NETWORK INNOVATION COMPETITION

NATIONAL GRID GAS TRANSMISSION

In Line Robotic Inspection of High Pressure Installations

July 2014

Project Code/Version No: NGGTGN02

Gas Network Innovation Competition Full Submission Pro-forma

Section 1: Project Summary

1.1 Project Title: In Line Robotic Inspection of High Pressure Installations

1.2 Funding Licensee: National Grid Gas Plc (Transmission)

1.3 Project Summary:

National Grid Gas Transmission (NGGT) aims to move away from predictive asset type modelling towards condition based monitoring of its critical assets. These assets are ageing and many have already reached the end of their intended asset life.

Partnered with two Small Medium Enterprises (Synthotech and Premtech) which have proven records of success in innovation projects, NGGT is seeking to introduce in line inspection of below ground pipework at high pressure installations (AGIs), in order to determine the true condition of these assets. This will allow for pre-emptive fault detection, more targeted planned interventions to be undertaken, thereby extending the life of assets which remain in good condition and cost optimisation.

There is currently no available technology which can in line inspect below ground pipework on AGIs at pressure above 2Barg. AGIs operate pipework at up to 100Barg. Current methods of inspection for below ground pipework on AGIs involve visual inspection via excavation which is both financially and environmentally expensive. As such it does not regularly take place and reliance on survey techniques to target excavations is favoured. These surveys only provide a partial view of asset condition and can be inaccurate leading to unnecessary excavation to investigate potential problems. Not fully understanding the condition of our assets increases the likelihood of an asset failure at an AGI with resultant environmental and financial cost and customer disruption.

NGGT has a proven history of developing effective in line inspection technology, evidenced through In Line Inspection (ILI) of pipelines via Pipeline Inspection Gauges (PIGs). As such it believes it can develop a robotic in line inspection device which can operate at up to 100Barg. This will allow NGGT to implement an intelligent and proactive asset management strategy, reducing the requirement for inefficient and expensive excavations, extending the life of assets and reducing the likelihood of an asset failure at an AGI thereby improving our national resilience.

1.4 Funding

1.4.1 NIC Funding Request (£k): 5,674.51

1.4.2 Network Licensee Compulsory Contribution (£k): 630.5

1.4.3 Network Licensee Extra Contribution (£k): 0

1.4.4 External Funding - excluding from NIC/LCNF (£k): 0

1.4.5 Total Project cost (£k): 6,305.01

Project Code/Version No:
NGGTGN02

Gas Network Innovation Competition Full Submission Pro-forma

Section 1: Project Summary continued

1.5 Cross industry ventures: If your Project is one part of a wider cross industry venture please complete the following section. A cross industry venture consists of two or more Projects which are interlinked with one Project requesting funding from the Gas Network Innovation Competition (NIC) and the other Project(s) applying for funding from the Electricity NIC and/or Low Carbon Networks (LCN) Fund.

1.5.1 Funding requested from the LCN Fund or Electricity NIC (£k, please state which other competition):

1.5.2 Please confirm if the Gas NIC Project could proceed in absence of funding being awarded for the LCN Fund or Electricity NIC Project:

☐ **YES – the Project would proceed in the absence of funding for the interlinked Project**

☐ **NO – the Project would not proceed in the absence of funding for the interlinked Project**

1.6 List of Project Partners, External Funders and Project Supporters:

Premtech Ltd
Unit 5 Charter Point Way
Ashby Park
Ashby de la Zouch
Leicestershire
LE65 1NF

Synthotech Limited
B2b Crimple Court
Hornbeam Square North
Hornbeam Park
Harrogate
HG2 8PB

1.7 Timescale

1.7.1 Project Start Date: 5 Jan 15	**1.7.2 Project End Date:** 26 Nov 18

1.8 Project Manager Contact Details

1.8.1 Contact Name & Job Title: Tony Jackson Engineering Manager – Pipelines & AGIs	**1.8.3 Contact Address:** Gas Transmission Asset Management National Grid House Warwick Technology Park Gallows Hill CV34 6DA
1.8.2 Email & Telephone Number: XXXXXXXXXXXXX@nationalgrid.com XXXXX XXXXXXX	

Gas Network Innovation Competition Full Submission Pro-forma

Section 2: Project Description

This section should be between 8 and 10 pages.

2.1

a. **Aims & Objectives:**

Traditionally the onshore pipeline industry has only been able to in line inspect high pressure pipelines using PIGs. In line inspection of pipelines provides the most accurate and reliable information on the condition of buried pipelines, other inspection methods external to the pipeline have a number of limitations. Currently, below ground pipework on AGIs however cannot currently be in line inspected because of a number of engineering challenges associated with complex pipework geometries, lack of access and retrieval points and flow factors.

The project has 4 key objectives:

- To accurately and reliably determine the condition of high pressure below ground pipework at AGIs using an internal inspection robot.

- To generate a proactive, rather than reactive, risk based approach to the management and maintenance of aging assets, based on the knowledge of the actual condition of pipework.

- Minimise the occurence of annual unnecessary excavations and eradicate premature replacement of assets reducing significant carbon emissions and generating cost savings of circa £58m over 20 years.

- Minimise the likelihood of asset failure through proactive asset management, thereby significantly reducing the risk of a high pressure gas release into the atmosphere and the consequential financial, environmental and reputational impact.

b. **The Problem which needs to be resolved:**

NGGT has an obligation to operate and maintain our network in a safe and reliable manner, to do this we must understand the condition of our assets. We believe there is significant scope to improve our asset management strategy for below ground pipework at AGIs which contains 350kms of unpiggable pipework.

Pipelines are asset managed through, amongst other activities, in line inspection i.e. inserting a device within the pipeline. Currently we in line inspect over 7,000 kms (99.5%) of our National Transmission System (NTS) using PIGs. However, PIGs are not suitable for pipework on AGIs and some other pipeline sections, for a number of reasons including, most notably:

- AGIs have complicated geometries associated with both above ground and buried pipework e.g. tight bends and changing pipe diameters which PIGs cannot negotiate.

In addition:

- PIGs are dependent on the flow speed of the gas for drive, and the gas flow through an AGI can be highly variable (either faster or slower than a PIG requires).

- There is a lack of appropriate launch and receive facilities.

We have over 200 unpiggable AGIs on the NTS, including terminals, compressor sites, multi-junctions and offtakes, which are critical to the operation of the network and the security of the country's gas supply. Our asset management strategy on these involves external visual inspection of above ground assets. Below ground pipework however is currently not so easily inspected. We rely upon the original design safety features i.e. thick walled pipe, external coatings and cathodic protection combined with Close Interval Protection Surveys (CIPS), which are used to ensure that the cathodic protection is working effectively, and finally asset life modelling.

If it is suspected that below ground pipework is compromised, we currently excavate the relevant area to expose the pipework for more detailed inspection thereafter potentially undertaking remedial action. Both operations are performed at fully or slightly reduced pressure. Depending on the circumstances this may require the full isolation of the site pipework as well as its complete vent and purge. This procedure is both costly and environmentally challenging and inevitably risks disruption to the operation of the network and consequently disruption to customers.

Importantly such excavation and disruption may be entirely unnecessary as CIPS and other current techniques are by no means infallible. CIPS simply provides complex data which upon human interpretation can indicate whether the cathodic protection of pipeline is in all probability working effectively or *may* be compromised. Importantly the data can be affected by a number of external factors which can highlight an alleged issue with the cathodic protection where there is in fact none.

Additionally reliance on whether cathodic protection is working effectively fails to account for other ways in which assets could be compromised. Corrosion due to external interference (rock damage for example) or on areas where CIPS cannot collate data (i.e. disbondment) are concerning and expose the network to much risk. Network licensees currently do not have equipment or methods to tackle this and as the age of our assets continues to grow, reaching the end of their original design life (40 years +) this shortfall in capability becomes evermore more worrying. As such, the ability to understand asset condition, particularly below ground pipework at AGIs, is vitally important to enable us to develop effective risk based maintenance and asset replacement strategies and prevent potential major disruptions to the national gas network and environmental damage.

c. **The Method being trialled to solve the problem:**

An in line inspection robot designed to provide an accurate assessment of the current condition of the below ground pipework at high pressure gas installations.

d. **The Trials being undertaken to test the method works:**

The in line inspection robot will undergo a series of offline and online trials to ensure it can effectively solve the current asset management challenge of inspecting below ground pipework at high pressure installations. The robot may undergo trials at Eakring but a bespoke trial pipe configuration will also be built by a third party contractor in order to trial the robot within a high pressure environment. Thereafter it will be trialled on complex and simple live sites such as Bacton Gas Terminal and Lupton respectively.

e. **The solution that will be enabled by solving the problem:**

There are three clear solutions which will be enabled by solving the current challenge NGGT has with its asset management strategy for below ground pipework at high pressure installations.

1) Repair and maintenance of critical assets will be better targeted allowing for a reduction in unnecessary excavations.

2) The life of assets will be extended due to an accurate understanding of condition ensuring that premature replacement will be prevented.

3) The likelihood of a high pressure release will be significantly reduced.

2.2 **Technical description of the project:**

IN SCOPE	
• Design, development and construction of a remotely controlled robot able to take and supply visual and physical information from within live, high pressure (up to 100 barg) pipework.	• Design, development and construction of a modular trials facility, to fit within a 25m x 25m footprint, to allow off-site, but under pressure, field trials of the robot within an inert medium such as compressed air or nitrogen.
• Design, development and construction of a portable 'launch and retrieval' device for the robot.	• Creation of drawings to show the expected extent of the live trials.
• Survey of three UK sites selected for the live trials to allow creation of representative digital 3D models.	• Live trials and demonstration of the robot on typical large, medium and small AGIs on the UK NTS.
• Formal Process Safety Assessments to cover all trials.	• Production of specification documents. •
• Production of detailed design documents covering the launch and retrieval device.	• Production of detail design documents covering development of the robot.
• Production of procedure documents.	
OUT OF SCOPE	
• Trials on sites other than those selected.	• The robot shall not be deployed in pipework carrying anything other than high pressure Natural Gas.
• Robotic inspection of anything other than specified AGI pipework.	• Unplanned trials e.g. emergency.

Project Description continued

Fig 1: Innovative Robot within pipework.

Overview of Project: To design and develop a remotely operable robot that can be inserted into live, high pressure (up to 100barg), mild steel pipework systems to undertake both visual and physical inspection of the otherwise inaccessible buried sections of the system. The robot will be self-powered, highly articulate and able to move at will throughout the pipework.

A detailed Project Management Plan can be found at Appendix D. It lays out the in line robotic inspection of AGIs project in **five clear stages**, of which, each have a dedicated time allocation and budget.

The project stages are explained in summary below:

Stage 1: 3D Prototype Stage (Alpha)

Stage 1 of the design process involves the development of 3D computational models by Synthotech in accordance with the initial design scope and specifications. These 3D computational models will then be printed using a technique known as ‘Rapid Prototyping’ that uses powders and plastic print 3D space models, the models will then be fitted with off the shelf electrical, electronic, and pneumatics / hydraulics to provide limited functionality. These space models are used to test first principles of concept design and will be developed further during stage 2 (Beta). Key outputs from this stage are detailed below:

- Critical Path Timeline – Identifying all key tasks and their inter-relationships.
- Manufacture / Print and Assembly of 3D Prototypes.
- Testing and Development Reports.
- Review environmental, statutory and regulatory requirements.
- Stage 1 Technical Report (including Financial Review).

Simultaneously, Premtech will design and develop the insertion and extraction device. Its design must be specific to the robot proposed by Synthotech, therefore a close working relationship between Premtech and Synthotech will be required. It will be designed and appraised in accordance with relevant NGGT design codes.

Site surveys and laser scan profiling will be carried out to support the data taken from as-built drawing records of each site. Production of 3D digital models of the chosen live trial sites will be produced from this data for numerous uses later in the project (example in the diagram below).

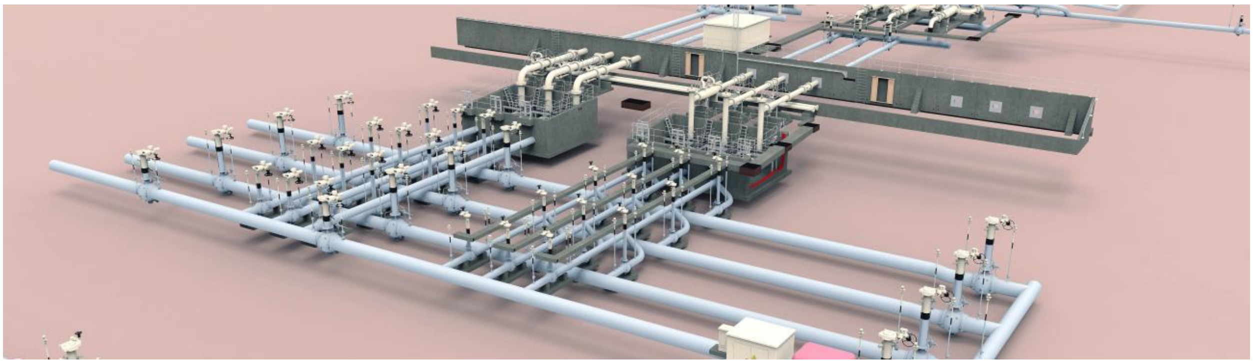


Fig 2: 3D Modelling

Stage 2: Bench Test Prototype Stage (Beta)

Once Stage 1 (3D Prototype Stage) has been completed, the next phase will be the Bench Test Prototype Stage (Beta). At the end of this stage the project should be very close to reaching the desired outcomes. This phase will see the development of the 3D space models with conversion to metallic and plastic components as well as the addition of bespoke electronic (circuits and motors) drive mechanisms (gear boxes), software development, and power. Key outputs from this stage are detailed below:

- Implement Design and Specification changes from Stage 1 to Stage 2.
- Manufacture and Assembly Bench Test Prototype.
- Laboratory / Workstation Testing.
- Stage 3 Strategy and Testing Matrix Plan: Offline and Online Testing – this will ensure statistically sound and sufficiently robust approach is taken during Stage 3.
- Design Review and Design for Manufacture Analysis (DFM).
- Stage 2 Bench Test Demonstration.
- Stage 2 Technical Report.

Using the 3D trial site models, insertion and extraction point selection will take place early in this stage to allow site design changes to be carried out and reported. The selection of the insertion and extraction points will also allow robot route selection and determination, the extent of which will be limited by its design parameters and illustrated on a 'go no-go' style drawing (example in the diagram overleaf).

A large scale test assembly for field trials will be developed and designed in accordance with NGGT standards and specifications to allow the robot to be tested through pipework with geometry similar to that it will encounter on the sites whilst in a pressurised environment, it may also be trialled at Eakring.

Project Description continued

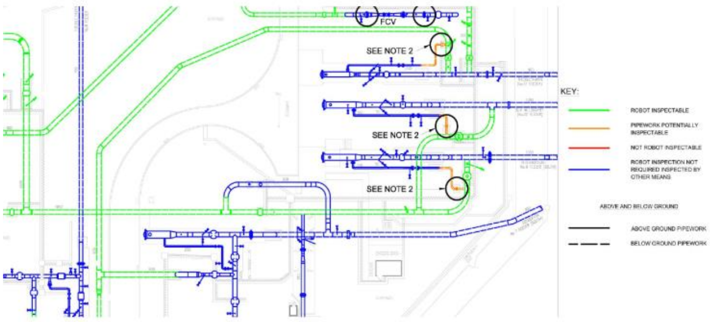


Fig 3: Colour coded routes

A wide variety of pipe diameters are found on AGIs; anything between 50mm- 1200mm is likely, this will require a robot that is able to adapt to suit changes in diameter. It is understood that it may not be feasible to produce a single design that is capable of expanding and contracting to cope with the full range of pipe sizes used on an AGI, as such, it is anticipated that an initial robot will be developed which will cover the range 750mm to 900mm diameters, a size range which covers a large portion of the AGIs on the NTS.

Obstacles such as process drains (pictured below) found throughout AGI pipework will be identified and either navigated through, modified or avoided.

Fig 4: Process Drain

The insertion and extraction device will also require much planning and development. It must operate within pipework whilst it is pressurised. It is proposed that the insertion and retrieval operation also be carried out whilst the pipework remains at high pressure. This will be achieved with the use of a device similar in nature to a pigtrap. Unlike a PIG operation however where the PIG is launched at one end of a pipeline and received at the opposite end, it is anticipated that the robot will be launched and retrieved from the same point. The insertion and retrieval device is conceptually shown in the picture below but will likely undergo much testing and adjusting prior to the field trial stage.

Fig 5: Insertion and extraction device

Following connection of the launcher and satisfactory isolation (double block and bleed) downstream of the connection point, the robot will be loaded through the door. The

Project Description continued

launcher will then be pressurised by interconnecting small bore pipework until the pressure equals that within the pipework. The ball valves, used to achieve the block, will then be opened to allow the robot to enter the pipework under its own power.

A key requirement for this project is that the robot can operate within pipework whilst pressurised thereby eliminating the need for outage periods or specific isolations during deployment. Although the majority of the AGIs on the NTS operate at ≤85 barg, they are constructed predominantly of Class 600 components, which have a Maximum Operating Pressure (MOP) of 100 barg; as such, the MOP of the robot has been set to match this figure.

AGIs are positioned all across the UK on feeders (pipelines) supplying gas both directly to industry and Gas Distribution Networks (GDNs), as such the flow rates vary considerably between AGIs. Those near to high demand consumers are likely to experience greater flow rates than elsewhere. Clearly the body of the robot will be positioned directly in the gas flow and will create a degree of drag, manifesting itself as a (generally) axial load that must be reacted by whatever restraining devices it is furnished with. The robot shall be able to withstand the flow rates typically found in pipework near to high demand consumers. It will be advantageous to choose the time at which a robot is deployed to coincide with times of lower demand, such as during summer months.

The construction of the field trial assembly will be completed during this stage (similar to that illustrated in the diagram below) as well as any modifications to live trial sites in order to allow the trials to take place.

Using knowledge gained during the site design changes in Stage 2 future site design requirements will be identified and reported. All of the preceding work at this point will be used to determine the inspection carbon footprint.

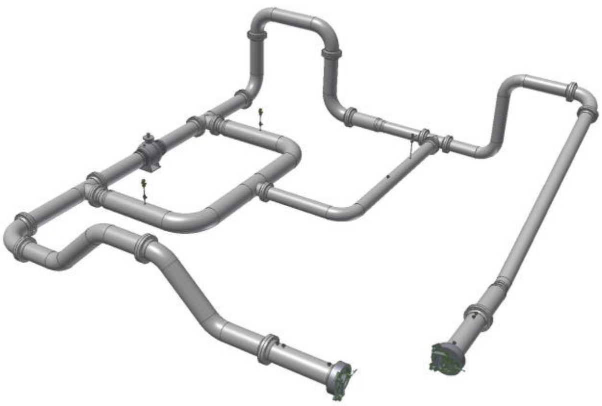


Fig 6: Field trial assembly

At the end of Stage 2, analysis of measurement and inspection data obtained during the field trials will take place. It is proposed that condition assessment algorithms will be developed to allow high confidence estimations to be made on the condition of pipework that is unable to be accessed by the robot. Data will also be used to establish a site condition index and condition assessment criteria.

Stage 3: Offline / Online Testing (Gamma)

Project Description continued

Stage 3 relates to the detailed process of testing the design and functionality of the robot and is essentially broken into specific stages:

1. Offline Testing – To be carried out on bespoke AGI simulation test rig.
2. Online Testing – To be carried out on an AGI under 'Live Gas' conditions.

Offline Testing: This will be carried out on the specifically developed simulation rig, to provide a safe testing facility to validate the robot's ability to carry out tasks and determine improvement in design related to function or performance prior to commencing any 'live' trials.

Online Testing: This will be carried out under live gas conditions on selected NGGT AGIs during summer outage. The purpose of these trials will be to validate the design and performance of the robot in the 'real world' and allow for refinement of designs and processes for inspection of unpiggable sections of the AGI.

During Stage 2 a testing matrix will have been determined to ensure that the offline and online testing produces statistically sound and sufficiently robust results.
During both the online and offline testing, key project stakeholders (NGGT, NIC Panel, OFGEM) will be invited to witness testing, to allow for knowledge dissemination and for learning to be shared.

The key outputs for Stage 3 are detailed below:

- Implement Design and Specification changes from Stage 2 to Stage 3.
- Manufacture and Assembly Offline Prototype.
- Offline Testing Report.
- Online Testing Report.
- Offline Testing Report (repeated to resolve any issues from online testing).
- Stage 3 Stakeholder Demonstrations & Engagement.
- Process Ownership / Future Operators.
- Stage 3 Technical Report / Testing Matrix.

A more detailed review of the approach to field trials is provided in section 2.3 of this submission.

Stage 4: Data and Product Validation

Project Description continued

Stage 4 is focused on the development of the robotic platform into a commercially viable solution and the validation of data generated during the complex testing during stage 3. The data validation will be carried out independently of Synthotech and Premtech by Pipeline Integrity Engineers (PIE) in order to ensure third party assurance.

Stage 4 may require further online field trials on an AGI, but at this stage this will be purely to refine data capture results to allow the creation of algorithms to within an agreed standard deviation so that data collected can provide an accurate indication of the asset condition.

From a product validation perspective all online tests will be used as an opportunity to train the agreed process owner, which will be National Grid's Pipeline Maintenance Centre (PMC).

Key outputs of Stage 4 are defined below:

- Validation of offline & online data.
- Further online testing at AGI.
- Development of asset health algorithms.
- Design review & modifications to provide a pre-commercial robotic solution.
- Process owner training.
- Stage 4 technical report.
- Development of mobilisation plan.

Stage 5: Commercialisation and Mobilisation

Stage 5 relates purely to the activities required to provide a pre-commercialised robotic solution to the agreed end user, this involves the dissemination of all data required for operation, calibration and maintenance.
The project will provide one pre-commercialised robotic platform and one launch and retrieval system. It will be pre-commercialised as it will not be a new robot, it will simply be derived from the previous stages of the development process. All design specifications for a commercialised robot and associated launch and retrieval system will be completed at this stage and as such this will be an approved product allowing further purchases of commercialised systems by both NGGT and other UK Gas network licensees.

A suite of specifications will be written to cover installation design, insertion and extraction device, insertion and extraction procedure, robot design and the online and offline testing trials.

2.3 **Description of design trials**

During the design trials which will take place in stage 3 there will be a series of offline and online tests. The results will be recorded on a table much like the one below at fig 7.

Project Description continued

Task	Distance				Direction of travel		Obstacle Negotiation				
Operation	0m to 50m	50m to 100m	100m to 150m	200m	Forward	Backwards	Number of Bends	Pig traps	Vertical Sections	T-Bends	Pipe Diameter Change
Propulsion 24"	X	-	-	-	x	-	-	-	-	-	-
	X	-	-	-	-	X	-	-	-	-	-
	-	X	-	-	X	X	-	-	-	-	-
	-	-	X	-	X	X	-	-	-	-	-
	-	-	-	X	X	X	-	-	-	-	-
	X	-	-	-	X	X	1	-	-	-	-
	X	-	-	-	X	X	2	-	-	-	-
	X	-	-	-	X	X	3	-	-	-	-
	X	-	-	-	X	X	4	-	-	-	-

Fig 7: Example Testing Matrix

Offline Testing: This will be carried out on the specifically developed simulation rig, to provide a safe testing facility to validate the robot's ability to carry out tasks and determine improvement in design related to function or performance prior to commencing any live trials. The simulation rig will reduce the overall development timelines significantly as the development of the robotic platform is not reliant on access to the AGI. This simulation rig will allow planning and preparation for live trials, launch and retrieval, simulation of routes, obstacles, change in pipe diameters and simulated faults. This simulation rig will act as a training facility for all parties involved in the trials, including disaster and emergency drills. It is a vitally important component within the risk management plan. In addition this may be supplemented by further tests at Eakring, National Grid.

Online Testing: This will be carried out under live gas conditions on selected NGGT AGIs during summer outage. The purpose of these trials will be to validate the design and performance of the robot in the 'real world' and allow for refinement of designs and process for inspection of unpiggable sections of the AGI. Due to the nature and time constraints of online testing, further offline testing will be carried out to ensure that any concerns or improvements identified during initial online testing are addressed prior to commencement of Stage 4. During both the online and offline testing, key project stakeholders (NG, NIC Panel, OFGEM) will be invited to witness testing, to allow for learning to be shared and knowledge dissemination. During the final phase of offline testing there will also be an opportunity to share this learning with the other UK gas asset owners and operators, academic partners and affiliated technical organisations (IGEM, PIG, IMECHE). On completion of the offline and online testing phase demonstrable data will have been collected to provide statistically sound results, and at this stage a review of the carbon footprint savings achieved will be reviewed this may allow for the identification of potential opportunities to increase this carbon footprint saving e.g. use of technology on high pressure (>69 Barg) gas distribution pipelines and other gas assets.

2.4 **Changes since Initial Screening Process**

As part of a thorough risk analysis it has now been deemed important to build a bespoke pipe configuration (simulation test rig) upon which the robotic inspection device will undergo offline trials prior to trials on live gas sites. This will cost an additional £XXk. It was also decided that a contractor (Pipeline Integrity Engineers) should provide third party assurance, their costs are £XXk and have been added to the costs in appendix A.

Gas Network Innovation Competition Full Submission Pro-forma

Section 3: Project Business Case

This section should be between 3 and 6 pages.

3.1 **Background**

The business case for this project is based upon four critical aims and objectives which will improve the asset management of below ground pipework at AGIs:

- To accurately and reliably determine the condition of high pressure below ground pipework at AGIs using an internal inspection robot.

- To generate a proactive, rather than reactive, risk based approach to the management and maintenance of aging assets, based on the knowledge of the actual condition of pipework.

- Minimise the occurrence of annual unnecessary excavations and eradicate premature replacement of assets reducing significant carbon emissions and XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX.

- Minimise the likelihood of asset failure through proactive asset management, thereby significantly reducing the risk of a high pressure gas release into the atmosphere and the consequential financial, environmental and reputational impacts.

3.2 **NGGT exisiting inspection procedures and future requirement** (5-10 year business plan inc how this project links to it)

There are a number of inspection policies currently used at NGGT. Of note exisiting policy dictates that the following must be achieved:

- Pipeline/pipework must be protected against corrosion.
- Pipeline/pipework must be protected against external interference.
- Pipeline/pipework should not be adversely influenced by ground movement or natural or man-made causes (i.e. geological faults or mining).
- Modification, maintenance and repair of the pipeline/pipework are carried out in such a way that its integrity is preserved.
- The pipeline/pipework is not adversely affected by fatigue.

AGIs typically operate at prescribed stress levels categorised as %SMYS (specified minimum yield strength). The flow chart beow is an example of current inspection and survey philosophy for pipework up to 30% SMYS.

Project Business Case continued

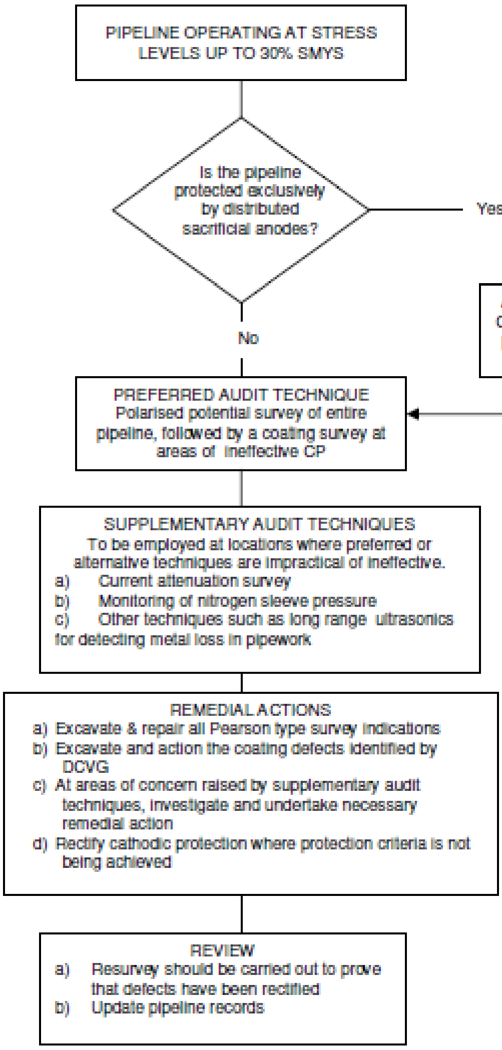


Fig 8: Maintenance Flowchart

Using the flowchart above it is clear to see that the high pressure in line robotic inspection proposal could significantly improve upon our current asset management approach. Over the short to long term this innovative equipment will provide more robust data rather than continued reliance on the survey techniques which are currently the only inspection tools prior to actual excavation.

It would be highly beneficial to have in line inspection to complement existing inspection methods in order to make sure that the condition of an asset is understood and consequentially effectively maintained. NGGT does this through PIG inspection of pipelines which as highlighted earlier cannot take place at over 200 high pressure installations. This in line inspection robot will bridge a current capability gap, which if addressed, could reduce the likelihood of an asset failure and the consequential financial, environmental and reputational damage.

3.3 **Customer benefits**.

NGGT has a variety of direct customers, which notably, are wholesale customers rather than UK domestic consumers. That said we do have an impact on UK end consumers and as such a reduction in the cost of our operations as well as a lower risk of unplanned disruption, will ultimately benefit them.

Benefits both financial and environmental are clear and compelling and examined below:

a. **Environmental**. The project is expected to deliver environmental benefits to customers in three main areas which are listed below and explained in detailed within section 4.1:

- Minimisation of potential asset failures leading to the release of environmentally damaging high pressure gas.
- Avoidance of unnecessary excavations for inspection.
- Avoidance of premature asset replacement.

b. **Financial**

If the project is successful it will reduce the costs associated with maintaining and replacing below ground pipework on AGIs. The current assets are approaching the end of their design life requiring more surveys, excavations and ultimately replacement; activities which could be disruptive to all customers.

- **Planned work**

  As previously described, when CIPS surveys are undertaken of below ground pipework on an AGI they provide relatively limited data, which is used to determine whether a further more detailed examination is required. In such cases, where a further examination is required this leads to excavating the potential problem area. A current example of this is at XXXXXXXXX XXXXXXXXXXXXX, where the CIPS survey identified a potential problem with the cathodic protection. To understand the impact of this National Grid has sanctioned the excavation of the problem area at a cost of £XXk. To undertake the excavation a number of activities need to be undertaken e.g.:

  - Ground Penetrating Radar survey to establish accurate location.
  - Isolation (under Non Routine Operation), depressurisation and excavation to a depth of 600mm below the problem area including provision of safe access and egress and removal of any ground water to allow for inspection.
  - Design additional temporary supports, if required.
  - Visual examination by a Competent Inspector.
  - Completion of any minor remedial works as identified during inspection.
  - If the inspection demonstrates that major remedial works are necessary, development of a capital project to replace affected area.

In undertaking an excavation there are also a number of risks to be managed:

- There is a risk the isolation may not be achieved due to isolation valves not fully sealing. If this occurs then the valve would be repaired or replaced which would require a full station and/ or pipeline outage due to the location of the necessary additional isolation valves.

- There is a risk of adverse weather conditions leading to build up of ground water. If this occurs dewatering will be required.

- Personnel risk, working within an excavation and undertaking operations on high pressure natural gas equipment.

If the above issue had occurred at a customer offtake or at more critical part of the network it may have been necessary to "turn-off" a customer e.g. a power station as at the lower pressure we may have been unable to meet the customer's required operating conditions. In such cases, we have to pay a constraint cost which we would agree with the customer before the work commenced. Typically the cost for constraining off a power station ranges from XXXXXXXXXXXXXXXXXXXXXXXXX.

If this project is successful, we would avoid the cost of an unnecessary excavation as we would be able to determine the condition of the below ground pipework through inspection by the robot. This would then allow us to determine the appropriate course of action before commencing any site works, reducing the depressurised time. In addition as described above, we would avoid the risk of a full station outage, the weather and also minimise the personnel risk.

At present we undertake only a limited number of excavations at AGIs, but we anticipate this increasing with the ageing of the asset. Our assumption is that by the start of RIIO-T2, we will undertake 15 excavations per annum of which half could be avoided, assuming an average cost per excavation, including the constraint cost, of XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX.

- **Replacement**

  Undertaking work based on a CIPS surveys, allows us to maintain the integrity of the network, but largely on a reactive basis. The inspection robot will enable us to be more proactive, through better understanding of the condition of our assets. As stated above, many of our AGIs are past their original design life. Depending on how these assets deteriorate this could lead to a bow wave of replacement activity within RIIO-T2. The ability of NGGT to manage a replacement programme, in terms of both resources and outages, will be dependent on having the best information available. The inspection robot would allow us to understand the condition of each site and develop a prioritisation matrix to ensure replacement expenditure is appropriately targeted and timed. In addition if problems are identified earlier enough minor remedial actions may be able to be undertaken, which prolong the life of the asset.

  In terms of XXXXXXXXXXXXXXX XXXXXXXXXXXXX of better information this is very difficult, but it would allow informed decisions to be made and information to be shared with stakeholders. XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXX XXXXXXXXXXXXXXXXXXXX XXXXXXXXX XXXXXXXXXXXXXX

Project Business Case continued

XXXXXXXX XXXXXXXXXX XXXXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXXXXXXXX. If this project is successful the information that it provides will allow us and our stakeholders to better determine where we XXXX XXXXXXXXXXX XX XXXXXXXXXX for our investment in terms of XXXXXXXXX XXXXXX. Our assumption is that consumers will avoid the cost of one major replacement project in both XXXXXXX XXXXXXX XXXXXXXXXXXXXX.

- **Unplanned Event**

  There is a risk that an unplanned event i.e. pipe break occurs at one of our AGIs. The inspection robot, with a programme of regular inspections, should reduce the likelihood of such an event. The impact of such an event at a critical compressor station during winter, would result in significant buy back cost. These are the costs, shared with consumers, that we pay to shippers where we are unable to meet our capacity commitments. In a worst case scenario this could also lead to a network emergency and the loss of gas supplies to consumers. From a benefits perspective we have assumed we will avoid one incident at a medium criticality XXX XXXXXXXXXXXXXXXXXXXXX. This is equivalent to "turning off" one large power station for just over 3 days on a planned basis. We believe that this is a conservative estimate, as during the period 1999-2012, XXXXXXXXXXXXXX XXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXXXXX XXXXXXX XXXXXXXXXXXXXXXXXXXXXXXXXXXXX natural gas.

- **Gas Transmission Summary**

  The total estimated long term financial benefits to be shared with customers over a 20 year period are ca. £60m. These estimated savings result from a reduction in the total expenditure associated with unnecessary excavation, the premature replacement / maintenance of below ground pipework and importantly the minimisation of the likelihood of a high pressure asset failure.

3.4 Wider UK Gas Industry Benefits

The benefits described above relate to the NTS, but we would expect to see similar, if not greater, benefits on the Gas Distribution Networks (GDNs) as well as other third parties. Many GDNs have already approached NGGT in order to express an interest in utilising this currently unavailable capability. Letters of support from Scotia, Wales and West Utilities and National Grid Distribution can be found at Appendix F.

3.5 Project Financial Analysis

The mandated NIC costings spreadsheet can be found in Appendix A with the benefits spreadsheet at Appendix B. A summary of key figures per year is below:

Year	Cost (£)
1	400,799.62
2	1,774,641.55
3	1,788,917.32
4	1,373,675.95

5	966,971.15

NIC bid preparation costs are likely to be in the region of £175,000 which will be funded through the NIA scheme, and include bid preparation, legal and procurement activities.

The project will be subject to robust project management practices, including a stage gate process throughout. NGGT will establish a Project Management Team with the other partners and appoint a project manager to ensure the project is delivered to time and on budget. For all procurement activity, NGGT will wherever possible, undertake competitive tendering.

Gas Network Innovation Competition Full Submission Pro-forma

Section 4: Evaluation Criteria

This section should be between 8 and 10 pages.

4.1 **Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and/ or existing Customers.**

This project unequivocally accelerates the development of a low carbon energy sector and delivers a range of environmental benefits with the potential to deliver financial savings through avoiding unnecessary excavations, extending the lifetime of assets, and from avoiding a high pressure failure – all achieved through pro-active and more accurate monitoring. A detailed examination of each aspect is below and at Appendix I:

a. **Minimised requirement to excavate reducing carbon emissions and generating cost savings:** Excavations are carried out for sites where it is considered likely that replacement of network pipework/components is required – largely on the basis of CIPS survey results and maintaining records of asset age. There is the opportunity to avoid excavations where better inspection capability indicates asset condition is adequate for continued operation.

The Bacton preliminary Life Cycle Analysis (LCA) estimated the excavation and reinstatement of material to replace 3700 linear metres of buried pipework would have produced 1,381 tonnes CO_2e. For the purposes of this study it is assumed that a broadly representative site would be around 10% of the size of Bacton, and therefore would require excavations generating around 138 tonnes CO_2e.

'Unnecessary' excavations are deemed to be those where excavation is undertaken, and the visual and other inspections indicate that replacement or repair of components is not necessary.

A simple calculation can be carried out based on assuming in 50% of excavations there is no replacement or repair of components. Based on 15 sites per year of this scale, typical excavation emissions nationally would be around 2,072 tonnes CO_2e. Avoiding 50% of these would equate to a national reduction in carbon emissions for AGIs of approximately **1,036 tonnes CO_2e per year**.

b. **Avoidance of premature asset replacement and increasing the life span of assets:** The Bacton LCA provided an estimate of carbon footprint for embodied components replaced of approximately 62,000 tonnes CO_2e. This represents the energy used to extract, process and manufacture pipeline, bends, tees and valves replaced. The 62,000 tonnes of CO_2e was for pipeline and components replaced at Bacton, an estimated 50% of which was assumed to be below ground.

A typical location is expected to be around 10% of this scale, with the embodied carbon of below ground assets at such a location estimated at 3,126 tonnes CO_2e.

Typically the lifetime of components in the network are assumed to be approximately 40 years. The important benefit offered by robotic inspection is that this effective lifetime can be extended – and this means the annualised carbon footprint (i.e. the carbon footprint spread across the lifetime of the components) becomes smaller. While some components may fail before 40 years, it is reasonable to assume that the proportion for which life is extended is greater than the proportion that needs to be replaced before 40 years. Indeed In Line Inspection (ILI) has allowed life-limiting defects in pipelines to be identified and repaired. This has significantly increased the useable life of the NTS and provided reassurance that the most critical flaws have been addressed.

Assuming a standard 40 year lifetime for a typical installation suggests an annualised carbon footprint of 78 tonnes CO_2e per year of life. Extending the lifetime of components offers the following benefits:

Lifetime extension (years)	Annualised carbon footprint for typical high pressure installation – below ground components only (tonnes CO2e)	% improvement
0	78	0%
10	63	20%
20	52	33%
30	45	84%

This indicates the carbon benefit of extending the operating lifetime of components in the network. Every year that the lifetime is extended is a year where new components (with all the embodied energy that they include) do not need to be installed.

Clearly this consideration cannot be extended across the whole network, the age profile varying considerably across assets. An exercise was carried out to model the likely benefits across the network, based on the potential extension in operational life achieved through use of robotic inspection. Example age profiles were produced for the purposes of this calculation as shown below:

Age brackets	Proportion of components in each lifetime bracket	
	Business-as-usual	With programme of robotic inspection
0 – 40 years	10%	5%
40 – 50 years	50%	20%
50 – 60 years	30%	50%
60 – 70 years	10%	25%

Extending the lifetime of components at a typical site would equate to approximately 6 tonnes CO_2e per year per site per year. Extrapolating this across the national network would suggest a carbon saving of around **1,109 tonnes CO_2e nationally each year**.

c. **Minimisation of Potential Asset Failures leading to the Release of High Pressure Gas:** By moving to a proactive process of monitoring using in line technologies the risks of unforeseen failure are significantly reduced. The impact of a large scale unforeseen failure would be considerable and could potentially result in large releases of methane to the atmosphere. The Global Warming Potential of methane is around 34 times that of carbon dioxide over the 100 year time horizon. A hypothetical loss of 200 tonnes of natural gas from a high pressure failure would equate to around **6,800 tonnes CO_2e** emitted to the atmosphere. In addition to this emission of methane would be the significant broader impacts arising from disruption to industry, businesses and households; endangering of human health; and associated knock-on effects.

Conclusion:

Based on these estimated age profile changes across the network a saving of around 1,109 tonnes CO_2e per year is delivered from avoided replacement, and 1,036 tonnes CO_2e per year from avoided excavations. This reduction is per year that the robotic technology is deployed.

Combining these annual benefits provides an estimated saving of around 2,145 tonnes CO_2e per year.

To put some context on the estimate of 2,145 tonnes annually saved through extending the lifetime of assets:

- OFGEM estimate is typical household energy consumption of 16,500 kWh of gas, and 3,300 kWh of electricity
- This amounts to an estimated energy footprint of approximately 4.5 tonnes per year for a typical household
- The carbon saving through extension to asset life and avoided excavation at a national scale is equivalent to the carbon emissions from energy consumption for approximately **477 UK households**, and the benefit is present each year.

The financial savings attributed to these environmental benefits are highlighted within the business case at 3.3 but in short are:

Environmental Benefit	Financial Saving
Reduced Excavations	XXXXXXXX
Avoidance of asset failure	XXXXXXXX
Extending life of asset	XXXXXXXX

4.2 **Value for money for gas customers**

The consumer will benefit either directly at the start of RIIO-T2 with lower forecast replacement costs and/or through the totex incentive. Any saving either capital expenditure or operating expenditure is subject to the totex incentive and the consumer in principle benefits at a rate of 56p for every one pound saved.

Value for money for gas customers and by association the UK domestic consumer will also be achieved through the following:

a) Through better asset condition assessment, knowledge and understanding, will allow NGGT to plan and focus expenditure and costs where needed.

Evaluation Criteria continued

b) By extending the operational life of existing assets, the requirement for new projects and associated expenditure can be reduced, removed or delayed. Asset replacement can be planned or unplanned, reducing either will provide both cost and carbon benefits to the Gas Customer.

c) Increased asset condition knowledge, should reduce the risk of asset failure and disruption, reducing the potential for Gas Customer interruption and outages. NGGT liabilities and costs associated with disruption and potentially failure to supply, will be less likely or reduced.

d) Inspection of buried pipework systems using the robot system will reduce the needed for excavations, which can be both complex and costly.

4.3 **Generates knowledge**

Several aspects of the project will provide learning and knowledge to both NGGT and the other Network Licensees, as defined below;

- **Condition Knowledge** – The project involves the deployment of the robot within existing live pipework on three differently sized AGIs. Results gained from the trials should lead to new approaches being taken in managing assets by allowing more accurate estimations as to their current condition in specific areas.

- **Design Knowledge** – The robot will require suitable flanged connection points to facilitate its insertion. Should the use of robotic inspection devices be deemed to be the ideal solution for inspecting buried live pipework then the knowledge gained during this project will be invaluable in determining what is required to allow such devices to be installed. The knowledge gained may be used during the design phase of new sites or incorporated within designs for planned modifications to existing sites to facilitate their installation.

- **Available Technology Knowledge** – As part of the project an extensive patent and technology search has been undertaken to ascertain what is currently available to the gas industry to allow in line inspection of buried pipework. This knowledge will be applicable to all operators, allowing them to focus their efforts on any alternative solutions.

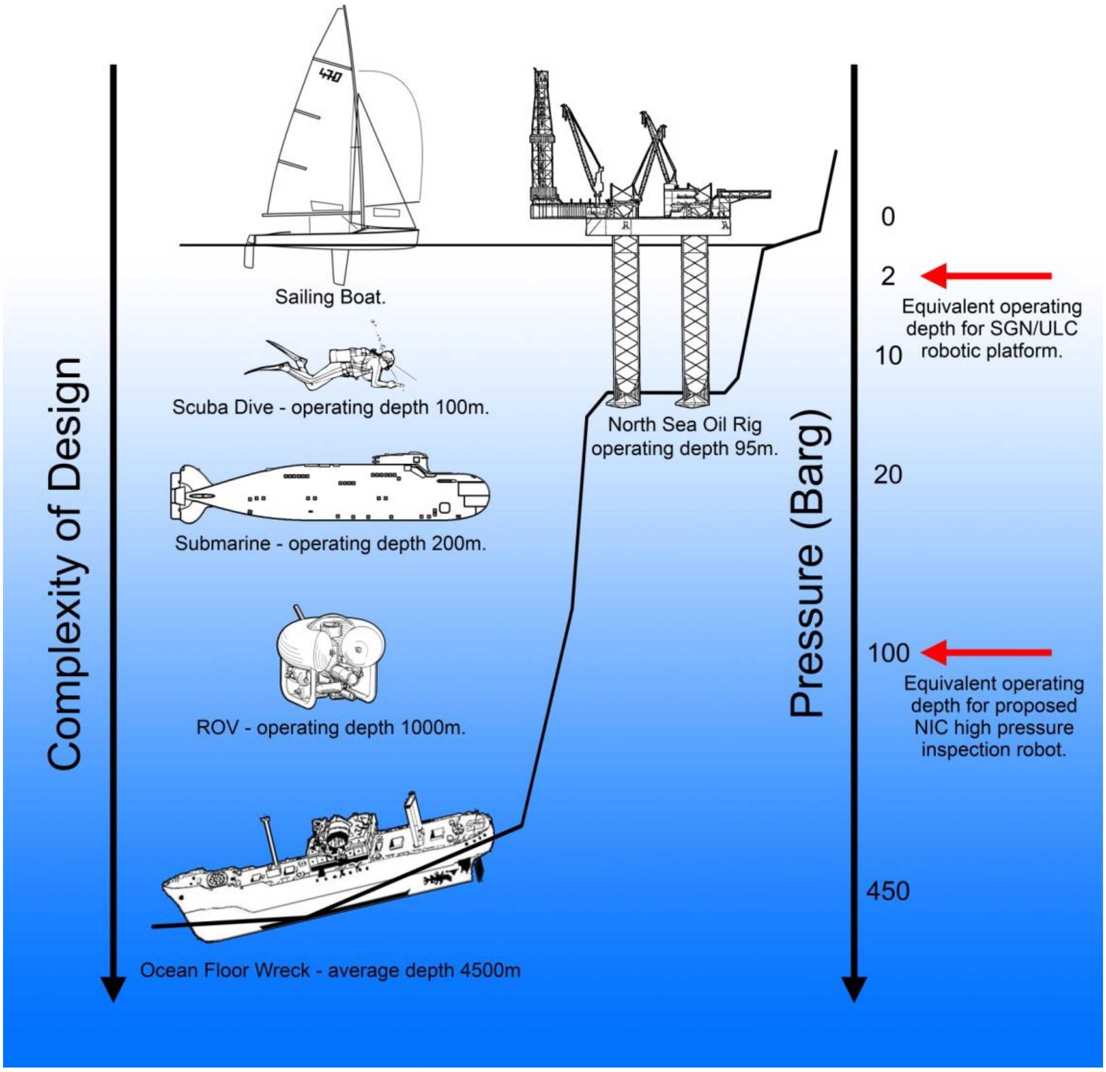
4.4 **Is innovative and has an unproven business case where the innovation risk warrants a limited development or demonstration project to demonstrate its effectiveness**

Due to the ageing assets on both the transmission and distribution networks it has been necessary to create new and innovative ways of establishing the integrity of and maintaining assets such as pipework. Current procedures can be inaccurate as well as financially and environmentally expensive, and as such it is necessary to draw upon new techniques in order to bridge capability gaps.

Gas Network Innovation Competition Full Submission Pro-forma

Evaluation Criteria continued

There is currently no robotic inspection device that can internally inspect below ground pipework on AGIs at pressure above 2 barg. This innovative design bridges the gap in capability allowing for internal inspection at up to 100 barg pressure. Scotia Gas ratifies this in their letter of support at Appendix F. Increased pressure has a huge affect on inspection devices/procedures. The diagram below demonstrates the difference between operating at 2 barg up to 450 barg and highlight the uniqueness of a robotic device which can operate under such high pressures.



Particular areas of innovation which will be explored and progressed through the life of the project are as follows:

- Robotic systems and inspection tools that can operate safely and reliably within a high pressure (up to 100 barg) operational gas installation, considering gas pressures, gas temperatures and gas flow rates, plus the pipework system configurations and geometry.

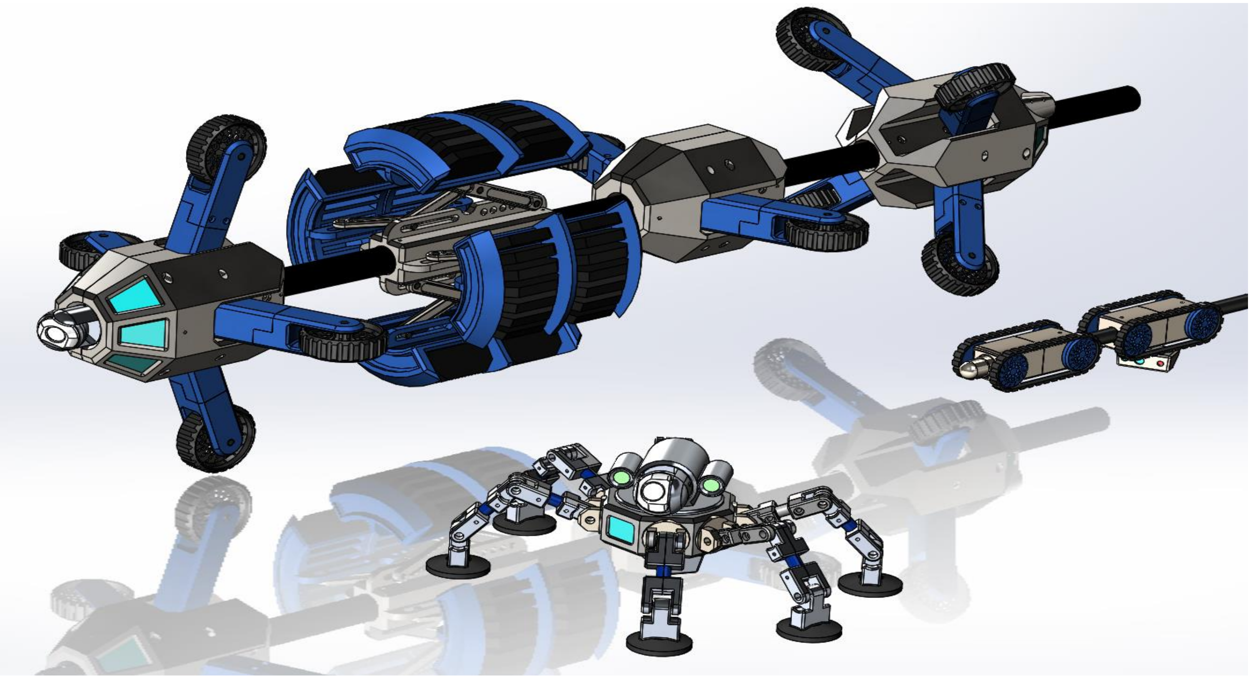
- Novel techniques to launch and retrieve in line inspection robotic tools from a live operational gas installation, operating at pressures up to 100 barg.

- High pressure glanding arrangements and alternative connection systems.

- Techniques associated with tethered and wireless in line inspection robot systems.

- Technologies to improve geo-location and tracing capability of below ground inspection systems.

This proposal categorically differs from previous robotics projects, in particular, Scotia's 2013 NIC funded Robotics project. The fundamental difference is that Scotia's inspection robot capable of conducting repairs to mechanical joints can only operate up to pressures of 2 barg. In lower pressurised gas distribution networks this constraint is entirely acceptable however in high pressured environments, in particular (but not exclusively) in gas transmission environments this robot simply cannot operate. It is vitally important for the assets at gas transmission sites, notably below ground pipework at AGIs to also be inspected accurately and maintained effectively as a consequence. The Synthotech/Premtech inspection robot (likely prototypes pictured below) can operate effectively in pressurised environments up to 100barg, making it entirely unique and innovative technology.



To be absolutely clear on the difference between current in line inspection robotic technology and this project see the comparison table at Appendix J.

4.5 **Involvement of other partners and existing funding**:

NGGT held a workshop with internal stakeholders to generate ideas and identify priority themes for the 2014/15 NIC. The workshop consisted of representatives from Asset Management, Safety and Sustainability, Market Operation, Capital Delivery and RIIO Delivery functions. The workshop identified six key themes which were then circulated to potential partners and suppliers and published on NationalGrid.com/ innovation. The themes were:

- Facilitation of highly flexible powerplant.
- Heat recovery from Transmission pipeline network.
- Unconventional gas facilitation.
- Towards a zero emissions compressor station.
- Alternative pipeline materials and methods.
- Outage avoidance (plug and play compressors, self-propelling in line inspection).

It also enthusiastically welcomed all other ideas and innovative suggestions from third parties. These themes were also shared with the other gas networks at the Energy Networks Association Gas Innovation and Governance Group meeting. As a result of this activity, a number of proposals were received, compared and assessed against the NIC criteria and National Grid's innovation strategy. The joint proposal received from Premtech and Synthotech on in line inspection of high pressure installations was chosen as the successful candidate. Below is an overview of each of the partner companies:

a. **Synthotech Limited:** a UK-based Small Medium Enterprise (SME) specialising in the innovation, engineering and delivery of 'Must Have' technologies for the utilities industries. Specialising in the development of robotic inspection solutions for pipes 4" to 48" diameter, Synthotech have delivered three IFI Projects and two NIA projects on time and within budget. These highly innovative technological solutions focus on providing asset condition intelligence from within the pipe, under live gas conditions. This approach ensures gas supplies to consumers are not interrupted, and ground excavations minimised, reducing environmental impact.

b. **Premtech Limited:** Premtech's primary focus is to provide engineering, consultancy and design management services for onshore pipeline and associated installation projects of all sizes. As a UK-based SME we are able to work closely with our clients which include almost all of the major UK Gas Distribution Network owner/operators as well as NGGT, gaining a place on several of the major framework agreement contracts. In addition to the professional services listed above we have been instrumental in delivering a number of innovation projects for NGGT, the most significant of which being the Building Information Modelling (BIM) Demonstration project; now in its second phase. Other projects include Renewable Power for Remote Installations, Pigtrap Door Seal Study and Direct Replacement Pre-heat Package (DRPP).

In order to provide Synthotech and Premtech with the support they require throughout this complex and ground-breaking project we have asked Pipeline Integrity Engineers (PIE) to provide third party assurance. They will support the technical team in developing and implementing the technical strategy, and providing integrity consultancy support in translating inspection results to asset management strategies and procedures.

Importantly the project is not simply a collaboration between NGGT, Synthotech, Premtech and PIE there are a number of other stakeholders and support partners each bringing their own value to what is a unique and innovative step forward in high pressure in line inspection asset management.

The diagram below illustrates the number of companies and organisations who are involved in some way with this project. You will also note, that there are project partner and stakeholder letters of support at Appendix F.

Evaluation Criteria continued

Gas Network Innovation Competition Full Submission Pro-forma

Section 5: Knowledge dissemination

This section should be between 3 and 5 pages.

☐ Please cross the box if the Network Licensee does not intend to conform to the default IPR requirements.

5.1 **Role of data, knowledge and learning dissemination**

a. **Categories of data, knowledge and learning.**

This project will deliver significant opportunity for knowledge dissemination across NGGT and The Gas Distribution Networks. Knowledge such as the below:

- **Technical Knowledge:** The ground breaking technology which is being developed throughout the course of this project regarding in line inspection robotics is something which all network licensees both domestic and abroad will benefit from. The Tech Watch at Appendix G highlights the range of available technology and importantly the fact that the technology sought for this project is simply not available. Several areas of technical knowledge which will be disseminated as appropriate will involve design, installation, commissioning and asset management.

- **Operational Knowledge:** Important knowledge regarding implementation including maintenance, repair procedures, risk management, safety processes and data collection.

- **Data analysis:** The knowledge gained as a result of the robotic inspection will allow certain algorithms to be implemented in order to predict asset condition across any given network. The way in which this is collected, processed and analysed must be shared if the robotic technology is to transcend across distribution networks.

b. **Key responsibilities for knowledge dissemination and learning.**

Ultimate responsibility for knowledge dissemination and learning will lie with the Project Manager and his project team. As such he will produce a sound communications plan which will include knowledge and learning dissemination procedures both internally and externally. In addition to this, the two prominent support companies (Premtech and Synthotech) will also have a role and will contribute to the dissemination of knowledge as well as learning from the project. Synthotech, for example, will play a vital role in partnering with Leeds University who, as an academic institute and one of the leading Universities in terms of robotics technology in the UK, can add real value, particularly in the gathering, recording and dissemination of data, its consequential interpretation and therefore production of knowledge.

c. **Primary stakeholders of project data, knowledge and learning.**

Knowledge dissemination continued

A number of organisations both internal and external to NGGT will have an interest in the project data, knowledge and learning which falls out of this robotics project and will be known as stakeholders. These will include:

- Leeds University
- Pipeline Industry Guild
- IGEM (Institute of Gas Engineers and Managers)
- All Gas Distribution Networks.
- Pipeline Integrity Engineers
- Ofgem
- The Energy Networks Association
- NGGT staff, contractors and Direct Service Developers and Manufacturers
- United Kingdom Offshore Pipelines Association (UKOPA)

d. **Methods of dissemination**

These will be extensively laid out in the Communcations Plan which will be written by the Project Manager as part of the comprehensive Project Management Plan but will likely include:

- Web based sharing techniques (project website, online knowledge seminars, social media).
- Press releases.
- Networking events/ industry conferences /seminars.
- Publications/journal/documentary.

Specific events which the project team will attend and potentially present to are:

- Yorkshire & North East Innovation Event – April 2015
- Water Research centre Innovations Event – May 2015
- IGEM Section Events (Presentations) – Various dates during year.
- PIG Section Events (Presentations) – Various dates during year.
- IGEM Gas Awards – May 2015
- IGEM Annual Engineering Update June 2015
- WGC World Gas Conference 1-5 June 2015
- Pipetech Summit – June 2015
- Gas and Storage Annual Conference – June 2015
- No Dig Live – September 2015
- International Gas Research Union September 2015

Knowledge dissemination continued

- Low Carbon Networks & Innovations - October 2015

Specific publications which the project manager will target are:

- Gi Magazine – IGEM
- PE (Professional Engineering) Magazine – IMECHE
- Pipeline and Gas journal
- Pipeline Industries Guild (PIG)
- United Kingdom Society for Trenchless Technology

The project manager will ensure that his communications plan commits to a number of timings and deliverables. These are:

- A public, web based launch on 5 Jan 15 to include a short promotional video and an interactive forum (perhaps a twitter account) so that questions can be asked to the project team as the project develops.
- At the end of stage 1 (30 Oct 15) the first knowledge and dissemination review will take place, the results of which will be appropriately presented and sent to all stakeholders identified at 5.1.d.
- An event to promote and demonstrate the pipework configuration made for the purpose of testing the new robot.

5.2 **Intellectual property rights (IPR)**

We have an agreement in principle where both parties are committed to the default IPR position.

At this stage, we do not know what specific forms of IPR will be created and consequently require registration, if any. As part of the design process, detailed prior art review is necessary and will be dependent on the solution pursued.

It is proposed if and where IPR is to be registered, that it will be done by Synthotech Ltd, following transfer of any foreground IPR created by NGGT.

Upon successful completion of the Project, royalties would be due from Synthotech Ltd (either from direct utilisation or licensing), if the project is rolled out. These will be paid to NGGT subject to an evaluation of their true commercial value, on either a per unit basis (e.g. per unit manufactured and utilised), or an annual basis. The final arrangements will be determined at a later stage in the project, but will be designed so as to ensure the best value for the GB gas customer.

Income from royalties, minus any costs incurred in maintaining and managing IPR, would be returned to customers in proportion to their funding. NGGT would retain the remaining portion (equivalent to our funding contribution) as profit. For this project, this would be 10%. NGGT would calculate and declare this Returned NIC Royalty income in our regulatory returns on an annual basis.

Gas Network Innovation Competition Full Submission Pro-forma

Knowledge dissemination continued

Under the provisions within the contract between both parties, Synthotech Ltd will be required to comply with the NIC governance document. Synthotech Ltd will grant to the Network Licensees and the Parties: an irrevocable, perpetual, world-wide, non-exclusive royalty-free right and licence to use, access, copy, maintain, modify, enhance and create derivative works of any Relevant Foreground IPR (including any Relevant Background IPR contained therein) within their network system.

A key section of the NIC governance relates to Relevant Foreground IPR. Under the NIC document, Relevant Foreground IPRs are defined as Foreground IPRs that other Licensees will need to utilise in order to implement the Methods (the proposed way of solving a Problem (the obstacle or issue that needs to be resolved in order to facilitate the low carbon future and/or provide some environmental benefit to customers)) developed in the Project.

Network Licensees will only have the right to use Relevant Foreground IPRs within their network royalty free. They cannot sell or grant sub licences to Relevant Foreground IPRs.

Where access to a participant's Background IPR is required to undertake the project, the participant shall grant a non-exclusive licence to this background IPR (Relevant Background IPR) to the other participants, solely for the purposes of the project during the term of the project. The Network Licencees will also be granted a licence for any Background IPR required to utilitise any Relevant Foreground IPR for which they receive a licence.

Gas Network Innovation Competition Full Submission Pro-forma

Section 6: Project Readiness

This section should be between 5 and 8 pages.

Requested level of protection require against cost over-runs (%): 20%

Requested level of protection against Direct Benefits that they wish to apply for (%): Nil

6.1 **Evidence as to why the project can start in a timely manner**

Much time has already been spent by both NGGT and its partner companies Synthotech and Premtech to ensure that the in line robotic inspection project is ready in terms of project management procedures. The following management systems and preparatory work has already been implemented:

- **Global Tech Watch (GTW)** (a shortened version can be found at appendix G, the full version can be accessed upon request) - Synthotech have carried out a detailed GTW to provide clarity on existing and new technology that could be transferred, adapted or was emerging that could be used for this project. The purpose of a GTW is to ensure that there are no existing solutions and therefore prevent unnecessary duplication of solutions.

  Critical to every successful innovation project is the systematic process of gathering, auditing and reviewing all available information (due diligence) using 'best of breed' resources that are essential to establishing a robust project management structure including composition of the project management team.

  The aim of the GTW is to provide clarity on existing and new technology that could be used as part of the development project. Synthotech undertook the GTW by carrying out a detailed and systematic analysis of technology that may already exist that could be used for all aspects of the initial scope.

  Initial Scope:

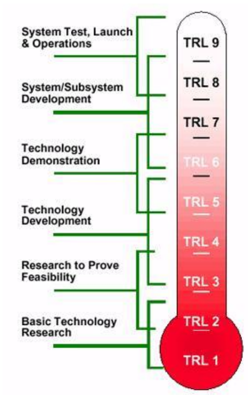
  - Robotic tool / platform.
  - Robot to provide high quality camera survey.
  - Laser scan of a specific area for inner surface profile.
  - Wall thickness measurement of pipe, at set locations.
  - Robot to know where it is in the AGI network – location.
  - Robot Suitable for 24" to 48" pipe. 36" most common size on NGGT network.
  - Up to class 600 - 100barg Operating Pressure.
  - Bend negotiation.
  - Obstacle negotiation.
  - Deployable technology for inspection of smaller pipes within network.
  - Relaying of data.

Gas Network Innovation Competition Full Submission Pro-forma

Project Readiness continued

These searches were used to determine the technology / solutions that will be taken forward to the concept stage for the 3D Prototype (Alpha) design phase of the project. The GTW output process can be broken down into four specific phases:

- Scope / Design audit - Premtech / Synthotech – Define operational requirements.
- Data collection – Online Searches, Journals, Published Papers, Patents – These searches are not only gas they are designed to look at available technologies from all utilities and Engineering sectors and disciplines.
- Analysis & Review of the data collected – this is appraised on the basis of the Technology Readiness Level (TRL), these are measures used to assess the maturity of evolving technologies (devices, materials, components, software, work processes, etc) during their development and in some cases during early operations.



Once the above assessments have been undertaken a suitability matrix is developed to score the technology that has been identified on the basis it is Transferable (No real change needed), Adaptable (modifications to process or product), and Emerging. The table below is an example of a suitability matrix.

Motion System		Suitability Criteria												
		24-42" Pipelines	Metallic Pipelines	Variable Speed	Steerable	Climb Steep Gradients and	Against flow	High pressure & High Flow	Negotiate Parallel Barred	Mutliple Bends	Torque	Range	Payload Capacity	**Total Score**
Wall Press	**Dual-contact**	4	4	4	4	4	4	3	0	4	3	3	4	**41**
	Multi-Contact	4	4	4	4	4	4	4	0	4	4	3	4	**43**
Free weight	**Wheeled**	4	4	4	4	0	4	0	4	4	1	3	3	**35**
	Tracked	4	4	4	4	0	4	0	4	4	2	3	3	**36**
Push Rod	**Manual**	4	4	4	4	2	4	2	4	2	1	2	2	**35**
	Propelled	4	4	4	4	3	4	3	4	2	2	2	2	**38**
Pig		4	4	0	0	4	0	4	0	4	3	4	4	**31**
Telescopic		4	4	4	4	4	4	2	4	4	4	0	2	**40**
Walking		4	4	4	4	2	4	3	4	4	2	3	2	**40**
Magnetic	**Wheeled**	4	4	4	4	4	4	1	4	4	2	3	3	**41**
	Tracked	4	4	4	4	4	4	3	4	4	3	3	3	**44**

Project Readiness continued

This detailed search identified that there is a significant amount of technology that could be transferred or adapted in relation to visual / non-destructive testing and location. In terms of the robotic platform designed to carry the inspection technology, no off-the-shelf solution was identified which could complete the above scope.

There are four main systems identified that can undertake some elements of the inspection of unpiggable pipes found in an AGI, the issue with the systems identified is their ability to cope with the pressures, flexibility for bend negotiation and distances. Additionally there were also concerns about the limited available market data on actual operation in relation to the requirements of this project.

1. Pipetel
2. Pipecrawlers
3. Rosen
4. Diakont

Therefore it is the recommendation of Synthotech that a bespoke design is required for this project, this is due to the scope and in-pipe complexity in coping with required distances, bends, entry and egress and 100 barg environments. Synthotech will work with third parties that were identified in the GTW, to use the technology that was identified as being transferable or adaptable to ensure that design effort is not focussed on duplication.

- **Patent Search** (in full at appendix H) – Synthotech have engaged with a third party specialist organisation to undertake a detailed analysis of patents in relation to techniques, technologies, applications that may affect the direction of the project.

  The aim of the patents search was to identify relevant prior patent documents (granted patents or pending applications) that could affect freedom to operate in the UK, as well as documents that may also be relevant to patentability (novelty) of technology to be developed as part of the project. Prior art includes previous patents, trade journal articles, publications (including data books and catalogues), public discussions, trade shows, or public use or sales anywhere in the world. The searches were limited to patent documents in order to manage the amount of work required to be done. It is useful to undertake a search in respect of granted patents and pending patent applications since the documents identified may affect the direction of the project.

  The Patent Search was undertaken by an approved third party patent attorney (Mark Yeadon of Yeadon IP Limited). Following detailed technical discussions about the scope of the project initial search criteria was developed:

  - Pipeline inspection system comprising of robotic devices for inspecting unpiggable pipes; particularly relatively narrow, bendy pipelines that are unpiggable.

Project Readiness continued

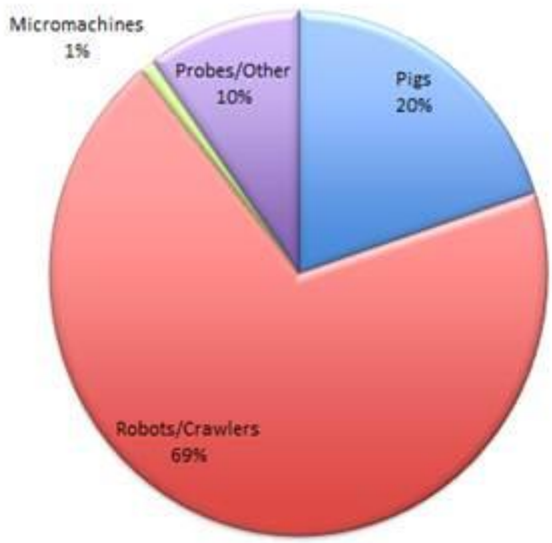
- Launch devices for launching robots or pigs into pressurised pipelines.

The results and findings from the search criteria were then analysed by Yeadon IP, prior to review by the Synthotech Project Team for inclusion in the Global Technology Watch.

AGI Robot Search

This was the search in respect of Unpiggable pipeline inspection. The results were informally classified according to device type (pigs, robots/crawlers, micro-machines and probes/other). The search was biased towards robots since the search was to reflect the requirement to inspect unpiggable pipelines rather than piggable pipe lines; however some pig related technology was found.

In terms of total numbers of patents, the AGI inspection robot search identified a total of 110 documents in the main search, out of over 3000 documents searched. Of these 110 documents, approximately 6 are granted and in force GB patents or pending applications that could mature into GB patents.



In conclusion, it appears that robot devices suitable for inspecting unpiggable pipelines are well known and some have been in the public domain for long enough that valid, granted patents can either no longer exist for the specific devices described in the documents, or are expected to expire imminently.

Launch Device Search

For the launch device search a total of 239 patent documents were identified in the main search. Of these, 70 of these are documents older than 20 years and therefore present little or no infringement risk. A number of these documents disclose

Project Readiness continued

technology that is believed will be of interest to Synthotech / Premtech, and which could form the basis for a technology platform with no freedom to operate issues.

Of the remaining 169 documents, 30 are pending applications that could lead to a patent being granted in the UK, or are granted patents that are in force in the UK already. A preliminary review of these documents indicates that routes to work around the technologies protected are very likely to exist.

In conclusion, it appears that devices suitable for launching pipeline robots into pressurised pipes are well known and some have been in the public domain for long enough that valid granted patents can either no longer exist for the specific devices described in the documents, or are expected to expire imminently.

Risks

As there is no clearly defined device as yet, risk levels are difficult to assess, however it is felt that the overall risk is relatively low. The risk levels associated with using relatively old technology (20 years or more) are very low, and a number of such technologies were identified. On this basis it is believed that development of technology for inspecting AGIs per se is not blocked. Should the project need to use third party protected technology, Synthotech will look to obtain a license.

- **NIC Review** – Synthotech have conducted a technical appraisal of the SGN/ULC NIC 2013 Awarded Project, and have confirmed that the projects are fundamentally different due to the operating pressure and environment that the robotic platform and inspection technologies will be required to work within. See table appendix J for further detail.

- **Pipe Modelling** (Premtech) – To determine operation scope for the robotic platform, i.e. size, pressure, bends, distances.

- **Stakeholder engagement and management procedures**.

- **Project Management Plan** – to include risk plan, communications plan, quality control and assurance plan, health and safety plan, compliance procedures and finance plan.

- **Risk Register** – Two risk registers have been compiled (appendix E) which highlight perceived risks regarding the technical aspects of the device as well as the project as a whole, these will help formulate a comprehensive risk plan.

- **Forecasted costs and timeframe** – A schematic of the project costs and projected timelines can be found at Appendix A.

The Project Manager will report directly to the Project Sponsor.

Project Readiness continued

The project team's organisation structure, showing lines of reporting can be found in Appendix C. One of the key criteria for building a robust Project Plan was in the selection of the relevant project participants and the forming of a competent project team.

As part of the proposal, NGGT has ensured that all members of the Project Team can commence project work in January 2015, are aligned to the specific project deliverables and are able to commit to and meet their scope of work and defined outputs. The work schedules have been developed together with Synthotech and Premtech to ensure the project will start in a timely manner as detailed in the project management plan at Appendix D.

6.2 **Evidence of how the costs and benefits have been estimated**

A comprehensive study of projected costs is at Appendix A. The likely benefits (environmental) have been third party reviewed by Arup Consulting, whose thorough report from which elements have been extracted and included in the main content of this proposal, can be found at Appendix I. The mandatory benefits table can be found at Appendix B.

6.3 **Evidence of the measures a Network Licensee will employ to minimise the possibility of cost overruns or shortfalls in Direct Benefits**

Project assurance methods such as Earned Value Management techniques, and benefits analysis methods will be utilised throughout the project lifecycle in order to forecast project health in terms of cost and time overruns. At every gate review these project assurance methods will produce results and those results will shape decisions regarding the future of the project i.e. does NGGT continue through to the next stage of the project.

6.4 **A verification of all information included in the proposal**

A number of external companies have been contracted by NGGT, Synthotech and Premtech in order to validate the information that has been included in this proposal. At Appendix I you will find a full carbon report from consulting company Arup who interrogated our environmental figures to provide independent validation. PIE have also been asked to support the technical team in developing and implementing the technical strategy, and providing integrity consultancy support in translating inspection results to asset management strategies and procedures.

6.5 **How the project plan would still deliver learning in the event that the take up of low carbon technologies and renewable energy in the Trial area is lower than anticipated in the submission**

This project will still deliver learning as it is focused on providing the asset owner with demonstrable data in relation to asset health. The project will deliver carbon savings as described in this submission, as currently there is no available technology that can be used to obtain this data without the need for excavations to physically inspect the asset. The project will deliver a robotic solution that through visual and non-destructive assessments will prevent the need for excavations.

Gas Network Innovation Competition Full Submission Pro-forma

Project Readiness continued

This robotic platform will allow asset owners to review the ageing asset, to determine if the life of the asset can be extended, if remediation work is required to specific areas, or if the asset needs to be replaced.

If this data can be used to extend the life of the asset then this will have significant benefits associated to the carbon footprint, as the costs and environmental impact associated to replacement of an asset are significant.

6.6 **The processes in place to identify circumstances where the most appropriate course of action will be to suspend the project, pending permission from Ofgem that it can be halted.**

Throughout this project NGGT will employ Association of Project Management sanctioned methods and procedures for analysing the health of the project in terms of time, budget and quality. If, at any point during each of the five stages, the project management assurance techniques of Earned Value Management for example highlights that the project is in a poor state of health an integrated baseline review will take place immediately and the best courses of action laid out.

Section 7: Regulatory issues

This section should be between 1 and 3 pages.

☐ Please cross the box if the Project may require any derogations, consents or changes to the regulatory arrangements.

7.1 **Regulatory Impact**

It is not considered that the project will require any derogation, licence consent or licence exemption. Consequently, there are no regulatory hurdles to the project commencing or completing on the desired timescales.

7.2 **Long-Term Regulatory Impact**

There is currently no perceived long term regulatory impact as a result of this project.

Gas Network Innovation Competition Full Submission Pro-forma

Section 8: Customer impacts

This section should be between 2 and 4 pages.

8.1 **Direct customer impacts**

a. The project will not have a direct impact on customer's premises nor is it planned to cause any interruptions to suppliers. The project does not require any customer disconnections or interruptions during installations or operation of the in line robotic equipment. The safety and security of supply will have the highest priority throughout the project duration with existing safety precautions being maintained or improved during every operational change or engineering operation.

b. **Risk of interruptions:** Risk of interruptions in the supply of gas to customers is low. Prior to the robot being subjected to a live trial it will undergo a series of rigorous staged tests and proving trials to demonstrate its readiness for each subsequent trial. Tests and trials will ensure the robot is subjected to conditions equal and greater in severity to those expected within the pipe. Only following successful results will it progress to the next stage. The live trials will be carried out with suitable contingency plans in place should failure of the robot occur. The chosen route of the robot will be such that gas may be routed in an alternative way to maintain supply should the section it is within be compromised or blocked. All likely failure modes at this stage will be managed by suitable contingency plans.

c. **Contingency Plan:** As part of the project management plan there will be a detailed risk policy, which will include a number of contingency plans. The offline tests at potentially both Eakring and on the simulation rig will allow for these contingency plans to be rehearsed and practised. Contingency plans such as actions on the robot being lost, damaged or unresponsive will be implemented during the offline trials under pressures ranging from 1 – 100Barg.

8.2 **Indirect customer impacts**.

There are no identifiable indirect customer impacts as a result of this project.

Section 9: Successful Delivery Reward Criteria

This section should be between 2 and 5 pages.

9. Genuine actions linked to outputs of the project with a realistic and challenging deadline, e.g milestones and criteria must be SMART (Specific, Measurable, Achievable, Relevant and Timely).

9.1 **Submission of stage 1 report:**

1) The Completion & Submission of Stage 1 Report will take place on 13 Oct 15, it will include the following deliverables which are both achievable and relevant to the progression of the project:

- Completion of Concept Study no later than 27 Feb 15.
- 3D robot prototype will be completed by 6 Aug 15.
- All site modelling completed, including modelling of Bacton, Hatton and Lupton sites by 20 Aug 15.

9.2 **Submission of stage 2 report:**

2) Completion and Submission of Stage 2 Report will take place on 23 Sep 16, it will include the following deliverables which are both achievable and relevant to the progression of the project:

- The field trial design will be completed no later than 20 Apr 16.
- The build and completion of the offline testing facility will take place no later than 23 Sep 16. Its location is still to be confirmed however by this date it will be sited and at readiness for testing.
- Bench test prototype will be completed by 14 Jul 16.

9.3 **Offline trials complete:**

3) Stage 3 comprises of 3 phases. Phase 1 is the offline testing stage which will be completed by 30 Apr 17. A completion report will be written by 30 Apr 17 which will ensure that the next phase (online trials at the specified live sites: Bacton, Hatton and Lupton) can begin.

9.4 **Online trials complete:**

4) Phase 2 of stage 3 is the online testing of the robotic inspection device phase. Online testing will take place at the identified sites of Bacton, Hatton and Lupton. The completion report will be produced by 29 Sep 17. The online tests will ensure that the robotic inspection device can effectively and accurately inspect and collect accurate data from sites without compromising network flow and capacity.

9.5 **Submission of stage 3 report**

5) At the end of the online and offline testing, a stage 3 report will be completed and submitted (phase 3 of stage 3). This will be completed by 26 Mar 18.

Successful Delivery Reward Criteria

9.6 **Completion of data analysis:**

6) Stage 4 this will comprise of data analysis, verification, technology completions and the final online testing completion report. The data analysis and verification report which will contribute to the completion of the stage 4 report will be completed by 19 Sep 18.

9.7 **Submission of stage 4 report:**

7) The stage 4 report will be completed and submitted by 17 Sep 18, this is achievable and measurable and is relevant as it will allow the network to begin procedures for implementation of the robotic inspection device into Business As Usual (BAU).

9.8 **Submission of stage 5 report:**

8) Completion & Submission of Stage 5 Submission will be complete by 26 Nov 18, this will set out specific implementation methods and will see the robot transferred into BAU.

Gas Network Innovation Competition Full Submission Pro-forma

Section 10: List of Appendices

Appendix A: In-Line Robotic Inspection of High Pressure Installations NIC Spreadsheet.

Appendix B: NIC Benefits Table.

Appendix C: Project Organogram (proposed project team structure)

Appendix D: Project Plan

Appendix E: Risk Registers, including Project Risk and Robotic Device Risk.

Appendix F: Project Partners – Letters of Support (including Synthotech, Premtech, PIE, UKOPA, Leeds University, Scotia Gas, Wales & West Utilities, IGEM)

Appendix G: Tech Watch – shortened version highlighting available technology in this field currently. Full version available on request.

Appendix H: Patent Search

Appendix I: Arup Consulting Carbon Benefits Report.

Appendix J: Comparison table between Scotia Gas robotic platform and our proposed robotic platform.

APPENDIX A

(Please note that the spreadsheets at Appendix A have been cropped to allow the A3 prints to be legible. The columns are empty and have been hidden but are active and viewable in the uploaded documents).

APPENDIX B

KEY

Method	Method name
Method 1	In Line Robotic Inspection of High Pressure Installations (AGIs)
Method 2	[Insert method names here]
Method 3	[Insert method names here]

Gas NIC – financial benefits

Financial benefit (£m)								
Scale	Method	Method Cost	Base Case Cost	Benefit			Notes	Cross-references
				2018-2020	2021-2030	2013-2050		
Post-trial solution *(individual deployment)*	Method 1	60m	150m	3.75m	28.75m	57.5m	Over 32 years the estimated financial savings are **90.8m**. These are realistic but slightly cautious figures and could actually equate to much more (upper limit cannot be realistically estimated) if for example, more than one asset failure was prevented over 20 years.	Financial benefits are analysed at length in Sect 3.3b. In short they are based on: - XXXXXXXXXXXXXXXXXXXX in preventing unnecessary excavation. - XXXXXXXXXXXXXXXXXXXX prevention of premature asset replacement. - XXXXXXXXXXXXXXXXXXXX prevention of an asset failure at a medium sized AGI.

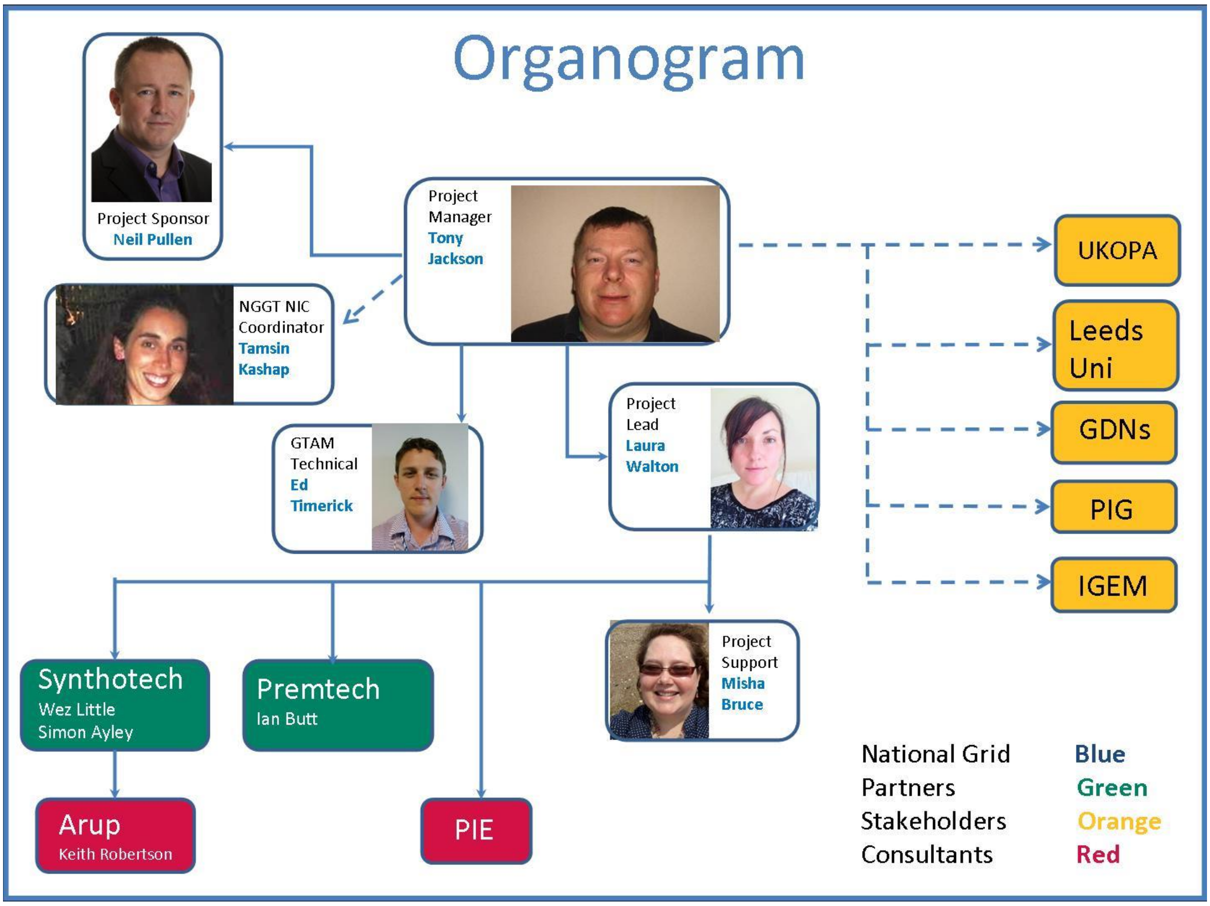
Licensee scale ***If applicable, indicate the number of relevant sites on the Licensees' network.***	Method 1						The above figures really represent the net financial savings if the robotic technology were deployed post 2018 on all un-piggable AGIs on the NTS.	N/A
	Method 2							
	Method 3							
GB rollout scale ***If applicable, indicate the number of relevant sites on the GB network.***	Method 1						Impossible to calculate at present as the total high pressure installation across all network licensees is not known, neither is the total cost of modification and roll out on all distribution networks.	N/A
	Method 2							
	Method 3							

Gas NIC – carbon and/ or environmental benefits

Carbon and/ or environmental benefit (MtCO2e)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**2018 - 2020**	**2030**	**2050**	**Notes**	**Cross-references**
Post-trial solution ***(individual deployment)***	Method 1	33,152 Tonnes	75,322 Tonnes	2072 Tonnes	11,469 Tonnes	28,629 Tonnes	Over 32 years the estimated environmental savings are **tonnes**. These are realistic but slightly cautious figures and could actually equate to much more (upper limit cannot be realistically estimated) if for example, more than one asset failure was prevented over 20 years.	Environmental benefits are analysed in detail in Sect 4.1 of the proposal and at Appendix I in the third party environmental consultancy (Arup) report. They are in short: - 1036 tonnes saving per year in preventing unnecessary excavation. - 1109 tonnes over RIIO-T2 &T3 in prevention of premature asset replacement.

								- 6800 tonnes over 20 years in prevention of an asset failure at a medium sized AGI.
Licensee scale ***If applicable, indicate the number of relevant sites on the Licensees' network.***	Method 1						The above figures really represent the net financial savings if the robotic technology were deployed post 2018 on all un-piggable AGIs on the NTS.	
GB rollout scale ***If applicable, indicate the number of relevant sites on the GB network.***	Method 1						Impossible to calculate at present as the total high pressure installation across all network licensees is not known, neither is the total cost of modification and roll out on all distribution networks.	
If applicable, indicate any environmental benefits which cannot be expressed as MtCO2e.	**Post-trial solution:** [Explain any environmental benefits which cannot be expressed as MtCO2e]						Beyond purely carbon emissions there are broader benefits from avoiding excavation and extension of asset lifetimes. Any project requiring excavation will produce localised impacts from: • Dust and air quality from excavation • Vehicle transport emissions and congestion • Noise and other nuisance • Potential pollution incidents from site runoff	
	Licensee scale: [Explain any environmental benefits which cannot be expressed as MtCO2e]							
	GB rollout scale: [Explain any environmental benefits which cannot be expressed as MtCO2e]							

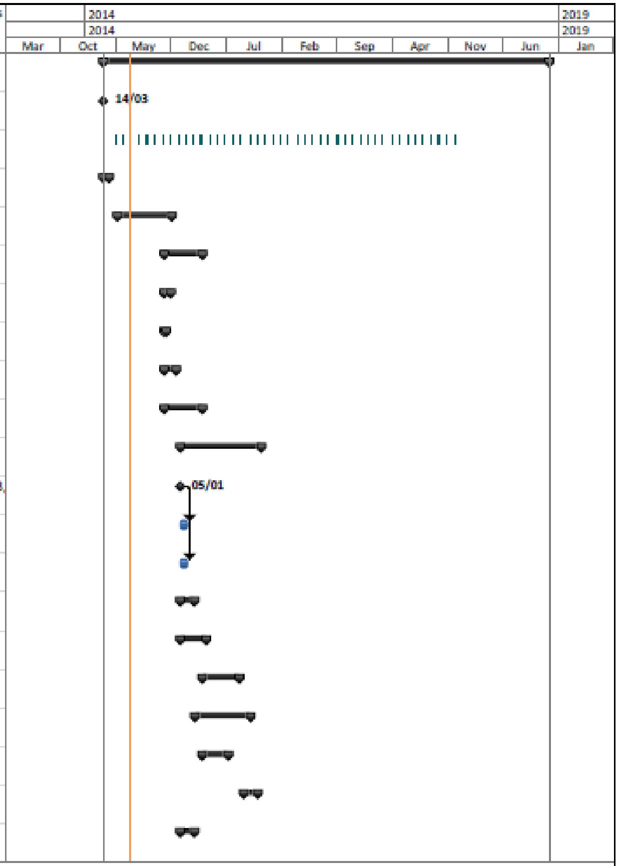
APPENDIX C


Organogram
Project Sponsor
Neil Pullen
Project Manager
Tony Jackson
NGGT NIC Coordinator
Tamsin Kashap
GTAM Technical
Ed Timerick
Project Lead
Laura Walton
Project Support
Misha Bruce
UKOPA
Leeds Uni
GDNs
PIG
IGEM
Synthotech
Wez Little
Simon Ayley
Premtech
Ian Butt
Arup
Keith Robertson
PIE
National Grid Blue
Partners Green
Stakeholders Orange
Consultants Red

APPENDIX D

Gas Network Innovation Competition Full Submission Pro-forma

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**NG NIC HP Project Management**	**1174 da**	**Fri 14/03/14**	**Mon 26/11/18**	
2			Project Start	0 days	Fri 14/03/14	Fri 14/03/14	
3			**Executive Board Reviews**	**894 day**	**Wed 30/04/14**	**Wed 29/11/17**	
48			**NIC Preparation - Initial Submission**	**16 days**	**Fri 14/03/14**	**Fri 04/04/14**	
55			**Full Bid Submission**	**149 day**	**Wed 07/05/14**	**Tue 02/12/14**	
68			**Project Management & Planning**	**95 days**	**Tue 04/11/14**	**Mon 30/03/15**	
69			**Management & Co-ordination Plans**	**19 days**	**Tue 04/11/14**	**Fri 28/11/14**	
75			**Design & Co-ordination registers**	**5 days**	**Tue 04/11/14**	**Mon 10/11/14**	
79			**Project Management**	**34 days**	**Tue 04/11/14**	**Fri 19/12/14**	
85			**Team Mobilisation & Set-up**	**95 days**	**Tue 04/11/14**	**Mon 30/03/15**	
94			**STAGE 1: Solution Development**	**220 day**	**Mon 05/01/15**	**Fri 13/11/15**	
95			Commence STAGE 1	0 days	Mon 05/01/15	Mon 05/01/15	70,71,72,73,
96			Develop technical strategy document	20 days	Mon 05/01/15	Fri 30/01/15	95
97			Develop Initial Basis of Design Document (BoDD)	20 days	Mon 05/01/15	Fri 30/01/15	95
98			**Concept & Methodology Documents**	**40 days**	**Mon 05/01/15**	**Fri 27/02/15**	
105			**Records & Surveys - Existing Sites**	**70 days**	**Mon 05/01/15**	**Tue 14/04/15**	
113			**Site Modelling**	**100 day**	**Mon 30/03/15**	**Thu 20/08/15**	
118			**Robot Insertion & Extraction Device - Design**	**150 day**	**Mon 02/03/15**	**Fri 02/10/15**	
127			**Replacement Asset Carbon Footprint**	**70 days**	**Mon 30/03/15**	**Thu 09/07/15**	
132			**Formal Process Safety Assessments (FPSA)**	**40 days**	**Mon 07/09/15**	**Fri 30/10/15**	
137			**Project Concept Study**	**40 days**	**Mon 05/01/15**	**Fri 27/02/15**	

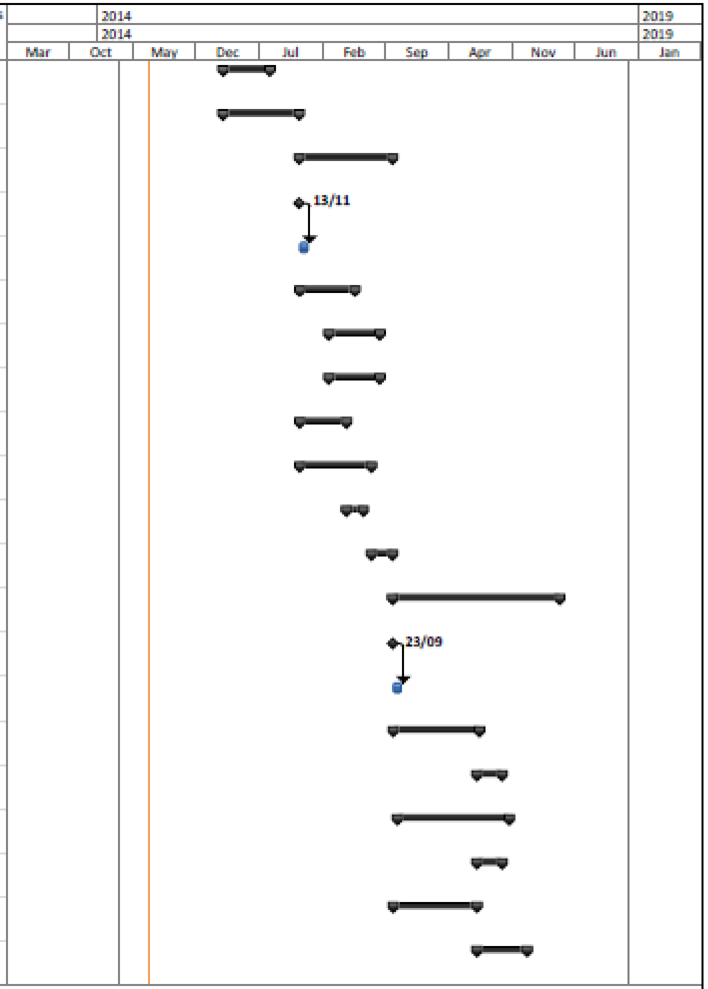


Project: NGNIC_Draft4
Date: Thu 26/06/14

Task | Summary | Inactive Task | Duration-only | Finish-only
Critical | Project Summary | Inactive Milestone | Manual Summary Rollup | Deadline
Split | External Tasks | Inactive Summary | Manual Summary | Progress
Milestone | External Milestone | Manual Task | Start-only

Page 1

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
154			**Alpha Prototype**	**110 day**	**Mon 02/03/15**	**Thu 06/08/15**	
172			**Stage 1 Completions**	**180 day**	**Mon 02/03/15**	**Fri 13/11/15**	
177			**STAGE 2: Development Testing**	**210 day**	**Fri 13/11/15**	**Fri 23/09/16**	
178			Commence STAGE 2	0 days	Fri 13/11/15	Fri 13/11/15	176
179			Update BoDD & Technical Strategy document	20 days	Mon 16/11/15	Fri 11/12/15	178
180			**Robot Insertion & Extraction points**	**120 day**	**Mon 16/11/15**	**Thu 19/05/16**	
188			**Robot inspection route drawings**	**120 day**	**Mon 22/02/16**	**Thu 11/08/16**	
196			**Site specific insertion & extraction device design**	**120 day**	**Mon 22/02/16**	**Thu 11/08/16**	
207			**Field Trial Design**	**100 day**	**Mon 16/11/15**	**Wed 20/04/16**	
215			**Beta Prototype**	**160 day**	**Mon 16/11/15**	**Thu 14/07/16**	
239			**Formal Process Safety Assessments (FPSA)**	**40 days**	**Thu 21/04/16**	**Thu 16/06/16**	
244			**STAGE 2: Completions**	**50 days**	**Fri 15/07/16**	**Fri 23/09/16**	
250			**STAGE 3: Field Trials**	**384 day**	**Fri 23/09/16**	**Wed 11/04/18**	
251			Commence STAGE 3	0 days	Fri 23/09/16	Fri 23/09/16	249
252			Update BoDD & Technical Strategy document	20 days	Mon 26/09/16	Fri 21/10/16	251
253			**Field Trial Procurement, Manufacture & Construction**	**200 day**	**Mon 26/09/16**	**Fri 14/07/17**	
258			**Field Trial Design updates**	**60 days**	**Fri 07/07/17**	**Fri 29/09/17**	
262			**Live site Inspection, Procurement, Manufacture & Constructio**	**260 day**	**Mon 10/10/16**	**Mon 23/10/17**	
267			**Live Site design updates**	**60 days**	**Fri 07/07/17**	**Fri 29/09/17**	
271	!		**Gamma Development**	**194 day**	**Mon 26/09/16**	**Thu 06/07/17**	
295			**Future Site Design Requirements**	**120 day**	**Fri 07/07/17**	**Fri 22/12/17**	



Project: NGNIC_Draft4
Date: Thu 26/06/14

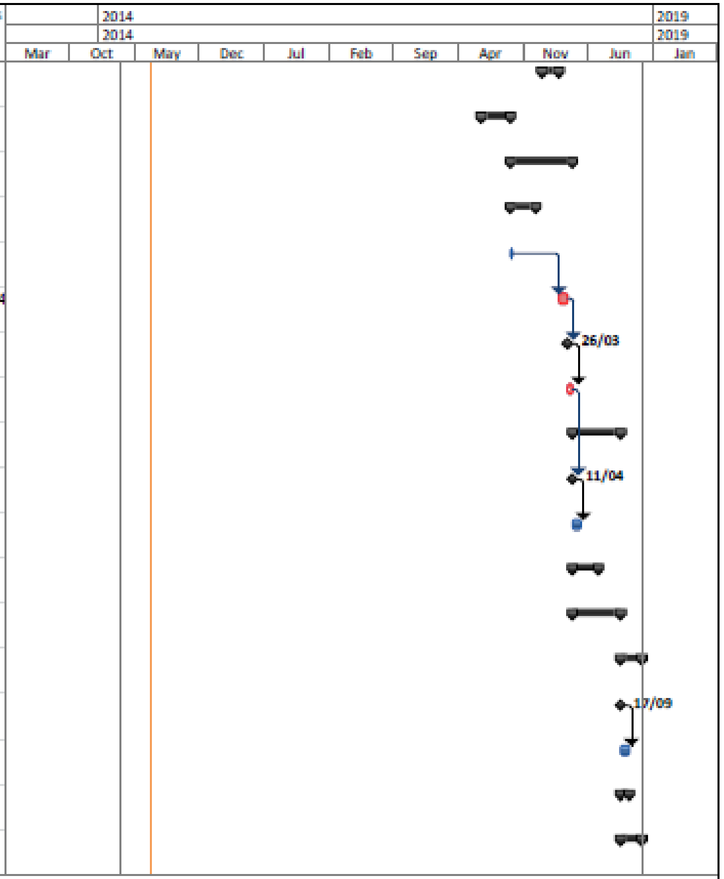
Task		Summary		Inactive Task		Duration-only		Finish-only	
Critical		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			

RIIO NIC NETWORK INNOVATION COMPETITION

Gas Network Innovation Competition Full Submission Pro-forma

Project Code/Version No:

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
300			**Inspection Carbon Footprint**	**40 days**	**Tue 02/01/18**	**Mon 26/02/18**	
305			**Delta Development**	**67 days**	**Fri 16/06/17**	**Tue 19/09/17**	
328			**STAGE 3: Completions**	**138 day**	**Wed 20/09/17**	**Wed 11/04/18**	
329			**Data assessment**	**60 days**	**Wed 20/09/17**	**Tue 12/12/17**	
334			Update risk register	5 days	Wed 20/09/17	Tue 26/09/17	327
335			Prepare & review STAGE 3 report	20 days	Tue 27/02/18	Mon 26/03/18	334,333,304
336			Submit STAGE 3 report	0 days	Mon 26/03/18	Mon 26/03/18	335
337			Prepare & hold Challenge & review meeting	10 days	Tue 27/03/18	Wed 11/04/18	336
338			**STAGE 4: Data Analysis**	**110 day**	**Wed 11/04/18**	**Mon 17/09/18**	
339			Commence STAGE 4	0 days	Wed 11/04/18	Wed 11/04/18	337
340			Update BoDD & Technical Strategy document	20 days	Thu 12/04/18	Thu 10/05/18	339
341			**Technology Completions**	**60 days**	**Thu 12/04/18**	**Fri 06/07/18**	
344			**STAGE4: Completions**	**110 day**	**Thu 12/04/18**	**Mon 17/09/18**	
354			**STAGE 5: Business Readiness**	**50 days**	**Mon 17/09/18**	**Mon 26/11/18**	
355			Commence STAGE 5	0 days	Mon 17/09/18	Mon 17/09/18	353
356			Update BoDD & Technical Strategy document	20 days	Tue 18/09/18	Mon 15/10/18	355
357			**Specifications**	**20 days**	**Tue 18/09/18**	**Mon 15/10/18**	
364			**STAGE 5: Completions**	**50 days**	**Tue 18/09/18**	**Mon 26/11/18**	



Project: NGNIC_Draft4
Date: Thu 26/06/14

Task	Summary	Inactive Task	Duration-only	Finish-only
Critical	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	

APPENDIX E

RIIO NIC NETWORK INNOVATION COMPETITION

Project Code/Version No:

Gas Network Innovation Competition Full Submission Pro-forma

PROJECT IMPACT REGISTER – NIC Submission

Key - Impact (1 to 5 – Low to High) x Likelihood (1 to 5 – Low to High) Low 1-7 Medium 9 -15 High 16-25

Project Impact					
Risk	Impact	Likelihood	Score	Rank	Mitigation/Control Measure
Development of an Robotic Platform to operate in a 100 barg environment to achieve a survey distance of up to 100m around up to 2 bends, taking visual and limited pipe condition data.	5	3	15	Medium	Possibility to operate at a lower pressure (up to 50 Barg)
On-site incident leads to cancellation of live trials.	4	1	4	Low	Alternative but similar site to be selected
Class 600 components not available for launcher construction.	3	2	6	Low	Order long lead items early in the design phase.
Offline Trial rig construction not available on time.	3	2	6	Low	Ensure robust plan is developed and agreed with constructor. Set time of completion with contingency buffer.
Cost of manufacturing trial rig is excessively high and not within budget allowed.	4	3	12	Medium	Estimated costing to be rigorously checked at conceptual stage.
Amount of modification work required at one or more of the live trial sites is beyond budget allowed.	3	2	6	Low	Look for savings that can be made elsewhere. Reduce number of live trials.
Robot is unable to operate within parameters required.	3	2	6	Low	Reduce parameters to acceptable levels
Live trial readiness levels lower than expected at time of trial.	3	2	6	Low	Postpone trial
Contamination within pipe causes loss of visual clarity during operation.	2	4	8	Low	Design of robotic system will mitigate this risk.

DESIGN PROJECT IMPACT REGISTER – NIC Submission

Key - Impact (1 to 5 – Low to High) x Likelihood (1 to 5 – Low to High) Low 1-7 Medium 8 -15 High 16-25

Description	Impact	Likelihood	Total	Total Risk	Notes
Robotic Solution Development					
Robot Platform to negotiate unpiggable pipeline up to 2 Barg	1	2	2	Low	Existing robotic platforms operate in this pressure range
Robot Platform to negotiate unpiggable pipeline up to 50 Barg	3	3	9	Medium	Existing Robotic platforms operate in this pressure range
Robot Platform to negotiate unpiggable pipeline up to 100 Barg	5	3	15	Medium	This is a complex robot design due to pressure complications but design of robotic platform is possible, but the scope of operation may be impacted e.g. Survey Distances, Wall Thickness Measurement, Bend Configurations
On board Robotic Tools (100 Bar Operating Environment)					
Visual CCTV Inspection	5	1	5	Low	Existing Technology
GPS and Location	3	3	9	Medium	Existing Technology
Optical Profiling	3	2	6	Low	Existing Technology increased complexity due to pressures
Wall Thickness Measurement	3	4	12	Medium	Limited technology in existence but it is not critical to the success of this project
Deployable Technology from Robot	3	4	12	Medium	Complex technology but may not be required
Control System Tethered	5	2	10	Medium	Existing technology
Control System Untethered	5	4	20	High	Complex communication and potential loss this is not preferred option see tethered
In Pipe Obstacles					
Distance up to 100m plus 2 bends	5	1	5	Low	Dependant on Bends
Distance up to 200m plus 4 bends	3	4	12	Medium	Limitation of Tethered System, increased risk of loss of robot
Unlimited Bends	1	5	5	Low	Not required to negotiate unlimited bends based on planned routes
Size Negotiations 24 to 36”	3	3	9	Medium	Feasible
Size Negotiations 36” to 48”	3	3	9	Medium	Feasible
Size Negotiations 24” to 48”	3	5	15	Medium	Complex design may not be cost effective solution
Process Drains / Thermo-wells	2	4	8	Medium	Could limit survey distance
Non Design / Development Risk					
Legislation	5	2	10	Medium	Safety cases etc
NGG Policy	5	1	5	Low	Will be a critical contributor to the project
Patents	2	3	6	Low	No critical patents identified
SGN/ULC NIC Project	1	1	1	Low	No conflict with this NIC project
Live Field Trials	5	2	10	Medium	Missing “live” trial window could delay project by 12 months
Robotic Launch, Pipe Planning, Test Facilities					
Design & Development of launch system for robotic platform	5	2	2	Medium	Technology Exists difficulty will be tether of robot
AGI Pipe Modelling and Route Planning	5	1	5	Low	No concerns – Premtech Core Competence
Design & Development of Offline Test Facility	5	1	5	Low	No Concerns - 3rd Party Construction
Overall Project Risk					
Overall Design Project Impact			15	Medium	Project is a medium design impact due to the complexity of the scope of operation of the robotic platform

APPENDIX F

WALES&WEST UTILITIES

Tamsin Kashap/Tony Stonehewer
National Grid Transmission
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

Wales & West House
Spooner Close
Celtic Springs
Coedkernew
Newport NP10 8FZ

Ty Wales & West
Spooner Close
Celtic Springs
Coedcernyw
Casnewydd NP10 8FZ

Telephone/Ffôn: 0800 912 29 99
Fax/Ffacs: 0870 1450076
Email/Ebost: enquiries@wwutilities.co.uk
www.wwutilities.co.uk

25th June 2014

Our reference:

Letter of support for NIC Project Proposal

Dear Tony Stonehewer

In response to your email of 17th June 2014, please accept this letter as support in principle to your NIC project proposal to develop a system for online inspection of High Pressure Installations using robotic systems and tools.

Internal inspection is recognised by the industry as the best means of assuring the continuing integrity of transmission pipelines but at the moment station pipework cannot be inspected with conventional in line inspection (ILI) tools.

Understanding the condition of your assets enables you to target your investment in a better way to manage risk effectively.

We look forward to learning of the developments made in this project.

Yours sincerely

Grant Rogers

Smell gas? Call us!
Arogli nwy? Ffoniwch ni!
0800 111 999
All calls will be recorded and may be monitored
[illegible]

ICS Institute of Customer Service

Wales & West Utilities Limited
Registered Office:
Wales & West House, Spooner Close, Celtic Springs,
Coedkernew, Newport NP10 8FZ
Registered in England and Wales number [illegible]

IGEM
Institution of Gas Engineers & Managers

23rd June 2014

National Grid Transmission
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

Dear Sir/Madam

Re: Network Innovation Competition 2014

We, at the, Institution of Gas Engineers and Managers, (IGEM), are delighted to provide our support and recommendation for your NIC project involving the inspection of high pressure assets using robotic technologies.

In particular the proposal sets out a 'first' for the UK Engineering community and places us firmly as leaders of innovation and excellence. We believe it will drive forward and cement the UK's reputation as a world leader for safety in the gas industry. Furthermore, we believe it will significantly extend the lifetime of the gas infrastructure assets as well as delivering significant carbon savings that will provide an overall positive impact on the UK economy.

At IGEM we believe that this type of collaboration, engineering excellence and innovative thinking is long overdue and have no hesitation in recommending and supporting your proposal.

Yours faithfully

Sarb Bajwa
Chief Executive Officer

Gas Network Innovation Competition Full Submission Pro-forma

Scotia Gas

National Grid Transmission
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

24th June 14

Dear Sir/Madam,

Re: Network Innovation Competition 2014

Thank you for the opportunity to comment on your NIC project 2014.

Having successfully implemented robotics into low pressure gas distribution pipework, we have seen at first hand the potential financial, operational and environmental benefits associated with this type of in-pipe technology. As you are aware, we have been recently awarded (2013) NIC funding for our own innovative robotics project, and have undertaken this in partnership with ULC Robotics, so can see similarities in the approach taken by National Grid Transmission in their partnership with Synthotech and Premtech. We have ourselves worked with Synthotech on a robotics and other innovation & technology projects under NIA.

It appears that this project will need to develop robotic technology which is, at present, unavailable across the NTS and all distribution networks both in the UK. The development of a robotic inline inspection device capable of inspecting complex pipework, operating at up to 100barG will face a number of unique and complex challenges. If successful however, it will potentially allow the network to operate at full capacity whilst conducting proactive and efficient asset management.

We do not think that this project conflicts with the above mentioned NIC awarded to our network for the following reasons:

1) Designed for Unpiggable pipeline configuration
2) Designed for significantly higher pressures (100barg)
3) Targeting inspection of asset condition only not remediation or replacement

We believe that there may be an opportunity to share some learning between both projects in relations to asset condition measurement methods. Although the pipeline operating environment will be very different due to the pressures involved, the sensors we are developing as part of our NIC project may be applicable, or there may be some learning from the sensor review we have completed. We will be submitting our SDRC 3 report in the coming months and will share the relevant outcomes.

We would also be happy to support technical peer review at the end of the project, and would invite you to do the same for ours.

Similar to the NTS, our transmission network is nearing the end of its design life and as such the requirement to conduct inspection to validate asset health is critical to maximising asset life and extending this asset life by demonstrable data.

Yours Sincerely

Angus McIntosh
Innovation & New Technology Manager
SGN

School of Mechanical Engineering
University of Leeds
Leeds, LS2 9JT
T +44 (0) 113 243 1751
T (Direct line) +44 (0) 113 3432156
F +44 (0) 113 242 4611

Dear Sirs,
The University of Leeds has a world class track record in robotics and has recently secured funds to form the EPSRC National Facility for Innovative Robotic Systems; a world class nationally focused £4.3M facility for designing and creating robotic systems. We have a very strong research theme in exploration robotics, which covers robotic systems designed to collect data and move in environments that are remote from, or inaccessible to, humans. Example research areas include: robots for live water pipe inspection, search and rescue robots, mine rescue robots and miniature mobile robotics for surgical intervention. One of our highest profile projects developed robotic systems to climb within shafts of the Great Pyramid of Giza, Egypt, discovering writing hidden for thousands of years. We also developed autonomous mobile robots that were finalists in the 2008 UK Ministry of Defense Grand Challenge.
I am delighted to confirm our support to Synthotech Ltd, for the Network Innovation Competition, to develop an online robotic inspection system for high pressure gas installations. Synthotech is a local, highly innovative company whose expertise aligns exceptionally with our research and the proposed project.
The challenges of operating robotic vehicles in pressure of up to 100 barg should not be underestimated. The pressure, combined with maneuvering in pipes of varying sizes that contain obstacles whilst performing visual inspection and material characterization, make this project extremely technically challenging.
I have a good knowledge of Synthotech, their technological capabilities, current projects and have no doubt they have the skills and capabilities and resource to undertake the work. We would be very pleased to work with Synthotech to contribute our technical knowledge and academic facilities towards this project.

Dr R.C.Richardson, CEng, FIMechE
Director of the EPSRC National Facility for Innovative Robotic Systems
School of Mechanical Engineering
University of Leeds
Leeds
LS2 9JT
Email: R.C.Richardson@leeds.ac.uk
19/6/2014

Therefore, I fully support this application and very much hope that it is successful.

Yours sincerely,

Dr R.C.Richardson

Tel. +44 (0) 191 2765300

262A Chillingham Road
Fax +44 (0) 191 2765451
www.pieuk.co.uk

National Grid Transmissions
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

Dear Sir / Madam

Re: NETWORK INNOVATION COMPETITION 2014

Pipeline Integrity Engineers (PIE) wish to formally record our support for the Innovation proposal by National Grid Transmissionin in respect to Online Inspections of High Pressure Installations Using Robot Systems and Tools.

Having had experience in R&D over many years in the Oil and Gas sector, we fully understand the importance of R&D initiatives that deliver new techniques and products which solve engineering challenges in a safe and cost effective manner.

The National Grid innovation proposal can make a significant contribution to the inspection and therefore integrity management of High Pressure installations in the UK. These installations have limited accessability, therefore any non-intrusive technique that can accurately and repeatedly inspect for damage or deterioration will have major benefits to UK industry.

Yours faithfully

G Senior
Director

20th June 2014

UKOPA

United Kingdom Onshore Pipeline Operators' Association

UKOPA Chairman
Ripley Road
Ambergate
Derbyshire
DE56 2FZ

20 June 2014

National Grid Transmissions
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA

Re: NETWORK INNOVATION COMPETITION 2014

We thank you for your invitation for United Kingdom Onshore Pipelines Association (UKOPA) to review and work alongside National Grid Transmission in the above mentioned application. UKOPA exists to provide the recognised and authoritative view of UK pipeline operators on strategic issues relating to safety management, operations and integrity management of onshore hydrocarbon pipelines. It seeks to effectively influence the development and implementation of pipeline-related legislation and standards for the mutual benefit of all stakeholders and promote safety and best practice in the pipeline industry. As such we actively encourage innovative new ways for all oil, gas and petrochemical pipeline operators to improve their maintenance and safety procedures. This then helps to reduce costs to all customers as well as decrease the pipeline sector's carbon footprint.

It is reassuring to see National Grid Transmission working with two carbon neutral companies (Synthotech and Premtech) to generate a new, ground breaking, in line inspection robot which can operate effectively within pressures of up to 100bar. Given that this technology is simply not available at present and the current methods of inspection at Above Ground Installations (AGIs) are inconsistent and often inaccurate (necessitating the occurrence of premature and unnecessary excavations), it is encouraging to see that a more intelligent solution to AGI inspection is being invented which we believe will have wider use within the oil, gas and petrochemical industry.

Yours faithfully,

Roger Ellis UKOPA Chairman

Project Code/Version No:

National Grid
Hinckley
Brick Kiln Street
LE1O ONA
Office (Ext): 01926 654893
e-mail: steven.vallender@nationalgrid.com
National Grid Transmission
National Grid House
Warwick Technology Park
Gallows Hill
Warwick
CV346DA 10July14

Dear Sir/Madam,

Re: Network Innovation Competition 2014

National Grid Distribution is delighted to offer support to National Grid Gas Transmission in respect of their in-line inspection of high pressure installations robotics project.

Our Gas Distribution Network (GDN) is comprised of complex pipework and has over 596 AGIs which are pressured at >7barg. Similarly to the NTS it is nearing the end of its asset life and as such the requirement to conduct inspection, maintenance and repair is becoming ever more important. Current reliance on survey based asset management and ad hoc, occasionally unnecessary excavation is inefficient and expensive. We would prefer to in-line inspect our high pressure assets if the technology became available and we believe that given some modification, this in-line inspection robot could be transferred onto the GDN network. We believe that this technology will not only significantly increase the lifetime of our infrastructure assets but will deliver carbon savings which will contribute to National Grid's commitment to reduce carbon emissions in line with the UK Government's Carbon Plan.

We are also extremely keen to share knowledge and learning with National Grid Gas Transmission. We believe that they have a robust knowledge dissemination plan and are committed to sharing best practise and look forward to sharing in this innovative thinking and engineering excellence.

Yours faithfully,

Stephen Vallender
National Grid Network Innovation and Investment

APPENDIX G

NIC Technology Watch Overview- On-Line Robotic Inspection of High Pressure Installations
Ref – FO8/GTW/OV/0614 Version 2

Introduction - This document illustrates the technology watch that has been completed as a precursor to the NIA submission of the F08 project. The tech watch is broken down into four main areas of investigation: Motion, vision, condition assessment and location tracking.

1 Motion

Various different methodologies are used for the transportation of robotic systems along pipelines. Basically they can be split into two options, powered and non-powered. Powered systems almost all use electric motors actuating either wheels or tracks. The main differences come from the size of the technology, and the technique used to maximise the traction. The non-powered systems use the flow of the pipeline or a differential pressure created to propel the device along the pipe.

1.1 Self-Propelled Systems

1.1.1 Wall Press

Wall press drive systems exert mechanical force through the areas where the drive system contacts the pipe in order to increase the friction level between the two and hence allow a higher tractive drive force to be applied. Many wall press systems also claim to have improved stability over free-gravity traction systems, and have other benefits including the ability to rotate along the pipe axis, and pull a greater load.

1.1.1.1 ULC Robotics – CISBOT

A robotic unit that is capable of repairing and sealing cast iron joints. CISBOT uses a wall press system with 3 wheels to traverse 16” to 36” mains. The robot is also capable of rotation in the pipe. A maximum travel of distance 300m. The system is not specifically designed for negotiating bends and would struggle to operate around multiple bends.

1.1.1.2 IBAK - MultiGator

*A robot designed for sewage pipe inspection and repair.*The IBAK MultiGator and ifs family of robots utilise a unique system of inflatable bags between the wheel sets that when inflated; exert a force which acts through the wheels and increases friction to produce a reliable grip in a range of pipe 230-800mm in diameter.

1.1.1.3 Inspector Systems – INSPECTOR Type 6000

Pipeline inspection robot for 440-750mm diameters, All three of the robots drive modules have eight wheels. These all press into the wall of the pipe and can provide propulsion in vertical pipelines. The system is capable of up to 500m travel distance. Pipe bend negotiation is achievable with a bend radius of up to 1.5D and 90 degree swept bends can also be negotiated. The robot is not steerable at a tee junction.

1.1.1.4 Pipetel - Pipeline Explorer

An un-tethered remote-controlled robot for inspection of underground gas mains, Multiple drive units along the length of the system, with small articulated modules allow for manoeuvrability through piping including 90° bends. Parts of the system are patented. The robot also has multiple sensor arrangements for in pipe measurements including deformation sensors and magnetic flux leakage. This system is the closest to the NIC brief but does not meet the required specification in terms of pressure rating. It is also unclear how the robot would cope with wireless command controls in the pipeline environments envisaged for the project.

1.1.1.5 Rosen – Robotic survey system

Unpiggable pipeline solutions, Rosen have many years of experience in the unpiggable pipeline industry. They have multiple robotic platforms for use in different pipe environments with a complete array of modular sensing systems that can be deployed for in pipe analysis. The robotic platforms have wheels in various wall press formats to create drive and enable it to stay stable in gas or liquid flow. The smallest is the Robotic Helix tool. This uses a helical drive with MFL sensors to assess multiple bend pipelines. Bigger systems include the RSS or robotic survey system. This is configurable for pipelines in the survey size of the NIC project. The system is limited to 1.5xD bends but can operate in pipes with high levels of debris in up to 20 bar pressure.

1.1.1.6 Foster-Miller - RoboScan™ Inspection Robot

A "modular transformer" concept robot that is polymorphic and adapts to its surroundings. The robot was designed to travel through smooth bends (1.5D<), mitred bends and tees through its unique 'triad' (the triplet of wheels) based design. The 'curling link' between modules actuates a motion the manufacturer had named 'preferential curl' which helps the robot navigate bends. This robot was proposed to travel through unpiggable pipes as per the NIC project. The project was cancelled in 2004.

1.1.1.7 Kiwa Gas Technology – Pirate

Development of an autonomous gas distribution system inspection robot, The technology was developed for small diameter pipe. The technology has not been developed into a commercialised solution.

1.1.1.8 Diakont - ILI RODIS

Pipeline inspection and multi sensor platform, The inspection robot performs a comprehensive pipeline examination in a single run, measuring wall loss, dents, corrosion and visual data. The robot can navigate mitre bends and unbarred tees, traveling up to 1300 ft. It is unclear if the platform can operate under pressurised conditions.

1.1.2 Free weight

The following robotic platforms use gravity to create traction and drive themselves. These systems are well suited to larger pipe diameters involved in the project. However the gas flow and pressures involved will rule out most existing systems in the market. These would likely require a robot to use some sort of clamping force to prevent it from being uncontrollable in the pipe. Many of these style devices are in use in the drainage industry.

1.1.2.1 ULC Robotics - Large VGC Crawler

Variable geometry crawler for pipe inspection, Uses variable geometry to adapt to pipeline diameter and geometry ranging from 20" to 48" pipes. The system has a 250 metre maximum travel distance from the insertion point. The system was developed for use in gas distribution mains but could not be used in the pressure range of this project.

1.1.2.2 RedZone - Solo

Autonomous pipeline inspection robot for use on sewage pipes, The robot is designed for use on 8-12" diameter pipes. This amount of autonomy would be complex to setup for the intended NIC project. The design is set to run from A-B along relatively straight runs without complex obstacles to overcome.

1.1.2.3 RedZone - Responder

Autonomous pipeline inspection robot for use on large diameter sewage pipes, This is the larger version of the solo robot designed for 36" and larger drains. This comes with multi-sensor inspection, combining conventional CCTV with synchronized laser and sonar dimension information.

1.1.2.4 Synthotech - Synthotrax

Pipeline Inspection Robot for gas pipelines, Tracked pipeline-inspection robot, capable of surveying up to 500m from one vertical 'live' launch excavation. Pipelines ranging in size 12" to 48" can be surveyed up to 2 barg pressure. System developed for use primarily in the UK distribution network. Full pan and tilt camera control. The system has also been developed to include profile laser scanning of PE pipe butt weld beads for condition assessment.

1.1.2.5 Adroctech - ADX

Robot for visual inspection of pipes and reactor vessels that are under water, The robot is capable of only 50m of travel in pipe sizes above 200mm in diameter.

1.1.2.6 Inuktun - Versatrax

Pipeline Inspection Robot family, The system uses modular track units and cameras that can be adapted to different pipe scenarios. Some setups allow long distance surveys (up to 2km), others allow for vertical climbing and multiple bends in various pipe sizes. This means the system falls into the free weight and wall press categories. This will be a key feature to the NIC project, allowing different configurations of the platform depending on the in pipe environment encountered.

1.1.2.7 AM Industrial - SP300 MaxiCam

Crawler systems for visual pipe inspection, AM Industrial produce robotic systems using 4 large wheels. Pipe sizes can vary from sizes 225-2000mm. Many other companies produce similar crawler robots for this purpose.

1.1.2.8 Inspector Systems – MAKRO plus

Untethered manoeuvrable service robot, Drive wheels on short modules allow the robot to fit round the maximum bend radius. The robot is primarily designed for small diameter pipelines outside the scope of the NIC project.

1.1.2.9 Quest Inspar – Robotic Lining Systems

A tethered remote-controlled robot for coating pipelines from 6" to 36" in diameter, Drive system features tracks at a high level of camber similar to the Inuktun system, but on a much larger scale. It is unclear if this can be used in pressurised pipelines.

1.1.2.10 Pure technologies – PureRobotics

Water and Sewage pipeline surveying robot, The inspection system consists of a modular, long-range, multi-sensor vehicle that is capable of providing a wide variety of high quality data. The robot is not designed for under pressure applications but does use a fibre optic tether for fast data connection speeds.

1.2 Other Propulsion Techniques

The most common other type of motion would be a push rod system. These are in common use for many pipeline activities. The other kinematic systems of the robots include telescopic systems and other novel technologies that are available for moving robotic systems.

1.2.1 Push Rod Systems

Push rods are limited in the travel distance attainable in the pipe sizes for this project.

1.2.2 Intelligent Pigs

1.2.2.1 Quest Integrity Group - InVista™ and HYDRA™

Lightweight intelligent pig platform, The InVista system is Capable of detecting pipeline wall loss and corrosion in unpiggable or difficult-to-inspect pipelines. It can navigate most bends apart from mitered joints. The system does not have any steering control and would therefore not be suitable for many of the pipe configurations envisaged for the NIC project. The system can inspect 6-24 inch mains. As the system is pig based it uses the pipeline pressure differential created to travel.

1.2.3 Novel Pipeline Motion Systems

1.2.3.1 Pipecrawlers - tethered intervention crawler

Unpiggable pipeline robot with brush drive, The intervention robot uses a brush drive system to travel along the pipe there are some patents on this technology. This enables the device to travel forwards and backwards in the pipeline. The device can traverse bends but little information is available on how many or what radius it can achieve. The system carries multiple sensors to scan the pipeline. These can be daisy chained together to add as many functions as required. The systems also has the pressure and travel distances required by the NIC project.

1.2.3.2 OC Robotics - LaserSnake2

A snake-arm mounted laser cutter for use in confined and hazardous spaces.

1.2.3.3 AIST – MTRAN3

A "modular transformer" polymorphic robot that adapts to its surroundings, However the technology is at an early stage of development and would be very complex to develop.

1.2.3.4 TiTech – SSR (Slim Slime Robot) or Active Cord Robot (ACR)

A tethered, remote-controlled, snake-like robot that has not been used in the application of pipelines, Drive system uses pneumatically actuated sections to achieve peristaltic locomotion and can perform a variety of movements including snake-like glides, "pedal waves", lateral rolling and pivotal turning. This robot has patented technology.

1.2.3.5 4 front Robotics - Cricket UGV

Walking robot with track feet, Highly articulated and reconfigurable robot for operations in complex confined spaces. This robot is suitable for numerous operations including search & rescue and sewer and pipeline inspection. The robot is able to adapt its moving mechanism (e.g.walking gate) and reconfigure according to the terrain. Using a sophisticated 3D control and navigation algorithms this vehicle can go up ladders, manoeuvre inside pipelines navigating around difficult obstacles. The system is not designed for pressurized environments but the agility of the platform would be perfect for the NIC robot.

1.2.3.6 SRI International - Electroadhesive robot

Newly developed system, featuring novel technology to stick to surfaces and move across them, The electroadhesion system is capable of holding up to 1.4N per square centimetre. Technology has not currently been used in pipelines and is still under development. Some Patents exist on this type of technology.

1.2.3.7 NR21 - C-Bot

Gecko inspired wall climbing robot, Based on biomimetics, it uses a gecko-inspired innovative foot design as a template to climb walls without any artificial adhesion. The robot is intended to carry ultrasonic sensors to scan objects for defects. There are many wall climbing robots in development but none have any real value as commercialized products yet. The technology used in these platforms should be looked at closely for the project, as some might be useful for the NIC platform to enable it to be better controlled and stabilized in the pipeline.

1.2.4 Magnetic Pipeline Crawlers

1.2.4.1 ULC Robotics - MMC

Robot used to inspect the annular space in lined pipes, Robot uses magnetic casing and tracks to 'stick' to the pipeline and travel along it. 85m maximum travel distance. The MMC robot for use in the annular space between pipelines hosts sensors to detect wall thickness of the interior pipe (using an ultrasonic thickness gauge), as well as the temperature and humidity of the pipe annulus. The use of ultrasonic testing equipment may be relevant to the NIC. However the robot would only be able to inspect a small section of the pipe in a reasonable timeframe.

1.2.4.2 Inuktun - NanoMag

Magnetic robot used to inspect steel pipelines, The NanoMag is a miniature crawler system with built-in rare earth magnets, allowing it to travel vertically, horizontally and even upside down on ferrous metal surfaces. The robot has a maximum travel distance of 30m. Both the NanoMag and MMC systems do not have the range or pressure rating required for the project but could potentially be developed to enable this technique to work.

1.2.4.3 Honeybee Robotics - Pipe Inspection Robot

Robot used to inspect the annular space in lined pipes, This robot is currently still under development by Honeybee Robotics.

1.3 Motion Systems Matrix

A matrix of motion systems technologies has been created from the review above. This table simply shows how effective each system is and its possible relevance and compatibility with the project.

Motion System		Suitability Criteria												Total Score
		24-42" Pipelines	Metallic Pipelines	Variable Speed	Steerable	Climb Steep Gradients and	Against flow	High pressure & High Flow	Negotiate Parallel Barred	Mutliple Bends	Torque	Range	Payload Capacity	
Wall Press	Dual-contact	4	4	4	4	4	4	3	0	4	3	3	4	**41**

	Multi-Contact	4	4	4	4	4	4	4	0	4	4	3	4	**43**
Free weight	**Wheeled**	4	4	4	4	0	4	0	4	4	1	3	3	**35**
	Tracked	4	4	4	4	0	4	0	4	4	2	3	3	**36**
Push Rod	**Manual**	4	4	4	4	2	4	2	4	2	1	2	2	**35**
	Propelled	4	4	4	4	3	4	3	4	2	2	2	2	**38**
Pig		4	4	0	0	4	0	4	0	4	3	4	4	**31**
Telescopic		4	4	4	4	4	4	2	4	4	4	0	2	**40**
Walking		4	4	4	4	2	4	3	4	4	2	3	2	**40**
Magnetic	**Wheeled**	4	4	4	4	4	4	1	4	4	2	3	3	**41**
	Tracked	4	4	4	4	4	4	3	4	4	3	3	3	**44**

0 (Not relevant, 1 (Relevant), 2 (Effective), 3 (Very Effective) 4 (Optimum Solution)

1.4 Motion Systems Conclusion

Upon brief assessment of the above criteria, the most suitable technologies appear to be wall press, magnetic, telescopic and walking systems.

2 Vision

Vision is a key feature of almost all of the robots. Collecting visual data may be the sole purpose of the robot, or it can be used to help the operator perform tasks such as navigate and locate scanning equipment. Most units feature standard cameras with LED lighting or pan and tilt camera systems. Some systems feature novel use of technology in conjunction to these standard technologies.

2.1 Cameras

There are two main categories of video camera available today, namely digital and analogue. The former is the type familiar to USB webcam users and mobile smart phone users. The latter will be familiar to security and CCTV users. The difference relates to how the signal is presented to the outside world.. For the NIC project a HD camera would most likely be linked to on-board computing, to enable the high data rate to be sent over long distance via either broadcast quality TV techniques or fibre optics.. The NIC project should allow a space envelope to allow adjustable focus and optical zoom functionality to maximise picture quality.

2.1.1 Digital Camera

Camera technology used to provide live video pictures from inside the pipe. Digital cameras are now commonplace and the quality of picture produced have improved massively over the last 10 years.

2.1.2 Analogue Camera

Camera technology used to provide live video pictures from inside the pipe, Video cameras which provide an analogue video output (often referred to as CVBS – Colour Video Burst and Sync) are available in three main technologies: CMOS, CCD and CCIQ. These can be purchased as complete units, often containing LED's for illumination..

2.1.3 CCD Board Camera

Charged Couple Device Board cameras are commonplace; a trade-off has been made regarding size and picture quality.

2.1.4 CMOS/CCIQ Board Camera

CCIQ and CMOS cameras process the image within the sensor, making miniaturisation of the technology possible. This is where most of the development has occurred in analogue camera technology.

2.2 Vision Systems

2.2.1 Infrared Camera Systems

Infrared Cameras are used to image infrared radiation, Infrared camera systems can be used to form images of temperature differences and changes. This can be used for leak detection by looking for the temperature change associated to the pressure drop.

2.3 Machine vision

Machine vision features an image capture device, a control system and a system(s) actuated relative to the captures, Machine vision is often used instead of a human operative, relative to financial/safety constraints. Machine vision systems can recognise shape, text, barcodes, location and measurement amongst other features.

2.4 Control Link

This section can essentially be split in two tethered and untethered robots. The tether connects the robot to the control unit allows data and power transmission between the two. If a robot is untethered any power needs to be stored on-board.

2.4.1 Tethered cables

2.4.1.1 Reinforced Electric Cable

Technology used to provide power to the robot and live video and data transmission from inside the pipe, Manufacturers of cables designed specifically for applications such as this exist. As pipe robot technology differs for every end process, so, too, does the power and signalling requirement. Therefore cables are custom made, and existing cables will be specific to other manufacturer's specifications and are therefore not compared in this report.

2.4.1.2 Fibre Optics

Technology used to provide communication to and from the system inside the pipe, Many solutions for integrating fibre optic communications into any given application exist. The advantage over other data methods using wires are generally much faster data speed can be achieved over greater distances travelled.

2.4.1.3 Wireless

Technology used to provide communication to and from the system inside the pipe, Wireless systems could in principle work for this project. Any robot using a wireless system would need to store power on board for drive and any other functions to be carried out. Examples of wireless systems are Inspector Systems and Pipetel. Red zone also have autonomous technology built into their robotic platforms.

2.5 Camera Conclusions

It is difficult to draw up matrices or conclusions from the investigation into camera technology without further research into the specific requirements of the system. Furthermore, some information will not become apparent until later in the design process. It is likely that off-the-shelf technologies will be used in combination to make a complete solution.

3 Condition Assessment

3.1 Magnetic Field Inspection Techniques

3.1.1 Magnetic Flux Leakage (MFL)

Magnetic Flux leakage has been used to assess the condition of metallic pipelines for many years. The system works by magnetising the ferrous metal pipe, and analysing the magnetic flux fields that are 'leaked' by using Hall-effect sensors (specifically a longitudinal field path). Eddy current sensors can be integrated to improve differentiation between internal and external defects.

3.1.2 Transverse Field Inspection (TFI)

Transverse field inspection is the name given to MFL when it is used circumferentially within the pipe (by inducing a circumferential field path).

3.1.3 Multi-axis MFL

Multi-axis MFL has been developed and used for pipeline inspection systems. It is particularly useful for assessing spiral-welded pipe.GE Energy use a 'MagneScan Triax' system that boasts three axes of fault detection. Spiral magnetic flux leakage (SpirALL or SMFL) is another methodology (patent pending by TD Williamson) that incorporates the advantages of both MFL and TFI.

3.1.4 Eddy Current Techniques (ECT, RFEC and SLOFEC)

Eddy current testing (ECT) is a similar technique to MFL but uses electromagnetic induction to detect flaws and as such, non-ferrous materials can be inspected with this technology as well as ferrous.

3.1.5 Magnetic Particle Inspection

Magnetic particle inspection is a method of inspecting ferromagnetic materials to detect surface and slight subsurface defects. The system works by magnetising the pipe, and then applying magnetic particles to the pipe surface. Where there is a magnetic flux leakage, the particles will be attracted causing a build-up – this is an indication of a fault.

3.2 Sound Wave Inspection Techniques

3.2.1 Electromagnetic Acoustic Transducer (EMAT)

Electromagnetic acoustic transducers use a form of ultrasonic technology to assess pipelines, using sound and echoes. The sound waves are generated in the material and therefore no liquid medium is required.

3.2.2 Ultrasonic (UT)

Ultrasonic testing uses soundwaves and echoes similarly to EMAT, but can only be done using a liquid medium (and is therefore not relevant to gas pipelines).

3.2.3 Acoustic Pulse Reflectometry

This method of inspection involves propagating a wave along the pipe, and analysing the reflections. This differs from EMAT and UT as the soundwave is delivered axially, through the pipe rather than radially. This limits the system to internal defects. The Acoustek system has been developed in conjunction with the University of Manchester, which claims a max pressure of 345bar in static or flow conditions, suitable for metallic or plastic pipe with a range of up to 10km from one access point.

3.3 Visible and Near-Visible Light Inspection Techniques

3.3.1 UV Inspection (Ultraviolet) and Fluorescent Penetrant Inspection (FPI)

Ultraviolet inspection systems have been used alongside Magnetic Particle Inspection (MPI) and Fluorescent Penetrant Inspection (FPI) for the internal diameter of landing gears and other cylindrical components; this could also be used for pipeline inspection. Shockform offer the UV-Inspect system that is specifically designed for landing gears.

3.3.2 Axial Laser Scanning

Laser scanning uses light to measure distance (similarly to Radar, but with visible light instead of radio waves) by illuminating the pipeline with a laser and analysing the reflected light. The system can detect geometry flaws and can produce a 3D model of the entire pipeline. This methodology can be used to detect pipe ovality and other, larger, geometric faults such as dents.

3.3.3 Circumferential Laser Scanning

Synthotech have developed their own laser scanning system for the inspection of PE pipelines. This laser scans the pipe circumferentially (with the camera at ninety degrees to the axial direction) to identify faults in weld beads and accurately check ovality of pipe.

3.3.4 Shearography

Shearography or speckle pattern shearing interferometry is a laser based interferometric technique that is sensitive to out-of-plane deformation of a surface. Under the action of a small load, the structure is deformed and the presence of defects is revealed by local strain singularities. This technique has been investigated for its potential use with gas pipelines by SPIE (the International Society for Optical Engineering) and has been used for piping in nuclear power plant facilities.

3.3.5 Infra-Red (thermography or IR)

Infra-red inspection technology or thermography offer non-destructive testing for a variety of defects. There is a variety of techniques including pulsed flash, pulsed transient and lock-in that differ in sensitivity and test duration.

3.3.6 Microwave Inspection Techniques

Oceaneering have developed a microwave inspection technique that can detect flaws (particularly in butt welds) in PE and other non-ferrous pipelines. The technique is done in a similar way to ultrasonic testing, but using microwaves rather than sound waves.

3.4 Ionising-Radiation Inspection techniques

3.4.1 X-Ray Inspection

X-rays have been used for pipeline inspection recently, and some are still under development. At present x-ray systems have limitations and difficulties, as the exposure film must be on the other side of the pipeline to the radiation source. This requires access both internally and externally (or at two points externally).

3.4.2 Gamma Ray Inspection

Gamma rays have also been used in radiography inspection of pipelines, similarly to x-rays, but are yet to be used from internally (within the pipeline). The main difference between gamma rays relates to the production of the rays (either from electrons or the nucleus) and there is little difference in the inspection technology.

Mechanical Inspection Techniques

3.4.3 Caliper Technologies

Caliper inspection systems measure the interior geometry of the pipeline mechanically. A series of sensors detect when the wheels are depressed by defects, or other pipeline geometry, this is done around the full circumference of the pipe for maximum fault detection.

3.5 Condition Assessment Matrix

A matrix of condition assessment technologies has been created from the review of technologies. This table simply shows how effective each system is and its possible relevance and compatibility with the project.

Defect Group	Macro-fault						Micro-fault								
Defect Type	Geometric Faults				Mechanical damage		Cracks			Metal Loss		Other			
Pipeline Defect / Inspection Technology	Ovality	Dents	Buckles	Pipe misalignment	Internal gouges, grooves and other mechanical damage	External gouges, grooves and other mechanical damage	SCC cracking	Circumferential cracks	Axial cracks	Internal corrosion	External corrosion	Laminations and inclusions	Relevance to F08	Total Score	Rank
MFL	0	4	4	0	4	0	2	4	0	4	0	0		22	3
TFI	0	4	4	0	4	0	2	0	4	4	0	0		22	3
Multi-axis MFL	0	4	4	0	4	0	2	3	3	4	0	0		24	1
ECT	0	0	0	0	3	2	4	3	3	4	4			23	2
MPI	0	0	0	0	0	4	2	2	2	0	3	0		0	
EMAT	0	1	0	0	1	1	3	3	3	4	4	4		24	1
UT	0	1	0	0	1	1	3	3	3	4	4	4		0	
APR	0	3	2	2	3	0	0	0	0	3	0	0		13	6
UV and FPI	0	0	0	0	4	4	3							0	
Laser Scanning	4	4	4	3	3	0	0	1	1	1	0	0		21	4
Shearography	0	3	2	0	2	2	2	2	2	0	0	4		0	
IR	0	1	1	0	4	4	0	1	1	4	4	4		0	
Microwave	0	4	4	0	3	3	0	0	0	3	3	4		0	

X-ray	0	3	3	1	3	3	0	2	2	3	3	3		**0**	
Gamma	0	3	3	1	3	3	0	2	2	3	3	3		**0**	
Caliper	4	4	4	3	1	0	0	1	0	0	0	0		**17**	**5**

0 (Not relevant, 1 (Relevant), 2 (Effective), 3 (Very Effective) 4 (Optimum Solution)

3.6 Condition Assessment Conclusion

Many relevant technologies will provide different levels of defect detectability. It is likely that a combination of technologies will be used together to cover a wider range of defects. A complete solution could comprise of EMAT, MFL and laser scanning. This would cover almost every defect – however it may become apparent that some defects are less likely to occur and are less severe, resulting in a lower risk.

4 Location Tracking

Tracking the location of the pipeline assessment tool will be necessary to give information regarding the location of any defect or fault found in the pipeline. This can be done in several ways; the simplest way is to measure the distance from the insertion point as odometers do. This technique is fine for straight pipelines but multiple bends become increasingly hard to track, especially if poor/no plans are available of the pipe network. Other more sophisticated systems use a variety of technologies together to give detailed location data.

4.1 Radio Location

Radio-location is the most prevalent location technique used within the gas industry at present, although many other techniques do exist. Sonde is commonly used on pipeline crawlers and in camera systems.

4.2 GPS Entry/Exit

The location of the inspection system's entry point can be pinpointed very precisely and accurately using GPS. This is usually done with a sensor in the pigtrap, or other similar insertion system. This does not track the inspection system in any way, and only records the global location of the entry point. The RedZone robot platform also has this technology built in to enable pipe mapping.

4.3 Odometer

One of the simplest methods is to use rotating wheels that contact with the inner wall of the pipe, and measure distance in the same way as a car. This technology is often built-in to caliper systems in pigs.

4.4 Tether Meterage

A method of tracking a tethered system is to use an odometer directly on the cable, and measure the length of the cable that has been pulled from the reel. This can also be done by measuring the number of rotations that the reel has completed.

4.5 Acoustic Tracking

Acoustic tracking systems use a sensitive microphone and amplifier setup to allow a pig to be heard from up to 2 miles away. This system has limited functionality, and offers little data on the in-line-inspection tool's location and distance. This system can also be used in liquid pipelines.

4.6 External Sensors

External sensors can be attached to specific points on the pipeline (this may or may not be intrusive), and confirm whether the inspection system or pig has passed that point. This system uses some form of transmitter/receiver set up which is often magnetic.

4.7 Electromagnetic Tracking Systems

Wireless transmitters and receivers can be used to track pigs and other inspection systems in pipelines which are particularly useful for subsea systems.

4.8 Magnetic Field Positioning

Magnetic positioning is a method used in IPS's (indoor positioning systems) but is limited in that a map of the area's natural magnetic field must first be mapped in order to measure the current position against. If the magnetic field at the ground surface corresponded closely enough to that under the surface in the pipe, GPS could be used to build the map at ground level. It is likely that the metal pipe will completely change the magnetic field within it against that at the ground – rendering this technology somewhat unusable.

4.9 Radio Triangulation

Radio waves can penetrate the ground to a limited degree hence the use of sondes within pipes and detectors at ground level to follow the signal. However to gain an accurate position through triangulation would require several signal sources spaced apart around the pipe. The volume of earth these signals would need to pass through before reaching the robot may well distort and attenuate them to such a degree that they become undetectable or unusable. Radio waves are also heavily attenuated by metal objects so passing through a metal pipe may also render them undetectable or unusable.

4.10 Inertial sensors

Using inertial sensors (gyro sensors and accelerometers together) within the pipeline allow for the inspection system to be aware of its geo-referenced position with a spatial uncertainty of less than 1m.

4.11 Combination of technology

Combining GPS entry with odometer and inertial technology can provide a total location solution. Baker Hughes offer a system with this triad of technologies that calculates a GPS coordinate for anomalies and features found in the pipeline to an accuracy of within 1m. Enduro pipeline services use GPS equipment that profiles and maps the pipeline using twin gyros to give angle and direction readings on all bends.

4.12 Location Tracking Matrix

A matrix of location tracking technologies has been created from the review of technologies. This table simply shows how effective each system is and its possible relevance and compatibility with the project.

Tracking / Location Technology	Defect Tracking: Global coordinate position	Defect Tracking: Distance from entry	Pipeline Tracking: Global coordinate position of features	Pipeline Tracking: Corner recognition	Pipeline Tracking: Corner angle and direction recognition	Pipeline Tracking: Height and/or depth of pipeline	Pipeline Tracking: Length of pipeline	Relevance to F08	Total Score	Rank
GPS entry	0	0	0	0	0	0	0		0	
Odometer	0	4	0	2	2	0	4		12	4
Acoustic Tracking	0	1	0	0	0	0	0		0	
External sensors	1	1	1	0	0	0	0		3	6
Electromagnetic tracking	3	3	0	0	0	0	0		6	5
Gyro sensors	0	1	0	4	4	4	1		14	3
Combination Technology										
GPS and odometer	4	4	4	2	2	0	4		20	2
Gyro and odometer	0	4	0	4	4	4	4		20	2
Gyro, GPS and odometer	4	4	4	4	4	4	4		28	1

0 (Not relevant, 1 (Relevant), 2 (Effective), 3 (Very Effective) 4 (Optimum Solution)

4.13 Location Tracking Conclusion

Location is of paramount important when inspecting the pipeline. It is apparent that in the specific case of this project, the pipeline geometry is well known and documented – but knowledge of the inspection system's location within this geometry is still necessary.

5 Overall Conclusion

At present, it is unclear as to which technologies are likely to be used. It can be said with some confidence that:

- A bespoke motion-system will be developed using some form of wall-press technique and/or magnets.
- A multitude of cameras will be used, these are likely to be off the shelf – and adapted to work with the requirements of the system.
- The condition assessment technology will be dependent on the carrier of the payload - a full-bore wall-press system is much better suited to delivering MFL technology than a partial-bore walking system.
- Location technology will also be dependent upon the motion system – an odometer cannot be used without wheels or a tether.

APPENDIX H

yeadon IP

G300955: AGI Project Patent Report
Synthotech Limited ('the Company')

EXECUTIVE SUMMARY

Preliminary patent searches have been conducted to assess freedom to operate in respect of the inspection of unpiggable pipelines. One aim of the search was to identify technologies relevant to the inspection of unpiggable pipelines that offer no freedom to operate limitations. A further aim of the search was to obtain an overview of the state of the art in respect of unpiggable pipeline inspection. Our preliminary conclusions are that there is good scope for the Company to develop inspection technology for unpiggable pipeline systems with freedom for the Company to make, sell and use the technology in the UK.

Background to Patents and Patent Searching

The patent system is designed to enable the owner of a granted patent to stop third parties from working an invention without consent for a period of up to 20 years from the filing date of the patent application. When developing or launching a new product, two important considerations should be borne in mind in order to make use of, and avoid falling foul of, the patent system. They are:

(i) Could one or more aspects of the product be patentable; and
(ii) Might a third party already have a patent that could stop the product from being sold in the territories of interest, i.e. is there 'freedom to operate' in respect of manufacture, sale and use of the product.

To address question (i), the merits of patent protection for the product should be considered including a review of the 'prior art'. The prior art includes any publicly available disclosures made prior to the filing date of a patent application including written or oral disclosures in any language, anywhere in the world. Once granted, a patent may be used to prevent others from taking unfair advantage of the investment of time, resources and funds made by the patentee in developing the invention. Whilst the patent application is pending, the existence of the application may provide a useful deterrent to third parties, dissuading them from copying the product.

Holding a granted patent does not necessarily ensure freedom to operate. In other words, obtaining patent protection for an invention does not give an automatic right to make and sell (or even use) an invention. A third party might still have a patent that they could use to limit freedom to operate.

To address question (ii), freedom to operate searches are typically undertaken where possible. The aim of such searches is to identify granted patents in the geographical territories in which the product is to be made, sold or used, and any patent applications that may give rise to granted patents in those territories. In the case of UK freedom to operate, UK patents or patent applications and European patents or patent applications designating the UK must be considered. Furthermore, international patent applications (which typically designate the UK on filing) must also be taken into account because they can ultimately result in grant of a patent with effect in the UK.

Limitations of Patent Document Searching

The patent searchers endeavour to ensure the accuracy and completeness of searches. However, because of possible human error, the 18 month patent publication cycle, the subjective nature of such searches and possible incomplete data supplied to us, we cannot guarantee that our search reports are 100% complete or error-free. Therefore, we disclaim the fitness of our searches for a particular purpose. The searches undertaken and this report in no way constitute a legal opinion.

In undertaking the searches and the identification of patent family members and the status of the various family members we have relied upon the following databases:

EPO worldwide database of patents and patent applications, 'espacenet': http://worldwide.espacenet.com/advancedSearch?locale=en_EP

EPO online register, 'EPOLINE': https://register.epo.org/advancedSearch?lng=en

UK Intellectual Property Office (UKIPO) online register of patents and patent applications: http://www.ipo.gov.uk/types/patent/p-os/p-find/p-ipsum.htm

Search Strategy - The purpose of the present patent searching project was to attempt to address question (ii) above whilst at the same time gaining an understanding of the areas of pipeline inspection technology that have already been subject to patent filings, which will be helpful in addressing question (i) above in due course. It is to be understood that the patent literature can be a valuable source of information about third party activities, providing useful competitor intelligence.

Two areas of pipeline inspection technology were considered to be particularly relevant:

(a) Pipeline inspection robots; and
(b) Inspection robot launch technology.

Professional searchers were employed to identify initially a pool of potentially relevant documents in areas (a) and (b).

In respect of area (a), the searchers attempted to identify an initial pool of documents disclosing devices with the following features in common:

"A pipeline inspection system comprising a robot that travels along relatively narrow, bendy pipelines that are "unpiggable"; the apparatus may be modular and may include means for video, ultrasonic and/or eddy current inspection."

In respect of area (b), the searchers attempted to identify an initial pool of documents disclosing devices with the following features in common:

"Launchers and receivers of pigs and pipeline robots; the devices may be used for pipelines under high pressure."

It was considered by the Company that the introduction of robots to pipelines that are under pressure was potentially a difficult task, and it was considered appropriate to determine whether any major obstacles exist to the development of technology for the launching of inspection robots into pressurised pipelines. It was considered that an airlock was likely to be required, and that it would be helpful to investigate freedom to operate in respect of the provision of an airlock in addition to inspection robots themselves.

Families of Patent Documents - The patent application process is relatively complex. It is possible for one initial patent application made in one country to result in the grant of a 'family' of patents in multiple jurisdictions around the word. Accordingly, for any given patent document identified by the searchers, it is prudent to identify any UK and European family members. By European family member is meant a patent application filed at the European Patent Office (EPO) under the European Patent Convention (EPC). Patent applications filed at the EPO can result in grant of a patent that has effect in the UK provided the UK was a stated designated in the European patent application. Such European patent applications and granted patents will be referred to herein as 'EP' documents or EP family members.

Accordingly, for each patent document identified in the main search reports provided by the searchers, we have undertaken to identify any UK or EP family members listed in the EPO database (espacenet) entry in respect of the document identified in the search reports.

For each UK family member identified we have then undertaken to determine whether the family member is a granted patent or a pending application by reference to the UKIPO online register of UK patents and patent applications.

In the case of EP family members, we have checked the EPO online register of EP patents and patent applications (EPOLINE). Where a European patent is indicated to have been granted, we have then checked the UKIPO register to determine whether the EP patent has effect in the UK.

In the case of international patent applications identified by the searchers, a determination has been made as to whether the patent application had expired or whether it was still pending at the time of the analysis. If the application was still pending, the application was identified as having the potential to lead to the grant of a patent having effect in the UK.

Granted patents in the UK, and European or international patent applications having the potential to result in granted patents in the UK, will be referred to herein as 'UK-relevant' patent documents.

Age of Documents - The maximum term of a patent in the UK is 20 years from the date of filing. This limit is set in statute. Accordingly, any patent application filed 20 or more years ago can no longer be in force in the UK. Accordingly, third parties other than the patentee are in principle free to make, use and sell in the UK apparatus that is disclosed in such documents subject to the existence of other IP rights. In the context of the present project, other relevant IP rights will likely be limited to registered designs. Registered designs protect the appearance of an article in terms of 3D shape or 2D ornamentation. Subject to a case by case analysis, registered design protection is generally relatively straightforward to work around since in principle it is limited to appearance and not function of the design.

Search Results

(a) Pipeline Inspection Robots

As noted above, the first searches related to the inspection of relatively narrow, bendy pipelines that are unpiggable. The searches covered modular robots, and robots that may include means for video, ultrasonic and/or eddy current inspection of pipelines.

A total of 110 potentially relevant documents were identified out of over 3000 documents identified in an initial pool of documents drawn up by the searchers.

For each of the 3000 documents, the searchers initially checked the title, abstract and main claims of each document. If a document appeared at face value to be relevant in light of this, the searchers then checked the description to see if the document was relevant.

As noted in the Search Strategy section above, for each of the 110 documents identified, we investigated whether UK-relevant patent documents existed. A total of 6 of the 110 documents identified by the searchers were determined to be UK-relevant patent documents.

A substantial number of documents were also identified that are patent applications filed at least 20 years ago. Accordingly, the subject matter of these documents should be wide open to the Company to exploit.

We will first discuss briefly each of the six UK-relevant patent documents before reviewing a selection of documents filed around 20 or more years ago, and for which we believe there are no freedom to operate issues at this time.

UK-relevant patent documents

D2: GB2501312 / EP2653238

The first of the 6 documents identified appears to relate to pig devices, and in particular to an 'intelligent pig' that can undertake ultrasonic inspection of pipelines. Pending patent applications were identified in the UK and before the EPO. The applications are still pending and so it is not easy to determine the final form of the claims. However the applications appear to be limited to pigs, propelled by fluid pressure in a pipeline. Since the Company is intending to produce a robotic inspection device that is provided with its own traction motor(s) rather than a pig-type device, this document is unlikely to be relevant to the Company's freedom to operate.

D4: EP1301740B

The second of the 6 documents, D4, is a European patent in force in the UK. The main text of the document is in French but an English language abstract is available, together with an English language translation of the claims. According to these translations, the device disclosed in the document appears to be a motor driven modular device having a train of modules coupled to one another. The pre-characterising portion of Claim 1 of the patent requires a robot free to slide inside pipework or another narrow passage, composed of a train of modules connected by flexible links. The claim indicates that the new and inventive part of the technology is that the robot has means of fixing modules to each other to stiffen the train. Based on a relatively brief review of the document it appears that the claim requires means for dynamically stiffening the train, i.e. increasing the stiffness in real time, as required. Accordingly, provided the Company avoids providing a robot with all of these features, including means for varying train stiffness, it should be possible to avoid infringement of this patent.

D31: EP1336792B1

The third of the 6 documents, D31, is also a European patent in force in the UK. The main claim of the patent appears to require a robotic internal gauge for remote-controlled operations within pipelines. The device apparently has a 'positioning tower' comprising supporting wheels which bear against an internal surface of the pipeline and a piston system for propelling the equipment. The claim also requires that the positioning tower can rotate about its longitudinal axis so as to change direction of movement, and that the supporting wheels are provided with a non-reversing system. Accordingly, it would appear that the Company can in principle avoid infringement of this patent by providing a robot that does not have (say) the positioning tower, and/or a non-reversing system for the wheels.

D38: EP1846689

The fourth of the 6 documents, D38, is a recently allowed European patent. It remains to be seen whether it will be validated in the UK. However, the claims of the patent require a 'tether-free sensor unit' (50) that is 'adapted to roll in the direction of flow of the liquid along the bottom of the interior of the pipeline, pushed by the flow of the liquid…' The unit has a magnetic sensor and/or an accelerometer to sense the number of revolutions of the unit, and an acoustic sensor for detecting the sound of a leak. It appears, on a cursory reading, that the Company should be able to avoid infringement of this patent relatively easily. I understand that it is not intended to inspect pipelines containing liquids, and therefore rolling of the robot is unlikely to be a requirement of the Company's system.

D59: EP2039440

The fifth of the 6 documents relates to an intelligent pig (IP) for monitoring tubes internally. The independent apparatus claim (claim 1) requires that the IP is provided with one or more flexible sleeves which extend from the body of the IP to the interior wall of the tube. Independent method claim 11 requires a method of monitoring a tube or pipeline, wherein an IP… is driven along the interior of the tube or pipeline by fluid pressure. I understand that the Company does not intend to provide a robot driven by fluid pressure. Accordingly, D59 should not present a freedom to operate issue.

D68: WO2013/191929

The last of the 6 documents relates to an eddy current inspection probe that employs wheels to reduce friction. Although the claims may be subject to amendment in due course before the application grants, the claims as they currently stand appear to require a modular construction with a nose section, a non-destructive sensor section and a tail section. The non-destructive sensor section is required to be suspended at one axial end from a nose section of the probe with a pivot coupling that enables the sensor section a limited degree of rotation relative to the nose section. A similar connection appears to be required to the tail section. The tail section requires a centering device having a plurality of contact points with the interior wall of the tubing, each contact point being biased outward around a circumference of the tail section, with substantially equal pressure.

The Company has indicated that this design is not of interest to them. Even if it was of interest, I believe that it should be possible to work around this patent by careful consideration of the type of sensor employed, and/or the manner in which the sensor is deployed in the robot to be developed.

Documents filed around 20 or more years ago

We now turn to briefly review of selection of documents relating to robots for pipeline inspection that date from around 20 or more years ago. As stated above, these designs should present relatively low freedom to operate risk issue to the Company if employed substantially as described in the documents. For any particular design of interest we propose to undertake a check for the existence of any registered designs in the name of the patentee that might pose a final hurdle to use of the invention. As noted above, it should be relatively easy to work around any such registered designs since they would be limited to the 3D shape of the structure.

D18: JP8198104A

D18 apparently discloses an intra-pipe running apparatus which permits running in a small bore bent part of a steel pipe having a small radius The device apparently has magnetic wheels accommodating permanent magnets so that the wheels are always in contact with the pipe wall. A wheel-supporting part appears to be provided for the purpose of steering, to ensure that an axial angle of the wheels to the pipe does not become zero. The wheels are apparently driven by a motor.

This design appears to be potentially highly relevant and may provide a useful starting point for further robot development.

D73: US5392715A

D73 apparently discloses an 'in-pipe running robot' and method of running the robot. The robot apparently has front and rear axles each of which is pivotable about a vertical axis of the robot to enable positioning of the robot to negotiate bends in the piping in a circumferential direction. The following diagram is helpful in understanding this aspect:

Again, this design appears to be potentially highly relevant and may also provide a useful starting point for further robot development.

(b) Pig and robot launching devices

The second searches related to inspection robot launch technology. The searches covered launching of robots as well as pigs, including launching into pipelines under pressure.

A total of 239 potentially relevant documents were identified out of over 2000 documents identified in an initial pool of documents drawn up by the searchers. Of these, 70 were documents older than around 20 years and therefore present little or no infringement risk. A number of these documents disclose technology that may be of interest to the Company, and which could form the basis for a technology platform with no freedom to operate issues

Of the remaining 169 documents, 30 are UK-relevant patent documents. A preliminary review of these documents indicates that routes to work around the technologies protected are very likely to exist.

In conclusion, it appears that devices suitable for launching pipeline robots into pressurised pipes are well known and some have been in the public domain for long enough that valid granted patents can either no longer exist for the specific devices described in the documents, or are expected to expire imminently.

We will first discuss briefly one of the UK-relevant patent documents before reviewing two of the documents filed around 20 or more years ago.

UK-relevant patent documents

A number of the documents identified related to the launching of pipeline pigs into undersea pipelines. In view of the number of documents identified that were filed around 20 years ago or more, only one of the UK-relevant patent documents will be discussed here.

D18 WO0171238A1

D18 discloses a pig launch device in which a pig is inserted into a receiver unit also referred to as a pig chamber. The receiver unit apparently provides an airlock to allow introduction of the pig to a flow of fluid in a pipeline through a valve in a branch duct of which the receiver unit is part. A pig receiver valve is movable between a position in which it is open to the branch duct and a position in which it is open to a flow duct through which fluid flows in the pipeline under pressure.

The main claim of the patent also requires that a passage is provided in the housing for introduction of an operating rod for transferring a pig from the pig-receiving valve to the pig chamber or vice versa, the passage being connected by an additional valve having double seals against the outside of the device.

I understand that the Company is not planning on employing pig devices in the inspection technology to be developed. However, care should be taken to ensure that launching of robot devices does not employ a launch device with the features of the main claims of this application. Since the technology being developed by the company relates to robotic technology rather than pig technology, careful consideration should be given to the use of a manipulator in the form of a rod to introduce robots into a pipeline in the manner described in D18. However, I believe it is likely to be relatively easy to work around D18, particularly in view of documents D6 and D26 described below.

Documents filed around 20 or more years ago

A number of the documents identified were filed more than 20 years ago. Two of those documents will be briefly discussed here.

D6: US5660202A

D6 apparently discloses a process and ‘hot tap’ apparatus for insertion of robots (33) into gas distribution systems. The apparatus is disclosed to have a housing adapted to be sealably secured to a pipe and enclose a portion of the pipe. The housing forms a chamber which is partitioned into an insertion chamber and a discharge chamber. The apparatus also has a cutting apparatus for cutting an opening in the pipe sized to receive the robot device.

This document appears to be directly relevant to the Company's activities, although I understand that is unlikely to be necessary to cut a pipe to allow introduction of a robot device to the pipe. Accordingly, systems for introducing robots into pressurised pipelines are clearly available and free for the Company to employ.

D26: US5139576

D26 discloses a launching mechanism for sequentially launching pipeline pigs into a gas transmission pipeline. The mechanism has a tubular pig storage and launching magazine for holding a plurality of pigs. A free piston is provided within the magazine and arranged to launch pigs into the pipeline through valve launch valve Va. Pigs may be loaded into the magazine through a closure mechanism.

D26 essentially discloses an airlock arrangement for launching pig devices. In an adaptation of this arrangement for robots, one could imagine a robot could be loaded into the magazine instead of pig devices and the magazine pressurised to the same pressure as the pipeline. After opening valve Va, the robot could be driven into the pipeline to undertake pipeline inspection.

Conclusions

It is clear from the documents cited in sections (a) and (b) above that that the principle of employing inspection robots to inspect pipelines, and the principle of loading inspection robots or pigs into gas pipelines that are under pressure through an airlock, are not subject to blanket patents preventing all freedom to operate in these areas. Rather, technologies to address inspection of pipelines under pressure using robotic devices have been in the public domain for a sufficiently long period of time that any patents relating to the fundamental principle of using those particular technologies will have expired by now.

As determined by the present search activities, and discussed above, patents do exist relating to features that apparently provide improved inspection robot performance in certain applications, and improved introduction of inspection devices into pressurised pipelines. However we anticipate that there will be good scope for working around any such patents during the course of the Company's technology development program in order to avoid patent infringement.

Basis of this Report

This report is intended to provide a guide to the Company to understand certain potential freedom to operate issues in respect of the AGI Project (hereinafter 'the Project'). This report is privileged, confidential and addressed exclusively to the Company. It may not be relied upon for any other purposes or by any other person, association or entity than the Company

This report is not to be transmitted, disclosed or circulated to anyone else, used, quoted or otherwise referred to for any other purpose without prior written consent from Yeadon IP and the Company.

The report is prepared with reference to Intellectual Property laws and principles as applicable at the date of this report. Such laws and principles are subject to change.

We have endeavoured to exercise true care in performing our analysis of the search results provided to us by the Searchers, and we have relied on the accuracy of the search results. The provision of the search results is subject to the disclaimer provided by the Searchers, contained in the Report provided to you. We do not warrant that the results are complete or without error. Any liability resulting from our services is limited to a refund of the search fees paid. Our report does not and is not intended to constitute a legal opinion in respect of the Company's freedom to operate.

As previously discussed with you, the present search activity has been undertaken in a relatively broad brush manner to identify potentially relevant technologies to the Company's freedom to operate in respect of AGI pipeline inspection using robots. We have not been given any specific design information for the system to be developed as yet because the project is in its relatively early stages. Consequently, we strongly recommend that, as the project develops, further freedom to operate searches are undertaken when the final form of the robot inspection tool and launch system are developed. We believe that you understand the limitations of the present search activity and fully accept that further searches will be required in due course.

We have also explained that the work undertaken to date should form a very useful basis for conducting further searchers in due course. We sincerely hope and trust that you will find the information we have obtained for you useful in the course of developing your new technologies. Yeadon IP is pleased to be a part of this project and we are look forward very much to continuing to work with you in the future.

Yeadon IP Limited is a full service intellectual property company handling all aspects of intellectual property protection and management. The Company has offices in Leeds, Birmingham and St Asaph, North Wales. The Company is led by Dr Mark Yeadon and specialises in intellectual property protection in the physical and chemical sciences including subject matter in the fields of mechanical and electrical/electronic engineering, optics and computer software.

The Company is well positioned to advise on IP protection by means of patent, trade mark or registered design filings. It also provides intellectual property agreements such as license agreements, and advises on the valuation and sale of IP. The Company has links to experienced lawyers and consultants offering services such as license negotiation, including the identification of prospective licensees.

The Company also provides search services, including patentability searches, infringement searches and competitor intelligence searches. These searches enable clients to identify potential opportunities to secure new intellectual property rights, reduce the risk of infringement of third party IP and keep abreast of developments by third parties in technical and commercial fields of interest. Specialist patent searching companies are commissioned to undertake patent searches, the results of which are then analysed and interpreted by the Company in conjunction with our client.

The Company believes that strategic, commercially focused advice is essential to enable companies to make informed business decisions. IP assets can play a key role in the growth of a strong business. Yeadon IP therefore works with clients to develop an IP strategy that enables clients to take full advantage of current and future growth opportunities, including the attraction of investment should the need arise.

Mark Yeadon (PhD)

Chartered UK and European Patent Attorney

For and on behalf of Yeadon IP Limited

June 25th 2014

APPENDIX I

Subject Synthotech NIS - Carbon footprint supporting statement REV C

Date Job No/Ref 209273-20

Carbon and environmental benefits of inline robotic inspection for AGIs

Key results

- Key carbon benefits from avoiding unnecessary excavations, from extending the lifetime of assets, and from avoiding high pressure failure – all achieved through pro-active and more accurate monitoring
- Extending the lifetime of assets is estimated to deliver reductions in carbon emissions of over 2,145 tonnes CO_2e per year nationally
- This is equivalent to the emissions from gas and electricity for over 477 typical UK households and is achievable each year

1 Introduction

Synthotech and Premtech are proposing the development of robotic inspection of high pressure gas installations which are not currently suitable for using PIGs (Pipeline Inspection Gauges). There is presently no reliable method available to survey the condition of buried pipework at high pressure gas installations due to the complexity and geometries of such installations.

The robotic technology offers multiple broad benefits: economic benefits, continuity of supply and reduced disruption included. The technology also offers a range of environmental benefits. A priority of National Grid is the contribution it needs to makes to achieving the 80% reduction in national greenhouse gas emissions by 2050, as set out in the UK Carbon Plan. It is incumbent on the National Grid to contribute significantly to this target in its role managing the national gas transmission network.

At present the identification of locations where buried pipework on high pressure gas installations requires maintenance or replacement is largely based on:

- CIPS survey techniques
- records of asset age
- excavation and testing (using visual and ultrasound methods etc)

Where it is suspected that maintenance is required then excavation will be carried out, and components inspected, assessed and potentially repaired or replaced.

This approach to monitoring and managing the state of assets results in a number of outcomes for areas of the transmission network:

- instances of excavation and inspection where none is necessary;
- premature replacement of pipework due to:
  - limitations of external testing methods;
  - sunk time, cost and disruption expended to excavate for inspection;
- unforeseen failure of pipework components.

These outcomes provide the basis of this paper, as they are the scenarios in which carbon emissions and environmental impact occur largely unnecessarily. This paper reviews the environmental benefits (primarily discussed in terms of carbon footprint benefits).

Some of the benefits realised by the development of the robotic inspection technology proposed by Synthotech and Premtech will be location specific, and some will offer benefits across the transmission and distribution networks, but collectively they have the potential to benefit the National Grid's whole client base, as well as contributing to national carbon targets.

2 Delivering carbon benefits through application of the technology

Three main areas have been identified where use of the technology offers carbon savings:

1. Avoided excavations for inspection;
2. Avoiding premature replacement of assets;
3. Unforeseen failure of pipework (and associated disruption).

A limited Life Cycle Assessment (LCA) was carried out for an installation at Bacton, which was reviewed as part of this study[1]. The assessment identified quantities of pipework, and excavation volumes, in order to estimate the carbon footprint associated with replacement of assets. This was a useful exercise in quantification of indicative carbon footprint for such a project, and took into account:

- the carbon emissions from plant and equipment used to excavate the site; and
- the embodied carbon within the pipework, bends, valves etc. which were replced.

The study did not include a number of external contributions to the total carbon footprint, such as the transportation of plant and equipment to site.

Also used to inform this note is information on the transmission network and forecasts of likely excavation exercises. National Grid Gas estimate approximately 15 large scale excavations at AGIs for a typical year, against a total of around 200 AGIs across the national transmission network.

[1] Note: the LCA was carried out by National Grid on behalf of Synthotech. The assessment process has not been independently verified by Arup. Outputs from the LCA have been used to inform carbon calculations in this study, but these are limited to embodied energy from pipeline components and emissions associated with excavations.

2.1 Avoiding unnecessary excavations

Excavations are carried out for sites where it is considered likely that replacement of network pipework/components is required – largely on the basis of maintaining records of asset age. There is the opportunity to avoid excavations where better inspection capability indicates asset condition is adequate for continued operation.

The Bacton preliminary LCA estimated the excavation and reinstatement of material produced 1,381 tonnes CO_2e for the 3,700 linear metres of buried pipeline replaced. For the purposes of this study it is assumed that a broadly representative site, around 10% of the size of Bacton, would require excavations generating around 138 tonnes CO_2e.

'Unnecessary' excavations are deemed to be those where excavation is undertaken, and the visual and other inspections indicate that replacement or repair of components is not necessary. In the majority of cases, where an excavation has been carried out, then there will be some repair or replacement necessary. Occasionally replacement will be carried out after excavation as the relevant parts are available (having been previously ordered) and it is preferable to avoid repeated disruption for replacement in the future.

A simple calculation can be carried out based on assuming in 50% of excavations there is no replacement or repair of components. Based on 15 sites per year of this scale, typical excavation emissions nationally would be around 2,072 tonnes CO_2e. Avoiding 50% of these would equate to a national reduction in carbon emissions for AGIs of approximately **1,036 tonnes CO_2e per year**.

2.2 Avoiding premature replacement of components

The Bacton LCA provided an estimate of carbon footprint for embodied components replaced of approximately 62,000 tonnes CO_2e. This represents the energy used to extract, process and manufacture pipeline, bends, tees and valves replaced. The 62,000 tonnes of CO_2e was for pipeline and components replaced at Bacton, an estimated 50% of which was assumed to be below ground.

A typical location is expected to be around 10% of this scale, with the embodied carbon of below ground assets at such a location estimated at 3,126 tonnes CO_2e.

Typically the lifetime of components in the network are assumed to be approximately 40 years. The important benefit offered by robotic inspection is that this effective lifetime can be extended – and this means the annualised carbon footprint (i.e. the carbon footprint spread across the lifetime of the components) becomes smaller. While some components may fail before 40 years, it is reasonable to assume that the proportion for which life is extended is greater than the proportion that needs to be replaced before 40 years.

Assuming a standard 40 year lifetime for a typical installation suggests an annualised carbon footprint of 78 tonnes CO_2e per year of life. Extending the lifetime of components offers the following benefits:

Lifetime extension (years)	Annualised carbon footprint for typical high pressure installation – below ground components only (tonnes CO2e)	% improvement
0	78	0%

10	63	20%
20	52	33%
30	45	84%

This indicates the carbon benefit of extending the operating lifetime of components in the network. Every year that the lifetime is extended is a year where new components (with all the embodied energy that they include) do not need to be installed.

Clearly this consideration cannot be extended across the whole network, the age profile varying considerably across assets. An exercise was carried out to model the likely benefits across the network, based on the potential extension in operational life achieved through use of robotic inspection. Example age profiles were produced for the purposes of this calculation as shown below:

Age brackets	Proportion of components in each lifetime bracket	
	Business-as-usual	With programme of robotic inspection
0 – 40 years	10%	5%
40 – 50 years	50%	20%
50 – 60 years	30%	50%
60 – 70 years	10%	25%

Extending the lifetime of components at a typical site would equate to approximately 6 tonnes CO_2e per year per site per year. Extrapolating this across the national network would suggest a carbon saving of around **1,109 tonnes CO_2e nationally each year**.

2.3 Unforeseen failure of the network

By moving to a proactive process of monitoring using inline technologies the risks of unforeseen failure are significantly reduced. The impact of a large scale unforeseen failure would be considerable and could potentially result in large releases of methane to the atmosphere. The Global Warming Potential of methane is around 34 times that of Carbon Dioxide over the 100 year time horizon. A hypothetical loss of 200 tonnes of natural gas from a high pressure failure would equate to around **6,800 tonnes CO_2e** emitted to the atmosphere[2]. In addition to this emission of methane would be the significant broader impacts arising from disruption to industry, businesses and households; endangering of human health; and associated knock-on effects.

2.4 Additional carbon benefits

The assessments set out above present a conservative estimate of the benefits, and exclude other considerations including the carbon impacts of transporting large plant equipment to site to support excavation. It may also be possible to achieve more efficient excavations in areas where this is required due to better intelligence on pipeline condition based on robotic inspection.

[2] Based on GWP potential of methane of 86 over the 20 year time horizon

2.5 Other environmental benefits

Beyond purely carbon emissions there are broader benefits from avoiding excavation and extension of asset lifetimes. Any project requiring excavation will produce localised impacts from:

- Dust and air quality from excavation
- Vehicle transport emissions and congestion
- Noise and other nuisance
- Potential pollution incidents from site runoff

3 Conclusions

3.1 National benefits of the technology

As shown above, the most significant carbon benefit arises from the extension of lifetime of assets, but with avoided excavations also contributing significantly to avoided carbon emissions as a result of robotic inspection technology.

Based on these estimated age profile changes across the network a saving of around 1,109 tonnes CO_2e per year is delivered from avoided replacement, and 1,036 tonnes CO_2e per year from avoided excavations. This reduction is per year that the robotic technology is deployed.

Combining these annual benefits provides an estimated saving of around 2,145 tonnes CO_2e per year.

To put some context on the estimate of 2,145 tonnes annually saved through extending the lifetime of assets:

- OFGEM estimate is typical household energy consumption of 16,500 kWh of gas, and 3,300 kWh of electricity[3]
- This amounts to an estimated energy footprint of approximately 4.5 tonnes per year for a typical household[4]
- The carbon saving through extension to asset life and avoided excavation at a national scale is equivalent to the carbon emissions from energy consumption for approximately **477 UK households**, and the benefit is present each year.

3.2 Contribution to the Government's Carbon Reduction Strategy

The Carbon Plan, 2011, sets out how the UK is set to achieve the challenging carbon emissions reduction of 80% by 2050. The plan sets out a series of carbon budgets set out to begin this process, highlighting the areas where action is to be focused. Many of the measures in the short term are focused on end users and increased efficiency, but longer term the requirement is for decarbonisation of grid energy and the transition for small gas and oil boilers to distributed energy and combined heat and power technologies. Even with the

[3] OFGEM Typical domestic energy consumption figures, 2011
[4] Based on DEFRA factors for electricity and gas from 2011

transition to lower carbon electricity generation from nuclear power and renewables there will still be a need to natural gas backup, and the need to ensure this is delivered with the lowest carbon overhead possible.

The use of the robotic technology offers carbon benefits to the transition network, reducing the 'scope 3' emissions of the natural gas supply to houses and business – i.e. the carbon emitted just delivering gas to its point of use. This note has focused on the application of the technology to AGIs, but there is the potential to extend use to other components of national gas infrastructure, broadening the potential carbon benefits.

APPENDIX J

Description	SGN ULC Element 1 & 2	SGN ULC Element 3	SGN ULC Element 4	HP Inspection Robot	Notes
System travels in pipe annulus	N	N	Y	N	There is no accessible annulus
System travels in pipe bore	Y	Y	Y	Y	
Operating Under "Live" Conditions	Y	Y	Y	Y	Complexity is related to operating pressure
Operates at Low Pressure <75mbar	Y	Y	Y	Y	Element 1-4 are designed for upto 2 barg only due to use on gas distribution
Operating at Medium Pressure (75mbar-2bar)	Y	Y	Y	Y	Element 1-4 are designed for upto 2 barg only due to use on gas distribution
Operating at Intermediate Pressure (2bar-7bar)	N	N	N	Y	Element 1-4 are designed for upto 2 barg only due to use on gas distribution
Opearting at incereased pressures (7bar-50bar)	N	N	N	Y	Element 1-4 are designed for upto 2 barg only due to use on gas distribution
Operating at Higher Pressure (50bar-100bar)	N	N	N	Y	Element 1-4 are designed for upto 2 barg only due to use on gas distribution
Operates on transmission line	N	N	N	Y	Element 1-4 are designed for on gas distribution only
Operates on distribution line	Y	Y	Y	N	The initial system is designed for Transmission not distibution netwroks but this technology could be easier transferred to distribution
Suitable for <6" pipelines	N	N	Y	N	Not required
Suitable for 6-24" pipelines	Y	Y	N	Y	Not Required
Suitable for 24 to 48" pipelines	Y	Y	N	Y	Yes but access and egress are more complex

Completes visual inspection	**Y**	**Y**	**Y**	**Y**	Design difference is technology would need to withstand higher pressures than Element 1 to 4
Uses a sensor array for pipeline assessment	**N**	**Y**	**N**	**Y**	Sensors to required to detect defects and wall thickness, design difference is technology would need to withstand higher pressures than Element 1 to 4
Requirement for GPS	**N**	**N**	**N**	**Y**	Need to know where the HP Robot is at all time
Can be used for repairs	**Y**	**Y**	**N**	**N**	Not required
Can be used for mains replacement	**N**	**N**	**Y**	**N**	Not requried