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

Aug 2022

Project Reference Number

NIA_NGGT0189

Project Registration

Project Title

HyNTS Defect Fatigue Behaviour

Project Reference Number

NIA_NGGT0189

Project Licensee(s)

National Gas Transmission PLC

Project Start

September 2022

Project Duration

3 years and 7 months

Nominated Project Contact(s)

Robert Best Box.GT.Innovation@nationalgrid.com

Project Budget

£107,500.00

Summary

The proposed project addresses the call topic area of 'low-carbon energy carrier roles in accelerating decarbonisaton pathways' by characterising the condition of legacy gas (methane) pipeline steels after service exposure. Existing hydrogen embrittlement relationships do not properly consider the effect of steel pedigree on degradation. This research will use the results of detailed characterisation to fully document steel microstructure and rigorously track hydrogen interaction with specific features. The results will be directly relevant to assessing the suitability of the current network for hydrogen gas transport. Moreover, the learnings will inform the design and manufacture of future systems. Support involving the supply of suitable legacy specimens has been obtained from National Grid and EPRI will provide review and input on methods used and aid dissemination of findings.

Nominated Contact Email Address(es)

Box.GT.Innovation@nationalgrid.com

Problem Being Solved

Hydrogen (H2) has the potential to become one of the world's most valuable green energy vectors to reduce the use of fossil fuels in the energy, transport and heating sectors, which together contribute to more than 70% of the UK CO2 emissions. The UK has an extensive network of natural gas pipelines. Hydrogen produced through clean pathways can be injected into natural gas pipelines, and the resulting blends can be used to generate heat and power with lower emissions than using natural gas alone. Blend limits depend on the design and condition of current pipeline materials, of pipeline infrastructure equipment, and of applications that utilise natural gas.

In this challenging scenario, the PhD student working on this project will assess the effect of hydrogen on the fatigue behaviour of metallic materials (i.e., steel, cast iron and brass) containing defects of different size and shape. This PhD project's aim is to deploy high-added-value technological and scientific knowledge that allows Linear Elastic Fracture Mechanics, notch mechanics, finite

element modelling, and advanced fatigue assessment techniques to be amalgamated together to effectively quantify fatigue damage in defected metallic components exposed to a mix of natural gas and hydrogen.

Method(s)

The aim of this PhD research project is to investigate and model the effect of hydrogen on the fatigue behaviour of steel, cast iron and brass when these metallic materials are weakened by defects of different size and shape.

This will be achieved by running a comprehensive experimental investigation involving hydrogen-soaked specimens that contain artificially manufactured defects. In parallel, a complex, multi-physics body of knowledge will be assembled to lay the foundations for a novel scientific paradigm that will give rise to a transformative way of assessing fatigue damage in metallic components working in hydrogenous environment.

The specimens being used to implement the present project will contain artificial defects manufactured by drilling superficial holes having diameter and depth ranging between 0.05 mm and 2 mm.

The specimens will be soaked in hydrogen gas at pressures of 10 bar for up to 9 months by using custom-build pressure vessels manufactured by Gilwood (Fabricators) Company Ltd that are rated up to a maximum pressure of 90 bar.

Force controlled fatigue results will be generated by testing as-machined and hydrogen-soaked specimens under a load ratio (R=smin/smax) equal to 0.1. This will allow the PhD student to investigate the fatigue behaviour of the tested metallic materials by considering the combined effect of defects, hydrogen and superimposed static stresses (mean stress effect in fatigue).

The experimental results being generated according to the above testing protocol will be used to assess and quantify the accuracy and reliability of an advanced structural health monitoring technique that will be developed and implemented by the PhD student as a part of his/her research project. This technique will be developed by combining Linear Elastic Fracture Mechanics, notch mechanics, finite element modelling, and advanced fatigue assessment knowledge. The unique features of the disruptive approach being formulated and validated via this PhD project will facilitate industrial uptake of the new scientific/technical knowledge being gained (through improved damage tolerance arguments) and its subsequent standardisation.

The outcomes from this PhD project will support National Grid in preparing the UK’s gas grid for a safe switchover from using methane natural gas to zero carbon hydrogen.

Data Quality Statement (DQS): The project will be delivered under the NIA framework in line with the agreed Energy Networks Innovation Process document NGGT internal policies. Data produced as part of this project will be subject to quality assurance to ensure that the information produced with each deliverable is accurate to the best of our knowledge and sources of information are appropriately documented. All deliverables and project outputs will be stored on our internal SharePoint platform ensuring backup and version management. Relevant project documentation and reports will also be made available on the ENA Smarter Networks Portal and dissemination material will be shared with the relevant stakeholders.

Measurement Quality Statement (MQS): The project is rated low in the common assessment framework detailed in the ENIP document after assessing the total project value, the progression through the TRL levels, the number of project delivery partners and the medium level of data assumptions. No additional peer review is required for this project.

Scope

This project covers the combination of empirical and theoretical means of assessing the fatigue performance of pipeline steels and

other NTS assets. Fatigue performance will be assessed with regards to the pipe properties including but not limited to: steel grade, age, wall thickness, presence of defects, pipe type and material properties.

Comparing empirical findings to theoretical models will allow for extrapolation of findings across the asset population which will ultimately contribute to the fitness-for-service assessment to assess pipeline suitability for hydrogen service.

Objective(s)

As noted above, the aim of the research is to assess the fatigue performance of NTS materials under varying conditions and determine the suitability of modelling techniques to predict fatigue performance across all NTS material types.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

The National Transmission System (NTS) is a key UK infrastructure for the transport of Gas to consumers, including those considered vulnerable. In a scenario where hydrogen replaces methane as a household heat source, it is essential the vulnerable are not excluded by virtue of fuel inaccessibility. In cases where vulnerable consumers already utilise gas it is likely that in a net zero future the optimum option is to provide a consistent energy solution. The transition to hydrogen within the NTS provides continuity of access to the vulnerable of hydrogen as a replacement to methane, with ongoing benefits of efficiency and economy of scale within a closely regulated environment. This project supports the transition of the NTS to hydrogen which in turn supports the availability of gas to the vulnerable.

Success Criteria

The following key criteria need to be met for the project to be considered successful:

- Study objectives met to time and cost
- Empirical data gathered
- Models constructed and refined
- Empirical data compared against models
- Report completed and disseminated

Project Partners and External Funding

Sheffield University

Professor Luca Susmel

Luca Susmel studied his undergraduate degree in the Department of Mechanical Engineering at the University of Padova, Italy, and completed his PhD between Padova and Dublin, Ireland.

From 2001 to 2011 he spent at least six months every year lecturing and doing research in the Department of Mechanical and Manufacturing Engineering at Trinity College, Dublin. In 2005, he was appointed Associate Professor in Structural Integrity at the University of Ferrara, Italy. He joined the Sheffield Department of Civil and Structural Engineering in 2011 to continue his research on the fatigue and fracture behaviour of engineering materials, components and structures.

Since 1998 Luca has focussed his attention mainly on problems related to the structural assessment of engineering materials and components. By working both in Italy (University of Padova, University of Ferrara, University of Udine), in Ireland (Trinity College, Dublin) and in the UK (University of Sheffield) he has devised several novel engineering methods suitable for designing components (experiencing stress concentration phenomena of all kinds) against static, dynamic, and fatigue failures. Luca’s modus operandi involves taking a conjoint theoretical and experimental approach to cracking problems and all the design methods he has formalised so far have been fully validated through systematic experimental work. Luca has unique expertise in designing notched and welded components against constant and variable amplitude multiaxial fatigue.

The work done in the above research areas has led to a large number of scientific articles published in international peer-reviewed scientific journals as well as to a book devoted to multiaxial fatigue assessment. His scientific papers have attracted significant interest from the international scientific community, as it is evidenced by his h-index as well as by the total number of citations. He is a member of the Editorial Boards of the two leading international journals in the fatigue and fracture field, namely “International Journal of Fatigue” and “Fatigue & Fracture of Engineering Materials & Structures”. Luca is also the Associate Editor of “Frattura ed Integrità Strutturale: The International Journal of the Italian Group of Fracture” and the Editor-in-Chief of “Theoretical and Applied Fracture Mechanics” (published by Elsevier) which is one the top journals in the fracture mechanics field.

UKRI - EPSRC

The majority of the funding for this project will come from UKRI. Professor Susmel made an application to the UKRI EPSRC Industrial CASE and was confirmed successful in the application in January 2022.

The project has a total funding of £100k and will receive £70k from UKRI with a £30k contribution from National Grid.

Potential for New Learning

The output from this PhD will have direct relevance to National Grid in their conversion of gas pipeline network from carrying methane to carrying hydrogen as the data obtained and the assessment of hydrogen embrittlement susceptibility with be based on their legacy pipeline steels. The PhD characterisation and modelling work will inform National Grid in the suitability of their conversion.

In particular, the study of the effect of defects on fatigue performance will inform asset lifecycle decisions and enable a better understanding of critical defect thresholds.

Scale of Project

The scale of this activity is limited to laboratory testing and fatigue modelling. This project will be carried out by a PhD student, yet to be selected, under the guidance of Professor Luca Susmel. The total project length is approximately 4 years.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL3 Proof of Concept

Geographical Area

The project will be based at the University of Sheffield campus with work undertaken at National Grid sites as required.

Revenue Allowed for the RIIO Settlement

None – Hydrogen network focussed project

Indicative Total NIA Project Expenditure

The project will be part funded by EPSRC, therefore, the total project cost is £100,000 but we will only be utilising £37,500 NIA funding. This is a combination of a £30,000 direct contribution and £7,500 of internal costs.

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:

The project will assess pipeline fatigue performance in hydrogen both in ideal conditions and with defects. This will have significant implications for the parameters used to operate the network.

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

Although this project does not directly affect vulnerable consumers the energy transition may and as such, we must consider the effect of the work we are doing through the NIA funding. The National Transmission System (NTS) is a key UK infrastructure for the transport of Gas to consumers, including those considered vulnerable. In a scenario where hydrogen replaces methane as a household heat source, it is essential the vulnerable are not excluded by virtue of fuel inaccessibility. In cases where vulnerable consumers already utilise gas it is likely that in a net zero future the optimum option is to provide a consistent energy solution. The transition to hydrogen within the NTS provides continuity of access to the vulnerable of hydrogen as a replacement to methane, with ongoing benefits of efficiency and economy of scale within a closely regulated environment. Ensuring robust NTS assets and consistent hydrogen production options will support the transition of the NTS to hydrogen which in turn supports the availability of gas to the vulnerable.

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)

RIIO-1 question N/A

Please provide a calculation of the expected benefits the Solution

This project will increase understanding of how defects react when regularly fatigued in a hydrogen environment. This is a critical point of understanding for the operation of the NTS and will inform defect tolerance specifications and operational practices.

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

This project is focussed on metallic pipeline materials, it will therefore be relevant to any assets that utilise steel of grades X52, X60, X65 and X80.

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

The learning from this project will provide insight into the impact of hydrogen on various metallic material structures, any metallic assets could be impacted by hydrogen and therefore this project could provide valuable insight for any network licensees with metallic assets that could be exposed to hydrogen.

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

RIIO-1 question N/A

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.

Benchmarking and literature reviews will be undertaken before commencing the project work. The team involved are academics with backgrounds in hydrogen material development whom are known as leaders in their field and have access to a wide range of data sources.

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

The fatigue performance of pipelines in hydrogen service is still not well understood. Having generalised models will be highly valuable when assessing the broader network for hydrogen service.

Relevant Foreground IPR

Foreground IPR will consist of understanding of pipeline fatigue performance and fatigue models.

Data Access Details

Closure and technical reports will be made available through the ENA smart networks portal and via university and EPSRC publication. Further data can be shared upon request through the innovation .box - box.GT.innovation@nationalgrid.com

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

Hydrogen development activities are not included in the RIIO-2 final determination, this work is to be managed through the innovation funds and reopeners.

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

Hydrogen has not yet been confirmed as a net zero energy solution for the UK and may not be transported in the NTS. Work must be undertaken to inform decisions on this net zero energy option.

This project has been approved by a senior member of staff

☑ Yes