scottish Hydrogen and Fuel Cell Organisation	https://www.shfca.org.uk/news
The British Ceramic Confederation	https://www.ceramfed.co.uk
The Salt Association	https://saltassociation.co.uk/
The Wall Street Journal	
UK Cleaning Products Industry Association	https://www.ukcpi.org/
UK Hydrogen and Fuel Cell Association	https://ukhea.co.uk/news/
UKPIA (UK Petroleum Industry Association)	https://www.ukpia.com/
Upstream	https://www.upstreamonline.com/
WPIF (wood panels) - WPIF Environmental Ltd	https://wpif.org.uk/

In addition to this, separate analysis was undertaken to identify LinkedIn pulse articles referencing the HS or IFS projects, and Twitter tweets referencing hydrogen supply or industrial fuel switching. This work was undertaken as a semi-automated activity outside the general web-scraping activity due to restrictions LinkedIn and Twitter place on web-scraping activities.

Google searches were used to identify LinkedIn pulse articles of interest to the evaluation, published in the period of interest since the beginning of Jan 2016. The searches sought to identify articles referencing specific projects or organisations supported under IFS and HS as well as undertaking more general searches.

Appendix E: Additional Project-Level Findings

Industrial Fuel Switching programme

Have IFS projects delivered planned outputs?

The delivery schedule for IFS was extended in response to the challenges of COVID, as explained in the process report. Within the extended timescale, the four IFS demonstration projects delivered their planned outputs.

All of the IFS demonstration projects involved physical demonstrations and trials, in addition to desk-work and modelling. In general, the demonstrations generated successful results but two elements of the trials were less successful than had been hoped:

- While the MPA project was successful overall, there were technical problems with a trial on one of the cement production sites leading to curtailment of the trial involving use of biomass and an electric plasma torch.
- The BLA trial was undertaken as planned, but the findings were less positive than anticipated, with hydrogen use being found to be technically feasible at 20% by volume but not 50% by volume.

A summary of IFS demonstration project characteristics and outcomes is presented the table below.

Table 7: Summary of IFS project characteristics and outcomes

	HyNet Northwest	Mineral Products Association	British Lime Association	Glass Futures
Main location	Northwest	National (with sites in Northwest and Peak District)	National (with sites in Peak District)	National (with sites in Northwest, Midlands, London, Scotland and Northern Ireland)
Sites and sectors	NSK Pilkington (float glass), Unilever (consumer	Hanson and Tarmac (Cement)	Tarmac Lime (Buxton)	Pilot-scale glass testing at Liberty Steel site (Rotherham)

	HyNet Northwest	Mineral Products Association	British Lime Association	Glass Futures
	goods), Essar (oil refinery)			
Expected outputs	Boiler test at Dunphy combustion. Physical trials of direct hydrogen-firing at NSK Pilkington, hydrogen boiler at Unilever site, plus FEED study for a new hydrogen-fired gas turbine CHP at Essar Oil's Stanlow refinery. Monitoring and dissemination activities.	Studies, design and modelling, culminating in physical trials of mixed hydrogen and biomass (MBM and glycerine) as kiln fuel on the Hanson site and biomass (wood pellets) and plasma burner in a calciner on the Tarmac site. Monitoring and dissemination activities.	Studies, design and modelling, plus demonstration of using up to 50% hydrogen, replacing natural gas in a full-scale lime kiln on the Tarmac Lime site. Monitoring and dissemination activities.	Lab and pilot-scale (300 kW) testing of alternative fuels including hydrogen, bio-oils and electricity, with modelling of alternative fuels for large-scale glass furnaces Economic model for each glass manufacturing site and updated UK glass decarbonisation road map Monitoring and dissemination activities
Actual outputs	Successful demonstrations: NSK Pilkington (biomass) and Unilever Port Sunlight (100% hydrogen). FEED study completed for hydrogen CHP	Partially achieved owing to technical issues. Main kiln trial was successful in reaching 'Net Zero' using 40% energy from hydrogen and	Modelled use of hydrogen at 50% by energy (77% by volume) but product quality problems encountered in physical trial at this level. Successful at 20% hydrogen by energy, with good	Construction of 350 kW test bed on Liberty Steel's Rotherham site allowed testing of hydrogen and biofuels under pilot conditions. Industrial scale demonstrations of 100% biofuels and 70-100%

	HyNet Northwest	Mineral Products Association	British Lime Association	Glass Futures
	plant at Essar Refinery	60% from biomass. Calciner trial less successful owing to technical problems with wood pellet delivery system and 100kW plasma torch.	product quality and no damage to kiln.	hydrogen (respectively) through part/all of the furnace for trial periods – shown to be technically feasible
Initial TRL	7	3	3	3
Final TRL[29]	8/9	7	6	9
TRL description	Technology proven in final form/ in real end-use applications	Planned operational system	Representative model or prototype	Technology proven in real end-use applications
Cost, performance and carbon savings?	Carbon savings from substitution of natural gas with hydrogen or biomass	Carbon savings from substitution of natural gas with hydrogen or biomass	20% hydrogen firing found to be acceptable. Higher levels caused problems with product quality	Biofuel trial saved 70-80% of carbon vs natural gas
Generated, validated and widely shared evidence?	Yes – wide networking and dissemination in HyNet cluster, including videos,	Yes – via partners, and via national and international trade bodies,	Yes – via partners (including all lime producers in UK), and via national	Yes – wide networking and dissemination across multiple sectors

[29] TRL levels as reported in the Department's Key Performance Indicators. Interview evidence suggested that some of these may have increased since project completion.

	HyNet Northwest	Mineral Products Association	British Lime Association	Glass Futures
	site visits and so on.	including videos, site visits and so on.	and international trade bodies	
Outcomes	Increased knowledge and confidence about hydrogen and biomass use on industrial sites	Increased knowledge and confidence about hydrogen and biomass use in cement kilns, up to 40% hydrogen by energy and 60% biomass.	Increased knowledge and confidence about hydrogen use up to 20% on lime sites	Increased testing capacity within Glass Futures. Increased knowledge and confidence about hydrogen and biofuels use on glass sites.
Next steps	Essar considering building new CHP that can take higher levels of hydrogen. Multiple follow-on projects	Information disseminated – no follow-on project as yet	Information disseminated – no follow-on project as yet	Further testing for other industries using test bed. Indirect influence on Glass Futures' new facility for further industrial fuel testing
Follow-on funding and activity	Multiple applications, initially led by Progressive Energy, to successor programmes (including second IFS programme) for industrial fuel switching trials by companies in the HyNet cluster, including	No direct follow-on activity within UK. Subsequent applications to successor programmes in the UK relate to process emissions (CCUS). Some interest from	No direct follow-on activity within UK. Subsequent applications to successor programmes in the UK relate to process emissions (CCUS). Some interest from international	Multiple applications, led by Glass Futures, to successor programmes (including second IFS programme) for industrial fuel switching trials in multiple sectors (e.g. glass, steel, ceramics). Indirect influence on potential

	HyNet Northwest	Mineral Products Association	British Lime Association	Glass Futures
	Kellogg's, Novelis and Essity.	international cement bodies	lime organisations.	Encirc/Diageo investment in £100m hydrogen fired glass furnace
Constraints	Dependent on cost and supply of hydrogen, plus management of additional NOx emissions from direct firing	Dependent on cost and supply of hydrogen,	Dependent on cost and supply of hydrogen, plus testing of long-term effects of hydrogen firing on costly kiln lining.	Dependent on cost and supply of hydrogen

To what extent have the IFS projects demonstrated the further development of IFS/HS solutions (e.g. increased TRL, amongst other measures)?

As shown in the table above, all the IFS demonstration projects reported progress in terms of Technology Readiness Level (TRL). TRL progress was more marked than for the HS programme, with three projects reporting significant progress from TRL 3 (proof of concept) to TRL 6 for the BLA project (representative model or prototype), to TRL 7 for the MPA project (system prototype in operational environment) and to TRL 9 for Glass Futures (complete system in final form in real end-use applications). HyNet Northwest also reported progress from TRL 7 to TRL 9.

This level of progress was achieved because all the projects involved an element of demonstration on full-scale industrial sites, in addition to desk research, FEED studies and pilot demonstrations.

Projects involved in the feasibility phase of the IFS programme were not required to report progress against TRL levels.

Have IFS projects demonstrated cost, performance and carbon savings from their solutions? Have they demonstrated actual (or potential for) improvements upon the current state of the art?

All of the projects were attempting types of industrial fuel switching on a scale, or of a type, that – according to evaluation evidence - had not previously been undertaken. For all of the projects, industrial fuel switching was found to be technically feasible, within certain limits. However, full roll out of industrial fuel switching to hydrogen was reported to be economically unviable at present without government support through the Hydrogen Business Model or other mechanisms.

HyNet's final report indicates that the hydrogen direct-fire trial at NSK Pilkington's float glass site was successful, with no impact on glass quality. The project estimated that the capital cost of switching similar (glass) sites to hydrogen would be around £500k per site. The trial identified some issues with NOx emissions at higher levels of hydrogen use, which may require additional permitting for long-term use.

Similarly, HyNet's final report indicated that the hydrogen burner trial at Unilever's Port Sunlight site was also successful. A dual-fuel natural gas/hydrogen burner was estimated to have a capital cost about 10% higher than a standard natural gas boiler, with similar levels of operating efficiency. The trial showed that NOx emissions thresholds set by Medium Combustion Plant Directive could be met when operating on hydrogen, subject to appropriate boiler design.

Finally, HyNet's final report indicated that there was a TRL of 9 for the hydrogen-fired gas turbine CHP plant, which was the subject of a FEED study, at hydrogen blends of up to 83% by volume. The additional capex for hydrogen-fired CHP was estimated to be only 1% higher than natural gas CHP. But, while hydrogen supplies remain limited, there would be additional capital costs involved in duplication of equipment for hydrogen and natural gas supply.

MPA explained in interview that the 'main kiln' and 'calciner' make up two parts of the cement production process. They commented that, to their knowledge, there had not previously been a 'Net Zero' trial in a main cement burner, using solely biomass and hydrogen. Owing to the nature of the main kiln process, this was reported to be more challenging than biomass and hydrogen use in a calciner. The MPA project was successful in testing a higher proportion of hydrogen (e.g. 40%) than used in other industry trials. They reported that other trials of hydrogen in main kiln processes tended to use a smaller proportion of hydrogen (e.g.1-2%) as a catalyst to enable more use of a wider range of biomass fuels.

BLA (now known as MPA Lime) reported that a 20% hydrogen and natural gas mix (by energy) did not affect the quality of lime produced and did not damage the valuable lining of the lime kiln, at least over the times observed for the trial. However, at higher levels of hydrogen use (e.g. 50%) there were problems with product quality. Nevertheless, it is significant that hydrogen can be used at 20% level, were hydrogen to be mixed with natural gas in the NTS.

Both the MPA and BLA trials found that substituting hydrogen for natural gas was not economic at current hydrogen prices, and international stakeholders commented that increased use of biomass was closer to being economic. Importantly, the MPA and BLA trials both focused on reducing emissions from energy use in cement and lime production processes and did not address 'process emissions' from the raw materials (e.g. limestone). Evidence from interviewees indicated that process emissions represent around 60% of carbon emissions from cement production and around two-thirds of carbon emissions from lime production.

Decarbonisation of energy use is one step in the decarbonisation route map for these industries but, in the long-term, CCUS systems would be required for cement and lime production to reach Net Zero.

Glass Futures successfully tested use of hydrogen and biofuels in pilot and full-scale industrial settings for glass production. In their tests, they found that biofuels (e.g. bio-diesel) could provide 100% of the energy input in a glass furnace for extended trial periods, with carbon savings of 70-80% compared to natural gas. Use of hydrogen (70-100% by volume) and/or biofuels (100%) was found to be technically feasible for both float and container glass production, but not currently economic.

Have IFS projects successfully generated, validated and widely shared evidence and learning about the feasibility of IFS/HS, and how?

Project leads reported that the findings from IFS projects had not generally been validated by external third-parties although findings had been cross-checked by project partners, often including technical consultants. CO2 emissions would have been verified externally by third-party verifiers on those sites that were part of the UK ETS scheme.

The credibility of findings was reported to be boosted where they were undertaken on a full-scale commercial site and the quality of the product could be demonstrated.

> *we did this project at a commercial site, we made clinker using it- In fact, we have a jar of it in our office and we go take it to our presentation go, “This is the first Net Zero kind of clinker.” So, yes, I don’t think, in terms of proving hydrogen in a working cement main burner, I don’t think it could get more robust actually. So, yes, we definitely achieved that. (Demonstration project lead)*

One project lead made the point that the level of proof required by industry tends to be lower than that required by scientific journals. They suggested that industrial firms may pick up and use findings before they are externally validated, if they offer commercial advantage.

> *Industry is not fussed about peer-reviewed academic journals to answer the questions it needs to answer to make money and stay alive. The world needs academic peer-reviewed journals to confirm what we believe to be true or to reinforce the science behind something that industry sees and uses for commercial benefit overall. [..] What you realise is that, when you’re at the front edge of development and advancements, sometimes it takes a while for things to be validated. (Demonstration project lead)*

All of the IFS projects delivered the dissemination activities required, both within and beyond the Department. For example, the HyNet IFS project had a structured programme of knowledge dissemination activities. These included three knowledge transfer webinars with HyNet Hydrogen Users Group which comprises over 40 major manufacturers located in the Northwest and North Wales. Other activities included demonstration visits, stakeholder engagement, videos and social media, with some of the latter showcasing industrial switching as part of wider HyNet activities.

Glass Futures was also highly active in disseminating finding via webinars, videos, articles, briefing sessions, training sessions and conference presentations. They were an affiliate member of the International Flame Research Foundation and also offered knowledge-sharing services to 40 Glass Futures member organisations (including firms that use glass as well as glass producers). These services included telephone advice, firm-level briefings, internal training sessions and board-level briefings:

> *The service we offer, it's attempting to be a relatively informal knowledge-sharing piece. As part of people being a member, they can pick the phone up and talk to any one of our specialists and pose questions and ask. I think it's building relationships and being recognised as a specialist in certain areas, it's almost an organic way of sharing things beyond the formal…[..] So we've been running internal training sessions to help dispel myths and educate people around, "What are the different types of hydrogen, what are some of the considerations that might impact the costs of hydrogen, what…?" [..] we're also helping [the glass-user] end of the supply chain to understand, probably, the complexities and the realities of these business cases. It isn't just, "Guys, flick the switch to hydrogen and you'll be okay." So we're trying to support knowledge, across the supply chain, to help people make more informed decisions and help progress everyone's knowledge of what's going on in this area. (Demonstration project lead)*

MPA reported that they publicised the cement project to their members across the cement trade, and also presented findings at multiple conferences in the UK (e.g. to Future Build). MPA also ran a seminar for the European Cement Research Academy and submitted an innovation case study to the Global Cement and Concrete Association, while a project partner made presentations and submitted articles to the international cement trade press.

- *So there has been a lot of presentations. There have been technical papers, produced as part of the roadmap. I was interviewed on BBC by Deborah Meaden for her 'Big Green Money Show' and I mentioned it then, and the report. So we have definitely spread it far and wide, and it has attracted a lot of interest. (Demonstration project lead)*

The BLA project undertook dissemination work but appeared to have been less active than the other IFS projects, partly because all three major lime producers in the UK were already partners in the project. As internationally-owned companies, these partners were able to disseminate the findings internationally within their own companies. BLA reported that they shared findings with BLA/MPA members via the MPA newsletter and publicised the project on their website, as well as presenting the project to the European Lime Association and International Lime Association. However, the final report had not been shared with the ILA ahead of the evaluation research, possibly because of changes of personnel within MPA/BLA. Although BLA had mentioned the trial at conferences, they reported that details had not been shared. The reasons for this is not clear but might be related to the perceived lack of success of the trials.

Have IFS projects contributed towards capacity building?

The Glass Futures project involved development of pilot-scale testing facilities for industrial fuel switching that had not previously been available to the glass industry, through the construction of a 350kW test bed on the Liberty Steel site in Rotherham. At the time of the evaluation research, this was being used for pilot-scale testing on behalf of a range of industries, not just glass but also metals and ceramics.

Both Glass Futures and Progressive Energy reported increased capability to support industrial fuel switching demonstration activities through knowledge and skills developed during their IFS projects. The role of these organisations was to facilitate demonstrations by industrial players.

> *I think it has increased our skill level. I think it's positioned us well to run further demonstrations which we are doing. (Demonstration project lead)*

All the projects reported increased knowledge and skills around hydrogen within project lead and project partner organisations. At site level, there was evidence of increased knowledge and skills about handling hydrogen on industrial sites, in terms of engineering, staff practices and compliance with regulations (e.g. Control of Major Accident Hazards Regulations (COMAH), 2015).

> *I think the sites themselves also learnt what needs to happen on site and what skills and training needs to happen when you have got hydrogen on your sites. I know Hanson did quite a lot of training around [this]- And all the staff on site were trained, whether they were going to be anywhere near the project or not. (Demonstration project lead)*

Networking and partnership building formed important parts of the Hynet NW and Glass Futures projects. This led on to further demonstration activity, as discussed under 'investment' in the 'programme impact' section above.

The impact of this capacity building on investment and activity levels is also explored in the 'investment' section above, while the numbers of jobs supported by projects are set out in the value for money section, under 'employment'.

What are the reasons for any differing levels of achievement between IFS projects, including for any under-achievement against expectations / intentions?

In broad terms, the four IFS projects delivered against expectations. Although the BLA project found that only 20% hydrogen mix be tolerated within the lime kiln trial, this generated learning about what did not work, as well as what did. Technical issues halted the MPA project biomass and plasma trial, but significant learning was generated by the hydrogen trial within this project.

Several factors were identified as affecting levels of achievement and effectiveness of dissemination. These were:

- **Nature of lead organisation:** for all of the IFS projects, the lead organisation was a coordinating or enabling body rather than an industrial producer in their own right. MPA and BLA were membership-based trade organisations, well-positioned to share findings with member firms in their sectors. Glass Futures also had a membership structure and offered knowledge-sharing services to its members. Glass Futures and Progressive Energy also played a more pro-active enabling role in leading further bids for Government funding, in partnership with industrial companies. This enabled them to act as catalysts for further activity in industrial fuel switching, as discussed further in the programme impact section above.

- **Scale of energy emissions versus process emissions:** there was consensus amongst cement and lime stakeholders that the scale of process emissions in the cement and lime sector means that full decarbonisation will require CCUS or similar processes in addition to decarbonisation of energy use. Driven by this rationale, BLA and MPA had led subsequent bids for CCUS but had not progressed industrial fuel switching further at the time of the evaluation research.
- **Cluster status** – interview and funding evidence suggested that much of the IFS activity and follow-on activity was located in the HyNet cluster and the nearby Peak cluster. There was considerable evidence from stakeholders that being part of, or close to, a Track-1 cluster (including the proposed HyNet HPP1 plant) increased industrial firm's confidence in being able to access hydrogen supplies within the next five years or so. This increased their interest in exploring industrial fuel switching options.
- **Policy uncertainty and infrastructure dependence** – all of the IFS demonstration projects reported that fuel switching to hydrogen was dependent on future Government funding such as the Hydrogen Business Model (HBM) and that delays to launching the HBM were constraining progress on follow-on activity. They also commented that fuel switching to hydrogen was dependent on adequate hydrogen supply as well as hydrogen storage and transport infrastructure. While hydrogen delivery by truck had been feasible for some of the demonstration projects, project experience suggested that truck-based transport would challenging for full-scale operation because of the low density of hydrogen and hence the large number of truck-loads required.

Hydrogen Supply programme

Have HS projects delivered planned outputs?

The delivery schedule for HS was extended in response to the challenges of COVID, as explained in the process report. Within the extended timescale, four out of the five HS demonstration projects (Dolphyn, Gigastack, HyNet HPP1 and Acorn Hydrogen) delivered their planned outputs. Additional activities were also undertaken, some of them funded by the Department and others by the project partners:

- Dolphyn focused HS-funded activities on the design of a 10MW commercial-scale demonstrator project, with agreement from the Department, because the progress meant that a 2MW prototype was not needed
- HyNet HPP1 partners funded and undertook further engineering work beyond the HS-funded FEED study for a ‘generic’ LCH plant. The additional work focused on issues specific to the proposed plant at the Essar refinery site
- Acorn Hydrogen partners funded and undertook parallel studies on alternative reformer technologies, in parallel with the HS-funded FEED study of a LCH plant, to improve the robustness of their future investment decisions

The HyPer project was significantly delayed, for reasons explained in the process report, and was still underway at the time of the evaluation research. However, the project was expected to reach completion and already showed signs of disseminating learning.

A summary of HS demonstration project characteristics and outcomes is presented in the table below.

Table 8: Summary of HS project characteristics and outcomes

	Dolphyn	Gigastack	HyNet HPP1	HyPer	Acorn
Main location	Trial location will be Milford Haven, Wales	Humberside (part of East Coast cluster – Track-1 status)	HyNet cluster (Northwest England – Track-1 status)	Cranfield University	St. Fergus (Scottish cluster – reserve status)
Expected outputs	Design for 2 MW prototype green hydrogen plant (floating	Design and assembly of 150 kW trial PEM electrolysis stack for	FEED study for 100kNm3/hour Low Carbon Hydrogen plant together with consents	Detailed design and construction of 1.5 MW pilot HyPer plant with integrated	Pre-FEED study for Low Carbon Hydrogen supply plant at 200 MWth at St Fergus with

	Dolphyn	Gigastack	HyNet HPP1	HyPer	Acorn
	offshore wind platform) Pre-FEED design for 10 MW commercial demonstrator	green hydrogen Trial of semi-automated machines for stack manufacture by ITM FEED study on 100 MW electrolyser system Monitoring and disseminatio n outputs	(blue hydrogen, using Johnson Matthey's LCH reformer process with CCUS) Monitoring, reporting and dissemination outputs	carbon capture (blue hydrogen) Testing and demonstratio n of pilot plant Monitoring and reporting outputs	CCUS (blue hydrogen, using Johnson Matthey's LCH reformer process with CCUS) FEED-level study for Advanced Reforming package within overall design
Actual outputs	Exceeded – design for 2 MW prototype superseded by verified design for 10 MW plant	Achieved – prototype system developed despite COVID and supply chain challenges	Achieved – FEED study completed for HPP1 plant, transferable to other locations	Not yet completed – project delayed owing to cost and supply chain issues	Exceeded – partners funded a separate study of alternative reformer technologies
Initial TRL	4	6	6	4	6
Final TRL[30]	5	7	7	(expect 5-6)	6
TRL description	Most project elements at TRL 7 but lowest component at 5 (testing in	Planned operational system	Planned operational system	Pilot plant not yet operated at time of research	Project validated TRL of JM LCH technology at 6 (representativ

[30] TRL levels as reported in the Department's Key Performance Indicators. Interview evidence suggested that some of these may have increased since project completion.

	Dolphyn	Gigastack	HyNet HPP1	HyPer	Acorn
	simulated environment)				e model or prototype)
Cost, performanc e and carbon savings?	Yes, Phase 1 report predicted cost savings. Patents applied for.	Yes, capital cost estimates more expensive than predicted but now more certain	Yes, FEED reported to confirm energy efficiency and feasibility of JM LCH technology	Yes, predicted 20-30% cost savings for blue hydrogen production	Yes, subject to parallel FEED study on alternative reformer technologies
Generated, validated and widely shared evidence?	Yes, dissemination subject to commerciality constraints	Yes, considerable disseminatio n activity as part of project outputs	Yes, considerable dissemination activity, particularly within HyNet cluster	Yes, dissemination via academic channels	Yes, considerable dissemination activity, particularly in Scotland
Outcomes	Concept supported; small-scale prototype developed	Progress towards commercialit y	Progress towards Final Investment Decision	Spin-off research projects already generated	Progress towards commerciality
Next steps	FEED, leading to Final Investment Decision on 10 MW demonstratio n plant	Construction of 5 MW module; investment in full-scale system	Post-Feed work for HPP1 at Essar site; contract negotiation and consents	Completion of HS project	Completion of parallel FEED studies of different reformer options
Follow-on funding and activity	£8.5 million funding for FEED, from second HS	£8 million funding for from second	Post-FEED work funded by participants in	To be confirmed when project complete	FEED work being funded by project partners

	Dolphyn	Gigastack	HyNet HPP1	HyPer	Acorn
	programme plus NZHF applications ERM contributed funding of £12 million Private investors interested	HS programme Post-FEED work being funded by project participants as well as government	expectation of Final Investment Decision, subject to Hydrogen Business Model support HyNet cluster has both public and private funding		Acorn cluster has, both public and private funding Indirect influence (with HyNet HPP1) on Johnson Matthey activity
Constraints	Regulatory issues to be resolved for offshore hydrogen	Viability depends on Hydrogen Business Model and NZHF	Viability depends on Hydrogen Business Model	Cost increases and supply constraints	Viability depends on Hydrogen Business Model and Scottish cluster status

To what extent have the IFS projects demonstrated the further development of IFS/HS solutions (e.g. increased TRL, amongst other measures)?

As shown in the table above, the HS demonstration projects reported progress in terms of TRL. Both Gigastack and HyNet HPP1 reported progress from TRL 6 (equivalent to a 'representative model or prototype') to TRL 7 (equivalent to a 'system model or prototype in an operational environment'). Dolphyn reported progress from TRL 4 to TRL 5 (equivalent to 'field validation of components'), with some elements of the technology package being TRL 7, and it was too early to assess progress by HyPer. HS feasibility projects were not required to report TRL levels.

No TRL progress was reported to the Department by Acorn Hydrogen, at the end of the project, possibly reflecting this project's consideration of alternative reformer technologies. In interview, Acorn respondents did not cite concerns about Johnson Matthey's LCH technology but rather the need to provide robust evidence on a range of technology options to inform the eventual investment decision. This was possibly appropriate in the context of Acorn Hydrogen's slower timescale for hydrogen production, given the 'reserve' status of the Scottish cluster and uncertainties about hydrogen transport in the national gas grid. In contrast, Gigastack and HyNet HPP1 were taking a faster approach, being located in Track-1 clusters with expectations of accessing local hydrogen storage and transport infrastructure in the relatively near term.

Have HS projects demonstrated cost, performance and carbon savings from their solutions? Have they demonstrated actual (or potential for) improvements upon the current state of the art?

There was considerable evidence, from the projects and from wider stakeholders, that the HS feasibility and demonstration projects involved technologies that would improve on the current state of the art for producing blue or green hydrogen. All the projects were predicted to save carbon by substituting hydrogen for fossil fuels in industrial or other end uses. Verco's collated and reviewed findings from the final demonstration project reports, showing that:

- **Dolphyn** – ERM developed the Dolphyn concept for the production of 'green' hydrogen at scale from offshore floating wind, with the aim of constructing and operating the first 10MW unit by the end of 2024 to coincide with commercial scale wind farm plans (100-300MW) which aim to be operational by late 2020s. Phase 1 included the detailed design for a 2MW Scale Prototype to FEED stage. Phase 2 moved forward with a 10MW Commercial Scale Demonstrator. The final report quoted a hydrogen target price of £6.15/kg for Aberdeen Hydrogen Hub, which was slightly higher than government assumptions about the current LCOH, but the project expects economies of scale to reduce costs to £1.50/kg by 2040.

  "The concept was compared to alternative centralised and decentralised options both onshore and offshore and was found to be the most economically advantageous solution for generating hydrogen at multi-GW scale."
  (Demonstration project lead)

- **Gigastack** – Gigastack is a multi-phase programme which has designed a 100MWe-scale electrolyser system to use renewable power from an offshore windfarm and provide renewable hydrogen to a refinery to replace fuel gas. The hydrogen will be delivered to multiple end customers including large industrial and flexible power generators in the area and to enable injection into the existing natural gas. Plant 1 will supply the Stanlow Manufacturing Complex via a dedicated hydrogen pipeline before the hydrogen network is complete, and hydrogen will be stored in salt caverns within the Cheshire salt basin. LCOH was calculated at £7.93/kg H2 in the base case, and £5.11-5.44/kg in the low-cost case. Economies of scale were expected to reduce costs to £2.80/kg by 2030
- **HyNet HPP1** – The HyNet project, based in the northwest of England and north Wales, combines fuel switching and Carbon Capture and Storage to supply hydrogen to industrial, transport and domestic & commercial gas customers. The hydrogen will be delivered to multiple end customers including large industrial flexible power generators in the area and to enable injection into the existing natural gas network. The project has been split into multiple stages, with Plant 1 aiming to supply the Stanlow Manufacturing Complex via a dedicated hydrogen pipeline before the hydrogen network is complete. The project aims to produce 3 TWh per year of low carbon hydrogen production by 2025, rising to 30 TWh by 2030, with hydrogen storage in salt caverns within the Cheshire salt basin. HyNet did not provide an LCOH but reported that hydrogen costs were in the range set by the UK Hydrogen Strategy
- **Acorn Hydrogen** – The Acorn Hydrogen Project plans to generate hydrogen from North Sea Natural Gas at the St Fergus Gas Terminal. The project aims to use the LCH or an alternative hydrogen reformation process to deliver hydrogen, with the project carbon dioxide emissions being captured and permanently stored using the Acorn Carbon Capture and Storage (CCS) infrastructure. Clean hydrogen will be blended into the National Transmission System (NTS) or used in the region for decarbonising heat and industry. At the concept evaluation stage, the LCOH was predicted to be 5.4-8.4p/kWh. Economies of scale, linked to blending into the NTS, could reduce the LCOH significantly over time

At the time of the research, it was too early to assess the achievements of the HyPer project which was demonstrating a new reformer method that potentially offers performance and cost savings, with integrated carbon capture. The project lead reported in interview that the project expects to see cost reductions of 20-30% compared to current blue hydrogen production methods (i.e. Steam Methane Reforming). The implications of predicted cost savings across the demonstration projects are discussed further in the ‘value for money’ section above.

Several project representatives commented that capital cost estimates were currently uncertain, owing to supply chain constraints and inflationary pressures. They noted a risk that the actual cost of contracting suppliers for different elements of construction would exceed the cost estimates set out in final reports.

Have HS projects successfully generated, validated and widely shared evidence and learning about the feasibility of IFS/HS, and how?

There was evidence of HS demonstration projects generating knowledge and validating it, both through internal quality processes within project partners and through third-party validation.

> *that has involved a third party multi-national engineering company doing their own evaluation, doing their own calculations and confirming that actually, yes, our numbers match and are sensible (Demonstration project lead)*

Two projects that had worked closely with potential private-sector investors mentioned that their findings had been subject to due diligence processes undertaken on behalf of potential commercial investors.

> *We're in the process of appointing the lenders' technical adviser, and they will go over the project with a toothcomb because they will have to produce a report to the lenders to say, "This is the project. These are the risks we perceive." (Demonstration project lead)*

All the HS demonstration projects had undertaken dissemination activities to share findings and outputs with partners within their consortia and with the Department. The projects also undertook wider dissemination activities, with Gigastack and Acorn being the most active. They referenced holding stakeholder supply events, supply days, networking, attending conferences, publishing updates and reports, and running communications campaigns.

> *We published what was known as 'deliverable 6', the hydrogen in Scotland report done by Element Energy. That went out into the public domain during the project. There was the end of project summary report. And the project over the past four years has participated in lots of public forums, whether it be All-Energy, the Scottish Hydrogen and Fuel Cell Association, annual conferences etc. Yeah, we get out and about, and we talk about and present updates on the project quite regularly. (Demonstration project lead)*

Dolphyn also ran supply chain engagement events, presented at conferences and networked within industry working groups. Some of their dissemination activities were closely linked with its approach to potential investors, with more information being shared with those who expressed commercial interest in the project.

> *So, we have the public reports, we've ran a number of supply chain engagement events and we put together packs specifically for those. We presented at a number of conferences, we put together packs specifically for those. We've joined industry working groups to help promote hydrogen in general and trying to stimulate supply chain and skills development and all of those good things [...] And then the other piece was the [..] process for bringing our investor on board we went out to a number of groups who would be potential investors into Dolphyn and invited them. So, it was invitation only, but it was 50 plus companies that we went to, and they were oil and gas operators, offshore wind operators and also*

financial investors. And at various stages of that process, as they got whittled down more and more, more and more information was available to them. (Demonstration project lead)

HyNet dissemination work included at least one major webinar (attended by around 500 people) plus further communications integrated into overall communications by the HyNet cluster. Despite research being ongoing, the HyPer project also reported in interview that they were highly active in disseminating updates via their website, social media, academic networks and conferences, as well through talking to companies about commercialisation.

The technology provider for HyNet HPP1 and Acorn Hydrogen (Johnson Matthey) was also reported to be actively promoting their LCH technology, both in the UK and internationally.

One demonstration project lead commented that, while there were sensitivities about capital cost data and some other commercially confidential information, the Department could have asked for more dissemination activity by the projects, particularly in making presentations within the Department.

Government will always want us to do more KT [knowledge transfer]. Industry will always want to do less. Yes, and I don’t think there is a solution to that. (Demonstration project lead)

Have HS projects contributed towards capacity building?

HS representatives commented on the need for more technical skills and capacity in the hydrogen sector in the UK, to support the transition to Net Zero. A skills shortage was seen as a potential constraint on roll-out of hydrogen technologies, not just a shortage of professional engineering skills but also skilled labour (e.g. welding and so on).

On a small-scale, the HS projects were reported to have upskilled individuals and organisations, developing hydrogen expertise within project lead and partner organisations. This expertise could then contribute to these organisations pursuing further opportunities within the UK and internationally.

Obviously, you’ve got lessons being developed at places like the Humber Refinery and around the Hornsea 2 site by UK workers who are becoming experts in their fields in that sense. They’ve got the opportunity to export to global markets where that expertise is welcomed. I guess it’s the same with the engineering firms. (HS-01)

Some partner organisations were reported to have grown during the HS programme. For example, Progressive Energy was reported to have grown from 14 to 40 people, influenced by this and other funding programmes. Some of the new staff were making a transition to hydrogen from the fossil fuel industry

Quite a number of those who have come in have come in from Exxon or one of the old industries. They’re young folks who have decided they don’t want to work *for one of those old industries. They want to work for a new one, ones working in energy transition, doing something good. So I think there's a lot of that going on. (HS-03)*

- In interview, project representatives pointed out that, at the end of the project, people tended to move on to new roles (within or outside their organisation), taking the skills with them. For example, individuals who worked on a project for the first HS programme might later work on a project for the second Hydrogen Supply programme, put forward by the same organisation

  Where I know things have changed is where individuals who were working on it, so on HPP1, are now working on HPP2. It is very clear that knowledge has moved with them. Now, that's very clear. (HS-03)

- Finally, networking and partnership building formed important parts of most of the projects. For example, Dolphyn, Gigastack and HyPer all reported in interview that they undertook activities to engage with potential suppliers (e.g. supplier days, supplier packs). Negotiation of investment and offtake arrangements with potential partner organisations formed a significant part of activities on all projects
- The impact of this capacity building on investment and activity levels is explored in the 'investment' section above, while the numbers of jobs supported by projects are set out in the value for money section, under 'employment'

What are the reasons for any differing levels of achievement between HS projects, including for any under-achievement against expectations / intentions?

As outlined above, all of the projects except for HyPer delivered or over-delivered against expectations. Several factors were identified as affecting levels of achievement and speed of progress post-project. These were:

- **Level of project management and financial management skills** – as evidenced in the 'process report', Departmental representatives reported that one of the major reasons for initial slow progress with HyPer was the lead organisation's inexperience in dealing with major capital projects. The project lead reported that the organisation had established a 'project office' and had upskilled itself on project and financial management in response to their experiences with the HS project
- **Nature of demonstration project** - a further factor influencing initial delays with HyPER was that this project involved construction of a sizeable demonstration unit, which was different in nature from desk-based FEED studies that dominated the other projects. The construction work was reported to be more impacted by supply chain constraints and cost increases associated with COVID and with EU Exit
- **Level of technology development** – it was inevitable that projects involving technologies that were closer to development at the start of the HS programme (e.g. HyNet HPP1) would tend to be closer to commercialisation at the end of the programme than those involving more experimental technologies (e.g. Dolphyn).

- **Cluster status** – interview and funding evidence suggests that both Gigastack and HyNet were helped by being part of Track 1 industrial clusters, which gave them access to additional sources of funding and a network of potential customers for hydrogen. The benefits were two-way - the existence of the near-viable HPP1 project in HyNet was reported to have boosted HyNet's case for becoming a Track 1 cluster. The 'Reserve' status of the Scottish cluster was reported to cause uncertainty for Acorn Hydrogen.
- **Policy and regulatory uncertainty** – the completed HS demonstration projects reported that they were dependent on future Government funding such as the Hydrogen Business Model (HBM) and Net Zero Hydrogen Fund, and that delays to launching the HBM were constraining progress on follow-on activity. Regulatory uncertainty around the regulation of offshore hydrogen pipelines and the proportion of hydrogen acceptable within the NTS were also reported to be constraining Dolphyn and Acorn Hydrogen, respectively.

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