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Pale Blue Dot.

Acorn Hydrogen Feasibility Study

Pale Blue Dot Energy - Acorn Hydrogen: Project Summary

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1.0 Executive Summary

The Acorn Hydrogen Project completed a feasibility study with support from the BEIS Hydrogen Supply Competition Phase 1 (HSC-1) between March and October 2019.

A 200MW Low Carbon Hydrogen (LCH) plant is planned, sized to enable blending 2% (by volume) hydrogen into the National Transmission System (NTS) at St Fergus.

A hydrogen development at St Fergus provides an outstanding location for an early project linked to Acorn CCS and provides a long term build out to >10TWh per annum based on blending into the NTS and conversion of the local gas system.

Strong regional support exists in North East Scotland to build upon the region's existing global hydrogen profile, utilise the strong local supply chain and provide a clear example of the energy transition, whilst supporting UK net zero obligations.

As a result of funding from both the UK Government Hydrogen Supply Competition (Phase 1) and Pale Blue Dot Energy (PBDE), PBDE has undertaken a comprehensive feasibility study to assess the potential for developing a clean hydrogen generation plant at St Fergus in North East Scotland.

The comprehensive scope of work included both technical and non-technical aspects.

The overall concept was found to be technically feasible with no technical showstoppers identified. Build out potential includes blending increased percentages of hydrogen into the NTS, regional conversion of the low pressure gas distribution system to 100% hydrogen and the use of hydrogen for power generation at Peterhead Power Station.

This report summarises the work undertaken during the Phase 1 Feasibility Study (HSC-1) and outlines the further work which is required to progress the Acorn Hydrogen Project towards Front End Engineering Design (FEED).

Ongoing engagement with BEIS regarding hydrogen related policy and business models will be critical to the ongoing progress and success of the Project.

The Aberdeen region is already recognised as a global leader in hydrogen for transport applications and expertise in delivery of large scale projects and the development of the Acorn Hydrogen Project can build upon the regional support base, which includes existing public support, to deliver an early bulk low carbon hydrogen project.

2.0 Introduction

The Acorn Hydrogen Project (the Project), located in North East Scotland (Figure 2-1), is an Advanced Reforming Process, with Johnson Matthey Low Carbon Hydrogen (LCH) technology at its core. This will deliver an energy and cost-efficient process for hydrogen production from North Sea Gas, whilst capturing and sequestering CO_2 emissions to prevent climate change. Clean hydrogen will be blended into the National Transmission System (NTS) or used in the region for decarbonising heat and industry. The plant could be on stream before the end of 2025. Figure 2-2 provides an overview of the hydrogen generation process.

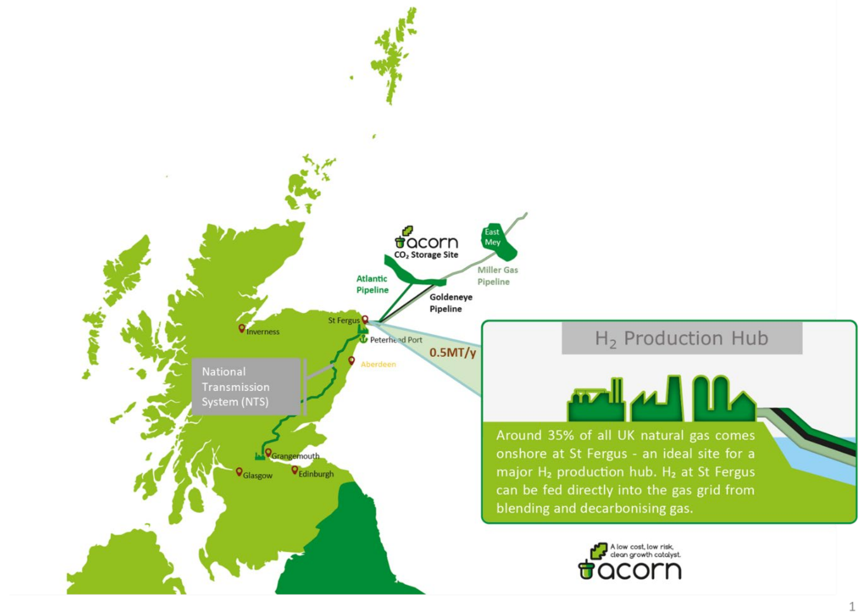

Figure 2-1: Acorn Hydrogen Project Location in North East Scotland

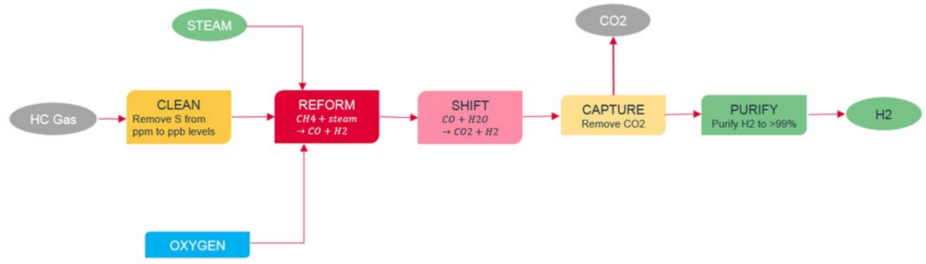

Figure 2-2: Base Case Hydrogen Generation Process

The Project will combine Johnson Matthey LCH reformation technology, with best available 'Shift' and 'Capture' technologies to create an Advanced Reforming full scale plant with efficiencies above 80%, and integrating the CO_2 capture process in an energy efficient manner, to provide the lowest technical costs compared to other systems.

Acorn Hydrogen is a phased approach to address the recommendation by the UK Committee on Climate Change, initiating the development of a UK strategy for decarbonised gas within the next three years, driving the future use of the gas grid in the UK under a 'low-regrets' opportunity, whilst facilitating the future deployment of low-carbon hydrogen at scale.

The plant would be potentially the first operational low carbon hydrogen plant in Europe, operational before the end of 2025 and enabled for early development by the Acorn Carbon, Capture and Storage (CCS) Project which is under development at the same location. St Fergus is identified as an ideal location for developing low carbon hydrogen for a range of reasons, as depicted in Figure 2-3:

- St Fergus is the delivery point for North Sea natural gas, with 35% of the UK's natural gas being processed and delivered to the NTS at this location and gas import forecast to continue at similar rates at this location for the long term future;
- Acorn has a CO_2 storage licence in place and St Fergus is close to some of the best CO_2 storage reservoirs in the UK, which are well characterised as a result of oil and gas activity and have large capacity;
- The Acorn CCS Project is under development, to re-use redundant offshore pipelines and deliver a low cost, high capacity CCS project, to sequestrate CO_2 from multiple sources, including from an Acorn Hydrogen Project;
- St Fergus is one of the only NTS entry points which can facilitate the commingling of hydrogen at low percentages, but at significant scale, to demonstrate the feasibility of achieving high CO_2 capture rates at reasonable cost whilst supplying the gas grid with clean hydrogen;
- There is strong stakeholder engagement in the current Project to enable gas transport and distribution with involvement of Total, SGN, National Grid, and Aberdeen City & Shire Councils;
- North East Scotland is home to the oil and gas and renewables supply chain, which has the capability, capacity, technology and assets to diversify into a future hydrogen supply chain. This also supports the Scottish Government's ambition for hydrogen.

The Hydrogen Supply Competition Phase 1 Feasibility Study (HSC-1) evaluated the technical and economic feasibility of a single development concept and included elements of technology selection screening. Further technology assessments are planned to continue beyond the close-out of HSC-1. If successful in applying for Hydrogen Supply Competition Phase 2 (HSC-2) grant funding, Pre-FEED will be undertaken with overall concept selection and more detailed engineering studies specifically around the Johnson Matthey LCH reforming island.

Figure 2-3: Benefits of St Fergus as hydrogen production location

Post HSC-2, a FEED phase would define an Acorn specific engineering design, with the necessary consents, commercial model and stakeholder engagement, to reach a Final Investment Decision. This will enable the Project to move into the detailed design and construction phase.

The Study has created new materials of relevance to other significant UK hydrogen projects, such as H21 and HyNet, and has built upon work already conducted through Acorn, HyDeploy, Hy4Heat, H100 and the Aberdeen Vision Project. Overall this helps to continue in signaling to government the potential for the future use of hydrogen as a gas grid energy vector.

3.0 Scope

3.1 Purpose

The purpose of this report is to outline the key findings of the HSC-1 Study which was undertaken between March 2019 and October 2019 and to provide an overview of the proposed next steps for the Acorn Hydrogen Project.

3.2 Scope

The deliverable scope includes the following aspects:

- Summary of work undertaken during Phase 1 (HSC-1)
- Outline of key findings
- Overview of further work required

4.0 Work completed during Phase 1

Since the commencement of the Phase 1 Feasibility Study (HSC-1) in March 2019, a wide range of work has been undertaken by the Study Team (Table 4-1).

No.	Work Package	Scope
1	Technical Definition: Low Carbon Hydrogen (LCH) Technology	• LCH basis of design • Multi-discipline activities definition to evaluate the feasibility of installing an LCH based hydrogen plant at St. Fergus • Process descriptions and process flow diagrams, utility consumption list, sized equipment list, catalyst and chemicals list and effluent data • An alternative technology screening report completed for LCH supporting unit operations within the overall flow scheme • Installed costs for JM equipment including (but not limited to) Gas Heated Reformer (GHR), Autothermal Reformer (ATR), Isothermal Shift & LCH inputs into operational expenditure (OPEX) • Parallel studies to identify opportunities to optimise performance and efficiency of the concept • Support on power utilisation, system flexibility and energy management • Identification of key project and safety and environment related risks, moving forward to the next phase of the Acorn project lifecycle
2	Technical Definition: Balance of Plant	• Development of a project basis of design capturing core data / assumptions • Multi-discipline greenfield and brownfield definition activities to evaluate feasibility of installing LCH based generation facility • Interface with JM in relation to core elements within LCH technology • Alternative technology evaluations for specific unit operations within overall flowsheet that complement the LCH technology • Parallel studies to identify opportunities to optimise performance and efficiency of the flowsheet • Identification of key project and safety-related risks • Production of EPIC cost estimate (accuracy +/- 40%) and development of engineering study cost estimates for FEED scope • Engagement with St Fergus terminal owner regarding site and services
3	Non-Technical Definition	• Identification of consenting and permitting requirements and development of Consents Register • An assessment of the hydrogen export opportunities / energy demand analysis • Description of the CO_2 export opportunity provided by the Acorn CCS Project
4	Route to Market	• Identification of relevant stakeholders and development of Stakeholder Engagement Plan • Assessment of hydrogen market size, export opportunities and potential business models • Development of a Public Project Summary
5	Development Planning	• Production of a development plan and budget for next phase of the Acorn Hydrogen Project • Identification of hydrogen plant cost and assessment of project economics • Assessment of build out potential to >10TWh scale
6	Project Management	• Project management of overall Study • Communications with BEIS • Budget management

Table 4-1: Phase 1 Work Packages and Scope

5.0 Phase 1 Key Findings

The Phase 1 Study (HSC-1) has generated a wealth of information and a greater level of understanding regarding the technical and non-technical aspects of the Acorn Hydrogen Project as summarised in this chapter of the report.

5.1 LCH Technology and Balance of Plant

The key findings of the technical work associated with the LCH technology and the balance of plant feasibility scope of work are as follows:

- The overall concept was found to be technically feasible with no technical barriers identified;
- The presence of hydrogen in the plant imposes specific safety issues but these are well documented and understood and can be adequately managed;
- There is adequate vacant space for a hydrogen plant at St Fergus. The estimated footprint of the plant is 320m x 140m (excluding the flare). Space is also available for later expansion / build out if required;
- The estimated electrical power demand of the plant is 16 MW;
- Transport logistical constraints will be important in defining the construction philosophy. It is expected that major equipment will be packaged and delivered to Peterhead port for onwards transportation via the single carriageway A90 to the site. It is presumed that new equipment would be mostly packaged into pre-assembled units (PAU's) to reduce onsite construction time as far as possible;
- Hydrogen storage allows the plant to respond to seasonal and intra-day variations in demand and grid dilution capacity. Storage options and facility assessments will be conducted in Phase 2.

5.2 Consenting and Permitting

Work has been undertaken to identify the consents and permits that would be required to both build and operate a hydrogen production plant at St Fergus and export the hydrogen to the NTS via the National Grid site at St Fergus. Engagement has been undertaken with key regulatory stakeholders to assist in delivery of the required consents and permits.

5.3 Hydrogen and Carbon Dioxide Export

The key conclusions of the work which has been undertaken to investigate hydrogen and carbon dioxide export are as follows:

- A 200MW plant using JM LCH technology has been assessed in HSC-1; initial hydrogen export is expected to be through the NTS at a 2% by volume blend, subject to changes in the Gas Safety Management Regulations (GS(M)R). 2% has been selected in conjunction with National Grid and SGN on the basis of a reasonable initial blend level.
- The Acorn CCS Project provides a route by which CO_2 can be transported and stored from the Acorn Hydrogen Project;
- A phased transition to 100% hydrogen for Aberdeen via a new pipeline is feasible;

- Other potential demands in the region include the St Fergus gas terminal, the Aberdeen transport hub and the Peterhead Power Station.
- There is significant opportunity to build out to more than 10TWh/y of hydrogen generation through export of hydrogen as a blend in the NTS and supplying hydrogen to the Aberdeen gas network.

5.4 Stakeholder Engagement

Relevant stakeholders have been identified and logged in a comprehensive Acorn Hydrogen Stakeholder Register which identifies the proposed method and frequency of engagement which is most appropriate for each stakeholder. The Register will continue to develop in the next phase of the Project.

The focus of the engagement activity in HSC-1 has been to foster strong relationships with infrastructure owners and operators and the relevant regulating bodies, whose understanding and support for the Project will be an important enabler for future development.

Key enabling stakeholders have been approached and face to face meetings have been held during which PBDE has sought feedback on preferences for frequency of engagement.

At this stage, specific community engagement activities have not been sought or deliberately created however, PBDE has responded to any enquiries received. In subsequent phases of the Project, PBDE will implement a programme of engagement activity with relevant communities. PBDE will also maintain a web presence for the Project.

Stakeholder engagement activities to date have been positively received. Regulators have appreciated an early understanding of the Project plans and have provided helpful feedback.

Engagement with industry partners has demonstrated the support, enthusiasm and opportunity for the Project to progress. The general awareness raising has been synergistic with the national dialogue on energy transition and hydrogen. Established supply chain parties are building enthusiasm for the Project and associated opportunities.

The Acorn Hydrogen Project has benefitted from its linkages to the Acorn CCS Project which has been gradually attracting more media attention and a wider public profile. This has created opportunities for the concepts being explored with the Study to be communicated to a wide range of stakeholders.

Acorn Hydrogen has been proactive in collaboration with other hydrogen and CCS Projects. PBDE has reached out to both HyNet to develop synergies regarding large scale gas to hydrogen production including Johnson Matthey LCH technology and the ERM Dolphyn Project to develop synergies between ‘green’ and blue’ hydrogen in North East Scotland. This is in line with the PBDE Hydrogen Coast Vision and outlined in the Hydrogen Coast paper (available at: https://pale-blu.com/category/news/). PBDE has also been actively engaged in meetings between UK regional CCS Clusters which are taking place every few months.

The Project will provide significant opportunities for knowledge dissemination as it progresses to the next phase of development. In order to maximise the benefits of the knowledge which is generated, a Knowledge Dissemination Plan has been developed. This will be a core part of the Stakeholder Engagement plan going forward.

5.5 Market Size, Export and Rate of Build

The key conclusions of the work undertaken during HSC-1 to assess the market size, export opportunities for hydrogen and potential rate of build are as follows:

- Acorn Hydrogen is well-suited to becoming the first low carbon hydrogen project in Europe (making hydrogen from natural gas with CCS);
- St Fergus is an excellent location at which to commence low carbon hydrogen production in the UK;
- The Aberdeen Vision Project with SGN and National Grid demonstrates the potential for 2% hydrogen in the NTS and for conversion of the Aberdeen gas system to 100% hydrogen;
- A 200MW plant is planned to suit 2% blend into the NTS;
- The Feasibility Phase design for a 100% hydrogen phased conversion for the Aberdeen gas distribution system has been completed and such a scheme is considered feasible;
- Significant further potential exists for hydrogen build out at St Fergus to increase the percentage hydrogen in the NTS, to supply industry and to enable low cost hydrogen transport;
- Government policies are needed in the imminent future to establish a robust supply chain, encourage new business models and inject investment into infrastructure, including capital investment;
- The North East Scotland 'Hydrogen Coast' (a collection of hydrogen projects located across Scotland between Orkney and Fife) can act as a catalyst for widespread application of hydrogen across the whole of the UK and is well positioned to maximise the learnings and opportunities for hydrogen production from renewable sources and from natural gas;
- Changing the GS(M)R grid specification for hydrogen is critical to all future business models;
- Early learning from the design and development of a hydrogen plant at St Fergus will provide valuable information for the development of other hydrogen projects across the UK.

5.6 Development Plan and Budget

HSC-1 evaluated the technical and economic feasibility of a single development concept and included elements of technology selection screening. The concept evaluated was a 200MW LCH plant, sized to enable a 2% (by volume) hydrogen to natural gas solution for the National Transmission System (NTS) at St Fergus.

Figure 5-1 outlines the Acorn Hydrogen Project Development Plan in relation to provisional planning for the wider Acorn CO_2 transportation and storage (and local CO_2 capture) due to the synergies between the two projects. The Acorn Hydrogen Project plans to utilise the Acorn CCS Project for CO_2 export. The schedule presents 'First Hydrogen' in 2025.

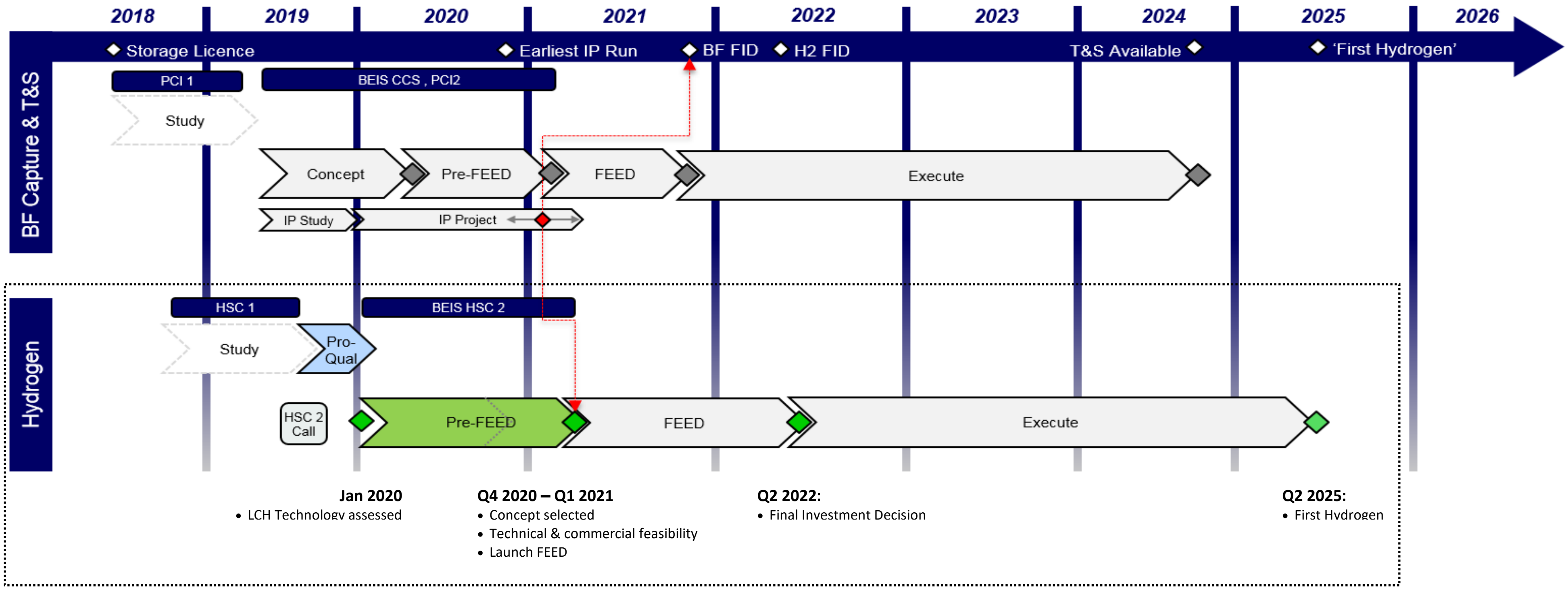

Figure 5-1: Acorn Hydrogen Project Development Plan

Technology assessment is identified as critical, with potential to improve system efficiency and reduce hydrogen cost.

The Project would progress into a Pre-FEED phase from January 2020 subject to a successful HSC-2 application. The key objectives of the Pre-FEED would be to select the single best value concept based on Project value drivers and prove technical and commercial feasibility. This is expected to take between 9-12 months followed by a period of close-out and preparation for the next phase. The proposed Pre-FEED phase is shown in more detail in Figure 5-2.

Total is in discussions with PBDE in order to establish the conditions by which Total could enter into HSC-2 and take a lead role in the delivery of the technical scope. In the event that the HSC-2 application is successful, Total and PBDE will seek to execute a formal sub-contract agreement as anticipated under the Technical Development Study Agreement (TDSA) which is governing their support of the Project.

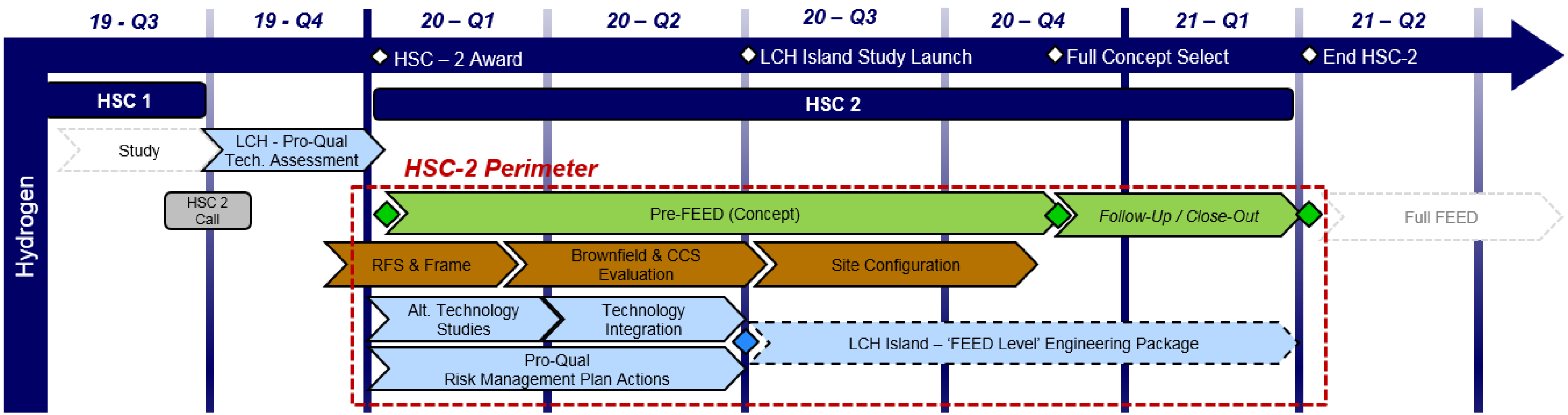

Figure 5-2: Acorn Hydrogen Pre-FEED including LCH Island Engineering Package

There are broadly two sets of tasks identified in Pre-FEED for concept selection, with one focussed on selecting the best site configuration / interfaces (brown steps in Figure 5-2) and the other focussed on technology selection (blue steps in Figure 5-2). Both sets of tasks are of course strongly dependent on each other. Concept selection would commence with a period of framing followed by screening of a large number of concept options. Using simple selection criteria, the three to four best schemes would be selected to study in more detail. In depth evaluation of the three to four short-listed concepts will involve a systematic comparative study. The final choice of the concept will be based on a certain number of well-defined and weighted criteria. A risk analysis will contribute to the decision. Brownfield elements will need to be carried out with an additional level of detail in order to ensure reliable estimates of cost, planning and shutdown duration.

To accelerate the LCH technology development, a FEED level package of studies are proposed to commence on a limited perimeter around the LCH reformer island during the Project's Pre-FEED phase. Prerequisites for commencing this will include completing a technology qualification plan, selecting supporting technologies (e.g. CO_2 capture) and confirming the available services / utilities from existing St Fergus site, sizing choice, boundary conditions for natural gas import and hydrogen / CO_2 export. Assuming prerequisites are in place by mid-2020, this limited perimeter FEED level work package could be completed by end of Q1 2021.

A subsequent Acorn Hydrogen Project FEED programme would be conditional on factors including evidence of commerciality (with line of sight on a workable business model) and availability of export routes for CO_2 and hydrogen. CO_2 export will depend on the progress of the Acorn CCS Project. Hydrogen export is dependent on readiness of regulations and the gas transmission networks, or alternative market, to receive hydrogen. The full FEED programme would then focus on the selected concept, reducing uncertainties and optimising the development scheme.

By the end of the FEED programme, the technology qualification plan will have been fully executed, the contractual strategy and project execution principles will be defined alongside delivery of the Statement of Requirements (SOR) and Basis of Design. At the end of FEED, the concept will have been matured to a point that will enable a financial investment decision (FID) to be taken. 15 months is currently assumed for FEED, including call for tenders and preparation for FID. FID is therefore forecast for Q2 2022.

Assuming a 3 year project execution period 'First Hydrogen' is forecast in 2025.

5.7 Hydrogen Plant Cost and Economics

Hydrogen plant cost and economics study has developed cost estimates (CAPEX and OPEX), analysis of the levelised cost of hydrogen and economic results for the Acorn Hydrogen Project.

The Acorn Hydrogen HSC-1 feasibility phase concept, referred to as 'Base Case', represents the Acorn design developed during the HSC-1 studies. It is based around a 200MW Johnson Matthey Hydrogen (LCH) technology.

The BEIS Counterfactual SMR with CCS referred to as 'BEIS Counterfactual', represents the counterfactual case developed by BEIS. It is based on a 300MW Steam Methane Reforming unit with carbon capture and storage.

All CAPEX estimates at feasibility level with accuracy of +/- 40% are shown in Table 5-1 and OPEX estimates are shown in Table 5-2.

A CAPEX of £203M is presented for the 200MW Acorn Hydrogen 'Base Case' assuming a company cost of 7% and no contingency. Using BEIS assumptions for the price of natural gas, electrical power and CO_2 emissions, along with OPEX assumptions, the associated levelised cost of hydrogen is 7.96p/kWh.

Table 5-3 shows a variety of parameters for the project.

CAPEX £M	Acorn Hydrogen 'Base Case'
Equipment Procurement	130.4
Fabrication	7.2
Installation	20.2
Construction Logistics and Rental	11.8
Contractor Engineering and Project Management	20.0
Owner's costs (7%) / Insurance	13.3
TOTAL (excludes contingency) £M	**203.0**

Table 5-1: Capital Expenditure Estimate for Acorn Hydrogen

OPEX £M/yr	Acorn Hydrogen 'Base Case'
Fixed OPEX	10.9
Variable OPEX	26.5
Total OPEX	**37.4**
Natural Gas Feedstock cost	62.4

Table 5-2: Operating Expenditure Estimates for Acorn Hydrogen

Parameter	Units	Acorn Hydrogen 'Base Case'
Natural Gas (100% availability)	kg/h	19,500
	MW (LHV)	252
Hydrogen (100% availability)	kg/h	6000
	Nm3/h	67,000
	MW (LHV)	200
CO_2 Captured (100% availability)	kg/h	51,000
CO_2 Emissions (100% availability)	kg/h	652
CO_2 Captured	%	98.7
Carbon Footprint	kg CO_2/kNm3	9.7
Hydrogen Net Efficiency (LHV)	%	74.7
CAPEX	£M	203
Total OPEX (exc. feedstock)	£M/y	37.4
Natural Gas Feedstock Cost	£M/y	62.4
Levelised cost of hydrogen (inc. feedstock)	£/kg	2.66
	p/kWh (LHV)	7.96

Table 5-3: Key Parameters for the Acorn Hydrogen Base Case

Given the feasibility level of concept definition, additional company costs and contingency are considered to have a potential impact on Capex up to +50%. The impact of such uncertainty in CAPEX, OPEX and pricing assumptions on the levelised cost of hydrogen is presented in the form of sensitivity chart Figure 5-3.

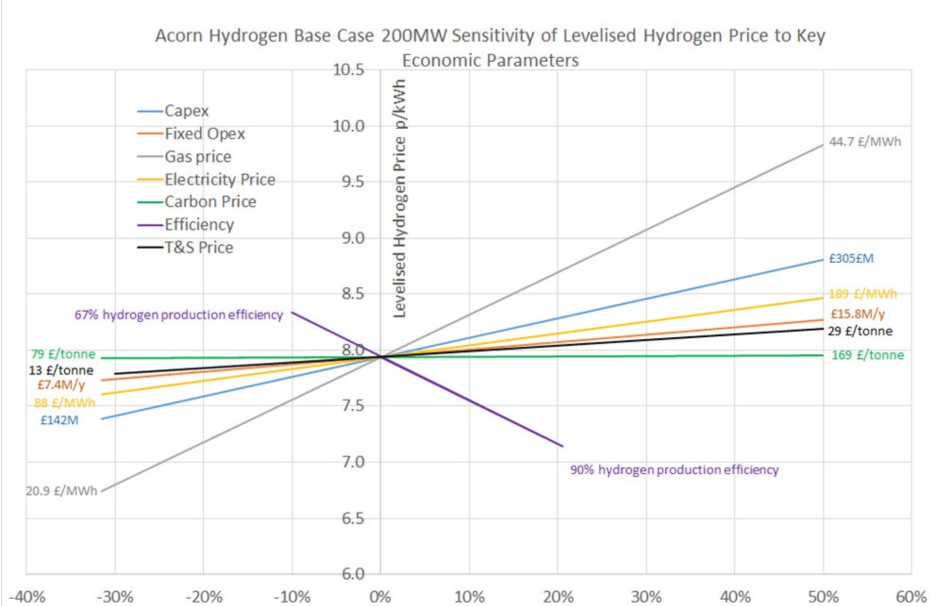

Figure 5-3: Levelised Cost of Hydrogen Sensitivity Chart

Whilst the Acorn Hydrogen Base Case has been sized under HSC-1 for nominal 200MW of hydrogen production, estimates have been made of development costs and associated levelised cost of hydrogen for a scale-up in hydrogen plant capacity. Scaling up to a 1300MW unit could reduce the levelised cost of hydrogen unit by around 15%.

The study has also assessed the possible reductions in the levelised cost of hydrogen associated with targeted improvements in efficiency. A 10% increase in hydrogen production efficiency from 75% to 82% in HSC-2 has been targeted and this would reduce levelised cost by 5%.

5.8 Acorn Performance

The performance of the Acorn proposed solution, compared against BEIS Counterfactual parameters is shown in Table 5-4 below. The table also describes the reasons for differences from the counterfactual SMR technology and discusses how the proposed LCH technology could improve on the standard SMR.

In summary, Acorn Hydrogen LCH will better supply end users compared to current state of the art counterfactual SMR solutions. End users require a safe, reliable, accessible, flexible, low cost de-carbonised gas solution, which can offer bulk hydrogen at the lowest possible price.

- **Safe** - LCH requires no continuously operating open furnaces, no extensive steam systems nor gas turbines as required under SMR. Steam is generated internally within the plant and power imported from green suppliers;
- **Reliable** - LCH is based on existing commercially available but, smaller scale reforming technology. Gas turbines are not required and supporting units such as ASU and PSA are mature, efficient and established technology;
- **Long term** - St Fergus site provides feedstock from up to 35% of the UK gas supply, direct access to the grid, and close-proximity to population centres with Aberdeen City active in the hydrogen economy. Industrial land is available for the 200MW unit and future scale-up and build-out solutions;
- **Flexible** - LCH will turndown to 40% of capacity without impact to efficiency and can do so within a short timescale. Potential storage has been identified to accommodate all potential gas demand fluctuations at St Fergus;
- **Low carbon hydrogen** - CO_2 capture from high pressure Syngas is more efficient than highly diluted contaminated atmospheric fluegas;
- **Low cost hydrogen** - LCH provides higher efficiency hydrogen conversion compared to SMR. It also provides considerable potential to reduce cost further through scale and efficiency improvements;
- **Natural gas supply at St Fergus** – Acorn Hydrogen provides the opportunity to leverage the large natural gas supply at St Fergus with LCH technology to produce hydrogen of scale for UK decarbonisation;
- **CO_2 storage resource and infrastructure** – Acorn Hydrogen is co-located with Acorn CCS to provide storage of the scale required to enable UK decarbonisation.

Parameter	Unit	SMR+CCS 'BEIS Counterfactual'	Acorn Hydrogen Project 'Base Case'	Discussion of Differences
Product Flow Rate	MW	300	200	• Acorn capacity is sized to meet 2% hydrogen in St Fergus export to the grid
Hydrogen Purity	%	99.9	99.9	• No significant difference
Hydrogen Output Pressure	barg	30	69	• Acorn hydrogen is compressed to 70bara to allow export into the grid. No hydrogen compression would be required for 30barg from a LCH unit
Net Efficiency (LHV)	%	67	74% Target Post HSC-2 80%	• Present efficiency of LCH is 74%. The improvement over counterfactual SMR 67% is due to: • Power for LCH is imported as "green" electricity at 100% efficient rather than generated from an onsite steam/power generation required for SMR • The GHR in the LCH process recycles heat at high quality and quantity without degrading the heat down to MP steam • No low-pressure post-combustion flue gas capture is required which improves overall process efficiency • Efficiency improvements will be investigated during HSC-2 with a target of further 5% improvement from: solvent technology; heat integration with the CO_2 compression and alternative carbon capture technology such as Cryocap or SEWGS
CO_2 Capture Rate	%	90.1	98.7%	• Integrated heat recovery within the plant and no requirement for fuel gas once operating allows for improved CO_2 capture rates • High pressure capture improves amine performance and reduces energy consumption • Use of ITS minimises CO slip
CO_2 Output Stream Purity	%	96	96.3	• No significant difference
CO_2 Output Stream Pressure	barg	30	120	• High pressure is required to ensure dense phase flow in the offshore pipeline and provide sufficient pressure for injection into the offshore disposal wells. The CO_2 leaves the Acorn Hydrogen plant at 2bara and wet. A £19/t OPEX charge is included to cover compression of CO_2 to 120barg and dehydration to 50 ppmv prior to transportation to offshore storage. The T&S service will potentially be provided by Acorn CCS project.
CO_2 Output Stream Temperature	°C	50	40	• Acorn cools CO_2 as low as possible to recover heat and improve efficiency
CO_2 Output Stream Max Water	PPMV	250	50	• Offshore storage injection pressure requires dehydration to 50 ppmv
Carbon footprint	$kgCO_2$/ kNm3	90.4	9.7	• Related to improved capture rate detailed above

Table 5-4: Performance of Acorn Hydrogen Base Case Against Counterfactual

6.0 Further Work

The subsequent phase of development will be Pre-FEED with the key objective being to select the best value concept and progress technical and commercial aspects

Pre-FEED (including a FEED level limited perimeter LCH engineering package) for Acorn Hydrogen is contingent on success from the HSC-2 application. The Pre-FEED phase would be expected to take approximately 15 months. On conclusion of Pre-FEED, the Project will have identified the best value concept, as determined by the Project value drivers, and matured the necessary technical and commercial elements to enable a decision to progress to FEED.

Several optional combinations of innovative new technology exist which are potentially feasible and could be put forward as development concepts. These will be assessed during the Pre-FEED phase to establish which is the most appropriate.

In order to achieve the above, the following pieces of work have been identified.

6.1 Hydrogen Plant Design

A technically and economically optimised single development concept needs to be developed. The key tasks required to accomplish this are concept-level design studies for the hydrogen development, specific advanced design work on the LCH reforming island, cost estimating and option analysis.

HSC-2 funding will deliver a single optimised concept at a Class 4 cost estimate level (-20%/+30%) ready to commence full project FEED. Concurrently FEED will be completed on the LCH reforming island at a Class 3 estimate level (-15%/+20%); excluding non-core units, site services and hydrogen storage.

The key activities necessary to complete concept selection include:

- **Alternative technologies -** The HSC-1 study performed a limited investigation into the use of alternative technologies, satisfying the justification for further value engineering. This related primarily to proprietary designs for CO_2 removal and hydrogen purification. The work did, nevertheless, identify potential for substantive concept improvements with respect to plant performance, efficiency and CAPEX. During HSC-2 this will be investigated further through the commissioning of paid studies by technology providers under confidentiality agreements to protect IP.
- **Alternative technology integration -** The integration of non-core units within the LCH reforming island will be optimised to maximise energy efficiency, reliability and cost.
- **Tie-ins -** Engagements will be progressed with the National Grid (Gas) along with third-party terminals to define tie-in locations, along with other shared services.
- **Plant capacity -** Based on the ongoing evaluation of the proposed national grid hydrogen specification and discussion with Aberdeen Vision Project (SGN), the capacity of the plant will be confirmed.
- **Integration -** The opportunities for cost savings though integration with existing third-party St Fergus infrastructure and the future Acorn CCS plant will be developed.
- **Hydrogen storage –** An assessment of specific hydrogen storage options and facilities will be conducted in Phase 2.

- **Cooling philosophy -** HSC-1 assumed direct air cooling. Other options will be investigated to confirm this philosophy. This may include shared facilities or a dedicated closed loop cooling medium system.
- **Power -** National Grid (electricity) will be engaged to define the modifications necessary to supply 16MW. It is likely that modifications will draw on synergies with supply to the Acorn CCS plant.

JM will undertake FEED on the reforming island which includes the GHR/ATR and the Water Gas Shift convertor. This will de-risk the cost estimate for the core of the facility at -15%/+20% and demonstrate upscaling feasibility around the core LCH. This would allow the Project to prepare a full set of FEED outputs for the core reforming island.

6.2 Plant Interface Design

Work is needed to ensure that plans are in place for all necessary services to a future hydrogen plant. Key tasks include interface specification, tie-in designs, preparation (and issue) of requests for services to terminal owners and cost estimating. Engagement with North Sea Midstream Partners at St Fergus is well underway.

6.3 Development Planning

A clear definition of the development scenario to be studied during FEED will continue to be created. Key tasks include scenario planning, analysis, preparation of the project execution plan and leveraging synergies with the Acorn CCS Project. Ongoing development planning for the Project up until First Hydrogen will continue to be progressed.

6.4 Consents, Permits and HSE

The Consents Register which has been created identifies the consents and permits that would be required to build and operate the hydrogen production plant and export the hydrogen to the NTS. The Consents Register will require frequent review through the life of the Project and ongoing updates as engagement with key regulatory stakeholders continues. The Acorn CCS process is currently subject to a separate consenting programme. Interfacing of these consenting processes will need to be considered should the projects be developed in parallel.

Key tasks going forward will include the preparation of statutory and non-statutory applications and carrying out initial HSE assessments or scoping surveys. There are also increasingly important synergies to be realised with similar ongoing studies and work associated with the Acorn CCS Project.

6.5 Stakeholder Engagement

Throughout the next phase, it is imperative that the Project engages with all relevant stakeholders. The BEIS HSC-2 Application has already received letters of support from multiple stakeholders who are close to the Project, for example North Sea Midstream Partners, National Grid, SGN, Aberdeen City and Aberdeenshire Councils and several others. The further development of the Project will require a broader and deeper engagement process, building on the work in the Stakeholder Engagement plan to take account of the Project programme for the next phase of work, funding and Project Partner input and requirements. The following specific recommendations from the work undertaken in Phase 1 will be implemented:

- Development of Acorn Hydrogen and Acorn CCS Project stakeholder engagement plans in parallel to ensure consistency and clarity of message in all Acorn Project communications. Any activity should make clear that the projects are linked but are discrete projects;
- Within the overall engagement plan, agree set dates and times with asset operators and site owners when stakeholder open house events could occur. These could be targeted to specific stakeholder groups as best suits the Project;
- Create a collaborative approach with other regions / clusters / hydrogen projects and share learnings and collaborate to address common challenges where possible. This builds on existing relationships with various projects.
- Engage with non-governmental organisations, relevant agencies and other organisations to build awareness and support for the project;
- Develop externally facing material to support stakeholder engagement;
- Engage with BEIS and Scottish Government to support policy development, respond to consultations and provide deliverables from the Project.

6.6 Knowledge Dissemination

Sharing of Project knowledge that might be useful to a wider audience will be a fundamental part of any future work and forms an important part of the Government's expectation, which PBDE will endeavour to ensure is met. Key tasks wll include:

- Development and implementation of the existing Knowledge Dissemination plan;
- Creation of a Project website to enable interaction;
- Sharing of Project deliverables via the website;
- Organisation of a Hydrogen conference;
- Presentation at other conferences;
- Issue of a quarterly newsletter;
- Continue to provide leadership to NECCUS, the public and industry alliance supporting the Scottish Industrial Cluster.

6.7 Finance and Economics

During the next phase of the Acorn Hydrogen Project development, a key objective will be to develop a clearer understanding of the business model for generation of low carbon hydrogen. Key tasks in this area of work will include the design and simulation of a range of potential business models to identify the most appropriate to pursue, i.e. the most cost effective and economically attractive. This will be underpinned by economic modelling and scenario analysis which will be undertaken using more detailed costings, and in consultation with BEIS to reflect any Government related business model evolution that may take place during the development of the Project.

As with the commercial aspects of the next phase of work, close collaboration with BEIS and other key stakeholders will be imperative.

6.8 Route to Market

It is important that going forward, a market and potential sale options for hydrogen is developed. Alongside this, the Project intends to progress transport / export options and identify and mature potential build-out options. Key tasks include market development, third party project support, scenario development and build out planning. Close collaboration with National Grid and SGN, will be a fundamental aspect of this work and enable the development of the financial, economic and commercial aspects of the Project.

In summary, the required work will include:

- Building upon the existing work undertaken regarding route to market;
- Continuing to work closely with National Grid and SGN to enable export of hydrogen from St Fergus by blending it into the NTS and through new hydrogen pipelines to convert the Aberdeen region gas distribution system to hydrogen;
- Development of potential applications for industrial use in the St Fergus area and in Aberdeen;
- Progression of potential hydrogen transport applications and linkages;
- Creation of a scenario based approach for build-out as input to technical and commercial workstreams to assess preliminary feasibility;
- Support to the broader regional work on the role of hydrogen in decarbonising the economy and creating economic value.

6.9 Commercial

One of the commercial aspects of further work will be to implement and manage a robust, commercially selective and competitive procurement process for any subcontracts required to fulfil HSC-2. Further, agreements will be developed with key third parties who require contractual terms with the Project. Such agreements will inform the design of any business models that are selected for assessment and selection.

Commercial agreements will be managed in a Commercial Agreements Register which is already established and will be further developed as the Project progresses.

PBDE and other members of the Project team will continue to engage with the UK Government in relation to hydrogen policy, business models and the GS(M)R specification. Each of these aspects are critical to the future realisation of a commercially feasible and operational hydrogen plant and will feed into both economics and route to market work.

6.10 Project Management

Project oversight and management will underpin the entire delivery plan for any future work. It is key to delivering the Project on time and on budget. Key tasks include project direction, coordination and control, with oversight across all aspects of the Project.

7.0 Conclusions

1. The HSC-1 Study has been completed within budget and to programme.
2. The overall concept was found to be technically feasible with no technical barriers identified.
3. St Fergus provides an outstanding location at which to progress hydrogen production from natural gas linked to access to the cost effective CO_2 storage provided by Acorn CCS.
4. At St Fergus hydrogen can be blended and exported in the NTS and used to convert the regional gas distribution system to hydrogen and used as a substitute for natural gas for power generation and used for other regional applications.
5. Consenting and permitting requirements have been identified and key regulatory bodies have been engaged.
6. The Acorn Hydrogen Project has widespread support from Scottish Government, Aberdeen and Aberdeenshire Councils and other consenting bodies.
7. A comprehensive Stakeholder Register has been developed and engagement has taken place with stakeholders relevant to the current stage of the Project.
8. Acorn Hydrogen has support of major industrial backers including Shell, Chrysaor and Total. In addition, National Grid and SGN are engaged as partners in connection with hydrogen export and knowledge sharing.
9. Site owners at St Fergus are engaged in the project, including Shell, National Grid and North Sea Midstream Partners.
10. A detailed plan is in place for the next phase, with areas of further work required identified across each workstream.
11. A development plan and budget are in place to take the project through to construction and operations.
12. Ongoing engagement with BEIS regarding hydrogen related policy and business models will be critical to the ongoing progress and success of the Project.
13. Considerable potential exists for massive build out of hydrogen production at St Fergus, utilising the large scale gas import facilities to enable decarbonisation of the UK’s gas system, supporting heat decarbonisation and enabling UKs net zero obligations.