# NIA Project Registration and PEA Document

## Date of Submission

Jun 2018

## Project Reference Number

NIA_CAD0022

## Project Registration

### Project Title

Hydrogen Grid to Vehicle (HG2V); Network purity for Transport.

### Project Reference Number

NIA_CAD0022

### Project Licensee(s)

Cadent

### Project Start

July 2018

### Project Duration

2 years and 9 months

### Nominated Project Contact(s)

Cadent Innovation Team

### Project Budget

£1,490,500.00

## Summary

This project is aiming to develop a technical demonstration programme proposal that investigates whether the gas network can be re-purposed to deliver transport grade/high purity hydrogen for fuel cell vehicle applications. This includes development of a commercial scale hydrogen purification demonstration (will require a separate funding application) in order to determine whether a cost-effective purification solution can be developed which allows hydrogen to be supplied from the gas grid and used in hydrogen refueling stations for fuel cell vehicles.

## Nominated Contact Email Address(es)

Innovation@cadentgas.com

## Problem Being Solved

The UK urgently needs to find cost-effective and scalable ways to decarbonise energy. The energy sector is pivotal and hydrogen as an energy vector can play a significant role in the transition to a low-carbon economy. Hydrogen can be utilised across the energy supply chain; for use within the gas grid to supply both heating and electricity, and for transportation within fuel cell vehicles (FCEVs). Converting the UK's gas grid to 100% hydrogen, or gradually increasing the level of hydrogen blended with natural gas, creates an opportunity to extract it downstream at the point of use for FCEVs. Depending on the uptake of hydrogen technologies across the UK, this could facilitate a nationwide network, reducing the CAPEX and OPEX required to develop new hydrogen refueling stations (HRS), further stimulating the uptake in FCEVs.

To achieve these objectives, several challenges need to be overcome. The purpose of this project is to investigate four of them including;

I. Identification and characterization of hydrogen contaminants across the supply chain; hydrogen production, storage, transmission and distribution, and to investigate the effect of impurities on fuel cells.
II. Identification and review of technologies that can be used for the separation and/or purification of hydrogen enriched natural gas and

pure hydrogen to meet stringent FCEV purity standards (99.999% purity), including technology development considerations for each.

III. Techno-economic review to determine the potential market size, rate of adoption, and associated technology cost and upscaling challenges for the above technology solutions; combine with (ii) to develop a business case for the development of hydrogen purification and/or separation systems.

IV. Design, build and commission a "first-of-a-kind", off-grid hydrogen impurity simulation rig, replicating real-world conditions to evaluate the impact of contamination on material degradation and fuel cell performance; used later (subsequent project) to develop and validate novel separation and purification techniques.

## Method(s)

FCEVs require hydrogen of significantly higher purity (> 99.9999%) than the hydrogen currently produced by industry for a range of other applications. These stringent purity requirements are based on accepted threshold levels of 14 specified contaminants, ranging from high parts per million (e.g. inert gases) down to low parts per billion (e.g. total sulphur compounds). For the purpose of this PEA, high quality means limiting these contaminants below levels at which fuel cell performance can be impaired. Contaminants can inadvertently be introduced to the hydrogen at various points in the supply chain, which consists of the following stages:-

1. Hydrogen Production – hydrogen can be produced by a range of methods, including Steam Methane Reforming (SMR) and electrolysis of water. These different methods will produce hydrogen of varying quality, i.e. with different contaminants depending on the source of hydrogen and equipment/processing.
2. Hydrogen Storage – large scale hydrogen storage has not been demonstrated in the UK, although prior to the conversion to natural gas in the 1960s it formed the major component of town gas. The method of storage, for instance storing hydrogen in salt caverns, will likely affect the quality of the hydrogen.
3. Hydrogen Transmission/Distribution – hydrogen is distributed around the UK at different pressures, and in pipelines made from a variety of materials ( NB. consideration will be taken for both new and re-purposed gas networks) . The introduction of contaminants in hydrogen arising from the use of these materials requires investigation. Furthermore, high strength steel components can be susceptible to hydrogen embrittlement and this risk needs to be factored into any decision to transition to a hydrogen grid.
4. Hydrogen End-Use Applications – Hydrogen can be used for domestic and commercial heating, using hydrogen boilers, or for transport, within hydrogen FCEVs. The end-use-application will greatly affect the quality of hydrogen required.

To extract hydrogen from the UK gas network for end-use applications, we need to know:-

1. What quality of hydrogen is required for end-use applications? Hydrogen quality is of lower concern for fuel burners than it is for FCEVs.
2. What contaminants are introduced by the various stages of the hydrogen supply chain? This will help suppliers/distributors understand what contaminants need to be removed so as not to affect the performance of fuel burners and FCEVs. This is further complicated by the fact that the UK is investigating two potential scenarios for the gas grid; 100% hydrogen and a hydrogen/natural gas blend, the latter of which will add additional contaminants that will need to be investigated.

NPL is participating in several pioneering research projects in this area under the European Metrology Programme for Innovation and Research (EMPIR) and the Joint Undertaking in Fuel Cells and Hydrogen (FCH-JU). NPL is coordinating the EMPIR Metrology for Hydrogen Vehicles (MetroHyVe) project and leads work packages in the EMPIR Hydrogen and FCH-JU HYDRAITE projects. NPL also sits on the ISO TC 197 standards committee which sets the ISO standard for hydrogen quality for both FCEVs and hydrogen boilers (ISO 14687). Through this role NPL provides information on the quality of hydrogen required for end-use applications to ensure the standard is fit-for-purpose.

Whilst these on-going projects seek to establish more accurate thresholds for existing contaminants in hydrogen when used within FCEVs, a shift to use of hydrogen extracted from the gas grid would open up the possibility of the presence of new contaminants not covered by existing standards. The main focus of this project is to investigate the full range of contaminants introduced by the various stages of the hydrogen supply chain and their impact on end-use applications. We will use information from other projects on the effects of known contaminants and therefore the limiting thresholds for these.

This will be investigated for 100% hydrogen networks and for hydrogen/natural gas blends.

## Scope

This proposal addresses the separation, purification, measurement, control and management challenges associated with taking hydrogen from the grid, and using it to power FCEVs (Hydrogen Grid to Vehicle), with a particular focus on the required purity steps to ensure FCEVs are not damaged by contaminants or poor quality hydrogen. Two scenarios will be considered: 100% hydrogen in the gas grid and hydrogen-enriched natural gas (20 % hydrogen in natural gas).

Key challenges for the project include:
• Understanding the purity of hydrogen in the gas network, for 100% hydrogen and hydrogen-enriched natural gas (20% hydrogen).
• Understanding the purity requirements for fuel cell applications, and limitations set by existing standards

Key challenges for the 100% hydrogen scenario include:
• Measuring purity to identify hydrogen contaminants and their concentration in hydrogen that is generated by different methods. Contaminants can arise based on the generation process used (e.g. SMR without pressure swing adsorption (PSA) and subject to the gas network environment (e.g. cleanliness of piping and infrastructure).
• Impact analysis of odorants on end use applications and proposed purification systems. Similarly to natural gas, hydrogen is odorless therefore to ensure hydrogen gas leaks can be detected an odorant will need to be added. The impact of any odorant on the purification system will be evaluated to understand the potential risk of fuel cell degradation (in vehicle). This aspect will be considered within the project 100% Hydrogen, an NIA project led by SGN, under the work package "Hydrogen Odorant and Leakage Detection", that will be led by NPL. The results of the SGN project will be used as inputs for this project.
• Identifying appropriate purification measures to remove key contaminants. Contaminants will need to be quantified and any subsequent effects on fuel cells investigated; as this will be vital for end-user reassurance of the quality of hydrogen they are receiving.

Key challenges for the hydrogen-enriched natural gas scenario include:-
• Measuring the purity to identify contaminants and their relative fraction for hydrogen-enriched natural gas. Analysis of the effect of contaminants on fuel cell systems according to end user requirements (i.e. ammonia, formaldehyde or formic acid) will be carried out. Contaminants can arise based on the generation process used and subject to the gas network environment (e.g. cleanliness of piping and infrastructure).
• Impact analysis of natural gas odorants on end use applications and potential purification systems. The impact of odorants would need to be evaluated for an understanding as to the effect on any purification system performance. This aspect will be considered within the project 100% Hydrogen; the results of the project will be used as input for this project.
• Identification of gas purification and separation technologies. The enrichment of hydrogen from 20 % to high purity may be realised using various technologies (e.g. membranes). A cost-benefit analysis is required in order to determine the best technical combination for separation and purification.

## Objective(s)

The objective of the project is to determine whether the gas network can be re-purposed to create added value from existing infrastructure. We will investigate the contaminations made by the hydrogen supply chain, in order to determine whether a cost-effective separation/purification system can be developed which allows hydrogen to be taken from the gas grid, either pure hydrogen (100%) or hydrogen-enriched natural gas, and used at hydrogen refueling stations for fuel cell vehicles.

## Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

## Success Criteria

• Develop a detailed understanding as to the contaminants added to hydrogen from various parts of the hydrogen supply chain
• Develop a detailed understanding as to the hydrogen purity requirements for use in FCEVs, especially for new or unknown contaminants and subsequently develop an understanding as to how these contaminants degrade FCEVs.
• Investigate state-of-the-art in separation / purification systems, including costs, requirements and considerations for future development work.
• Carry out a techno-economic analysis to understand the potential gas grid evolution scenarios, and therefore inform as to the most cost-effective purification / separation systems.
• Design, build and commission a hydrogen gas grid simulation with sections for development, trial and validation of cost-effective separation, and separation / purification systems. Use the rig to carry out materials testing on typical grid materials when subject to various contaminants.

## Project Partners and External Funding

Partners include;
• Cadent Gas, National Physical Laboratory, Sustainable Gas Institute, DNV GL, Kiwa

This project will be funded solely by Cadent using the NIA.

## Potential for New Learning

The hydrogen contamination challenges addressed by this project will contribute to the UK's emerging evidence base identifying which

control measures are required/available today to ensure FCEVs are supplied with an acceptable level of hydrogen purity. The study will also identify knowledge gaps which in turn will help inform future research and development opportunities. The results will be used/adopted by a broad range of stakeholders, including hydrogen producers, network operators, vehicle manufactures and technology developers, to improve the performance of low carbon transport solutions. The scope also reflects opportunities identified in a recent hydrogen workshop convened by the Hydrogen SuperHub, a consortium of leading academics and industry participants led by Imperial College and NPL.

## Scale of Project

Future scenarios developed by the Committee on Climate Change (2015), and others, suggest a hydrogen demand for transport in the order of 70 – 80TWh/year by 2050. The infrastructure required will include a significant hydrogen production, distribution and storage network which will leverage re-purposed natural gas pipelines and associated infrastructure. To realise the value associated with this opportunity, understanding and successfully mitigating the hydrogen purity and contamination risk to enable successful refueling of FCEVs will be essential.

The proposed scale of the project reflects the complexity of the hydrogen contamination challenge, and takes into account the skills, resources and capabilities required to complete a thorough investigation of the issues/challenges identified during the scoping phase. In order to avoid costly disruption to existing gas network operations, and to minimize HSE risks, the project will design, build and commission a "first-of-a-kind" lab-scale hydrogen contamination/impurity facilitiy to simulate gas network components and behaviour.

This facility will enable evaluation of the impact of contaminants on material degradation and fuel cell performance at a cost, and levels of disruption, significantly lower than at full-scale.

## Technology Readiness at Start

TRL2 Invention and Research

## Technology Readiness at End

TRL6 Large Scale

## Geographical Area

This study is focused on the UK, and in particular the specific hydrogen contamination characteristics associated with repurposing the UK natural gas network.

## Revenue Allowed for the RIIO Settlement

Not Applicable.

## Indicative Total NIA Project Expenditure

External Cost: £1,005,000
Internal Cost: £350,000
Contingency: £135,500
Total Cost: £1,490,500

# 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:

n/a

### 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)

Realising the benefits associated with fuel cell transport in UK, which represents a future hydrogen demand of circa >70 TWh/year by 2050, is essentially predicated on achieving compliance with the hydrogen purity standard ISO 14687-2. A recent workshop led by the H2FC Super-Gen hub (Jan 2018) demonstrated that there is currently limited understanding of how re-purposing the gas grid (to supply hydrogen) will impact hydrogen purity in particular the performance of FCEVs. This project seeks to address the current deficit in knowledge by identifying the sources of contaminants across the hydrogen supply chain, and investigating their effect on FCEV.

### Please provide a calculation of the expected benefits the Solution

N/A – this is a research project that seeks to determine the likely impact of contamination on future hydrogen transport applications including fuel cells.

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

The project results and outputs are highly replicable and relevant to all UK gas distribution networks. The specific nature and characteristics of UK gas networks will be reflected in the design of the hydrogen grid contaminant test facility. Sampling of contaminants will be conducted with support from a broad range of infrastructure providers ensuring that the study is representative of UK methods and working practice.

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

The cost of rollout will be clearer once the research project concludes. This will also enable the decision to be made as to whether to pursue development of advanced hydrogen separation and purification technologies with suppliers/technology developers/academics. The simulation rig will significantly reduce the front-end development costs for investigating new separation and/or purification technologies under real-life conditions developed using the understanding created through this project.

## 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

This project will consider how gas networks can be configured to transport/supply hydrogen for fuel cell vehicle FCEV applications. Whilst other work in this area considers the impact of hydrogen contamination on domestic appliances, this study will examine how the more arduous FCEVs purity standards can be satisfied given the contamination.

It is envisaged that the above results can be used by other Network Licensees to support their own efforts in leveraging existing gas infrastructure to supply hydrogen transport applications. Outputs will inform other key projects in relation to potential future hydrogen purity limits for UK gas networks. Finally, consideration will be given to presentation of the results to the IGEM Gas Quality Working Group and the ISO Standard TC 197 - ISO working group for hydrogen quality for both FCEVs and hydrogen boilers (ISO 14687).

### 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

☑ Has the Potential to Develop Learning That Can be Applied by all Relevant Network Licensees

### 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.

This is a first of a kind project in respect to understanding the impact of re-purposing the natural gas grid on hydrogen contamination in particular how such contaminants impact upon the future use of FCEV refueled using the re-purposed gas network.

A detailed review of current projects, and a dedicated workshop coordinated by the Hydrogen SuperGen Hub at Imperial College London identified no duplication.

### 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

Bulk hydrogen production and use of the existing natural gas distribution network to supply fuel to hydrogen refueling stations is a novel concept. Understanding and characterizing the source of contaminants associated with hydrogen distribution using existing infrastructure represents a vital gap in current knowledge.

## Relevant Foreground IPR

n/a

## 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

Use of hydrogen in vehicles represents a future/speculative business opportunity for most UK DNO's. The nascent market for hydrogen is not sufficiently well established to support such hydrogen contaminant research. NIA funding is sought to address these uncertainties and to reduce the risks associated with future commerecialisation of hydrogen.

## 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 project requires NIA support to overcome a number of risks. Technical risks include understanding sources of contaminants, material behavior including corrosion, and the impact of contaminant on the FCEV. Commercial risks include the feasibility of procuring, or developing a hydrogen separation and purification solution that is economically viable. The work will also inform future regulation and gas quality standards which do not currently exist.

## This project has been approved by a senior member of staff

☑ Yes