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

Nov 2021

Project Reference Number

NIA_NGGT0182

Project Registration

Project Title

Multifunctional graphene coatings for pipeline protection

Project Reference Number

NIA_NGGT0182

Project Licensee(s)

National Gas Transmission PLC

Project Start

January 2022

Project Duration

1 year and 4 months

Nominated Project Contact(s)

Corinna Jones, Box.GT.Innovation@nationalgrid.com

Project Budget

£820,000.00

Summary

The project reviews the opportunity of utilising graphene produced as a by product in methane pyrolysis as a pipeline protection coating. There are three aspects to be reviewed in the project: 1) Corrosion protection, 2) Hydrogen embrittlement inhabitation and 3) Pipeline state sensing. Graphene has the ability to both act as a barrier for materials and an integrated sensing system due to its conductivity. National Grid will work with Levidian to determine the extent to which these properties can be utilised on the NTS.

Third Party Collaborators

Levidian Nanosytems Limited

Cranfield University

Nominated Contact Email Address(es)

Box.GT.Innovation@nationalgrid.com

Problem Being Solved

As gas grids seek to increase the amount of hydrogen which is transported, the grid infrastructure must be able to mitigate the risk of hydrogen embrittlement and also to reduce corrosion. This project seeks to define how graphene can be used to enable greater hydrogen transportation in gas grids and simultaneously to reduce corrosion and to potentially allow more effective monitor of pipe conditioning.

The use of Levidian graphene presents an opportunity to also find a use for graphene which is produced as a by-product of hydrogen production through a methane plasma process. This could allow gas grids to take both the hydrogen from this process and the graphene for use across the network. Graphene has several use cases across many industries but has not yet been investigated in

relation to the national transmission system.

This lab-based study will determine the opportunity of graphene in combination with NTS materials and systems and develop protocol for a phase 2 large scale testing at National Grid.

Method(s)

The project will utilise graphene produced through Levidian's plasma process on material coupons in lab scale testing to determine its ability to prevent corrosion and hydrogen embrittlement. The project will evaluate the impact of coating thickness and application method on the structure of the resulting coating morphology down to the molecular level control and evaluate the protection provided. Due to the unique morphology of the graphene, its direct use or implementation into another material can be accomplished at the high level of surface finish. The graphene is expected to serve two roles, the barrier for hydrogen (as well as hydrogen sulphide/carbon dioxide/water) diffusion and also enhancement of the wear properties of the coatings.

In parallel, a development of smart coatings will be carried out for the internal/external surfaces of pipes to rely on the conductive properties of graphene and the ability to form 3D networks for sensing capabilities to detect failure in the main pipeline material . This will be undertaken on lab scale samples of NTS materials, but calculation will be carried out for the extended opportunity of 7000km of NTS pipeline. Corrosion protection systems already installed on NTS pipelines provide a current to the pipeline and help prevent corrosion. Using the smart graphene coatings, the cracking and other failure modes could be identified with little additional equipment with superior special resolution.

Measurement Quality Statement:The measurement approach used to meet Data Quality objectives will be through the identification of high calibre project partners whom are experts in their given field and the use of real data and materials from National Grid sites. In this instance the project will be limited to lab testing, science and technology development from TRL3 to TRL5 and therefore will combine knowledge from other industry applications with lab scale testing to inform new insights into the use of Graphene on NTS applications. The lab tests will be carried out by the Cranfield University, relying on high quality material processing environment, standardisation, coating technology optimisation and scale up strategies required for the phase 2 of large testing.

Data Quality Statement:The project will ensure that data used is of sufficient quality to deliver project objectives through the development of a robust testing plan developed through the design of experiments process, taking into account all key variables and managing them through the testing. The relevant data and background information will be stored for future access within the National Grid Innovation Sharepoint site.

Scope

The project will be split into 4 work packages:

1) Requirements and use case definition (Duration – 2 months)
Work Package lead – Levidian and National Grid

The work package will define in detail:

- Technical requirements: the graphene type and quality will be identified reflecting the desired use in the project with well-defined performance levels discussed and agreed
- Commercial requirements: the simulation of the volume and cost element will be taken into account to ensure the viability of the technology for large scale deployment
- Implementation considerations: the deployment approach, including deposition technology will be evaluated and considered
- Cross industry benchmarking: assessment of the technology will be carried out to consider its application to other sectors across the industry
- Testing plan development: the phase 1 coupon testing will be carried our leading to the selection of specific formulations and testing protocols. In phase 2, a large-scale evaluation of the technology at the National Grid facilities, will be discussed and proposed for subsequent implementation

2) Materials testing for corrosion and hydrogen diffusion resistance (Duration – 10 months)
Work Package lead – Levidian and Cranfield University

A dedicated Post Doctoral Research Assistant (PDRA) with appropriate background and PhD level researcher will be appointed to undertake this work. The work is based on the development of the coating formulation suitable for the deposition on selected pipeline material coupons.

- Two approaches will be considered: pure graphene deposition (graphene with graphene glue) and graphene in the matrix formulation (where the matrix will rely on the coating suitable version of epoxy or polyurethane).
- Different concentration of graphene will be established with proper characterisation of rheological properties.
- Wear testing of the coating will be carried out and correlated with the level of graphene used.
- The assessment of the surface adhesion to the pipeline material and optical microscopy characterisation will be used for the quality of deposition.
- Corrosion studies and the passive effect of the coating will be assessed on the pipeline material.
- The accelerated studies will be carried out on coupons involving temperature and moisture to assess the effect on the corrosion resistance.
- Hydrogen permeability studies using inhouse sensing system and specially formulated testing setup will be used to deliver direct outcomes from the project.
- Scale up plans will be developed to enable the second phase of deployment.

Interim reports will be delivered on a monthly basis and quarterly technical meetings at Cranfield.

3) Opportunities for pipeline health monitoring via smart sensing (Duration – 10 months)
Work Package Lead – Levidian and Cranfield University

A dedicated PDR with appropriate background and PhD level researcher will be appointed to undertake this work.

The work will rely on the development of graphene-based coating formulation with the engineered formation of 3D conductive networks. This structure will be capable of measuring electrical responses as well as any dielectric changes coupled to the corrosive or other microstructural changes in the pipe material.

Implementation of graphene into a suitable polymeric material will be part of the initial phase of this development following by the electrical testing. Environmental accelerated treatments will be used to generate signals and subsequent data processing.

Signal collection is critical for proper understanding of the smart coating performance. Furthermore, the use and development of suitable connections will offer the level of integration required on the pipeline material. Signal processing with appropriate AI algorithm will be required for the coating integration and use. Mechanical damage detection will be used as alternative to the environmental chambers, for controlled performance.

Interim reports will be delivered on monthly basis and quarterly technical meetings at Cranfield.

Data analytics and reporting (Duration - 2 months)
Work Package Lead - Levidian
- Technical report of all work carried out
- Progress report in March & June 2022
- Closure report at the close of the project

Objective(s)

Determine the opportunity to utilise a waste product in the pyrolysis process of methane to hydrogen (graphene) to improve network capability through:

- Corrosion protection
- Hydrogen embrittlement protection
- Enhancement of inner liner wear resistance

Pipeline health monitoring

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
- Materials testing complete to determine graphene capability on a range of NTS materials
- Testing of the capability for graphene to identify material failures and determination of the data required to identify the failures from the current changes
- Scale up protocols for phase 2 testing on large NTS assets
- Business case and strategy for graphene application to the NTS

Project Partners and External Funding

Gas Network – National Grid Gas PLC

Technical Lead - Levidian

Academic Partner - Cranfield University

Potential for New Learning

Graphene is being explored by many industries due to its unique properties but has yet to be investigated for the protection of the NTS assets. Work done by National Grid Electricity Transmission on the roadmap for advanced 2D materials and NGN on its use in heating systems has been reviewed and considered prior to scoping this work. The new learning created through this project is:

- Test data to prove graphene capability on decommissioned NTS asset material and new material
- Determination of the opportunity for using thin graphene coatings for pipeline state sensing
- Understand the hydrogen diffusion under the new graphene morphology
- Enhancing the lifeline of the pipeline networks
- Reducing the complexity of monitoring of the pipe due to the implementation of smart coatings

Scale of Project

This project is a lab scale testing activity that will provide insight into whether there is an opportunity to utilise by-products of hydrogen production as protective elements for the NTS. The learning will be relevant to NTS materials X52, X60, X65 and X70 and will consider the impact on X80. This learning will be transferrable to LTS applications and other assets on both transmission and distribution networks.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

United Kingdom – Warwick, Cambridge and Cranfield

Revenue Allowed for the RIIO Settlement

Not applicable to this R&D project

Indicative Total NIA Project Expenditure

£820,000.00

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 use of methane to produce hydrogen creates carbon that has to be captured. Pyrolysis releases this carbon in a solid format that is easier to capture than CO2 released in steam reformation. In this instance we are looking at a technology that improves the value of that waste carbon into a product that is usable in many scenarios.

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)

N/A RIIO-1 question

Please provide a calculation of the expected benefits the Solution

There will be no direct benefits from this project. The project results could enable the NTS to reduce its cost of corrosion repairs and maintenance, prevent the need for replacement of pipelines due to hydrogen embrittlement and improve safety by improved understanding of pipeline safety.

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, X70 and X80.

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

The cost of rolling out graphene on the network is unknown and further development on the application and commercial model is required, this will be completed through the project period.

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 technology developed in this project will be applicable to the pipeline operator and offer better servicing of the assets. The development of this learning could benefit other networks assets that a susceptible to corrosion or hydrogen embrittlement.

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.

The project will start with full literature review following by a complete report on the prior art before initiation of the relevant work packages. There will be no duplication of activities done as part of this program. The initial literature assessment already indicates that the materials and steps proposed here will be novel.

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 proposed work is moving from TRL3 to TRL5 and involves scientific exploration as well as engineering advancements in coating technology. The successful outcome from this research depends on the unique features of graphene, a high performance 2D material,

which is available on the scale and quality required by the project. We are proposing a systematic approach to the three technical challenges set in the project with coating formulation which has to be developed for the materials used in pipelines operating under certain conditions. The smart coating for sensing will have a number of innovative aspects, including graphene network formulation, elements of data processing and ways of signal collection.

Innovation also lies at the heart of the circular economy benefits of this technology whereby hydrogen can be produced through the process and the graphene by-product can then be applied to the grid infrastructure to enable greater hydrogen adoption.

Relevant Foreground IPR

The results of the tests will create knowledge around the capability of graphene to protect NTS assets but will not create any new systems. Follow on work from this project may then develop systems using graphene to protect the UK assets.

Data Access Details

N/A

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

The graphene opportunity has not been demonstrated and therefore this work is too low a TRL to progress through BAU activities.

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

The proposed work is for the application to gas pipelines. Guidance on the pipeline materials and conditions is required to deliver the desirable technology.

This project has been approved by a senior member of staff

☑ Yes