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Provision of Hydrogen End User Skills and Standards for Heat Supporting Research and Evidence

Ref.: 5045/04/2021
Proposal

Client:	BEIS
Ref:	5045/04/2021 (Lot1)
Project:	Lot 1 Purging and Tightness
Authors:	[This has been redacted]

1 Project Overview

This proposal is put forward for BEIS's consideration by Steer Energy Solutions Limited, alongside subcontractor Kiwa Gastec. It details how Steer would approach the work required in Lot 1 of "Provision of Hydrogen End User Skills and Standards for Heat Supporting Research and Evidence".

The ITT document provides a clear overview of the aim of the project: to research and gather evidence for piped systems with respect to hydrogen (i) for purging and (ii) tightness and material compatibility. Much of this proposal builds on the findings and recommendations produced by Steer for the Hy4Heat project.

Since then, Steer have started the HyPurge project with SGN to review network standards on purging and venting, (IGE/SR/22 and IGE/SR/23) and inform the commissioning of the hydrogen network for the H100 Fife project. This proposal builds directly on the HyPurge project by taking the network learning outcomes and applying them to downstream of the ECV, exploring purging and leak tightness testing of domestic and commercial installations.

Steer welcome discussions with BEIS on any aspects of this proposal and the programme of work presented in this document.

2 Skills and Expertise

This section outlines the skills and expertise in Steer and Kiwa as a whole, and as individuals. It also details the facilities to be used for this work, alongside an outline of our safety management and track record.

2.1 Steer prior projects

Steer was founded in 2012 with the aim of 'getting ideas from the lab into the field' for the energy industry across a range of diverse specialities and disciplines. We now have 8 members of staff and a predicted 2021 turnover of circa £1m. Clients range from micro-SMEs to large oil and gas operators and utilities firms. Collaborators have ranged from lone-specialists, to SMEs and universities. We have now delivered around £5m of projects covering the innovation, development and commercialisation of new technology, with the majority of this funded by the Gas Industry.

Previous clients include BEIS, Scotia Gas Networks, National Grid Transmission, Wales & West Utilities, Cadent, Northern Gas Networks, Shell (via Wood Group Kenny), Taqa Bratani and Sarco Stopper.

Details of a selection of previous projects, many funded by the UK GDNOs through the Network Innovation Allowance scheme are provided to demonstrate skills and expertise relevant to this tender. In particular Hy4Heat WP7 Lot 1 for BEIS and the HyPurge project recently kicked off with SGN are relevant to work proposed in this document. The experimental setup and tooling, risk assessments, and data capture templates are available for use in this project, resulting in significant economies in experimental setup that are reflected in the price vs. size of test programme.

These projects demonstrate that Steer has the ability to not only carry out required experiments, but to use the information gathered to develop and understand the theory behind the experiments.

Hy4Heat WP7 Lot 1: Steer's work examined the theory of gas leakage and compared the relative leak rates between methane and hydrogen, directly relevant to Lot 1 of this project. Pressure drops due to varied flow rates in copper pipes and elbows are directly relevant to Lot 4 of this project.

A first variation order tested a recently decommissioned commercial gas installation. Whilst comparative leak rates in methane and hydrogen matched the theory and lab findings, the process allowed us to identify challenges to carrying out field operations such as purging between gases.

A second variation order carried out a detailed study into purging of domestic systems and associated venting into rooms. This work closely followed the IGEM/UP/1B standard to identify changes required for transition to hydrogen. This proposal now builds directly on the processes and tooling used in the Hy4Heat project.

HyPurge: This is a current project for SGN examining the changes required for Hydrogen purging gas network pipelines to enable the commissioning of the H100 Fife network to hydrogen. This work is based on a study of the IGE/SR/22 and IGE/SR/23 standards. Building on the Hy4Heat work, this project extends the purge theory for larger diameter pipes, up to 250 mm diameter. At the time of writing, purges have been carried out in pipe sizes up to 100 mm internal diameter. Minimum required purge speeds and other processes identified in the standards are being generated for hydrogen. Work will also take a limited look at vertical systems for risers.

Exovent: Steer are proud to support the Exovent charity in the promotion of negative pressure ventilation as an emergency response to the COVID-19 pandemic, and in the development of a modern negative pressure ventilator. [This has been redacted] is the [This has been redacted] of Exovent, and developed the first proof of concept devices. The pressure and flow control ranges are similar to gas industry usage, and Steer developed technology and tooling during lockdown that will be pertinent to the measurement studies of this project.

[This has been redacted] [redacted]

PhotonFix®: This is a new sealant recently accredited for use in metallic mains. The project required re-assessment of the GIS-LC suite of standards to identify the correct set of tests to be applied to demonstrate 50 year sealing performance.

Many of the tests carried out involved demonstrating leak rates less than 2.8 l/hr during and after stress testing of cast iron joints sealed with PhotonFix. The test programme required the use of nitrogen, but we extended the project scope to test in methane and hydrogen adding to the knowledge base of hydrogen leakage behaviour.

Gas Polymerisation: Development of methods to exploit the behaviour of vaporised monomers in various gas flows (along pipes and through leak passages) to provide a 'self-delivering' sealant capability for live gas pipes. The initial work began by identifying candidate chemistry systems, moved to laboratory and workshop testing of apparatus and has reached the point of demonstrating leak sealing with minimal in-pipe deposition. The success has been founded upon the collaboration of two UK university chemistry departments, specialist commercial CFD consultancy, in-house analytical flow regime modelling and extensive literature reviews.

2.2 Kiwa prior projects

Kiwa Ltd is a UK based private company wholly owned by the Kiwa Group (which has its headquarters in the Netherlands). Kiwa Gastec is a trading division of Kiwa Ltd. It undertakes energy consultancy activities including feasibility studies, research and development, verification of greenhouse gas emissions, operative certification and product testing services for a wide range of commercial customers.

With roots in the testing of heating systems (formerly, Coal Research Establishment), Kiwa has developed a long and wide-ranging experience with renewable gas, liquid, and solid fuels. Kiwa also has experience with heating technologies through numerous practical projects evaluating real life performance of heat pump, gas boiler and biomass systems. Over the past 10 years, Kiwa has had a deep involvement with the work to progress hydrogen as a major energy vector across all energy sectors in the UK, particularly as a solution to decarbonising the UK's heat demands.

Kiwa has played a significant role in many of the major projects undertaken in the UK to develop the knowledge and understanding of hydrogen energy systems. A few example projects are outlined below:

Kiwa SMR: Kiwa is currently developing its own hydrogen production site to be able to feed large quantities of hydrogen into its testing laboratories. This includes both the production site and a new hydrogen laboratory space, including facilitating the connection of domestic-scale appliances.

BEIS Hy4Heat: Kiwa is the technical lead on this government programme developing the standards, appliances, components and safety case to de-risk the provision of distributed hydrogen for heat.

SGN H100: Kiwa completed the feasibility and FEED designs of the hydrogen system utilising renewable electricity from offshore wind to produce hydrogen distributed through pipelines to 300 homes for use in domestic heating.

Cadent HG2V – Hydrogen Grid to Vehicle: Kiwa was part of a consortium addressing the challenges associated with impurities picked up through hydrogen pipeline distribution. Kiwa developed work addressing purification challenges around impurities such as odorants.

BEIS H Appliances Project: An investigation of the state of the art of hydrogen heating equipment including domestic, commercial, and industrial scales of technologies.

The use of distributed hydrogen presents feasibility challenges which Kiwa has experience of addressing. Our experience shows that there are complex relationships between production systems, storage, and delivery systems and demand profiles. Studies which Kiwa have led or made a major contribution to understanding these issues, include:

NGN H21 Leeds City Gate: Feasibility of conversion of city of Leeds to hydrogen – Kiwa: provided modelling of hydrogen demands (including daily and seasonal variations), identified storage / pipeline requirements, and considered impacts on appliance conversion.

Hydrogen for Heat and Motive Power at Tyseley Energy Park: This feasibility study looked at developing city scale hydrogen distribution from a central production hub in the city. The demands modelled in this project were heat networks, domestic properties, and bus and rail transport demands. Extensive modelling of heat networks and transport demands led Kiwa to develop techniques for matching demands to reduce the supply burden of seasonal variations in heating demand.

SGN Methilltoune study: A real world study in Scotland examining the feasibility for an existing wind turbine to be the basis of hydrogen supply for the local area. Kiwa provided the analysis of the per second power production and gas demand data in the location and provided design and sizing requirements for supply, including production and storage requirements.

2.3 Project personnel

The Project Leader will be [redacted] – a founder of Steer. Short biographies are provided for [redacted], colleagues and collaborators, demonstrating relevant experience and expertise. Resumes for the key individuals ([redacted]) are provided as Annexes to this proposal.

[redacted] – ***Project Leader:*** [redacted] has spent time in academia and industry and has been involved in technology transfer and R&D in the energy sector since 1997. He has worked on a range of different technologies and disciplines from electromagnetic compatibility, remote leak sealing and location technologies and tooling to manage ageing infrastructure. More recently he has worked developing new tools and processes for the gas industry. During lockdown he was a foundation member of the Exovent team and developed a number of prototype negative pressure ventilators, one of which is being used by the medical team at University College Hospitals London to further research into this process.

[redacted] is experienced in running multi-disciplined groups where there is a high degree of collaboration between the participating parties. This leads to all members directly and fully informed during investigations, understanding their responsibilities but able to contribute to the wider success of the work.

[redacted]***:*** [redacted] is a founder of Steer, and is responsible for all of Steer's Business Development activities. He will act as the Commercial Lead on this Project, as well as supporting [redacted] in the technical delivery.

[redacted] has a MEng (Civil and Structural) from the University of Aberdeen and an M.Sc (New Venture Creation) from Glasgow Caledonian University. He was been involved with research throughout his career, first as a Research Assistant in the Environmental and Industrial Fluid Mechanics Research Group (University of Aberdeen), then commissioning work in his role at Brinker Technology and now Steer.

[redacted] was awarded a Royal Society of Edinburgh Enterprise Fellowship in 2001, and was a founding member of the Young Academy of the Royal Society of Edinburgh (2011 – 2016). He is a member of the Energy Innovation Centre's Innovator Impact Panel.

[redacted] is a Senior Development Engineer at Steer, with a Masters in Manufacturing Engineering and Management from the University of Warwick. An experienced project manager and mechanical engineer, he has a demonstrated history of managing high value projects to completion in Oil & Gas, Mechanical and Industrial Engineering industries. He has been heavily involved in Hy4Heat and other projects exploring the hydrogen safety case with Steer, both from a technical and organisational perspective. [redacted] has also been involved in numerous other projects with Steer, from ground up innovation and tool development, to product testing.

[redacted] will support [redacted] with project delivery, in particular with experimental investigation and interpretation of results. He will also contribute to development of the theory and understanding.

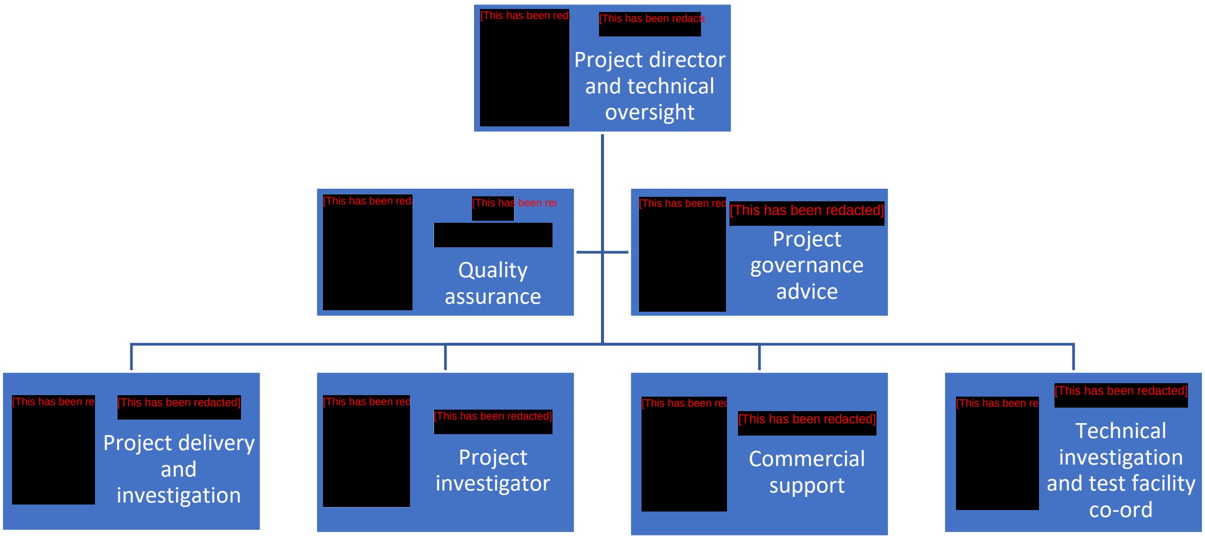
[redacted] With a Physics degree from Swansea University and a strong background in experimental physics, [redacted] will support [redacted] in the development and accurate implementation of the detailed test programme.

[redacted] carried out the experimentation for the work for Hy4Heat WP 7 Lot 1 last year, and HyPurge this year. He will perform a similar role in this work, carrying out experiments, data presentation for analysis of the results.

[redacted] [redacted] has fulfilled this role since 1994. He has over 40 years' experience in the energy sector and has a wide knowledge of energy vectors (biomass, gas, oil, coal, and hydrogen) from the industrial to domestic scales of operation. Early in his career he gained significant experience in the design and operation of commercial and domestic appliances. His role includes responsibilities of Head of Testing Laboratory for the UKAS accredited solid fuel, oil and gas appliance testing laboratory and Head of Certification Body for UKCA Approved Body activities. He has had technical direction/ technical expert roles for key hydrogen projects and programmes including: BEIS Hy4Heat Programme, Cadent Foundation Tyseley Energy Park hydrogen study, H21 Leeds City Gate, and H100. [redacted] will provide industry perspective to the project and review outputs and reporting.

[redacted] is a chartered engineer with 18 years of international design, construction and operations experience in the chemical industry. He now heads up the consultancy team at Kiwa Ltd. He concentrates on innovative research and development issues, and technical support to clients focusing on hydrogen gas applications. His industry experience in hydrogen production and chemical plants is particularly valuable for projects supporting hydrogen production, handling and use. He has made significant technical contributions to delivery of projects under the Hy4Heat programme, H100 Fife and HyDeploy, as well as undertaking technical due diligence work on behalf of investment funds. [redacted] will be overseeing the quality assurance of the project.

[redacted] has excellent project management and organisational skills. She has led and coordinated national field trials of domestic heating appliances and experimental studies. She has technical knowledge and practical experience of innovative research into hydrogen as well as a large variety of domestic and commercial technologies at varying scale and complexity. [redacted] will be assisting in the literature search, fitter and FCO surveys and will facilitate the gas tightness testing for the Kiwa lab facilities.



2.4 Safety

Steer has a strong focus on carrying out work safely, and in its seven years of operation has not encountered a lost time incident. It's HSE Policy is available on request.

Steer bring in external consultants when required - for example, prior to starting to work with hydrogen venting we contracted Strategic Safety Systems Ltd. to carry out a DSEAR review of operations.

2.5 Steer facilities

This project has a significant element of empirical testing requiring accurate measurement of flow and pressure over a very wide range.

Measurement equipment

Steer have developed their gas research facilities over the past nine years, and are continually making improvements. Recently we have built comprehensive test and measurement and control systems with gas supplies in hydrogen, methane, nitrogen and air. Utilising a robust plug and play philosophy, we are able to accurately measure and control flows in the relevant gases from 0.003 sl/m to 50 sl/m (110 sl/m in hydrogen) using calibrated Bronkhorst flow controllers. We have recently added calibrated flow measurement capability up to 500 sl/m for the test gases. We have a range of dataloggers which have been improved over the summer to give a suite of 16 channel loggers capable sample rates of 0.1 samples per second.

We have pressure measurement and logging capabilities from 0.01 mbar to 400 bar using a range of calibrated pressure gauges.

We have further developed our capabilities for gas detection using a range of logging gas sensors to detect flammable gases; particularly hydrogen in ppm, %LFL of fuel gases and %vol of fuel gases. These will be used to investigate dispersion of hydrogen and methane inside and outside of pipelines.

Since completing the Hy4Heat project work, Steer have been independently investigating likelihood and consequences of ignition during purging operations. This has led to a deeper understanding of the relative risks of purging in methane or hydrogen in a domestic system.

Purge test installations

Steer have already been testing hydrogen purges in up to 100 mm diameter pipe. We have tested purges in pipe lengths up to 50 m, and shorter pipes in a variety of orientations. In the HyPurge project purging tests will be carried out in MDPE network pipes up to 250 mm diameter. Steer are in the process of securing a location for testing long lengths of pipe in a variety of orientations.

Since the Hy4Heat project, Steer have been independently investigating the likelihood and implications of ignition during purges. To date tests have been carried out to understand the consequences of ignition during purges up to 50 mm diameter pipes and with gas flows up to 5 m^3/hr.

Tightness test installations

During the Hy4Heat project Steer developed our test setup to rapidly assess and measure equivalent leakage in different items of infrastructure. Steer also routinely carry out leakage tests on multiple fixtures and fittings ranging from 24-inch cast iron joints to ¼ inch stainless steel tube fittings, and gas emergency response leak sealing tools. This tooling and expertise will to be used for tightness testing of components at Steer and will be taken on site to test third party installations as identified and agreed with the steering group.

2.6 Kiwa's facilities

Kiwa are in the process of building a hydrogen facility for training and research. This includes bespoke test labs which can be used for whole system installation testing for the tightness testing work. Kiwa have a bespoke gas dispersion test facility which can be used to assess concentrations of gas in air from known leaks and for purging and ventilation of small systems. A range of calibrated gas analysers can be used with ventilation studies. Kiwa have carried out range of ignition consequence tests at the

Moreton in Marsh fire college. Kiwa also have a database of material performance and test reports and along with system component testing in the UK and Holland that have been carried out in recent times.

2.7 Social value and ethics

Being a company that often looks for creative ways of solving problems, we are aware of the significant advantages in having a workforce with different backgrounds and experiences can offer. Therefore, although a micro-SME, Steer has proactively instigated an Equality and Diversity Policy to ensure that workforce equality is prioritised.

By nature, we work at the forefront of new technology with our customers, where often training does not exist off-the shelf and must be bespoke. We aim to develop our staff with specialist knowledge by immersion on the job, mentoring by senior staff and associates from our professional community, with the aim of developing their capabilities and careers. We encourage our staff to apply for chartership and other training opportunities, where appropriate. We also provide formal CPD training wherever identified as desirable or necessary for the staff members' development.

We also take on young individuals with the intention of providing useful exposure to the energy sector, and transferable skills for their future employment. A number of these have gone on to study at universities such as Bristol, Bath and Warwick.

As part of our day-to-day work, we are extremely aware of the requirements for flexibility in working, and responding appropriately to health requirements for our staff. We have recently gone through a process with an employee, ensuring that they could come back from long term absence in a way that enabled them to build up an appropriate level of confidence and energy to carry out the work.

We have a documented manifesto which outlines our business and service philosophy. We believe that this aligns well to the overriding tenets of the Governmental Social Research Code, such as being rigorous and impartial, relevant, accessible, outward facing, and performing with integrity.

Steer has a strong ethical ethos running through its core. Extracts from our manifesto include: "we will be prepared to do the right thing – even when it hurts – the technology comes first"; "we would not do a project that we felt others were better suited to"; "we are open minded and not aligned to any technology, product, or software – we will always apply best-fit to our solutions"; "we strive to be generous with our knowledge time and energy", and "we aim to build something more than us – we want to contribute positively to society".

We have a community of associated specialists whom we bring to specific projects when technical expertise outside of Steer's capabilities is required. We actively collaborate with partners as called upon by the project scope and engage with all stakeholders concerned. We draw upon our community of experts to ensure wide perspective.

As part of our work, we are uniquely placed to be able to work with small suppliers and niche technology areas within the UK market place. An example of this is our use of artisan craftspeople, who are more commonly directed to carry out lead restoration projects, to carry out legacy lead and yarn jointing on a set of cast iron pipe joints, which themselves were created as a special commission by a local foundry.

3 Methodology and proposed approach

The methodology for all of the proposed work follows the same pattern. A rapid literature review will identify the current state of the art, and produce a baseline for the theory and understanding. This theory is used to inform the test programme and the results of the test programme are a deliverable and also used to further the theory and understanding. Additional learning from each test programme generates the most value from that test programme.

This understanding will be used in conjunction with reviews of relevant standards, such as IGE/UP/1 to identify whether the processes are suitable for hydrogen. Elements that are gas specific, such as Tables 7-11 for maximum permitted leak rate (MPLR) and test time duration (TTD) calculations need to have a suitable value for hydrogen added to the table. Other non-gas specific elements such as Table 12, minimum purge flow rate and velocity need to be confirmed suitable for hydrogen or have alternative values produced. A large experimental study is then proposed to identify and define the required alterations to standards, processes and systems.

The experiments and equipment used in this project will build on the HyPurge and Hy4Heat project work, saving on set up times as test equipment, risk assessments and procedures can be re-used with only minor adaptations for different test fixtures. The data set from the results can be processed quickly using ready templates, leading to a large data set in a short space of time maximising value to BEIS.

3.1 Proposed approach for purging work

There are three main considerations when comparing purging of installations to hydrogen and natural gas. The first is efficiency of purge, the second is the likelihood and consequence of ignition of the mixture inside and outside of the pipe during the purge process, and finally the consequences of venting gas during the purge process, including the requirement to flare and need for flame arrestors.

Steer aim to follow the flow and pressure relationship method, used in the Hy4Heat purge work, to measure purge efficiency in real time. Test programmes proposed are comparative for both methane and hydrogen, and identified changes required for safe operation in hydrogen will be reported. Due to the flexible nature of our test rigs, a large number of configurations will be tested in a short space of time. This will allow for variation of pipe diameter, pipe length, flow speed, and pipe orientation, including vertical upwards and downwards. There is also scope for a number of representative features such as branches, dead legs, and ‘U’ sections.

The likelihood and consequence of ignition will be carried as part of the purge tests, building on independent work already carried out by Steer. Literature searches will define the sources and likelihood of ignition. Testing will include purges over ignition sources inside and outside of the pipe to understand consequences of any ignition. The possibility of ignition passing from the outside to the inside of the pipe will be investigated.

The purge efficiency studies and ignition studies will be used to generate evidence of whether existing venting arrangements are as adequate for hydrogen as natural gas is again one of experimentally based research. Existing purge fittings and tooling will be assessed for use in both methane and hydrogen. Venting requirements will build on measurement studies of dispersion of the hydrogen and natural gas. Depending upon the outcomes of the research, recommendations are to be made on the inclusion and design of flame arrestors or other specific pieces of equipment to ensure safety of the purge operation. The results of this work will feed into the venting requirements in section 6.4 of IGE/UP/1 and associated documents.

3.2 Proposed approach for tightness work

The philosophy for the work aims to gain access to the largest possible sample size for field aged components and installations. Instead of trying to find samples of aged components and test as many as possible within the fixed time and budget, the plan is to access data from existing field visits from reported leakage. The approach favours surveying existing data over trying to generate new data from limited sources, and has the potential to generate a much larger data set, specifically targeting areas of most leakage. The programme of work kicks off with a review in the project inception meeting so this approach can be reviewed at that point. Should additional works be desired by BEIS then these can be added to the project accordingly.

The tightness study will build directly on work carried out by Steer and Kiwa in the Hy4Heat project. We know from Hy4Heat WP7 that volumetric leakage from any given feature or component will be between 1.2 and 2.8 times greater for hydrogen than from natural gas. This ties into known theory, as the molecular size of both natural gas and hydrogen are in the order of 10^{-10}m whereas the minimum detectable leak size following the standards is in the order of 10^{-4}m. This significant difference in scale suggests that a system that leaks in hydrogen but not in methane is likely to be on the scale of a molecular sieve, and would be undetectable outside of scientific laboratories, and not pose any risk.

The IGE/UP/1 standard has a specific MPLR for each gas and this will need to be determined for hydrogen. This can then be used as a reference to identify if any specific installation component or joint type will be more challenging for hydrogen systems than for natural gas systems. The first call operative (FCO) survey carried out by Kiwa for Hy4Heat can be further analysed to examine the most common scenarios of leaks. The aim is to identify if there are any specific components or jointing processes that routinely leak at low levels in methane but could leak excessively in hydrogen and cause challenges to conversion from methane to hydrogen. This will use existing data from a large number of systems, rather than seeking to find specific aged systems. An additional survey can be carried out to explore commercial systems as well as the domestic systems in the database. Any particular fitting or jointing type found to be commonly problematic can then be further investigated for the reason of leakage and to recommend a course of action prior to conversion to hydrogen.

Finally, we will attempt to identify a small number of existing aged installations that can be safely tested in methane and hydrogen. These tests will generate data points of evidence to support the scientific theory and support the laboratory results.

The output of the work will also aim to provide evidence for including hydrogen as a gas type for calculation of test parameters in the tightness testing procedures for IGE/UP/1 and IGEM/UP/1A.

3.3 Incorporation with industry

The project involves fitter and FCO surveys. We will incorporate a steering group comprising project delivery partners, BEIS and preferred members. In addition, we will form an advisory panel with key stakeholders, representatives from IGEM purge committees, appliance manufacturers, GDNOs and HSE proposed as members.

The project is to be governed by the steering group but will be informed by the advisory panel. This will enable the project team to understand the drivers from all interested parties and to disseminate the results directly back to those interested parties thus delivering a no-surprises result from the project.

4 Detailed scope of work

The project will be split into a number of specific work packs as shown in the Gantt chart below and then in depth in the subsequent sections.

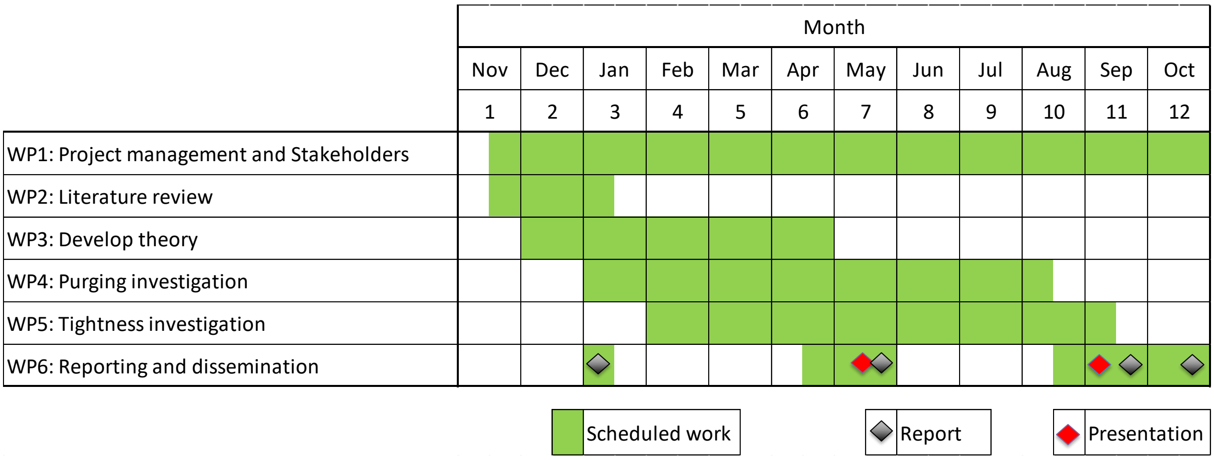


Figure 1: Gantt chart showing key milestones

4.1 WP1: Project management and stakeholders

The project kicks off with the inception meeting where all assumptions, work scopes and project deliverables can be confirmed by the BEIS and the steering group. Steer will produce a proposed approach to the study at this meeting. We expect that shortly after this the final project plan containing key phases of work, a weekly activity plan, and delivery dates will be provided to BEIS.

The proposed steering group comprises representatives from BEIS, Mott MacDonald, Steer and Kiwa. It is expected that the steering group will also be a forum to manage dissemination and sharing of literature reviews between different Lots of the overall programme of work.

Subsequent steering group meetings will allow the project to be adjusted to ensure the desired outcomes of BEIS are targeted.

Monthly reports will also be provided, containing a general overview of the progress and KPIs, as well as quarterly evaluation against KPIs.

An advisory panel will be formed, including steering group members and potentially representatives from IGEM, BSE, HSE, HHIC and EU Skills.

Contribution: Steer will carry out the day to day running of the project. Kiwa will provide technical assurance for the project.

WP1 Activities	WP1 Responsibilities
Project inception, set up panels, schedule and deliver meetings	Lead: [This has been redacted] (5 days), Support: [This has bee [redacted] (10 days), [This has been redacted] (1 day) [This has been [redacted] (2 days) [This has been redacted] (1 day)

4.2 WP2: Literature review

This is split into two sections, purging and tightness with respect to methane and hydrogen. The literature search will include published reports from relevant projects such as those produced by Steer and Kiwa for the Hy4Heat, H21, H100, HyHouse, HyDeploy and other projects. It will also include resources such as those identified in the HyResponse project which address many combustion issues with hydrogen.

Discussions will be held with appropriate IGEM and BSI committees and appliance manufacturers via the HHIC to ensure any additional purge points suggested for hydrogen (and to be experimentally investigated below) are considered appropriate and viable. Relevant data will be sought from all the GDNO's on recent incidents and near misses arising from poor purging.

Pertinent work to include where possible references regarding purging processes from different countries, industries and sectors for the main topics of purging, ignition, venting and tightness. Topics for purging literature searches include:

- Purging processes, tooling and factors affecting efficiency
- Ignition processes, likelihood and consequences
- Venting processes and tooling
- Dispersion processes and mechanisms

Topics for leak tightness literature searches include:

- Leak tightness with respect to different gases
- The impact of hydrogen on components and materials commonly found in gas pipes, (only a modest amount of work will be done on this topic; information will be taken from others it is expected that Lot 2 will also contribute to this work)

Sources of information include hydrogen project reports, relevant standards, gas industry practices (installer reviews) as well as other industry sectors and academic research.

Methodologies for classifying relevance of literature review will include: key word identification, reader review and analysis, cited references, and peer reviewed references. Classification shall follow the tender requirement: either (a) Fully relevant, (b) partially relevant, or (c) no relevant evidence.

We believe that literature reviews should be shared across the different lots from the programme of work. It is likely that slightly different algorithms will be used by different organisations, and the interpretation of the results are likely to be different.

Contribution: Steer and Kiwa will both contribute to the literature review; each bringing unique experience and contact lists to the project. Steer will coordinate the documentation but both parties are expected to share knowledge bases and interpretation of the references. This is also expected to include two-way sharing with other lots in the overall programme of work.

WP2 Activities	WP2 Responsibilities
Purging literature review Tightness literature review	Lead: [redacted] (4.5 days), Support: [redacted] (1 day), [redacted] (5.5 days), [redacted] (10 days), [redacted] (1.5 days)

	[This has been redacted] (3.5 days), [This has been redacted] (2 days)

4.3 WP3: Develop theory

This work underpins the requirement to understand the processes being researched in the project it informs and guide the experimental work.

The theory will build upon work carried out during the Hy4Heat project on leak tightness and on purging. This is being further developed by Steer during independent work and in the HyPurge project for SGN. Steer have already reported on the novel way of identifying and quantifying the purge process which relies on measuring the pressure and flow upstream of a restriction during a purge, and using this to calculate the density of the gas being vented. As the gas transitions from air to fuel gas, the change in gas properties results in a change in flow rate. This change can be measured and the purge progress visualised. This enables the efficiency of each purge to be quantified providing a method of comparison between purges of different systems. Ignition theory will be added to this work, building on experimental studies carried out independently by Steer since the Hy4Heat project, which have demonstrated the likelihood and consequence of a naked flame igniting the vented gases from pipeline purges in hydrogen and methane.

Leak tightness theory will be built upon existing work and will involve comparison of methane and hydrogen in measurable leak sizes using standard gas equipment as per tightness tests in IGE/UP/1. The theory will include studies relating to degradation of materials over time but will also include safety aspects of quenching gaps in fittings.

The literature review of WP2 will document the current state of the art and inform the experimental body of work in WP4 and WP5. The experiments will then further knowledge in key subject areas. This work pack provides resource to draw conclusions from both the prior art and the experimental work. The theory developed in WP3 will be used to back up the recommendations made by the reports.

Topics of theory will include:

- Detailed purging processes
- Gas flow inside and outside of the pipe, dispersion and ventilation into a controlled space
- Ignition inside and outside of the pipe
- Material compatibility and effects of hydrogen on materials commonly found in gas installations

The theory will be used to back up information provided by the standards but also will draw learning from current industry practices. Again, liaison will be undertaken with appliance manufacturers, IGEM and BSI committees. Care will be taken to ensure there is no fundamental difference in the purge procedures likely to be adopted by GDNO's for distribution pipework and this work item unless there is transparent and agreed reasons. This will involve extensive liaison with appropriate IGEM committees. Dutch practice on purging will also be considered.

Contribution: Both parties will contribute to the development of the body of theory for purging and leak tightness. Steer will manage and document the theory for use in guiding the experiments Kiwa, as technical assurance will agree the conclusions borne from the theory.

WP3 Activities	WP3 Responsibilities
Purging theory review Tightness theory review	Lead: [redacted] (5 days), Support: [redacted] (1 day), [redacted] (4.5 days), [redacted] (2 days), [redacted] (1 day)

4.4 WP4: Purging experimental work

The purging work is split into three main elements: purging efficiency, likelihood and consequence of ignition and subsequent ventilation requirements. All of the work will refer to relevant standards and current purge tooling to identify any modifications required for purge tooling and processes to enable a safe transition to hydrogen.

Purging investigation

The experimental work will use the Steer method of measuring purge for a wide variety of components and systems as per HyPurge and Hy4Heat. This will be backed up by gas concentration measurements. The study will focus on the difference in purge efficiency when purging between air and hydrogen vs. purging between air and methane. IGE/UP/1, IGEM/UP/1A and /1B will be used as a guide for these operations.

The purge efficiency will be quantified with respect to:

- pipe diameters in a selection of common sizes and material types as specified in IGE/UP/1 and IGE/UP/1A (expected to be up to 150 mm diameter)
- pipe lengths (up to 50 m), unless experimentation indicates significant differences in the purge process for longer lengths
- pipe orientations including: horizontal, vertical up and down, and sloping
- purge speed, achieved using different purge to quantify the minimum purge speed required to achieve efficient purging.
- features, such as elbows, ‘U’ sections, inverted ‘U’ sections and blind tees, exploring situations where gas could collect and become trapped in a system.

It will not be possible to test all variations in all configurations, but the number of tests is expected to be between 500 to 1000 tests ensuring that the effects of each parameter is well understood. Important configurations include large diameter vertical pipes as well as horizontal pipes, and large inverted ‘U’ sections that might be expected to be seen in factory pipework and other large installations. The test programme will include tests over a range of pressures, up to 40 mbar. It will also include tests over a range of ambient temperatures from -30°C to +50°C however it should be appreciated that it will not be possible to maintain the larger installations at extremes of temperature.

Output from this work will be used to assess the tables in IGEM/UP/1A, IGEM/UP/1B and IGE/UP/1 (up to 150 mm diameter), in particular the minimum purge speeds, and determine if they are suitable for hydrogen as well as for methane.

Ignition study

The ignition work will build upon recent independent work carried out by Steer in likelihood and consequences of ignition during domestic purging. The work will be supported by discussions with component and appliance manufacturers.

The test programme is expected to include examining:

- Likelihood and impact of ignition:
  - Inside the pipe during the purge
  - Outside the pipe during the purge
  - Outside the pipe after the purge
- Ignition of different concentrations of gas in air
- Likelihood and consequences of an ignition outside the pipe transferring to the inside of the pipe
- Gas composition inside a pipe during a purge and the effect of ignition inside the installation

The tests will be carried out using ignition devices and monitoring tooling inside and outside of the pipe. Some of these tests can be carried out at the same time as purging operations but many of them will require an independent test programme. The outcomes of this experimental study will end up being a set of case studies around ignition to provide evidence towards a safety case for determining relative risks between hydrogen and methane.

Ventilation study

This will be an extension of the work carried out for domestic purging carried out by Steer during the Hy4Heat project. IGEM/UP/1A assumes purging to a suitable vent stack out of the property. IGEM/UP/1B permits purging into the property for limited volumes of gas. The effects of gas release within properties can be further investigated using Kiwa's gas concentration measurement room, however it is expected that the majority of work will involve purging using a suitable flow meter and purge stack as recommended in IGEM/UP/1A. The ventilation study will be informed by the results of the purging and ignition studies.

WP4 Conclusions

The purging experimental study will compare results between methane and hydrogen purges over a range of UP/1B UP/1A installation sizes. It will examine the relative flammability of the two gases during purges and examine the likelihood and consequences of ignition during the purge process. Finally, the requirements and implications of venting the purge will be linked to the theory and discussed in the formal reports.

Contribution: Steer will carry out the experimental work and Kiwa will provide assurance.

WP4 Activities	WP4 Responsibilities
Purge efficiency study, purge ignition study, purge ventilation study	Lead: [redacted] (11 days), Support: [redacted] (14 days), [redacted] (43 days), [redacted] (1 day)

4.5 WP5: Tightness investigation

IGE/UP/1 states: "*Tightness testing is carried out to ensure that pipework has a leak rate (LR) below a level which could ever be considered to form a hazard caused by the size of the leak, assuming adequate ventilation of the pipework has been provided.*"

The details of tightness testing specified in the various IGEM standards should be reviewed in relation to using hydrogen as a fuel gas. This should include the tightness test pressure (TTP), maximum permitted leak rate (MPLR), and tightness test duration (TTD). The work should provide evidence to enable the relevant fuel dependent factors to be determined for hydrogen when calculating TTD and MPLR following UP/1. It should also provide the evidence to enable an adaptation of Table 9 in UP/1A to be used for hydrogen as a fuel gas. This work may need to include evidence of the relative dispersion of hydrogen and methane in poorly vented areas.

The tightness programme is to be delivered from a mixture of existing data analysis and testing. A survey of historic events will result in a much larger data set on failing field aged components than from testing alone. The investigation will start by examining FCO data collected by Kiwa during Hy4Heat. FCO data for commercial installations will be added to the study and additional fitter surveys will add to the data set. This enables the study of a large number of leakage incidents, identifying the cause to see if any one particular component or joint type is more prone to leakage than another. This will be used to guide the component test programme. This scope of the test programme will be discussed and confirmed with BEIS at the inception meeting and subsequent scoping meetings once historic leakage data has been examined.

Component leakage testing

Component tests will be guided by the results of the FCO study to identify test components and jointing techniques employed in domestic and commercial systems prone to leakage. This builds on Steer's component leakage tests for Hy4Heat. Leakage from an installation to atmosphere will be considered as will bypass leakage of valves within the installation. Care will be taken where possible to analyse the failure mechanisms of different components such as Type A and B valves, and (for example) failures arising from 'black dust', sub-optimal crimping of valve bonnets and issues arising from swarf presence.

It is noted that this work package contains some reference to material suitability. Whereas this can be considered in the context of some sealants and valve design (eg seal loading pressure) we feel most of the general suitability and degradation of materials is to be covered under Lot 2 *'Research and Evidence Gathering for Material and Component Suitability - Domestic and Non-Domestic with Respect to Hydrogen'*. Close collaboration is considered essential between these two work packages.

Discussions with BEIS, the steering group and the advisory panel will be essential early on in the project to understand the concerns regarding leak tightness. The eventual work programme can then be tailored to address those specific concerns within the budget constraints of the project.

System leakage testing

The ITT calls for whole system testing such as the work that Steer carried out on the decommissioned boiler building at MOD site Worthy Down. This work identified the significant challenge in securing such sites for testing, in particular the logistics of handing over responsibility for the site and the challenges of purging and venting safely between test gases. Two existing sites that could be used for this work have been identified. One is Kiwa's testing and training labs, and specific time has been factored into the proposal for these tests. Other training facilities, such as, Blue Flame Associates' training lab may be sought for whole system testing. Steer are entering into discussions to explore this additional option. GDNOs may also be consulted to identify recently decommissioned installations that can be used for testing prior to demolition.

Site identification and selection will be discussed with BEIS, the steering group and the advisory panel. This will ensure that this approach generates the evidence required for the completion of the full programme of work.

WP5 Conclusions

The results of the survey and subsequent tests will be fed back into the body of theory generated in WP3. Conclusions will also be passed to the advisory panel.

Contribution: Kiwa will review FCO and fitter survey and freedom of information requests. Steer will manage the test programme Both parties will review the relevance of the investigation results and seek installations to test.

WP5 Activities	WP5 Responsibilities
Standards review, FCO survey and fitter survey, component leak tests, review material compatibility study, system leakage study	Lead: [redacted] (6.5 days), Support [redacted] (2 days), [redacted] (12.5 days), [redacted] (22 days), [redacted] (2 days) [redacted] (1 day)

4.6 WP6: Reporting and dissemination

This work pack will take the outputs of the project and present them in formal reports and project presentations. It also dedicates resource to provide regular updates to the BEIS HSSH project manager at least fortnightly via video conferencing.

This work pack will examine how information is to be disseminated to the advisory panel. The contents of the reports will be presented in a format that will assist IGEM, BSI standard writers and the compilers of appliance installation instructions. Consensus will be sought from the advisory panel to guide the formatting and content that most effectively achieves this requirement.

Specific deliverables are:

- Project inception meeting including signing off the final project plan
- Monthly updates to communicate project progress and deal with any significant variation to the project plan
- Literature review report including sections on both purging, and tightness and material compatibility
- Interim meeting presentation when approximately 50% of the work has been carried out. This will present progress to BEIS and standards bodies.
- Interim project report will be delivered to BEIS following the interim meeting when approximately 50% of the work has been carried out
- Final project presentation provides an opportunity to present the project outcomes to BEIS and standards bodies on completion of the project. This will allow for feedback to the incorporated into the final report.
- Draft written report on Purging and Tightness and material compatibility

- Final written report incorporating feedback from BEIS. The report will also include separate sets of raw and processed data as per ITT requirements.

WP6 Activities	WP6 Responsibilities
Monthly, quarterly updates, interim and final presentation and reports	Lead: [This has been redacted] (13 days), [This has been redacted] (2 days) [This has been redacted] (12 days), [This has been redacted] (10 days), [This has been redacted] (1.5 days) [This has been redacted] (1 day) [This has been redacted] (2 days)

5 Management of delivery

We recognise the three KPIs that will be used to monitor the work:

- Timeliness of delivery: Work delivered to timescale agreed
- Quality of delivery: Work delivered to the standard agreed
- Risk register: Up-to-date risk register maintained

5.1 Timeliness of delivery

This work is research, and is therefore complex and challenging, requiring significant diligence to ensure the timely delivery of quality results, delivering maximum value to BEIS across the whole range of the programme lots.

We anticipate fortnightly or weekly video meetings, and monthly updates indicating project progress and results. During these meetings we will also focus on:

- Timely production of outputs
- Identifying any resourcing during peak periods
- Working across consortia
- Delivering user-friendly complex technical data

5.2 Quality of delivery

As Project Lead, [This has been redacted] is accountable for the validity of the work and responsible for ensuring that regular reviews of the records of each researcher are conducted. In order to support this, Steer has asked Kiwa to provide technical and quality assurance to the project. This ensures the appropriate processes are in place to assure the quality of the research undertaken. Our interim and final reports will be accompanied by a statement of the quality control that has been undertaken in their production.

As part of this, Kiwa will support Steer in ensuring that all procedures and methods used are documented, providing a clear audit trail from raw data to findings and conclusions. This includes appropriately labelling (clearly, accurately, uniquely and durably) the data obtained during the work. Steer will store the data on a cloud-based server (www.tresorit.com), which has versioning, as well as creating multiple physical backups.

Kiwa's quality management system is designed to meet the requirements for accreditation to ISO 17025 for testing and to ISO 17065 for product certification. For a test laboratory compliance with ISO 17025 is a means of ensuring that both the technical competence requirements and management system requirements are met.

This approach gives confidence that the processes are fit for purpose, and any modifications or changes to this process are recorded and noted. This will be of a standard to allow the work to be repeated, if necessary.

5.3 Risk Register

An initial risk assessment has been conducted for this project, and will be updated as the project progresses. This outlines the mitigation for each of these risks, demonstrating that the factors that can affect the quality and timeliness of the work are addresses and minimised in their potential detriment.

5.4 Key project risks

Outlined below are a number of key project risks identified at this time.

Id no	Risk Description	Risk Score	Mitigation	Risk Score
1.2	Project deliverables not met	8	Incorporate project milestones; Regular update meetings; Steering group to advise; Vendor has experience successfully completing similar projects, including for BEIS; Advisory panel will provide external perspective	1
2.7	Incorrect outcomes taken from literature review	6	Vendor has many years of relevant experience; Multiple staff members to be included; QA system and peer review; All have historical knowledge of previous Hydrogen projects and are well versed in fluid dynamics	2
3.1	Lack of understanding of theoretical principles	9	Vendor to have experience and relevant expertise; Expertise proven in previous projects; Theory is similar to previous work carried out; Reporting and interpretation of findings to be reviewed by steering group; Staff have relevant experience and training, and work is reviewed, peer assessed and approved	1
3.2	Conflicting theories found	2	Vendor to investigate and provide empirical evidence where necessary Analyse the sources for each theory and discover why, and which theory is more applicable Knowledge of fluid dynamics within both companies, and options for bringing in external support, if required	1
3.6	Vendor complacency in their own understanding	6	Theory will be looked at from first principles, to ensure nothing is missed Existing understandings will be questioned and verified	2
5.1	Invalid results	16	Steering group to review test plans and procedures; Vendor experienced in laboratory work and experimentation; Calibration of instruments to be traceable; Accuracy and precision of instruments to be adequate and	2

Id no	Risk Description	Risk Score	Mitigation	Risk Score
			appropriate; Findings are analysed regularly during testing, and anomalies can be investigated	
5.3	Tests not carried out correctly	9	Vendor is experienced as a testing laboratory; Kiwa to provide technical assurance and independent review; Experienced individuals carrying out the work; QA and review procedures in place; Ability to repeat and re-configure experiments easily;	2
6.1	Confirmation bias	9	Internal QA and steering group approval of procedures; Kiwa to provide 3rd party review and advice	2
6.2	Reporting not clear	2	Experience of vendor at producing clear and concise reports; Reports will be peer assessed and reviewed by multiple personnel; Acceptance of BEIS' ITT reporting standards	1

6 Pricing

This project is validate for 60 days from 24th September 2021.

The costs for the project are contained within Annex A.

The invoicing structure follows the version outlined in the original ITT for this Project, and is also contained in Annex A.