Low Carbon Hydrogen Supply 2 Competition Application Form Stream 2

Proposal Summary

1. Name of Applicant Organisation This should be the lead organisation/co-ordinator for the proposed project
Gemserv Limited

2. Project Name
Tyseley Ammonia to Green Hydrogen

3. To which technology theme(s) are you applying? Please refer to Section 2.3 of the Stream 2 Guidance Notes/ ITT for further information on themes. Select the most applicable theme(s) for your technology.
Hydrogen Storage and Transport Solutions
Net Zero Hydrogen Supply Solutions

4. Stream 2 Estimated Start Date
* 01/11/2021

5. Stream 2 Demonstration Project Duration (months)
1 39

6. Stream 2 Estimated End Date
* 31/01/2025

7. Stream 2 Total Demonstration Project Costs (£) Please enter the total amount of BEIS funding for Stream 2 that you are applying for excluding VAT.
8492604.49

8. Please give a brief description of the project. (Maximum 400 words)

As the UK looks to decarbonise its energy system, we are going to see increasing deployment of large scale intermittent renewable generation located far from end users. The ability to effectively store large quantities of energy under a dispatchable form will be key to delivering the security and flexibility required by the energy system. Green hydrogen produced via electrolysis is a key enabling solution and it is likely that we will increasingly see electrolysers co-located with offshore wind assets. However, the low volumetric density of hydrogen means that it must be either compressed to high pressures, liquefied or transformed into a carrier to be dispatched over long distances.

Ammonia is a carbon-free, dispatchable hydrogen carrier that enables the storage and transportation of large quantities of renewable hydrogen over long distances. It is a primary candidate to deliver a secure supply of renewable hydrogen for stationary, transport or mobile applications in the UK benefiting from its existing infrastructures, ease of storage and well-defined regulation and safety history for over 75 years.

Although ammonia production, handling practices and supply chains are mature and well-established, efficient hydrogen discharge processes from ammonia still need to be developed. More specifically, efficient ammonia cracking technologies able to generate pure hydrogen are still missing despite worldwide efforts to accelerate developments which remain at low maturity level.

The Tyseley Ammonia Project will design, build, commission, and operate the world's largest and most efficient ammonia to hydrogen conversion unit, demonstrating 200kg/day production of transport-grade hydrogen. It will be located at Tyseley Energy Park and co-located alongside an existing refuelling station. The hydrogen will be used to refuel local vehicles including 20 fuel cell buses that have been ordered by Birmingham City Council. The ammonia cracker combines decomposition and purification stages into a single, compact unit, with lower operational temperatures due to recent innovations in membrane technology. The project aims to dramatically improve the efficiency and economics of ammonia cracking, accelerate the development of hydrogen solutions in the UK and position the country at the forefront of an emerging global market.

9. Please explain why public sector funding is required to take this innovation forward. (Maximum 300 words)

This demonstration project would not take place in the absence of public sector funding. There are risks associated with the project that could not be borne by the project team without the support of Government. The technology has never been deployed at this scale before meaning that there are costs associated with design and implementation that would not be incurred in nth of a kind projects. In addition, the market for this technology is still in its infancy. The availability of low cost clean hydrogen at the point of use that could be delivered by this solution will help to support and accelerate the role out of fuel cell transport, however the market is not sufficiently developed to support technology development. Green ammonia production is still very nascent, this project will help to stimulate the supply chain but it is not currently sufficiently developed to justify the investment in the project at this stage. The core technology is being developed by an SME that could not justify internal spend on development of this solution without public funding. It would continue to focus on its other applications that are lower risk and commercially viable in the short term.

Public funds will enable the coming together of a consortium of experienced, professional industrialists and academics to collaborate and pool their expertise to accelerate the development and dissemination of new knowledge and technology in the UK. In absence of this funding, the parties would either be working individually to develop their interests in this project in isolation, or not at all, given the insufficient stimulus to catalyse project development in favour of other opportunities.

Eligibility Criteria

1. Technology Categorisation The technology must be in scope of one of the themes described in Section 2.3 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT.

	Yes	No
Is the technology in scope?	X	

2. Innovation and Technology Readiness This Competition is to support the development of innovative Low Carbon Hydrogen supply solutions. It is to support the development of technologies that are not yet commercial from Technology Readiness Levels (TRLs) 6 to 7 at the start of the projects. (Further information on TRLs can be found in Appendix 1 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT).

	Yes	No
Will your technology / system be at TRL 6 – 7 at the start of the project?	X	

3. Technology Scope The focus of the Competition is to support the development and demonstration of innovative hydrogen supply solutions as detailed in Section 2.3 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT. Exclusions: Funding will not be provided for projects where the technology development focuses on: Upstream energy production (power and fossil fuel extraction) End-use technologies (for example boilers, and other hydrogen appliances) Technologies where the core technology has previously been operated commercially (in UK or Internationally) Power generation from hydrogen (for example fuel cells or CCGT) Gas-grid systems (onshore) Novel CCUS technologies which aren’t intrinsically linked in the hydrogen production process

	Yes	No
Does your application exclude costing/budget for any of these technology exclusions (listed above)?	X	

4. Project Status BEIS is unable to fund retrospective work on projects.

	Yes	No
Can you confirm that your application does not seek funding for retrospective work on this project?	X	

5. Additionality Projects can only be funded where evidence can be provided that innovation would not be taken forwards (or would progress at a much slower rate) without public sector funding.

	Yes	No
Can you confirm that this project would not be taken forward (or would progress at a much slower rate) without public sector funding?	X	

6. Contract Size Demonstration (SBRI) contracts for up to £10m per project with a total of £30m across the Stream 2 competition are available, with a maximum of £5m for engineering design. Stream 2 Projects must be completed by 1 February 2025.

	Yes	No
Can you confirm the funding requested from BEIS for your project cost for Stream 2 will be equal to or below £10m with a maximum of £5m for engineering design and is 100% of eligible project costs?	X	

7. Eligible Project Costs SBRI is aimed at organisations working on research and development (R&D) of an innovative process, material, device, product, or service prior to commercialisation. Funding is available for R&D activities only, including related dissemination activity. Projects requesting funding for commercialisation activities are not eligible. The full list of eligible project costs is set out in Appendix 3 and outlined in Section 5 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT. BEIS must fund 100% of eligible project costs, no match or in-kind funding is allowed.

	Yes	No
Can you confirm that requested funding is for eligible costs and BEIS will fund 100% of those costs?	X	

8. Project End Date Projects must be completed and approved by BEIS by 1 February 2025. Projects need to allow time for the BEIS monitoring officer to review the project; this process can take up to a month and should be included in your project plan.

	Yes	No
Can you confirm that the project will meet the specified project end dates?	X	

9. Risk Benefit Sharing The sharing of risks and benefits is an important aspect to the SBRI approach. Projects receive financial support and retain any intellectual property generated, with certain rights of use retained by BEIS. Project outputs are also expected to be shared widely and publicly and project teams are not permitted to include profit in the eligible project costs.

	Yes	No
Do you agree to this approach?	X	

10. Delivering Multiple Projects If project consortium member(s) are part of multiple successful applications, they must be able to deliver on them and they must not have applied for funding for the same piece of work more than once.

	Yes	No
a) If you or your consortium are part of multiple successful applications, would you be able to successfully deliver all projects if necessary?	X	
b) If you or your consortium are part of multiple successful applications, could you please confirm that you have not applied for funding for the same piece of work more than once?	X	

11. Multiple Applications If you intend to submit multiple applications, you must comply with the following limits of entry into the competition: Lead organisations may only enter one application into the Stream 2 competition as the project lead. A technology provider/OEM are limited to one application for a particular technology/solution requiring development.

	Yes	No
a) If you are the lead organisation, as the project lead can you confirm only one application has been submitted for stream 2?	X	
b) If you or your consortium are part of multiple applications, could you confirm that the main technology being developed is different in each application i.e., only one application per particular OEM's technology has been submitted?	X	

12. Prompt Payment For contracts of £5m or more, if you intend to use a supply chain for this contract, you must demonstrate you have effective systems in place to ensure a reliable supply chain. If the application value is over £5m, and you intend to use a supply chain, please complete the document in Appendix 4, Declaration 7 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT.

	Yes	No
If your contract size is greater than £5m, can you demonstrate you have effective systems in place to ensure a reliable supply chain?	X	

Contact and Lead Organisation Details

1. Primary Contact Details

[This information has been redacted]

[redacted]

[This information has been redacted]

[redacted]

3. The registered address of the Lead Organisation

Address Line 1	8 Fenchurch Place
Address Line 2	-
Address Line 3	-
Town/City	London
Postcode/ Zip Code	EC3M 4AJ

4. County (If Applicable)

Greater London

5. UK Region (If Applicable)

London

6. Country

United Kingdom

7. Project Location: Is this registered address the location where the main activity of the proposed project will be carried out? You will be asked to provide project location details in the separate BEIS Project Cost Breakdown/ Finance Form.

No

8. Lead Organisation Type

Private Company

9. Lead Organisation Size

Medium Enterprise <250 employees

10. Number of employees in Lead Organisation (including directors)

217

11. Lead Organisation Company Registration Number

04419878

12. Turnover Amount of Lead Organisation (in most recent annual accounts) Please include the currency of the amount in your response.

[redacted]

13. Turnover Date (in most recent annual accounts)

* 31/03/2021

14. Balance Sheet Total of Lead Organisation (total assets net of depreciation) Please include the currency of the amount in your response.

[redacted]

15. Balance Sheet Date (total assets net of depreciation)

* 31/03/2021

16. Is the Lead Organisation able to recover VAT?

Yes

17. Lead Organisation Maturity

>10 years

18. How is the lead organisation currently funded? (Choose all that apply)

	No Funding	Founders (including bank loans)	Friends and Family	Public Sector Grants	Angel Investment	Venture Capital	Private Equity	Stock Market Flotation
	X							

19. Lead Organisation Status: a brief introductory description of the company. (Maximum 400 words)

Gemserv Ltd is an expert provider of professional services in a world driven by data and technology. We are purpose-driven, providing professional services across multiple sectors including cyber & digital, the public sector, health, energy and low carbon to tackle today’s social and environmental challenges. Established in 2002, the business provides a range of consultancy and outsourcing capabilities including market design, governance, digital transformation, cyber and assurance, application support, competition, and stakeholder management services. We are one of the UK's Leading Management Consultants for 2021, recommended by clients and peers, and rated by sectors and services in a special report by the Financial Times. Gemserv has offices in London, Birmingham and Ireland.

20. Does the lead organisation have a parent company? (If yes you will be asked to provide details)

No

Criterion 1: Innovative Low Carbon Hydrogen Supply Approach

Criterion 1: Innovative Low Carbon Hydrogen Supply Approach This criterion will be used to assess the novel approach to Hydrogen Supply in the proposed demonstration project.

Applicants should have already determined in outline, that their Hydrogen supply solution is technically feasible and meets, or has the potential to meet, the relevant industrial regulatory requirements, including health and safety and air quality. In their responses under this criterion, applicants are expected to justify that their project is sufficiently proven in terms of technical and regulatory feasibility to warrant funding for their proposed pilot demonstration. In making these justifications, applicants should reference any outputs from their earlier work, identify where further development is needed to confirm feasibility and explain how the pilot demonstration will be designed and executed to provide these confirmations. Highest marks will be awarded to the innovative low carbon hydrogen supply solution that best describes the design and the work expected to be carried out through the project. In the text box below, the applicant should: Describe what is innovative about your solution. Clearly state the aim of the demonstration trials proposed by, for example, stating what levels of performance constitute a successful trial. Describing how and why the demonstration will accelerate the development of low carbon hydrogen. Provide the latest evidenced justification for the technical and regulatory feasibility of the proposed demonstration pilot. This should reference any relevant earlier work, including engineering designs, engineering calculations and the outputs of other feasibility research and recapitulate the innovative nature of the solution. Clearly set out where there is remaining uncertainty about technical and regulatory feasibility and explain how your demonstration pilot will address these uncertainties. (Weighting for Criterion 1 – 5%) (Maximum 2,000 words)

The Innovation:
The Tyseley Ammonia to Green Hydrogen Project will demonstrate an innovative new ammonia cracking technology capable of producing 200kg/day of fuel cell grade hydrogen. If awarded funding this project would be world-leading and deliver:

• The most efficient ammonia cracking technology ever demonstrated
• 200kg/day of hydrogen-the largest scale output from an ammonia cracker ever deployed anywhere in the world. The largest to date has been 5kg/day.

This innovative technology will demonstrate how ammonia can act as profitable hydrogen carrier and enable:

• Storage of large amounts of renewable energy generated at times when supply exceeds demand.
• Transporting hydrogen in the form of ammonia from distant generating sites to end users. This will enable cost effective distribution of renewable energy nationwide from large-scale production linked directly to large-scale generation (e.g. offshore wind).
• The import and export of renewable energy from regions of the world where renewable electricity generation is very low cost, enabling global green energy corridors for the UK’s energy import and export diversification.

The technology has the following innovative characteristics which make it unique amongst ammonia cracking technologies, delivering higher performance and improved economics:

• The cracking process carries out ammonia decomposition and hydrogen purification in a single unit. Consequently, its footprint is reduced compared to the current state of the art technology that requires separate units.
• The final product is a high purity hydrogen stream suitable for various applications including vehicles using PEM fuel cells, complying with ISO 14687 and accompanying standards.
• The unit operates at lower temperatures and requires fewer utilities to deliver hydrogen at higher purity than current state of the art crackers. It can deliver a Hydrogen Recovery Factor (HRF) >97% through process electrification and >82% with an integrated gas burner. HRF is defined as the percentage of the hydrogen contained in the ammonia input stream that is converted to pure hydrogen. This means that the unit has higher efficiency and will deliver lower cost hydrogen than current state of the art crackers.

Crackers producing 5kg/day of hydrogen are commercially available today, utilised within industrial manufacturing processes such as annealing, sintering, galvanizing and in furnaces. The ammonia cracking technology demonstrated under this competition is completely unique in its way of operating and scale reached.

Commercial ammonia crackers exist in simple but inefficient furnaces operating at high temperature (700-1000 °C) producing forming gas (a mixture nitrogen, hydrogen and ammonia – up to 10%vol). Considering the stringent limits on nitrogen (100 ppm) and ammonia (0.1 ppm) in PEM fuel cell in mobility applications, expensive purification units must be implemented downstream to reach appropriate hydrogen standards. Our approach uses a membrane reactor combining both the decomposition reaction and product purification in a single piece of equipment, allowing it to operate at much lower temperatures with improved efficiency and system footprint.

Current commercial ammonia crackers generally employ nickel catalysts which operate above 900°C, heated by electric element heaters. Many do not include gas separation post cracking as there is no requirement for removing the nitrogen content. Some have generated 0.75kg/day of pure hydrogen per day by cracking ammonia with an electrically heated ruthenium catalyst and using a palladium membrane separator to purify the hydrogen for PEM fuel cell use. Our core technology employs Pd-based membranes allowing us to operate at lower temperatures and achieve greater efficiencies.

Recently, extensive effort has been made in Australia to develop an efficient purification method downstream of conventional ammonia crackers to deliver high purity hydrogen. The two system units developed are composed of a basic furnace for cracking and a palladium membrane coated on a vanadium system. This system has been showcased and tested at the scale of 5kg/day at a refuelling station in Australia. While this technology improves on conventional crackers, it still relies on two distinct units with poor thermal integration and low overall efficiency compared with conventional systems. Our innovative approach is a significant departure from this approach and is capable of higher efficiencies at lower cost.

The aim of the project:
The aim of this project is to demonstrate that the use of ammonia as a hydrogen carrier will reduce the delivered cost of hydrogen to the end user. This will be achieved by designing, building, commissioning, and operating an ammonia to hydrogen conversion unit to produce 200kg/day of hydrogen. It will be located at Tyseley Energy Park and co-located alongside an existing ITM Motive refuelling station. The refuelling station will offtake, demonstrating that the hydrogen produced is suitable for fuel cell transport applications. The hydrogen will be used to refuel local vehicles including 20 fuel cell buses that have been ordered by Birmingham City Council.

This trial will be considered successful if the following performance metrics are realised:

• HRF over 82% with heat integration using a gas burner (see Figure 1.1) and HRF over 97% through electrification (see Figure 1.2).
• Fuel cell hydrogen purity meeting the ISO 14687.
• Ammonia cracking system availability exceeds 90%.
• Cost of hydrogen delivered to the HRS is competitive versus counterfactual production routes (discussed in criterion 2a).
• Ammonia transportation costs 50% lower compared to compressed or liquified hydrogen.

As the UK looks to decarbonise its energy system, we are going to see increasing deployment of large scale intermittent renewable generation located far from end users. For example, the UK is targeting 30GW capacity of offshore wind by 2030. The ability to effectively store large quantities of energy under a dispatchable form will be key to delivering the security and flexibility required by the energy system.

Green hydrogen produced via electrolysis is a key enabling solution and it is likely that we will increasingly see electrolysers co-located with offshore wind assets. However, the low volumetric density of hydrogen means that it must be either compressed to high pressures, liquefied or transformed into a carrier to be dispatched over long distances.

Ammonia is a carbon-free, dispatchable hydrogen carrier that enables the storage and transportation of large quantities of renewable hydrogen over long distances. It is a primary candidate to deliver a secure supply of renewable hydrogen for stationary, transport or mobile applications in the UK benefiting from its existing infrastructures, ease of storage and well-defined regulation and safety history for over 75 years.

Although ammonia production, handling practices and supply chains are mature and well-established, efficient hydrogen discharge processes from ammonia still need to be developed. More specifically, efficient ammonia cracking technologies able to generate pure hydrogen are still missing despite worldwide efforts to accelerate developments which remain at low maturity level.

This demonstrator will accelerate the development of low carbon hydrogen in the UK by providing the missing link between large offshore hydrogen production and the end user leading to a lower cost of hydrogen at the point of use. It will also unlock the capability for the UK to import and export hydrogen globally.

The technical and regulatory feasibility of the pilot:
This project is based on the 200kg/day ammonia cracking technology first developed in 2019 through the Harwell Ammonia to Green Hydrogen feasibility study delivered under the BEIS Hydrogen Supply Competition (Appendix B). The study established a full conceptual design of the 200 kg/day

demonstrator and a detailed cost estimation.

Figure 1.3 provides the flow diagram of the proposed hydrogen supply solution. Liquid ammonia is supplied from an ammonia storage unit that will be located nearby on site. The ammonia gas pumped at ca. 7 bar enters a series of heat exchangers to reach the reaction temperatures. Ammonia is then cracked at high temperature in the main reaction/separation unit at temperatures in the range of 400ºC. The endothermic decomposition reaction (Equation 1.1) produces a gas mixture composed of a blend of hydrogen, nitrogen and traces of unreacted ammonia.

In contrast to commercial ammonia crackers, which produce hydrogen with further need of downstream purification, the key innovation of this solution relies on a high selective reactor-separator system combining both hydrogen selective separation and reaction in a single unit removing any need for further purification. This is the so-called membrane reactor, which is a proven and innovative technology the accomplishes a high degree of process intensification. The combination of reaction and separation brings along several advantages compared to conventional reactors: higher process efficiencies, reduced footprint, and operation at milder conditions as illustrated in lab test results in Figure 1.4. Two independent streams are generated at the outlet of the cracking unit. While pure hydrogen is recovered through the membranes in the permeate, the reactor outlet, also referred to as the retentate, is used for heat integration. This retentate is first cooled down by preheating combustion air, and subsequently is burnt in a gas burner. This heat will sustain the endothermic cracking reaction, enabling virtual isothermal conditions.

This design was validated during the initial feasibility study (Appendix B). A membrane reactor unit was built at lab scale and the concept of ammonia decomposition using the technology was demonstrated. During the experimentation phase full ammonia conversion was accomplished, well above the thermodynamic restriction for this reaction, and up to 95% of the hydrogen was extracted from the reactor in the same unit.

These results demonstrate the potential of the proposed technology:

• The selective separation of hydrogen displaces the thermodynamic equilibrium according to Le Chatelier's principle towards the decomposition of ammonia and increases the kinetics of the reaction, thus lowering the operating temperatures needed;
• Hydrogen is directly separated within the reactor avoiding downstream separation like Pressure Swing Adsorption units, which are costly and maintenance-intensive for distributed applications.

The multiscale approach of modelling, experimental work and techno-economic analysis has improved the evidence for and confidence in the ammonia cracking technology's role in pure hydrogen generation and the energy transition. Its utilisation has significant potential to contribute to cost-effective UK hydrogen economy.

Since 2019, the technology has been further developed and the proposed pilot has been developed at a greater level of detail. The regulatory considerations introduced by ammonia are also better understood through the addition of Yara to the consortium. The outline plant design has also been developed to in greater detail at the Tyseley site. We are therefore able to demonstrate with a greater level of confidence the technical and regulatory feasibility of the pilot.

There are remaining feasibility questions arising from scaling up the solution that will be addressed through the pilot:

• No ammonia cracker has ever been deployed for the target level of efficiency and at this scale. H2SITE is currently exploiting a similar technology commercially for hydrogen production from feedstocks other than ammonia. Adapting existing designs of hydrogen production for ammonia cracking leads to less system complexity. In addition, this technology has proven to be suitable for hydrogen production from ammonia at small scale yielding very high efficiencies in experiments under the Harwell feasibility study.

• The membrane components have been validated only at small scale for ammonia cracking running for about 2000 hours. Tests were conducted to analyse the degradation of the Pd-based membranes under different operating conditions. These tests proved its superior performance regarding selectivity –the capability to let hydrogen permeate over other molecules- but also its stability over time in high temperature conditions. As ammonia cracking is an equilibrium limited reaction, the selective separation of hydrogen through the membranes will allow the system to move beyond this thermodynamic restriction yielding higher ammonia conversions. It favours ammonia decomposition at lower temperatures, extending membrane lifetime.

• Heat needs to be properly distributed in a larger reactor avoiding hotspots that damage the membranes and diminish the reaction efficiency. On this purpose the ammonia cracking unit will be run making use of a fluidized bed catalyst, and a reactor heat exchanger type to distribute heat evenly.

• The ammonia supply chain for mobility applications needs to be implemented. Bulk ammonia is typically stored at harbours and transported by tankers. In this project, bulk ammonia will be stored onsite, and the logistics and regulatory normative need to be followed and respected. YARA has a broad experience with handling ammonia, and thus the technical and administrative barriers will be solved during the initial phase of the project.

Please enter the core content of your response to this criterion in the text box. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. Additionally, applicants may use evidence of relevant earlier work (limit to 20 pages), all assumptions / calculations / references to respond to this criterion which should be detailed in the attachment below and will be assessed. To complete this section you may upload evidence of relevant earlier work, all assumptions / calculations / references with your application. Max upload size per file – 20MB Max number of files – 1

- File: Appendix B Previous Work.pdf - Download

Criterion 2: Performance and Cost Reduction of the Hydrogen Supply Solution

Criterion 2a: Performance of the proposed solution The applicant should provide a detailed explanation of the performance of the proposed hydrogen supply solution and compare it to the current state of the art solution and the applicable counterfactual parameters (see Appendix 2 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT), define the assumptions made and the basis for those assumptions. Describe the impact of different operating conditions, for example if the hydrogen supply solution is operating at a variable throughput. Details of the impact on the efficiency of the process should be presented including impact on OPEX costs, longevity and performance. In the text box below, applicants should: Provide details of the performance and flexibility of the proposed solution at the demonstration site and when rolled-out across multiple, suitable sites in future. Explain how the demonstrator will be used after this project has been completed or indicate the decommissioning strategy. Provide evidence of how and why this solution allows performance benefits when compared to the current state of the art and applicable counterfactual parameters. Provide an explanation of the technical barriers to deployment and description of the plan during the demonstration to overcome/scope-out/understand these barriers better. Provide an overview of any relevant performance validation that has previously been conducted. Applicants should detail the approach of the performance validation process that will be followed during the demonstration phase. Provide an explanation of why it is believed that the hydrogen supply solution will be acceptable to the market in terms of ease of installation and reliability (Weighting for Criterion 2a – 10%) (Maximum 2,000 words)

Performance and flexibility:
The ammonia cracker deployed under this demonstration pilot will deliver 200kg/day of fuel cell grade [redacted]
integrated with the existing buffer tanks in hydrogen refuelling stations. It would then be compressed to 350 or 700 bar depending on the application.
In the future the ammonia cracker could be utilised at other end uses such as industrial applications or injected into the gas grid. Most industries and the gas grid require hydrogen at a lower pressure. Therefore, a suitable decomposition reactor can be installed to provide hydrogen at low pressure eliminating the energy consumption required by compressors.
The ammonia cracker solution is flexible by nature and able to deliver dispatchable energy. The greatest impact on the OPEX is the cost of ammonia. Therefore, the varying of operational conditions

and hydrogen demand is unlikely to have a notable impact on efficiency on OPEX.
The 200 kg/day unit fits in a 20 ft container, does not cause NOx emissions -as opposed to other ammonia cracking technologies- and is easy to install and decommission. Moving forwards, when deployed across multiple sites, there is flexibility as to the system size. For larger capacities, the system can be installed in a standard 40 ft container, and they can also be stacked together for linear expansion to production capacity.

Performance benefits vs state of the art:

There are several counterfactuals that should be considered and which the solution performs well against.

- The new innovative ammonia cracker vs existing state of the art cracker.
- Hydrogen produced onsite through electrolysis vs hydrogen produced offsite, converted and transported as ammonia and cracked onsite
- Transporting hydrogen as ammonia vs transporting hydrogen as hydrogen.

The first of these has been addressed in criterion 1. The cracker unit has a similar footprint to state-of-the-art electrolysers and the outlet pressure of the hydrogen is the same. The ammonia cracker can deliver hydrogen at lower cost than onsite electrolysis because it is able to capitalise on lower electricity costs and therefore lower hydrogen production costs delivered by large scale offshore wind [redacted]

[redacted]

[redacted]

Performance validation:

H2SITE has preliminary designs of the ammonia cracker shown in Figure 1.3 and full designs of membrane reactors for hydrogen production from a wide variety of feedstocks. The membrane reactor technology has a high feedstock flexibility, and its adaptation to produce hydrogen from ammonia is straightforward. Only safety requirements and selection of materials will require major adaptation. Therefore, we can have reasonable confidence that the performance will be similarly high. In addition, the performance validation that took place under the Harwell study demonstrated HRF in excess of 97% in the lab tests.

The 200 kg/day ammonia cracker will comprise two different validation stages. The first upon commissioning of the system, the second one during operation onsite. The main activities during the two performance validation phases are:

- Initial Validation Assessment. The detailed engineering of the system to meet all the performance requirements, which will be validated during the Factory Acceptance Tests (FAT). The indicators used to validate performance are:

o Hydrogen Recovery Factor (HRF).
o Hydrogen purity.
o Ammonia consumption per unit of hydrogen produced by the system.
o Electric power consumption.

o System efficiency

If deviations are observed between the targeted performance and the results obtained during FAT, modifications will be undertaken. Potential modifications will include an increase in membrane area, or the selection of different operating conditions.

Once the system is validated at the assembly location, it will be transported and installed onsite. Once all the civil works and connections with utilities are completed, the performance will be reviewed during the Site Acceptant Test (SAT), where the same indicators will be validated.

• Project Validation Assessment. All the variables included in the system will be continuously monitored by the SCADA that will be included in the system. This will allow real time monitoring of all performance indicators that will be used to assess the KPIs of the project and the technology. These indicators are:
o Hydrogen recovery of 97% during system electrification, and above 82% during system integration with a burner.
o The product hydrogen purity, meeting the ISO14687 standard for fuel cell (mobility) applications.
o The ammonia consumption per unit of hydrogen produced, which will give the system efficiency, and will be successfully validated when ammonia consumption is within ±5% the estimated Heat & Mass Balances.
o The system availability exceeds 90%.
o Response factors to environmental conditions. This is important as ammonia storage is largely dependent on ambient temperature.

Due to the endothermic nature of the ammonia decomposition (Equation 1.1), heat needs to be supplied to the system. The compactness of a membrane reactor makes electrification possible, where heat and the utilities can be used when green energy is available. This will enable greater flexibility and smart use of the grid based on real time emission factors. This project will develop a tool that will switch between options depending on the electricity source available. This project will also investigate actual efficiencies of the two potential solutions for this function:
• Ammonia cracking unit with hydrogen burner. Performance will be assessed by operating the unit with a NH_3-H_2 burner. A small amount of the produced hydrogen will be diverted to the burner. This option is suitable for those cases in which clean electric power is not available or is expensive. No carbon dioxide or NO_x is emitted to the atmosphere. Figure 1.1 shows a rough estimation of the Heat & Mass Balance.
• Ammonia cracking unit with electric heating. This option is suitable for those cases in which clean electric power is available, and the system efficiency is maximized as it enables to recover >97% of the hydrogen available in the system by heating up the reactor electrically and make use of auxiliaries to maximize process efficiency. Figure 1.2 shows the Heat & Mass Balance estimation.
H_2 supply acceptance by the market in terms of reliability and ease of installation:
In addition to producing cost-competitive H_2 for targeted markets, this solution constitutes a sound proposition for ease of installation and reliability:
• Ease of installation. The ammonia cracking unit is compact and can be packed in a standard ISO container (20 ft container for the 200 kg/day unit without the compression stage; 40 ft container for larger units).
• Reliability: the reactor reliability is yet to be validated. However, all the components incorporated to the full ammonia cracker are commercial except for the reactor. The reactor comprises a vessel, a commercial heating system, the membranes a radiant tube. It does not include moving parts. Although there will be a learning curve for the team to operate it effectively, H2SITE's experience with this technology in hydrogen generation from other feedstocks enables confidence in the high reliability of the technology.
Technical barriers to deployment:

There are several uncertainties around the technology that arise from the fact that it has not yet been demonstrated at scale. It is possible that these could present technical barriers to deployment. These potential barriers will be explored during the project:

• Uncertainty of the long-term performance at longer operation periods. This is required to demonstrate stability over time. The pilot will be operated for a minimum of 10,000 hours and performance monitored over this period under a range of operating conditions.
• Uncertainty of the load change performance. It is important to assess hydrogen purity, recovery rate and energy performance when the unit is operated below optimal load. The pilot will be operated below optimal load to establish whether there is any impact on hydrogen purity, recovery rate and energy performance.
• Uncertainty of the response time which will be used to assess the flexibility of the solution when coupled with a highly intermittent power source. This will be assessed during the lifetime of the
• Uncertainty as to the resilience of the system at scale. The project will look to assess reactivity to stress tests including frequent and sharp temperature and pressure variations.

• Lack of operation record for this technology, that might compromise the reactor availability. The lab tests in which H2SITE key technical leaders took part offered great insight into the optimum performance for the membranes to maximise yield and extend their lifetime. Operating conditions will set accordingly.
• Reactor availability and performance might be compromised by reactor hot spots. The ammonia cracking unit incorporated a fluidised bed catalyst and a radiant tube to favour the reaction and distribute heat evenly. This will be monitored and optimised throughout the pilot.
• Reactor availability is also compromised under high thermal stress. The unit will incorporate systems –closed loop control systems and backup power systems- to ensure that slow start and stop manoeuvres take place. This performance metric will be monitored throughout the pilot.
• The catalyst has not been tested with industrial ammonia, as opposed to the very pure synthetic ammonia used in lab tests. Adaptations might be needed over the catalyst and other systems during FAT (Factory Acceptance Tests).
Decommissioning plan:
A final decision is yet to be made by the project consortium regarding decommissioning of the demonstrator. ITM Motive, has expressed its desire to continue offtaking after project completion provided that a cost competitive product can be delivered. Otherwise, the equipment mobilised for H2 production could potentially be utilised elsewhere.

Please enter the core content of your response to this criterion in the text box. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. Additionally, applicants may use evidence of relevant earlier work (limit to 20 pages), all assumptions / calculations / references to respond to this criterion which should be detailed in the attachment below and will be assessed. To complete this section you may upload evidence of relevant earlier work, all assumptions / calculations / references with your application. Max upload size per file – 20MB Max number of files – 1

- File: Appendix C Previous Work.pdf - Download

Criterion 2b: Lifetime costs of the proposed solution With reference to relevant prior work, describe the likely lifetime costs of the Hydrogen Supply solution compared with the applicable counterfactual parameters (see Appendix 2 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT) including round-trip efficiency, providing the assumptions made. Costs should be broken down, where possible/relevant, into CAPEX (and financing at IRR 10% where applicable), OPEX (broken down into fuel, maintenance, labour, consumables), carbon cost, for main plant equipment. We also expect a current and estimated future (2035) levelized cost where relevant. Describe how demonstration will firm up these costs. Where applicable, include in this analysis the capture rates, the system benefit costs, the impact on the purity of hydrogen, accessibility to hydrogen and round-trip efficiency. How do these compare against state of the art? Highlight the main uncertainties associated with these cost estimates and explain how the design and execution of your demonstration pilot will address these uncertainties. Applicants should note the following: The applicable technical parameters should match those stated in the counterfactual including the relevant pressures, purities and flow rates. These boundary conditions should be used to develop costs of a counterfactual. If a different set of boundary conditions is more representative for your hydrogen supply technology, this can also be included, in addition, to help support your application, but would require justification. Compare and justify all costs and cost reduction of the proposed system to the current state-of-the-art hydrogen supply solution or closest comparable existing solution. To calculate (and enable us to compare) lifetime costs, bidders should use BEIS's estimates for cost of carbon, electricity and natural gas prices in 2035 (assume these costs and prices do not change). These are provided in in Appendix 2 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT. If a different cost assumption basis is more representative for your hydrogen supply technology, this can also be included, in addition, to help support your application. All units of measurement provided for the analysis should match those stated in the counterfactual. (Weighting for Criterion 2b – 10%)

(Maximum 2,000 words)

Lifetime cost comparison approach

This project is looking to make the case for the utilisation of ammonia as a hydrogen carrier to enable:

• The storage and transport of hydrogen over large distances, connecting large centralised renewable generation with distributed hydrogen users.
• The import and export of hydrogen driven by geographical disparities in the cost of renewables.

We are therefore concerned not with the cost of hydrogen at point of production which does not include storage and transportation costs, but the cost of delivered hydrogen at point of use. This is the point at which a fair commercial playing field is established. We will be therefore comparing the levelised cost of hydrogen (LCOH) for our supply solution which comprises of green ammonia production, ammonia transport and ammonia cracking with counterfactuals such as decentralised onsite production through electrolysis or centralised production with transport of hydrogen in ships and trucks.

This project is focused on reducing the cost of the last step in the ammonia hydrogen supply chain i.e. the ammonia decomposition and selective hydrogen recovery. We will therefore be providing detail on these costs whilst using assumptions on the costs of green ammonia production and ammonia transport.

Lifetime cost of ammonia cracker for the demonstration project and supply solution:
The levelised cost of H2 (LCOH) is a metric that accounts for the CAPEX and the O&M fixed (maintenance and insurance mainly) and variable costs (utilities), over a plant lifetime and a plant availability considering the targeted capacity. To make a fair calculation, all costs are brought to date through the net present value (NPV). The financial variables over the plant lifetime are included too. A detailed list of the assumptions used for the cost calculation in this project is given in Table 2.2.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2030.

These improvements in the core technology, coupled with external market factors and learning by doing will result in a reduced LCOH for delivered hydrogen by 2035. The cost of cracking ammonia into [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted] increases with greater distances. This cost compares favourably with the roundtrip cost of our solution as the input cost of green hydrogen would be common across both solutions.

In the future it may be possible to repurpose the gas grid to carry and store hydrogen. This solution is not comparable with our solution as it is not currently capable of delivering hydrogen at the same purity level.

The other thing to note is that one of the main benefits of ammonia as a hydrogen carrier is that it enables global hydrogen imports and exports. The Harwell study determined that the total cost of shipping ammonia from Qatar through the Suez Canal to the UK (6,266 nautical miles) in a typical dual [This information has been redacted] including canal fees, port costs, insurance and return of the empty vessel. There is no equivalent feasible counterfactual for this application. Hydrogen's volumetric energy density is too low to be transported over these distances and all other conventional methods of importing and exporting energy contain carbon.

Please enter the core content of your response to this criterion in the text box. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. Additionally, applicants may use evidence of relevant earlier work (limit to 20 pages), all assumptions / calculations / references to respond to this criterion which should be detailed in the attachment below and will be assessed. To complete this section you may upload evidence of relevant earlier work, all assumptions / calculations / references with your application. Max upload size per file – 20MB Max number of files – 1

- File: Appendix D Construction Delivery Plan.pdf - Download

Criterion 3: Social Value

Criterion 3a: Short term development plan. In the text box below, the applicant should provide a summary of the short-term development plan that comprehensively appraise the outstanding technical challenges of the solution and its commercial benefits and risks relative to the applicable counterfactual parameters. In the response, please cover the following: Present the plan for further development, commercialisation and exploitation of the hydrogen supply solution. What are the main technical and commercial challenges and risks to getting the solution to market; and how will you overcome them? A summary of the business plan must be presented that highlights the route to market and estimated time to secure market share. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 3a – 5%) (Maximum 1,000 words)

Commercial benefits of the solution:
Hydrogen is expected to provide a substantial contribution to the UK's 2050 net-zero target as a clean fuel for transport, industry and heat. The locations where zero-carbon or low-carbon hydrogen can be most cost effectively produced are where there are consistent levels of wind or sun. Such locations are often distant from end-user populations and consequently, it would be necessary to transport the hydrogen in large quantities, over long distances. Unfortunately, hydrogen has a low energy density by volume and the high cost of transportation rapidly offsets any cost benefits arising from its source.

The solution proposed is an ammonia cracker that is capable of delivering 200kg/day of hydrogen at the point of use. This solution would capitalise on the lowest cost of renewable energy generation and the low cost of transporting this renewable energy in the form of ammonia to deliver a low cost of hydrogen at the point of use. This approach rests upon the maturity of ammonia production, storage and transportation, which are well-established and widely practiced with optimised costs. The remaining challenge is to demonstrate that an ammonia cracking process can be operated effectively and at sufficiently low cost to enable a profitable business model to be established for end use applications. This project not only will demonstrate the technical feasibility ammonia cracking reactors, but will also assess the LCOH of commercial scale projects of this nature. Both metrics -technology maturity and competitive LCOH- are expected to make this type of project bankable.

Target market:
In the short term the consortium will be targeting the transport sector. This is because:
• The UK has highlighted HGVs, buses, trains and commercial vehicles as key early markets for hydrogen. These larger and high utilisation vehicles are well suited to the use of fuel cells over batteries as a decarbonisation pathway due to fast refuelling times and higher energy density of hydrogen offering efficiency benefits and longer ranges. These vehicles will have distributed and decentralised refuelling requirements and will require high purity fuel cell grade hydrogen. The transport use case is therefore a good match for the technology which is able to reliably deliver competitive cost of hydrogen and high purity level.
• The price sensitivity for hydrogen is lower in transport than other use cases. Hydrogen will be used to displace higher value transport fuels such as petrol and diesel. As highlighted in other sections, there is significant cost down potential of the solution and the technology will be applicable to many end uses in the future. In the short term, through targeting the transport sector, the higher price that can be achieved for hydrogen will allow the solution to be deployed in commercial settings whilst cost down is delivered.
• Following the conclusion of the project, the solution will be eligible for the RTFO under the current terms which will improve the economics for the end user and enable the technology to be deployed on a commercial basis within these settings.
• The demonstrator is being deployed in a transport setting which will create confidence in the market for the solution for this use case. This will reduce the risk for early-stage deployment following the conclusion of the project.

Route to market:
Potential early-stage customers include bus operators, HGV operators, train operators, commercial fleet. The consortium will look to install and operate crackers at third party refuelling stations across the UK. Stations will be for public refuelling, or owned by large individual end-users such as rail, bus and HGV operators for their captive use. It is anticipated that the initial market entry will be in the captive segment by alignment with specific projects for the decarbonisation of trains, bus fleets, material handling, etc. The project consortium will also explore licensing the technology to third parties.

Risks in commercialisation:
There are several risks associated with this solution when compared with the current alternative of onsite electrolysis or tube trailer delivery. In the short term, the green ammonia supply chain is still nascent therefore there are supply risks associated with utilising this as a feedstock. Also, operational requirements that were contingent on the availability of hydrogen could make this solution unattractive if a source of ammonia could not be guaranteed. This is mitigated by the maturity of the existing ammonia supply chain, meaning that in the event of green ammonia not being available for a period of time during the early-stage development of the supply chain, brown ammonia could be utilised. This is however viewed as a contingency measure rather than a base case scenario.

In addition, the safety requirements of storing ammonia onsite are more stringent than storing hydrogen, therefore this adds additional risk to the solution. This will be mitigated by the inclusion of Yara within the consortium who have expertise in the handling and storage of ammonia and will support with site selection.
There are a number of outstanding uncertainties that arise from the technology having never been deployed at this scale anywhere in the world to date. These uncertainties have been described in detail in other sections and would be addressed through the project.

Market share projections:
[This information has been redacted] [redacted]

Criterion 3b: Long term development plan. In the text box below, the applicant should provide a summary of the longer term development plan that highlights the route to market and estimated time to secure market share including highlighting the key challenges to achieving commercialisation at scale (assuming there is a demand for bulk low carbon hydrogen), timescales, build rate, and estimated development costs, UK job creation and development of a supply chain to develop a future hydrogen economy. In the response, please cover the following: Discuss the timescales and development costs and any potential supply chain constraints to support a future hydrogen economy particularly focusing on the UK 2030 hydrogen ambition and 590 TWh by 2050 (based on National Grid's Future Energy Scenarios). This should include potential cost savings through learning by doing, UK job creation, the development of a supply chain to meet future demand, air quality impacts (NOx, amines, particulates etc.) and carbon (CO2eq) savings across the economy (direct or indirect). Where possible, please separate emissions into Scopes 1 and 2 (direct and indirect), UK and international, and for theme 1 (Low Carbon Hydrogen Production) please include upstream emissions from natural gas (please see details in Appendix 2 of the Low Carbon Hydrogen Supply 2 Stream 2 ITT). The applicant should also detail the potential wider environmental impact (local and global) from the roll out of the proposed hydrogen supply solution and limitations in the supply of rare materials, and how they could be mitigated. With reference to the response against Criteria 5 (Project Delivery) how will these be mitigated? Route to market and market potential of the proposed solution discussing the alternatives and the competitive advantage, highlighting future innovations and learning rates and how the hydrogen supply solution could reduce the costs of achieving net zero. Explain how the demonstration will accelerate the development of low carbon hydrogen economy in the UK. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 3b – 10%) (Maximum 2,000 words)

The use of ammonia as a hydrogen carrier enabled by the development of low cost efficiency cracking technology has many long term benefits for the UK:
• Hydrogen targets: The use of ammonia as a hydrogen carrier will improve the economics of offshore wind enabled electrolysis increasing the rate at which the UK can deliver hydrogen production technologies. This will support the UK's ability to hit its 2030 targets by delivering 1GW of capacity. It will also enable the UK to import hydrogen in bulk at low cost derisking the UK's decarbonisation pathway and providing resilience as the UK looks to utilise large volumes of hydrogen to meet Net Zero.
• Environmental: The deployment of cracking technology would enable the deployment of distributed hydrogen solutions which would decrease carbon emissions by up to 55MtCO2e/annum by 2050 (see Table 3.1 for background assumptions).
• Economic: The development and deployment of cracking technologies in the UK will place the UK at the forefront of an emerging area which is likely to be a substantial global market in the coming decades. It is an area that many countries are starting to develop solutions and the UK has the opportunity to take a leading position. We estimate that 97,000 jobs and £16bn GVA could be delivered in the UK through early investment in cracking technologies enabling the use of ammonia as a hydrogen carrier.
• Global: The use of ammonia opens up new opportunities for the import and export of hydrogen as a commodity. This will be important as the cost of hydrogen production varies geographically. It will enable economies that have higher costs of production to access low-cost hydrogen.

Commercialisation and deployment between 2030 and 2050:
The consortium is targeting widespread deployment of cracking technology in the UK. This will initially be targeted at the transport sector to 2035 with a view to expanding beyond transport from 2035-2050. The UK Hydrogen Strategy (Ref 1) estimates that by 2035 there could be 20-45TWh of hydrogen demand from the transport sector. Much of this will be distributed demand that could be serviced by ammonia crackers. If 15TWh of transport demand was serviced by ammonia crackers this equates to just over 6,000 200kg/day units deployed in the UK by 2035. This would support UK hydrogen production targets, by 2030 the consortium estimates that it will have deployed 1GW of distributed hydrogen capacity, meeting 20% of the UK's 2030 target. In the short term, the consortium expects to have significant domestic market share of ammonia crackers (80%) based on the successful completion of the demonstration project. There is also likely to be an export market for the product by 2035, focused around ammonia exports from the Middle East, Australia and other areas of opportunity. The consortium will also be targeting these markets during this time period.

The National Grid in its Future Energy Scenarios estimates that demand for hydrogen could reach 590TWh by 2050. Although CCUS enabled hydrogen production has a key role to play in scaling hydrogen solutions and providing lower cost bulk hydrogen in the short term, it is assumed that by 2050, an increasing proportion of hydrogen demand will be delivered by electrolysis rather than CCUS enabled production routes. The use of ammonia as a hydrogen carrier will improve the economics of delivering this via offshore wind coupled with green ammonia production rather than onsite electrolysis. It would also enable the import of hydrogen from geographic areas where hydrogen production is cheap such as the Middle East or Australia.

The project consortium estimates that 25% of the total hydrogen demand in 2050 could be transported using ammonia either via imports or from offshore wind assets in the UK. This equates to 60,000 installed units in the UK by 2050. By 2050, the consortium expects to have a lower market share of ammonia crackers (50%) as other competitors enter the market. However, the consortium views this scale up rate of production to meet domestic demand as feasible and does not foresee any unresolvable issues in supply chain development.

In 2018, the UK imported 5.8 million tonnes of liquified natural gas (LNG) and liquified petroleum gases (LPG) equivalent to 88 TWh from locations such as the Middle East, Russia and the USA. Liquid ammonia has the potential to substitute these imports as a low/zero carbon alternative Substitution of all the 2018 imports of LNG and LPG would require 14.1 million tonnes of ammonia or 235 shipments per year in typical LPG vessels of 60,000 tonnes capacity. The cracking plants could be either owner/operated or the technology could be licensed to others. It is possible to have agreements with overseas suppliers in place by 2025 with initial shipments from 2030.

The realisation of the above scenario will require coordinated investment in the production of low/zero-carbon H2 in locations with favourable renewables generation and integration with ammonia production facilities. Substantial export opportunities exist for this technology as the proposed approach is expected to be adopted by several countries with limited access to renewables.

Commercialisation and development challenges:
As highlighted in the lifetime cost question, the technology has significant cost down potential that will be delivered over the coming years. Part of this cost down will be delivered through increased deployment of the solution at scale leading to lower production costs and lower cost of key components. There will be a need for further investment in membrane technology to improve lifetime and performance. It is expected that the membrane lifetime will increase to 5 years by 2028 and the cost of the membranes will decrease by 40% over the same time period. H2SITE are already investing in this R&D activity and will continue to do so over the next 5 years. The industrialisation of the system will result in a better data management, which will enable a deep knowledge on the maintenance needs and will allow the increase in the plant availability to 95% by 2030.The project consortium expects to deliver significant savings through the demonstration project which will enable the project team to optimise the performance of the cracker and understand the membrane performance in a real-world setting. This ‘learning by doing’ will accelerate the development of the technology.

There are a number of challenges impacting commercialisation of the ammonia cracking technology. Firstly, the timeline for commercialisation of the technology is linked to the development of the green ammonia supply chain. As the last link in the value chain, there are limitations on deployment whilst the green ammonia production solutions are being developed. This challenge is mitigated by the fact that the technology can be deployed utilising conventional ammonia whilst the green ammonia supply chain is maturing without impacting the economics. This will de-risk any early-stage projects which are reliant on a source of ammonia to be viable. Whilst the use of brown ammonia is not a long-term solution, it could be utilised as a contingency.

Environmental benefits:
Our assumption is that by 2050 of the 147TWh that could be delivered through the use of ammonia as a hydrogen carrier this would be utilised proportionally as per the National Grid FES across end use scenarios including transport, power generation, heat and industry. This means that there would be the following hydrogen demand from these sectors Road and Rail: 9TWh, Shipping: 22TWh, Power Generation: 23TWh, Heat: 53TWh, Industry: 39TWh. Utilising BEIS emission factors for natural gas and transport fuels gives a total carbon emission saving of 55MtCO2e/annum by 2050.

In addition, the displacement of natural gas and transport fuels by hydrogen will result in a reduction of NOx and particulates. This will have a subsequent impact on health and wellbeing, and lead to a reduction in healthcare costs.

Economic benefits and supply chain development:
The commercialisation of the ammonia cracking technology in the UK will deliver significant economic benefit for the UK. It will help to create and protect jobs, both direct and indirect and deliver GVA. We estimate that 97,000 jobs could be supported by 2050 and £16bn GVA delivered to the UK through the use of ammonia as a hydrogen carrier. These figures have been calculated using the Hydrogen Taskforce Economic Impact Assessment model which utilises data from industry alongside Office of National Statistics Input-Output tables and Supply & Use Tables. It considers direct and indirect but not induced impact.

The availability of ammonia cracking technology will support and encourage the fledgling green ammonia industry in the UK and help to develop supply chains in the UK. Whilst many countries are competing to lead in hydrogen production, there is greater scope for the UK to be a global leader in green ammonia technologies. With green ammonia being a key decarbonisation pathway for agriculture and shipping alongside the use of ammonia as a hydrogen carrier, the economic benefit that would be derived from being a first mover is substantial. The world's first at scale demonstration of ammonia cracking technology would place the UK at the forefront of green ammonia supply chain development.

It is expected that there will be global demand for ammonia cracking technology. There are several countries that have declared interest in exporting hydrogen using ammonia such as Australia, Saudi Arabia and United Arab Emirates. Saudi Arabia have announced a $5bn green ammonia plant to be operational by 2025 for the purposes of export. The intention is to crack this ammonia back into hydrogen for refuelling purposes. There are also several areas that have declared interest in importing hydrogen in the form of ammonia such as the EU and Japan. There is recognition that ammonia will have a key role to play in enabling hydrogen imports and exports over large distances. As such, there will be significant demand for ammonia decomposition solutions such as the one developed under this project. It is expected that there will be significant export potential for the ammonia cracker should the demonstration be successful, and this would deliver significant economic value for the UK.

Global impact:
The use of ammonia as a hydrogen carrier opens up global markets for hydrogen. This is important because, as highlighted by the Hydrogen Council in its 'Path to Hydrogen Competitiveness' Report, the cost of hydrogen production varies geographically based on the expected cost of renewables. Through the use of ammonia as a hydrogen carrier, hydrogen can be produced globally in the areas where it is most cost effective to do so and exported to end users. This will lower the cost of decarbonisation globally.

There are no adverse environmental impacts associated with this solution and no rare materials required (instead regarding palladium as a raw critical material).

Criterion 3c: Knowledge dissemination strategy. In the text box below, the applicant should explain the current plans for taking the knowledge and experiences arising from the demonstration pilot and ensuring that these are effectively communicated and shared within the relevant stakeholders. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 3c – 5%) (Maximum 1,000 words)

Dissemination will be focussed on engagement with organisations that will be important through the next stages of development, including but not limited to:

• Customers in the markets identified in the market assessment as presenting early-stage opportunities
• Stakeholders within areas of the energy system where green ammonia is a key enabler e.g. offshore wind or shipping
• Stakeholders within the hydrogen industry for whom the use of ammonia could strengthen their business case or open up new markets e.g. electrolysers, SMR, refuelling station operators.
• Existing hydrogen projects exploring enhanced value prospects e.g. HyNet, Acorn/ NECCUS, Zero Carbon Humber and so on.
• Policy makers with a view to ensuring that the opportunity presented by ammonia is reflected in policy and strategic decisions, such as the RTFO, the cluster sequencing process, hydrogen business models etc.
• Academia, particularly for the catalyst development that will end the project at a higher TRL level, primed for commercialisation and roll-out

Tyseley Energy Park (TEP) in Birmingham is rapidly developing into a major UK asset in hydrogen technologies and their implementation. With the ITM hydrogen filling station sitting on site since 2020, the 20 hydrogen fuelled buses gradually arriving in Birmingham since July 2021, the Incubator Space, and the University of Birmingham (UoB) Energy Innovation Centre (BEIC) having been inaugurated in July 2021, TEP has created a critical mass to attract hydrogen technology and business. In so far as the choice of siting the project at TEP is ideal in proliferating the project idea to businesses and public audiences, it incidentally utilities existing infrastructure which ensures the hydrogen refuelling aspects do not dilute the focus of this project, which is the transport, storage and conversion of hydrogen as ammonia and the benefits thereof.

The project team intends to implement a five-tiered plan to dissemination:

1. In-person and virtual guided tours and on-site Q&A sessions to give the public a real-world 'feel' of the technology, its infrastructure, and the context it sits in;
2. Workshops and webinars of a more detailed character to inform stakeholders, engineers and scientists, politicians, and financiers of the technical realities, issues, and opportunities the project technical approach offers;
3. Dissemination of information to the general and scientific/technical public via publications in journals (general and scientific) and presentations at conferences and workshops;
4. Networking with the various stakeholder groupings and industrial and governmental institutions; and
5. Integration of learnings from the project into academic practice, as in the MSc programme, CPD modules and Summer Schools delivered through UoB;

The project team will be supported by the UoB Birmingham Energy Institute (BEI) Communications Team with publications, press releases and event organisation.

1. As TEP sits close to Birmingham city centre, and is accessible via public transport as well as road, one primary option will be to bring in interested parties to see the technology in actual operation and demonstrate the viability and safe and reliable operation of hydrogen supply installations. With the ITM hydrogen filling station (HRS) and BEIC sitting next to the demonstrator, and the Birmingham hydrogen buses coming in for fuelling, the project context is not only explained in theory put becomes a 'theme park'. As such it will be welcoming to visitors and offer unique insights into not only a single technology, but also the various elements of a hydrogen economy. As the Covid pandemic has taught us, besides offering in-person experiences, we also need to open up to virtual events, with web-based walk-throughs and Q&A sessions to allow persons from all over the UK and the globe to partake in the experience. UoB has collected a wealth of experience when successfully navigating the 2020/21 pandemic that will be the basis of offering in-person, hybrid, and virtual formats of visitor engagement. We will be initially organising tours on demand, moving to bi-monthly frequency.

2. We will be targeting two events annually that address the different communities according to the relevance of the project phases: permitting (regulators, associations, institutions, and politics), technical and scientific audience (including industry and industry networks), and finance and business entities. The format will be topical workshops primarily be delivered on-site, but also virtually to attract a global audience.

3. The consortium will provide publications to business and technology-oriented press, disseminating project outcomes to the wider business and industry community. As a demonstrator, the potential to publish scientific papers is limited, but these will - mainly focussing on data analysis of the demonstration performance and the validation of the project design – target the Open Access journals published by MDPI (Energies, Biomass, Sustainability), the Journal of Power Sources, and the International Journal of Hydrogen Energy. The World and European Hydrogen Conferences (WHEC, EHEC, Hydrogen Summits), the European events around Hydrogen Europe, and the national events (NEC conference, AllEnergy, H2FC Supergen Hub and others) will be key. More specialised events will be considered as they materialise, provided they offer material means of broadcasting our project, milestones achieved, and lessons learned. The approach for the minor events will be to proliferate the project ideas, rather than concentrating on technical presentations, and thus making best use of opportunities.

4. We will be working with the UK and international hydrogen hubs and centres in order to share information and interact with stakeholders across the board. This includes the UKFCHA, SHFCA, the H2FC Supergen Hub, the Teesside hydrogen hub, the IDRIC at Heriot-Watt University, Hydrogen Europe, and many others. As industrial decarbonisation takes up pace, we expect more networks to form, and we will proactively engage with such developments. Located in the Midlands and with UoB as a core partner, the project will support the development of the Energy Research Accelerator (ERA) and the Midlands Engine.

5. The project details and results will find their way into the educational offerings of UoB. In their experience, students much appreciate practical and real-world oriented content. The project will serve to offer PhD students industrial placement opportunities and at the same time support scientific projects by supplying real-world data to inform process modelling and catalysis research.

Criterion 4: Project financing

To complete this section please upload a completed BEIS Project Cost Breakdown/ Finance Form for Stream 2 here. Max upload size per file - 5MB Max number of files - 1

- File: hys2-project-cost-breakdown-form_Tyseley_final.xlsx - Download

In the text box below, the applicant should: Provide justification of costs and ensure all costs are eligible. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 4a – 10%) (Maximum 1,000 words)

The Tyseley Ammonia Project was conceived with a specific aim of developing a cost-effective and low-regrets solution to providing locally available hydrogen in the UK, without the requirement for production to be co-located. The leading organisation for this bid, Gemserv (via the previously distinct Ecuity business), led the Ammonia to Green Hydrogen project delivered as part of the first Low Carbon Hydrogen Supply Competition, and so understands the relative cost benefits of this project.

In reference to the Project Cost Breakdown submitted as part of the application, the consortium has undertaken a gap analysis and confirmed that all costs needed to execute the programme of work set out under Criterion 5, Project delivery have been identified. Appendix D provides a breakdown of construction-related capex and how this is reflected in the delivery plan for this project.

Specifically, in the case of staff costs, the consortium can confirm that different grades of staff are assigned to tasks in a way that is appropriate for, and proportionate to the complexity of the tasks assigned. Day rates are charged at cost and ascribed according to the number of working days assumed by the Project Cost Breakdown. For those organisations based in the UK, the day rates are consistent with PAYE records. Overhead justifications are provided within the Excel file.

The primary reasons for the low-cost nature of Tyseley Ammonia Project are as follows:
• The consortium directly includes the ammonia feedstock supplier, Yara, and as such is intending to benefit from cost-efficiency measures that are only possible when dealing with a wholesale supplier

• The project is designed to operate using the optimum flow assurance conditions and a preferred choice of technology such that capital and operational costs of the demonstration plant are minimised without materially impacting overall performance.

• The project plans to utilise existing Hydrogen Refuelling Station infrastructure (ITM Power) and available utilities, corridors and laydown areas that have already been established as part of the Tyseley Energy Park master planning.

• The project has selected a decentralised approach to ammonia decomposition, in order to benefit from the cheaper transport and storage cost logistics of ammonia versus hydrogen.

Also, by considering the feasibility of both a pipeline and shuttle option for transporting hydrogen from the demonstration plant to the HRS, the most cost-effective transportation solution will be selected. The learning from this project can de-risk further hydrogen projects across the UK that employ hydrogen storage or ammonia conversion technologies. This is primarily achieved through the development of investment frameworks, infrastructure sequencing activities, support mechanisms and risk allocation. All of which are essential to the scaled deployment of a wider national hydrogen economy, with strong resiliency plans for importation and the ability to replicate and export opportunities for UK plc with respect to the conversation of ammonia and supply of hydrogen.

In delivering this project by 2025, Governments aim of increasing market confidence and competition in forms of hydrogen transport and storage through demonstrations, as a policy instrument for hydrogen business models and cluster sequencing activities involving hydrogen in the mid-2020s is achieved.
The project aims to deliver value for money to the Government by selling the hydrogen produced at market value. However, we have included the cost of the ammonia within the project budget. This is because there are some uncertainties that arise from the current market infancy and volatility:

• Offtake issues: The ITM Motive station could encounter technical difficulties, low demand and in this case the hydrogen produced by the cracker would need to be vented.
• Ammonia market volatility: The project consortium intends to source green ammonia where available with grey ammonia as an alternative option. The project economics are sensitive to the price of ammonia. Given that the demonstrator will not come online until 2023, there is uncertainty around the price of ammonia that can be achieved by the project based on market volatility.

The primary purpose the project is to demonstrate the performance of the core technology and the low carbon hydrogen solution that is delivered through it. This approach allows the consortium to guarantee the minimum period of operation. We must stress that the project will, under no circumstances, generate profit. The funding allocated to the cost of ammonia will only be used in the event that the hydrogen must be vented or that there is a disparity between the price that can be obtained for the hydrogen and the cost of the ammonia.
Another significant cost included within the project is the ammonia storage. We have chosen to deliver and store ammonia in bulk rather than through cylinders. Whilst the project could be delivered through cylinders (and indeed this is a backup option), the challenges and mechanisms around ammonia storage are an important part of demonstrating the case for ammonia as a hydrogen carrier and understanding the challenges of future deployment. As such, we have chosen to use the mechanism that would be utilised in future projects that have a longer duration and are at larger scale. The ammonia storage tank has been depreciated to zero by the end of the project because there is no resale market for this type of asset.

Criterion 4b: Value for money to HM Government In the text box below, the applicant should describe why the proposal represents good value for money for HM Government. The answer should explain the following: How the availability of public funding makes a material difference to the actuality and pace of moving the solution towards commercialisation, and Qualify and quantify the savings that are being passed on to HM Government to reflect the asymmetric balance of risks and benefits accruing to the project consortium and HM Government. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 4b – 15%) (Maximum 1,500 words)

Our understanding is that, by the late 2020s, an ambition of Government is to see some initial volumes of hydrogen stored as ammonia, and recognise this as a leading option for decarbonisation of sectors that cannot be easily electrified (in particular Heavy Vehicle Transport and Shipping). In doing so, it is their intention to support demonstration projects to reduce associated costs, complexity and efficiency losses of hydrogen-based fuels.

The Tyseley Ammonia Project will fulfil this ambition, 5-years ahead of schedule, by demonstrating the end-use, conversion, storage and performance credentials of ammonia- all key aspects of the hydrogen value chain (Figure 4.1). The project, therefore, offers excellent value for money for HM Government in delivering against its legally enshrined Net Zero Carbon target.

This project is also deemed complimentary to other underground hydrogen gas storage
[This information has been redacted] [redacted]
conversion of all UK underground gas assets would provide 4.8TWh of hydrogen storage capacity (see Table 4.1). However, this only reflects around 8% of the projected hydrogen storage capacity required by 2050. In order to address this shortfall, new hydrogen storage capacities should be developed in both the short and long term. Given the repurposing of underground gas storage assets can take up to 7 years to implement, the Tyseley Ammonia Project offers an accelerated pathway to demonstrating hydrogen storage, on a manageable scale, whilst kickstarting hydrogen storage capacity in the Midlands.

Benefits Afforded by Public Funding:
Public funds will enable the coming together of a consortium of experienced, professional industrialists and academics to collaborate, pool their expertise and accelerate the development and dissemination of new knowledge and technology in the UK. In absence of this funding, the parties would either be working individually to develop their interests in this project in isolation, or not at all, given the insufficient stimulus to catalyse project development in favour of other opportunities. It is recognised that most organisations involved have processes in place which determine the portfolio of

projects they wish to devote their limited (and often stretched) resources to, in order to sustain and grow their businesses. As such, the consortium believes this public funding would substantially reduce the associated risk profile and insurance implications of the project, which in turn, results in a more cost-effective means of energy storage and hydrogen supply to the electorate.
Were Government to consider an equivalent Exclusive Development Contract, rather than fund this project through an SBRI contract, we believe the accrued industry-standard margins, development fees, IP licensing fees and other risk-associated fees would collectively represent over 60% additional costs arising to the UK taxpayer. Such additional costs may be higher still, given the relative niche area of the market and the resulting lack of competition from other OEMs.

Given any foreground IPR will likely be shared amongst the partners when developed via SBRI, the licensing fees for future plant roll-outs may also result in preferential rates given to the consortium partners involved.
Once the committed lifecycle of the project has concluded, the consortium partners are at liberty to inject additional funds into the project, extending its workings based on a commercial relationship without government capital support. The project will include a mechanism to facilitate additional investment from consortium partners and third-party investors to utilise the demonstration plant, whilst ensuring the consortium first delivers in full the requirements set out by the SBRI contract. Based on preliminary discussions, we believe there is appetite within the consortium for asset reuse, and we would be delighted to work with BEIS and other departments to express the follow-on opportunities from this project.

Optimising Value for Money:
As outlined in the recent Hydrogen Strategy (Ref 1), Government believes hydrogen 'will be critical to the deep decarbonisation of the UK economy' and can 'provide greener, flexible energy across power, heat and transport'. The Hydrogen Strategy further states 'hydrogen can only be considered as a decarbonisation option if it is readily available, at the right price, the right volume and with sufficient confidence in its low carbon'.
The Tyseley Ammonia Project is wholly aligned with this statement:
• It delivers green hydrogen that is converted locally, is co-located with the end-user refuelling point, is sourced from a well-established and internationally available ammonia supply chain and introduces redundancy measures at ITM Motive's HRS in the case of shut-downs and maintenance.

• It will provide a green source of hydrogen within a price range acceptable to passenger car customers and bus and truck customers.

• It is configured such that 200/kg of hydrogen will be delivered to the HRS at Tyseley Energy Park- a scaled-up approach from previous 5kg/day experimental design work and at appropriate volumes to encourage fleet operators, small public service vehicle operators and private customers to adopt a hydrogen transport option. This is in line with many corporate sustainability objectives employed nationally and the evolving public consumer choice of more sustainable means of travel.

• It ensures the supply chain origins of the green ammonia will be verified as a renewable product
Beyond these core principles, value for money can be ascribed in the following ways:
• Existing asset use: The use of the ITM Power Hydrogen Refuelling Station, primarily through the dispensing infrastructure and consumer base, will substantially reduce the capital exposure to the project in order to secure a route to market for the hydrogen offtake.

• Existing outline planning permission: The Tyseley Energy Park- as the host location of the demonstration plant- already possesses outline planning permission for specific uses, thereby providing a developed position with which to secure more detailed planning permission, reducing up-front development expenditure and planning risk.

• Prior use of technological development: The ammonia cracker technology is a true example of international technology sourcing with flow of technological development and commercialisation from abroad to the UK. Government is benefitting from previous research and development of the advanced membrane reactor that has been developed over more than 10 years with a dedicated investment of over £6million during this time.

• Regional and economic benefits: The project will further develop both the wider aspirations of the Tyseley Energy Park development and a research and infrastructure project in the midlands, providing a direct economic stimulus. The retention of high value research and manufacturing jobs within existing and emerging industries will reduce the tendency for the relocation of industries currently facing significant economic threats from the Covid-19 pandemic and the growing exposure to carbon pricing. Subject to availability, all equipment will be bought in the UK, favouring SMEs with the right skills and capacities to deliver. The demonstrator will then be assembled in ENGIE UK facilities with factory acceptance testing, followed by containerised shipment to Tyseley Energy Park.

• Competitive stimulus: The demonstrator will catalyse mass market-uptake of ammonia conversion technologies and foster a more comprehensive and explicit understanding of operational costs and logistical challenges. The model for co-locating electrolytic production and ammonia conversion will 'set the mold' for future HRSs that desire a resilient supply chain without heavy reliance on either the grid or local renewable availability. Following which, market forces will introduce prospects that wish to compete with this cracker technology. Whilst there are certain characteristics which make this technology unique, we believe this will ultimately force OEMs and developers to seek cost savings to remain profitable, thus making hydrogen supply from ammonia more affordable in the future.

• International advantage: As the opportunity presented by hydrogen becomes better understood globally, the requirement for hydrogen carriers is gaining increasing attention and investment. There are a number of other organisations globally that are developing hydrogen carrier technologies, particularly in China and Germany. This funding will place the UK at the forefront of these developments and bring forwards an important technology with significant export potential, rather than relinquish its interests and encourage the technology to be developed overseas.

• Progressing the skills agenda: In line with recommendations made by the Engineering and Construction Industry Training Board (ECITB), the consortium is optimally positioned to help create and attract well-rounded hydrogen expertise in the UK. The consortium will encourage a pro-active attitude towards collaboration, improve work efficiencies through digitisation and work with key Governmental bodies to retain and develop the comprehensive skills required to develop low-carbon projects- skills the UK could export in the future.
As no previous examples of commercial-scale ammonia to green hydrogen projects yet exist in the UK, it is difficult to clearly define the cost-competitiveness versus other public funding opportunities available to HM Government. However, the consortium is confident in the unique qualities of the project and will ensure it offers excellent taxpayer value for money.

Criterion 5: Project delivery

To complete this section please upload a completed Gantt chart (or Outline Project plan) and Key Work Packages with your application. Key Work Package document not to exceed 6 pages. Max upload size per file - 10MB Max number of files - 2

- File: Tyseley Ammonia Project- Gantt Chart.xlsx - Download
- File: Key Work Packages.pdf - Download

In the text box below, applicants are expected to: Explain how the project team, if involved in multiple Hydrogen Supply 2 applications will ensure they have sufficient capacity to deliver multiple projects. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 5a – 15%) (Maximum 500 words)

The roles of any of the consortium partners within other projects applying for either Stream 1 or 2 of this competition, in so far as they are successful, have been configured to ensure all required resources are not overcommitted.
This has been straight-forwardly addressed by each consortium partner considering the current and foreseen pipeline opportunities and the resources that has already been committed to such efforts. To provide further mitigation:
• Finances for this project and any other projects seeking funding have been compared by the relevant consortium partner against the total number of days allocated to the personnel involved.

• The eventuality of overstretched resource commitments has been considered as part of the Risk Register document, with appropriate mitigations offered.

To complete this section on Project Team please upload a completed CV package and Organogram here. Max upload size per file - 20MB Max number of files - 2

- File: Appendix E Delivery Structure & Organogram.pdf - Download
- File: Appendix F CV Pack.pdf - Download

In the text box below: The applicant should present their proposed governance arrangements between the partners to ensure effective project delivery The applicant should list any external parties responsible for delivering goods or services worth more than 10% of the total project value and explain how they will ensure that these parts of the project do not give rise to delays in the delivery of the project. The applicant should provide details of the relevant skills, qualifications and experience of main project team members, including descriptions and evidence of previous relevant work carried out. Include brief details of relevant team member previous projects, including the date, location, client and project size. Applicants who wish to support their response with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these as part of the Referenced Figures single attachment (max. 20MB allowance provided) in the Further Information section of this application form. Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within the Referenced Figures single attachment will not be assessed. (Weighting for Criterion 5b – 10%) (Maximum 3,000 words)

A high-level view of the project delivery structure, organogram and key personnel CV's is provided in Appendix E and Appendix F respectively.

Either during or before the agreement of the SBRI contract, both Heads of Terms followed by a Collaboration Agreement will have agreed amongst the consortium parties to articulate and support delivery of their respective obligations of the project, in compliance with the terms of the SBRI contract and underpinning BEIS terms and conditions. IP provisions will be handled via a multi-party IP Interface Agreement, facilitating delivery of activities and information exchange between the consortium partners, ITM Motive, and any other party that may be engaged in connection with the project. Subcontractor Agreements will be devised on terms no less onerous than provisions of the SBRI contract and Collaboration Agreement, ensuring end-to-end accountability, performance, risk management and fairness.

Each consortium partner shall appoint at least one individual to be a member of the Project Board. The Project Board will oversee the delivery of the project and is primarily responsible for strategic oversight, steerage, consortium and BEIS reporting, risk management and ultimate resolution of arising issues. All significant matters relating to the project will be considered by the Project Board and will meet quarterly as a minimum. Linkage of communications between BEIS, the monitoring officer and the consortium will be routed through Gemserv to ensure knowledge continuity, with all consortium members having visibility of forwarded key correspondence. Amongst other remits, the Project Board will review and approve invoices, approve final deliverable to be submitted to BEIS, and agree the various stage-gate progressions at key milestones of the project.

A Technical Committee will be convened on at least a bi-weekly basis to offer a platform for technical discussions on deliverables, coordinate plant design optimisation and interconnections between the HRS and the demonstration plant, and discuss overall interim technical status of the project.

A Stakeholder Engagement Committee will be convened on an ad-hoc basis to plan, coordinate and implement key engagement and knowledge dissemination opportunities for the project as they arise.

In accordance with PRINCE2 methodology, our project management approach will develop and maintain a risk register, which will be reviewed monthly, or at a frequency of your choosing. However, BEIS will be directly informed either by email or during monitoring meetings, as soon as a new risk is identified, and escalation will occur as soon as possible to mitigate delays in addressing any urgent issues.
Gemserv will deliver the project management and integration activities, including the appointment of:
• The Project Director (Clare Jackson) - responsible for overall cohesion of the consortium, chairing meetings of the Project Board, ensuring provisions of the SBRI contract are upheld and managing the relationship with BEIS and the monitoring officer.

• The Project Manager (a Gemserv PMO function) - coordinating, where appropriate to do so, the preparation of progress reports, overall financial administration, implementing decisions of the Project

Board and all remaining monitoring requirements set out by the BEIS, the monitoring officer and the consortium.

Risk Management Processes:
BEIS can be assured that Gemserv's Risk Management Framework and Methodology is based upon the principles of ISO 31000, with executive level accountability. BEIS will be actively involved in our risk management process, with the risk register reviewed at the regular meetings as a specific agenda point. To aid management, identified risks will be presented in a risk map (see below), to provide BEIS with a pictorial view of the key risks and their respective severity. We will actively discuss risks with BEIS to agree the appropriate risk mitigation, ensuring that any solution is as simple as possible, but proportionate to the level of risk associated with the project. Once mapped, BEIS will receive a Risk Treatment Plan, a tool that identifies the controls that are needed to address each of the identified risks. Risk actions will also be included within this process to transfer, accept, reduce, or avoid the risk, following best risk management practice. We will provide a clear and direct escalation point from our Project Manager to the Director of Low Carbon within Gemserv to manage any significant risks and issues as required. This approach will ensure a transparent, effective, and agile working relationship that quickly identifies, manages, and mitigates any risks to the project deliverables.

Quality Assurance Processes:
BEIS can be confident that Gemserv has the appropriate strategies, policies, and systems in place to quality assure and quality control outputs so that all material design, data collection and analysis is of a high standard and excludes errors. Quality is the backbone of our service delivery, demonstrated by our certification to ISO9001:2015 and our Quality Management System (QMS) which is independently reviewed and certified by LRQA. This includes an industry best practice change control process and continuous improvement cycle. As part of our Quality Control (QC) measures, we will agree objectives and consistent assessment measures that can be combined to give a view of the efficiency and success of the project. A quality plan will be developed to support the methodology, which will ensure that no deliverables are released until they have undergone a thorough internal quality check, with further quality reinforcement across the collective procedures on the consortium partners. A Quality Improvement Plan will identify, track, and respond to any complaints or concerns from BEIS, and we will provide an escalation route to a Gemserv Director if BEIS is not satisfied with any response.

To ensure that we are always meeting quality expectations we will ask for feedback on our approach and deliverables at meetings and any feedback will be captured, and actions developed to address concerns or to develop alternative approaches. We will also ensure that feedback from the demonstration activities and engagement with the steering group are integrated into our approach going forward. We will use our 8-week project Health Check meetings to formally review progress, deliverables, and our approach, to ensure that we are meeting the requirements of the project and the quality expectation. Our team (both within Gemserv and the other consortium partners) will ensure that all material design, data collection and analysis is of a high standard and without errors, prior to submitting to BEIS. This approach will be supported by our QMS and by ensuring that a senior member of the project team has an independent review of any deliverables. This will ensure that all requirements have been delivered to BEIS's expectations. All data and spreadsheets will utilise checking formulas and macros to highlight any errors.

We have proven expertise in delivering analysis and insight based upon the Governments Green Book guidance, and we regularly have our work peer reviewed by academics to validate the approach and methodologies used. As such, our standard or work and insight is trusted by both Government and Industry.

Project Team:
The consortium possesses all necessary expertise to successfully meet and exceed the expectations of BEIS in the delivery of this project. The team includes personnel from the following organisations, selected due to both their unique and collective experience in project development, technological development, academic prowess, supply chain excellence, asset construction and delivery performance:

Lead Organisation - Gemserv:
Gemserv is an expert provider of professional services in a world driven by data and technology. They are purpose-driven, providing professional services across multiple sectors including cyber & digital, the public sector, health, energy and low carbon to tackle today's social and environmental challenges. Established in 2002, the business provides a range of consultancy and outsourcing capabilities including market design, governance, digital transformation, cyber and assurance, application support, competition, and stakeholder management services. We are one of the UK's Leading Management Consultants for 2021, recommended by clients and peers, and rated by sectors and services in a special report by the Financial Times. Gemserv has offices in London, Birmingham and Ireland. Gemserv runs the Hydrogen Taskforce which is a cross-industry coalition of leading companies that are at the heart of the UK's energy system, helping the UK achieve net zero carbon by 2050 and to

secure support and investment for hydrogen across its many applications. The team also authored the Hydrogen Taskforce’s introductory report: Hydrogen’s Role in delivering Net Zero.

Partner 1 - H2Site:
H2SITE was created in March 2020 as a deep-tech spin off from TECNALIA and the Technical University of Eindhoven, with ENGIE as its main industrial investor. Our goal is to use our membrane technology to solve the problem of expensive and inefficient hydrogen transport and activate the hydrogen economy. H2SITE produces renewable hydrogen for small and medium consumers for mobility and industry segments. We produce locally, using available resources such as ammonia, biomethanol, DME, biogas or formic acid or hydrogen separation from blended gas streams. To do so, we use our patented technology of advanced membrane reactors. H2SITE builds the membranes, designs the reactors and installs the units onsite, monitoring them remotely.

[This information has been redacted]
[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Partner 3 - Yara:
Yara is the world’s leading fertiliser company and a provider of environmental solutions which help address global challenges and create positive change. Yara grows knowledge to responsibly feed the world and protect the planet. Supporting our vision of a world without hunger and a planet respected, they pursue a strategy of sustainable value growth, promoting climate-friendly crop nutrition and zero-emission energy solutions. Yara’s ambition is focused on growing a climate positive food future that creates value for their customers, shareholders and society at large and delivers a more sustainable food value chain. To achieve their ambition, they have taken the lead in developing digital farming tools for precision farming, and work closely with partners throughout the food value chain to improve the efficiency and sustainability of food production. Through their focus on clean ammonia production, they aim to become a key enabler of the hydrogen economy, driving a green transition of shipping, fertiliser production and other energy intensive industries.

Founded in 1905 to solve the emerging famine in Europe, Yara has established a unique position as the industry’s only global crop nutrition company. They operate an integrated business model with around 17,000 employees and operations in over 60 countries, with a proven track record of strong returns. In 2020, Yara reported revenues of USD 11.6 billion.

Partner 4 - University of Birmingham:
Founded in 1900, the University is one of the leading research-based universities in the United Kingdom; the breadth of research expertise is a distinctive characteristic of the University. The last UK Research Excellence Framework in 2014 confirmed that 87% of the University’s research has global reach, meaning it is recognised internationally in terms of its originality, significance and rigour. Birmingham is 81st in the 2020 QS World University Rankings, cementing our position in the top 100 universities globally and placing us 14th out of the 24 Russell Group universities to feature in the ranking. Examples of current and previous success in relation to this project, bolstering the overall capacity of the project with respect to knowledge dissemination, include:
• The Birmingham Energy Institute (BEI): A cross-college hub within the university, driving technology

innovation and coordinating the thinking required to solve the challenges facing the UK as it seeks to develop sustainable energy solutions in transport, electricity and heat supply. Research, education and global partnerships are at the heart of our vision. By creating technology and guiding policy today we aim to help shape energy solutions of tomorrow in Energy Storage, Nuclear Energy, Hydrogen and Fuel Cells, Transport, Oil and Gas, Bioenergy, Wind Energy, and Materials. The BEI director, Prof Martin Freer, is also director of the Midlands based Energy Research Accelerator (ERA) that combines the expertise of eight universities and the BGS in the field of energy research.

• The Birmingham Centre for Fuel Cell and Hydrogen Research (CFCHR): The University heads the consortium of five UK universities delivering the Centre of Doctoral Training (CDT) in “Fuel Cells and their Fuels” (EP/L006707/1). More than 90 highly trained graduates from the previous DTC and the current CDT have moved on to work in the field with industrial and academic institutions. The CFCHR manages several key research facilities, infrastructure and equipment to carry out work in research for hydrogen production and handling, fuel cell materials and design, testing and characterisation, as well as microscopy and other techniques of post-test analysis. We own four laboratory Tyseley Energy Park:
Partner 5 - Tyseley Energy Park:

Tyseley Energy Park (TEP) is a collaboration of passionate technology innovators, academics, scientists, project developers and proactive public sector bodies. Our intent is simple, challenge the norm and innovate to find solutions that will underpin the transition to low or zero carbon future. TEP’s mission is to transform clean energy innovation in Birmingham and the region by stimulating and demonstrating new technologies and turning them in to fully commercially viable energy systems that contribute to Birmingham’s commitments to reduce CO2 emissions by 2030.

Criterion 5c: Risk Assessment The applicant should provide a detailed risk register to outline the key project risks and risk mitigation techniques for the project (in the interests of thoroughness, we encourage you to think about risks and structure your risk assessment according to whether the risks are, or relate to: technical, legislative/regulatory, environmental, policy, economic, commercial, financial or project management). The risk register should include: Description of risk; cause of risk; risk owner; overall risk rating (probability x impact), mitigation action, and residual risk after mitigation action. Description of any contingency planning. Applicants should attach a risk assessment table to this criterion, which will be assessed. (Weighting for Criterion 5c – 5%) To complete this section please upload a completed Risk Register for Stream 2 here. Max upload size per file - 10MB Max number of files - 1

- File: Risk and Mitigants Register.xlsx - Download

Collaborative Application

Is this a collaborative application? If yes you will be asked to provide contact and organisation details for each partner.

Yes

Partner 1 Contact and Organisation Details

Contact Details

[This information has been redacted]

Title [redacted]

Name

Position

Email

Mobile Number

Organisation Website www.h2site.eu

Organisation Name

Hydrogen Onsite S.L.

The registered address of the Partner Organisation

Address Line 1 Parque Científico y Tecnológico de Bizkaia

Address Line 2 Edificio 204 – Laida Bidea

Address Line 3 -

Town/City Zamudio

Postcode/Zip Code 48170

Country

Spain

Organisation Type

Private Company

What is the size of the organisation?

Micro Enterprise <10 employees

Number of employees (including directors)

6

Company Registration Number

B95955316

Turnover Amount (in most recent annual accounts) Please include the currency of the amount in your response.
[redacted]
[redacted]

Balance Sheet Date (total assets net of depreciation)
* 31/10/2020

Is the Organisation able to recover VAT?
Yes

Organisation Maturity
1-5 years

How is the organisation currently funded? (Choose all that apply)

	No Funding	Founders (including bank loans)	Friends and Family	Public Sector Grants	Angel Investment	Venture Capital	Private Equity	Stock Market Flotation
	X			X				

Does the organisation have a parent company? (If yes you will be asked to provide details)
No

Additional Partner

Do you need to add an additional partner?
Yes

Partner 2 Contact and Organisation Details

[This information has been redacted]
[redacted]

[This information has been redacted]

[This information has been redacted]

[This information has been redacted]

[redacted]

Additional Partner

Do you need to add an additional partner?
Yes

Partner 3 Contact and Organisation Details

Contact Details

[This information has been redacted]

Title	[redacted]
Name	
Position	
Email	
Mobile Number	
Organisation Website	www.yara.co.uk

Organisation Name
Yara UK Limited

The registered address of the Partner Organisation

Address Line 1	Harvest House
Address Line 2	Europarc
Address Line 3	-
Town/City	Grimsby
Postcode/ Zip Code	DN37 9TZ

County (If Applicable)
Lincolnshire

UK Region (If Applicable)
East Midlands

Country
United Kingdom

Organisation Type
Private Company

What is the size of the organisation?
Medium Enterprise <250 employees

Number of employees (including directors)
240

Company Registration Number
03818176

Turnover Amount (in most recent annual accounts) Please include the currency of the amount in your response.
[redacted]

Turnover Date (in most recent annual accounts)
* 31/12/2020

Balance Sheet Total (total assets net of depreciation) Please include the currency of the amount in your response.
[redacted]

Balance Sheet Date (total assets net of depreciation)
* 31/12/2020

Is the Organisation able to recover VAT?

Yes

Organisation Maturity

>10 years

How is the organisation currently funded? (Choose all that apply)

	No Funding	Founders (including bank loans)	Friends and Family	Public Sector Grants	Angel Investment	Venture Capital	Private Equity	Stock Market Flotation
								X

Does the organisation have a parent company? (If yes you will be asked to provide details)

Yes

Parent Company Details (for Partner Organisation)

Parent Company Details

Organisation Name	Yara International ASA
Address Line 1	Drammensveien 131
Address Line 2	-
Address Line 3	-
Town/City	Oslo
Postcode/ Zip Code	0277

Country

Norway

Number of employees (including directors)

16,800

Company Registration Number

986228608

Turnover Amount (in most recent annual accounts) Please include the currency of the amount in your response.
[redacted]

Turnover Date (in most recent annual accounts)
* 31/12/2020

Balance Sheet Total (total assets net of depreciation) Please include the currency of the amount in your response.
[redacted]

Balance Sheet Date (total assets net of depreciation)
* 31/12/2020

Organisation Maturity
>10 years

Additional Partner

Do you need to add additional partners?
Yes

Additional Information

The answer to the following question will only be taken into account once the application has been fully assessed to ensure projects are not double funded. Have you applied, or are you planning to apply, for any other government funding for this project?
No

Programme Performance Indicators and Benefits

How would you describe the nature of your innovation project?
Product Development

State how many FTE jobs could be retained in your organisation as a result of participation in this project? (enter a number)

2

State how many FTE jobs could be created in your organisation as a result of participation in this project? (enter a number)

1

What is the number of Partner Organisations supported to deliver the project? (enter a number)

5

Will the project be conducting consumer trials?

No

If yes how many consumers do you expect to participate?

0

Technology Readiness Level at Project Start

	1	2	3	4	5	6	7	8	9
						X			

Expected Technology Readiness Level at Project Close

	1	2	3	4	5	6	7	8	9
								X	

What do you think are the current market barriers to the commercial exploitation of your innovation? Please select all that apply.

Accessing export markets

Accessing UK based markets/customers

Capital intensive demonstration phases

Lack of clarity on Government policy

Lack of industry standards

The Low Carbon Hydrogen Supply 2 Competition will aim to realise the following benefits. Please select which benefits your innovation could potentially contribute to. This is not a scored section.

	Yes	No
Supply Chain Development Help support the growth of 'clean growth' supply chain companies in key technology and engineering sectors.	X	
Export Opportunities Support development of domestic and export markets. Multiple countries are developing hydrogen strategies, which have low carbon hydrogen production targets of multiple GWs. A recent update to the Energy Innovation Needs Assessment (EINA) estimates that by 2050 an active UK hydrogen economy could generate a GVA of £11.7bn and support 100,000 jobs from both domestic and export markets. Without support for innovation projects the hydrogen economy is unlikely to achieve this market share.	X	
Policy Insights Provide insight into costs, performance and what is required to remove technology and market barriers to deploying hydrogen supply solutions.	X	
Spillover Benefits Result in knowledge spillovers, where discoveries made from advancing your innovation could enable developments in other sectors. The projects could also provide wider benefits supporting the development of a hydrogen economy.	X	
Green Jobs Increase number of jobs working on 'building back better' in the UK.	X	
Carbon Savings Increase carbon savings through improved efficiencies, greater capture rates or through enabling greater applicability for hydrogen to decarbonise the energy system.	X	
Reduced Costs Increase and de-risk the range of products on the market which could enable greater competition.	X	

Public Description of the Project

The public description of the project should be a brief non-confidential description of the project that BEIS may use in online or printed publications. Please describe the project objectives, key deliverables and the expected project benefits. (Maximum 400 words)

As the UK looks to decarbonise its energy system, we are going to see increasing deployment of large scale intermittent renewable generation located far from end users. The ability to effectively store large quantities of energy under a dispatchable form will be key to delivering the security and flexibility required by the energy system. Green hydrogen produced via electrolysis is a key enabling solution and it is likely that we will increasingly see electrolysers co-located with offshore wind assets. However, the low volumetric density of hydrogen means that it must be either compressed to high pressures, liquefied or transformed into a carrier to be dispatched over long distances.

Ammonia is a carbon-free, dispatchable hydrogen carrier that enables the storage and transportation of large quantities of renewable hydrogen over long distances. It is a primary candidate to deliver a secure supply of renewable hydrogen for stationary, transport or mobile applications in the UK benefiting from its existing infrastructures, ease of storage and well-defined regulation and safety history for over 75 years.

Although ammonia production, handling practices and supply chains are mature and well-established, efficient hydrogen discharge processes from ammonia still need to be developed. More specifically, efficient ammonia cracking technologies able to generate pure hydrogen are still missing despite worldwide efforts to accelerate developments which remain at low maturity level.

The Tyseley Ammonia to Green Hydrogen Project will design, build, commission, and operate the world's largest and most efficient ammonia to hydrogen conversion unit, demonstrating 200kg/day production of transport-grade hydrogen. It will be located at Tyseley Energy Park and co-located alongside an existing refuelling station. The hydrogen will be used to refuel local vehicles including 20 fuel cell buses that have been ordered by Birmingham City Council. The project aims to dramatically improve the efficiency and economics of ammonia cracking, accelerate the development of hydrogen solutions in the UK and position the country at the forefront of an emerging global market.

Further Information

Referenced Figures (will be assessed) The applicant's response must be entered in the text box(es) where provided in the Assessment Criteria section. Applicants who wish to support their responses with figures (e.g. illustrations/PFDs/graphs/charts/schematics) may attach these here as part of the Referenced Figures single attachment (max. 20MB allowance provided). Applicants must clearly label the figures in the attachment and reference the figures in their response within the text box to ensure they are assessed. Any further text submitted within this attachment will not be assessed. To complete this section, you may upload referenced figures here Max upload size per file – 20MB Max number of files – 1

- File: Appendix A References and Figures (S1-S4).pdf - Download

Supporting Information Additional letters of support or other supporting information can also be submitted here before you submit your online application form, where they add background/ supporting information (this could include but not limited to relevant papers, assumptions/ calculations to back up the assertions made in the application) to the application. However, the assessment will be based on the information directly written in the online application; you should not assume that any additional information will be cross-referenced or reviewed as part of the selection process. Applicants may upload up to 4 such attachments (max. 20MB per attachment). Upload further information documents here. Max upload size per file - 20MB Max number of files - 4

- File: BEIS_Additional_Project_Partner_Contact_and_Organisation_Details.xlsx - Download
- File: Letters of Support - Combined.pdf - Download
- File: HS420_-_Ecuity_-_Ammonia_to_Green_Hydrogen.pdf - Download

Declaration Forms

To complete your application, you must download, complete and sign where relevant and upload the following documents using the 'choose file' option below. Statement of non-collusion Form of Tender Conflict of Interest form Standard Selection Questionnaire Code of Practice GDPR Assurance Questionnaire Prompt Payment If convenient you can use e-signature to sign the documents. Max upload size per file - 5MB Max number of files - 7

- File: Declaration 1- Gemserv.pdf - Download
- File: Declaration 2- H2SITE.pdf - Download
- [redacted]
- File: Declaration 4- Yara.pdf - Download
- File: Declaration 5- University of Birmingham.pdf - Download
- File: Declaration 6- TEP (1).pdf - Download
- File: Declaration 1- Gemserv.pdf - Download

Application Form Checklist

As well as the completion of this Application Form please check that, if required, you have provided the following information.

	Yes	No
Organogram	X	
CV package	X	
Stream 2 Gantt Chart or Outline Project Plan	X	
Stream 2 Key Work Packages	X	
Stream 2 Risk Register	X	
Project Cost Breakdown / Finance Form	X	
Declarations	X	
Attached supporting documentation ***Clearly Referenced***	X	

Signatory Page

Enter details below

Name of Organisation	Gemserv Limited
Signature ***Please insert name***	[redacted]
Position in Organisation	[redacted]
Date (DD/MM/YYYY)	27/08/2021

Do you give BEIS permission to contact you/your organisation in relation to your application and to provide updates on its progress. We may also share with you further details on the Low Carbon Hydrogen Supply 2 competition when available? Consent is required for the application to be submitted.
Yes