Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.

NIA Project Registration and PEA Document

Date of Submission

Dec 2021

Project Reference Number

NIA_NGGT0183

Project Registration

Project Title

Inhibition of Hydrogen Embrittlement Effects in Pipeline Steels

Project Reference Number

NIA_NGGT0183

Project Licensee(s)

National Gas Transmission PLC

Project Start

December 2021

Project Duration

2 years and 7 months

Nominated Project Contact(s)

Lloyd Mitchell, Box.GT.Innovation@nationalgrid.com

Project Budget

£664,873.33

Summary

Oxygen has been shown in several studies to almost eliminate the effect of hydrogen has on pipeline steels. Whilst there is strong evidence available for certain steel grades and operation conditions, these are not universally applicable for operation on the National Transmission System (NTS). To ensure we have sufficient levels of confidence for NTS pipelines, we must gather experimental evidence for NTS specific materials and operating conditions (X52-X80 @ 40-85bar). This study will evaluate the impact on tensile strength, fracture and fatigue properties in hydrogen with 0, 100, 250, 500 and 1000ppm oxygen.

Preceding Projects

NIA_NGGT0139 - Hydrogen in the NTS – foundation research and project roadmap

Third Party Collaborators

ROSEN

Nominated Contact Email Address(es)

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Problem Being Solved

The National Transmission System (NTS) is comprised primarily of carbon steel pipelines with varying steel grades, material compositions and dimensions. As the case for repurposing the UK gas system to transport hydrogen becomes stronger, it is important to understand the effect which hydrogen has on pipeline materials and what measures can be taken to reduce overall risk. Hydrogen is known to ‘embrittle’ steel pipelines and this effect has become one of the main concerns for repurposing the system as a whole.

Hydrogen embrittlement is a metal's loss of ductility and reduction of load bearing capability due to the absorption of hydrogen atoms or molecules by the metal. The result of hydrogen embrittlement is that the fracture toughness and fatigue life of the pipeline are reduced which increases the risk from 3rd party damage and frequent pressure cycling. Unmitigated, this could necessitate a 'downrating' of the pipeline to reduce the overall risk, thus reducing the operating capacity of the pipeline.

Oxygen has been shown in several studies to almost eliminate the effect of hydrogen has on pipeline steels. Whilst there is strong evidence available for certain steel grades and operation conditions, this is not universally applicable for operation on the NTS. To ensure we have sufficient level of confidence for operating NTS pipelines in hydrogen service, we must gather experimental evidence for NTS specific materials and operating conditions (X52-X80 @ 40-85bar). This study will evaluate the impact of hydrogen on pipeline material properties (fracture toughness and fatigue crack growth rate), on both parent metal and welds, at varying oxygen concentrations between 0 and 1000ppm. This information will feed into our overall assessment of pipeline risk in hydrogen service.

Method(s)

The research element of the project will be split into 3 main phases: Functional requirements, concept development and research delivery. The method for this project will be a combination of desktop studies and laboratory based testing.

The initial proposal is to conduct 54 tests in total (18 in air for baseline characterisation, 36 in hydrogen), however this may change as a result of Phases 1 and 2 of the project. This would include KIH, Fatigue Crack Growth Rate and Rising Load Fracture Toughness tests at 100 barg in varying oxygen concentrations across the base metal, girth weld HAZ and girth weld metal.

Measurement Quality Statement

The laboratory will be accredited to ISO 17025, which means mandates procedures in place to ensure reliability. All tests will, where possible and required by the design of experiments, be performed in accordance with recognised international standards (e.g. CSA CHMC1, ASTM E1820 for fracture toughness or ASTM E1681 for KIH testing). Testing will be performed by experienced laboratory personnel, and all test results will be reviewed by suitably qualified engineers before being reported.

Data Quality Statement

The project will ensure that data used is of sufficient quality to deliver project objectives by the individuals within the project team, both from National Grid Gas Transmission and the 3rd party supplier on the project. The relevant data and background information will be stored for future access within the National Grid Innovation Sharepoint site.

Scope

The scope of this project will be to fully understand the impact of oxygen on the embrittlement of pipeline steels exposed to hydrogen.

Phase 1 will review all publicly available data on the topic and use this information to identify gaps and ultimately develop the final test plan. This will cover available research findings as well as test methodologies. Once the literature review is complete, a functional requirements document will be created to capture the findings.

Phase 2 will use the findings of Phase 1 to develop a test rig and test programme proposals to fulfill the functional requirements of the project. The proposed options will be discussed with National Grid and the confirmed test rig design and test programme will be finalised.

Phase 3 of the project will conduct laboratory-based tests on pipeline samples at varying pressures, oxygen concentrations and loading conditions. The samples will come from pipelines which have been in service transporting natural gas and are therefore representative of NTS pipelines. The tests will be conducted in a manner which is as close as possible to tests which were conducted for the 'Roadmap to FutureGrid' NIA project to ensure that the results are comparable.

Phase 4 will ensure that NIA governance requirements are followed, and that all activity through the project is logged and disseminated to the energy industry.

The benefit of this project will ultimately be the proof needed that there are mitigations available for hydrogen embrittlement in the steel pipelines that National Grid Gas Transmission own. With this knowledge the challenge of embrittlement can be managed and the existing NTS can be utilised to transport a blend of natural gas and hydrogen up to 100% hydrogen and prevent the need for expensive replacement of large sections of transmission pipelines.

In scope

- Effect on fracture toughness, fatigue life

- Pipeline steels (X52, X60, X80)
- Effect of oxygen inclusion

Out of scope

- Other pipeline steel grades and materials
- Other material tests such as elongation and tensile strength (these could be considered as follow on work depending on the findings of this work and the relevance of the impact of hydrogen)
- Permeation rates

Objective(s)

To determine the extent to which hydrogen embrittlement effects can be mitigated with the addition of small quantities of oxygen into the gas mix. This includes:

· Characterising the scale of the effects

· Comparing the effects across different steel grades

· Comparing the effects across different pipe components

· Comparing the effects across different oxygen concentrations

This evidence gathered should ultimately feed into a recommendation as to whether this is a viable mitigation method for hydrogen embrittlement effects and what further work would be required to facilitate its use on the NTS.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

Due to the nature of the National Transmission System and position within the gas industry this project will affect all consumers in the same way and will not have an increased impact on consumers in vulnerable situations.

Success Criteria

· Test programme developed which covers the required breadth of test parameters based on National Transmission System requirements and available literature

· Test programme complete including fracture toughness and fatigue life testing

· Testing complete using qualified methodologies

· Generalised conclusions determined for oxygen effect on NTS pipelines

· Go/No-go recommendation for further study of oxygen as a hydrogen embrittlement inhibitor for the NTS

Project Partners and External Funding

Following a competitive tender process Rosen have been initially chosen as the primary delivery partner for the project.

No external funding has been sought.

Potential for New Learning

The potential of oxygen to act as an inhibitor to hydrogen embrittlement effects has been well studied through the chemical industry. This research covers a number of different material types and operating parameters but does not well represent those of the NTS. This project will assess the degree to which oxygen can inhibit embrittlement effects specifically on NTS materials and operating conditions. Many combinations of parameters will be used to develop generalised rules which can be used to assess the wider scope of the technique as a risk mitigation method.

This project will develop the following findings:

· The scale of the effect of oxygen as a mitigating element for hydrogen embrittlement

· For which materials the effect is most favourable

· What the differences are between the effects on base metal, HAZ and girth welds

· What the optimum oxygen concentration is to inhibit embrittlement effects

The findings of the project will be disseminated through FutureGrid stakeholder events and through the NSIB (Network Safety and Impacts Board) as part of the Hydrogen Grid R&D programme.

Scale of Project

The scale of this project allows it to cover a wider variety of NTS parameters and operating conditions. This is required to generate generalised findings which can be used to determine the potential economic benefits of using this technique vs other risk mitigation measures.

This is also a more cost effective way of undertaking research than assessing each combination of parameters separately which would be required if smaller research projects were undertaken.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

The desktop-based elements of this project will be undertaken at Rosen's offices in Newcastle-Upon-Tyne in the UK. The laboratory-based elements of this project will be undertaken at Rosen's newly developed hydrogen test facility in Lingen, Germany.

Revenue Allowed for the RIIO Settlement

Not applicable to this R&D project

Indicative Total NIA Project Expenditure

£664,873.33

Project Eligibility Assessment Part 1

There are slightly differing requirements for RIIO-1 and RIIO-2 NIA projects. This is noted in each case, with the requirement numbers listed for both where they differ (shown as RIIO-2 / RIIO-1).

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations (Please complete sections 3.1.1 and 3.1.2 for RIIO-2 projects only)

Please answer **at least one** of the following:

How the Project has the potential to facilitate the energy system transition:

Hydrogen embrittlement effects are a known issue for high pressure hydrogen transportation through steel pipelines and therefore research into potential mitigations for this will be key to providing the evidence base for how the National Transmission System (NTS) is utilised in the energy system transition of the future. Preventing the need to replace large sections of the NTS will facilitate the adoption of hydrogen in the transmission network and remove the need for expensive and time-consuming construction activities for new pipelines.

How the Project has potential to benefit consumer in vulnerable situations:

N/A

Requirement 2 / 2b

Has the potential to deliver net benefits to consumers

Project must have the potential to deliver a Solution that delivers a net benefit to consumers of the Gas Transporter and/or Electricity Transmission or Electricity Distribution licensee, as the context requires. This could include delivering a Solution at a lower cost than the most efficient Method currently in use on the GB Gas Transportation System, the Gas Transporter's and/or Electricity Transmission or Electricity Distribution licensee's network, or wider benefits, such as social or environmental.

Please provide an estimate of the saving if the Problem is solved (RIIO-1 projects only)

N/A RIIO-1 Question

Please provide a calculation of the expected benefits the Solution

N/A as this is a research project.

Please provide an estimate of how replicable the Method is across GB

The results of this study can be applied to the National Transmission System (NTS) across the UK and as the pipe samples are representative of NTS assets the results will be replicable across the UK. The findings of this project will also be directly applicable to the operation of Local Transmission System (LTS) pipelines in all distribution network regions.

Please provide an outline of the costs of rolling out the Method across GB.

N/A

Requirement 3 / 1

Involve Research, Development or Demonstration

A RIIO-1 NIA Project must have the potential to have a Direct Impact on a Network Licensee's network or the operations of the System Operator and involve the Research, Development, or Demonstration of at least one of the following (please tick which applies):

☐ A specific piece of new (i.e. unproven in GB, or where a method has been trialled outside GB the Network Licensee must justify repeating it as part of a project) equipment (including control and communications system software).

☐ A specific novel arrangement or application of existing licensee equipment (including control and/or communications systems and/or software)

☐ A specific novel operational practice directly related to the operation of the Network Licensees system

☐ A specific novel commercial arrangement

RIIO-2 Projects

☐ A specific piece of new equipment (including monitoring, control and communications systems and software)

☐ A specific piece of new technology (including analysis and modelling systems or software), in relation to which the Method is unproven

☑ A new methodology (including the identification of specific new procedures or techniques used to identify, select, process, and analyse information)

☐ A specific novel arrangement or application of existing gas transportation, electricity transmission or electricity distribution equipment, technology or methodology

☐ A specific novel operational practice directly related to the operation of the GB Gas Transportation System, electricity transmission or electricity distribution

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

Please explain how the learning that will be generated could be used by the relevant Network Licensees

Although National Grid are the only gas transmission company in the UK, the gas distribution networks also operate a local transmission network (LTS) which is a lower pressure than the NTS but is comprised of similar steel pipelines. Therefore, the results of this project will be of significant interest to those who manage the LTS and are looking for the impacts of hydrogen embrittlement on their assets.

Or, please describe what specific challenge identified in the Network Licensee's innovation strategy that is being addressed by the project (RIIO-1 only)

N/A RIIO-1 Question

Is the default IPR position being applied?

☑ Yes

Project Eligibility Assessment Part 2

Not lead to unnecessary duplication

A Project must not lead to unnecessary duplication of any other Project, including but not limited to IFI, LCNF, NIA, NIC or SIF projects already registered, being carried out or completed.

Please demonstrate below that no unnecessary duplication will occur as a result of the Project.

Research into hydrogen embrittlement and possible methods for the inhibition of this has not been carried out on behalf of the UK gas networks to date. Phase 1 of this project will summarise the work completed to date form other industries and from Transmission System Owners (TSOs) around the world to ensure that no duplication occurs. The project will be focusing on the assets that National Grid Gas Transmission own and operate and therefore it is unlikely the exact proposed test plan will have been completed elsewhere.

If applicable, justify why you are undertaking a Project similar to those being carried out by any other Network Licensees.

N/A

Additional Governance And Document Upload

Please identify why the project is innovative and has not been tried before

This project is innovative as the use of oxygen to inhibit hydrogen embrittlement has not been investigated on the scale of a gas transmission network before. As hydrogen has not been allowed in the transmission network above a very low limit before this work into preventing the effects of embrittlement is considered innovative.

The findings of this project could be used to develop low cost solutions to mitigate the effects of hydrogen embrittlement which could reduce the overall cost of repurposing the transmission system.

Relevant Foreground IPR

Foreground IPR for this project will consist of completed summary reports for Phase 1, a test plan for Phase 2 and the complete test results on NTS representative assets in Phase 3.

Data Access Details

Any data generated as a direct result of this project will be available upon request. Details of the origins of pipe material samples may be redacted. Where data is sensitive this will be de-sensitised as required to enable the use within the project to support the successful outputs and limited to the internal partners. We will document any reasons for de-sensitising data and publish a de-sensitised version incorporating the minimum number of changes. The project will adhere to the data sharing policy as stated in 2.13-2.16 of the RIIO-2

NIA Governance Document - https://www.ofgem.gov.uk/publications-and-updates/riio-2-nia-governance-document and our own Data Sharing Policy - https://www.nationalgrid.com/uk/gas-transmission/insight-and-innovation/transmission-innovation

Please identify why the Network Licensees will not fund the project as apart of it's business and usual activities

As the gas networks in the UK are not permitted to transport any level of hydrogen above the low levels allowed under the current gas regulations, research into hydrogen and therefore this project on hydrogen embrittlement is not considered business as usual for National Grid Gas Transmission.

Please identify why the project can only be undertaken with the support of the NIA, including reference to the specific risks(e.g. commercial, technical, operational or regulatory) associated with the project

As this research relates to hydrogen and hydrogen embrittlement it is not considered business as usual, therefore National Grid Gas Transmission require the support of the NIA mechanism to fund the research into potential future challenges facing the NTS. The low TRL of this project favours the use of NIA funding as gas separation is not currently carried out on the gas transmission network today. The technical, commercial and operational risks within the project mean that NIA is the best option to support this project.

This project has been approved by a senior member of staff

☑ Yes