Innovation Funding Incentive

Annual Report 2012/13

Gas Transmission

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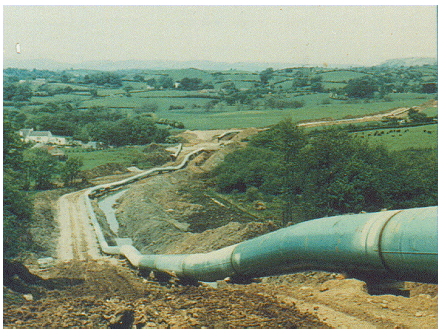
Project title	Risk Assessment Methodologies for Pipelines and AGIs		
Project Engineer	**Dave McCollum**		
Description of project	**Research into the ongoing improvement of risk management software and associated databases for the management of safety risks on gas transmission pipelines. Development of models and procedures through the joint venture, PIPESAFE Group, and other collaborations.** **Research into the management of safety risks on above ground installations. Development of models and procedures through the joint venture ORDER collaboration.**		
Expenditure for financial year	Internal £12k External £192k Total **£203k**	**Expenditure in previous (IFI) financial years**	**Internal £26k** **External £162k** **Total £188k**
Total project costs (collaborative + external + NG)	**£973k**	**Projected 2013/14 costs for National Grid**	**£144k**
Technological area and/or issue addressed by project	**Above-ground installations (AGI), such as compressor stations and terminals, that are associated with high pressure natural gas transmission pipelines present potential major hazards (i.e. fires or explosions) in the unlikely event of accidental releases of gas, due to a range of potential causes. Under the Pipeline Safety Regulations and the COMAH Regulations, National Grid is required to manage the risks associated with these assets effectively, and to be able to demonstrate to HSE that risk is managed to a level which is considered As Low As Reasonably Practicable (ALARP).**   **High-pressure natural gas transmission pipelines present potential major hazards, such as fire risk, in the unlikely event of accidental releases of gas, due to a range of causes. But particularly due to accidental interference damage by third parties. Under the Pipeline Safety Regulations, National Grid is required to manage the risks associated with these assets effectively, and to be able to demonstrate to HSE that risk is managed to a level which is ALARP.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk** / **Overall Project Score**

	15	-5	**20**
Expected benefits of project	**This project supports National Grid in optimising the safety of new facilities through appropriate layout and design, and in achieving ongoing improvements in the efficiency and effectiveness of the management of risk associated with AGIs on the high-pressure gas transmission pipeline network.** **This project also supports National Grid in achieving ongoing improvements in the efficiency and effectiveness of the management of risk associated with high-pressure gas transmission pipelines.** **Through collaboration with other gas transmission companies, National Grid is able to participate in, and benefit from, the development of international best practice in risk management, and to share learning from incidents.**		
Expected timescale of project	Reviewed Annually	**Duration of benefit once achieved**	**5 years**
Probability of success	80%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£204k**
Potential for achieving expected benefits	**High potential that the benefits will be realized. Collaboration reduces costs significantly and enhances the likelihood of success. Results from the project are constantly being implemented by National Grid, including a new version of the Hazard Assessment Methodology Manual (HAMM) for pipelines. Experiments performed as part of the Effectiveness of Safety-improving Measures (ESM) project have demonstrated the effectiveness of polyethylene (PE) slabs in providing cost-effective and practical protection for pipelines against third party interference where required and the possibility of implementing them as an alternative to the concrete slabs currently used is being investigated.** **Transmission pipelines and associated installations are recognised by National Grid as important process safety risks, with the potential for high impact, low frequency events, which are currently under review internally. The two reports reviewing incident trends on National Grid's transmission pipelines and high pressure gas installations provide a measure of safety performance that feed into Key Performance Indicators being developed as part of this initiative. Participation in these international working groups supports National Grid's aspiration to be seen as a leader in the area of process safety.**		
Project progress **[Year to End of March 2013]**	**As an ongoing practice, results from this innovation project are continuously being implemented. This includes:** **A new version of the Hazard Assessment Methodology Manual (HAMM) for pipelines currently awaiting approval for use; National Grid document HAZ16.** **Training for both new and advanced users of the hazard and risk**		

assessment software, and hazard awareness training has taken place, explaining the principles behind model development.

The methodology developed for risk assessments of low toughness pipelines as part of the PIPESAFE collaborative project have been applied and have demonstrated that the risks associated with these older pipelines was acceptable (ALARP), mitigating their continued operation.

Experiments performed as part of the ESM project have demonstrated the effectiveness of PE slabs in providing cost-effective and practical protection for pipelines against third party interference where required and implementation of this new information through specification modifications to permit their use as an alternative to the concrete slabs currently used is being pursued.

An updated version of the PIPESAFE package (for hazard and risk assessments of gas transmission pipelines) was prepared for implementation in 2013/14, and was delivered through the PIPESAFE collaboration, including improved consequence models for pipeline fires and rupture crater dimensions based on new research. As part of this IFI project, a review of recent developments was carried out to provide recommendations for updates to the Hazard Assessment Methodology (HAMM) - a document specifying how risk assessments of high pressure gas pipelines must be carried out has been produced. A revised draft of HAMM was prepared to support the use of the new version of PIPESAFE.

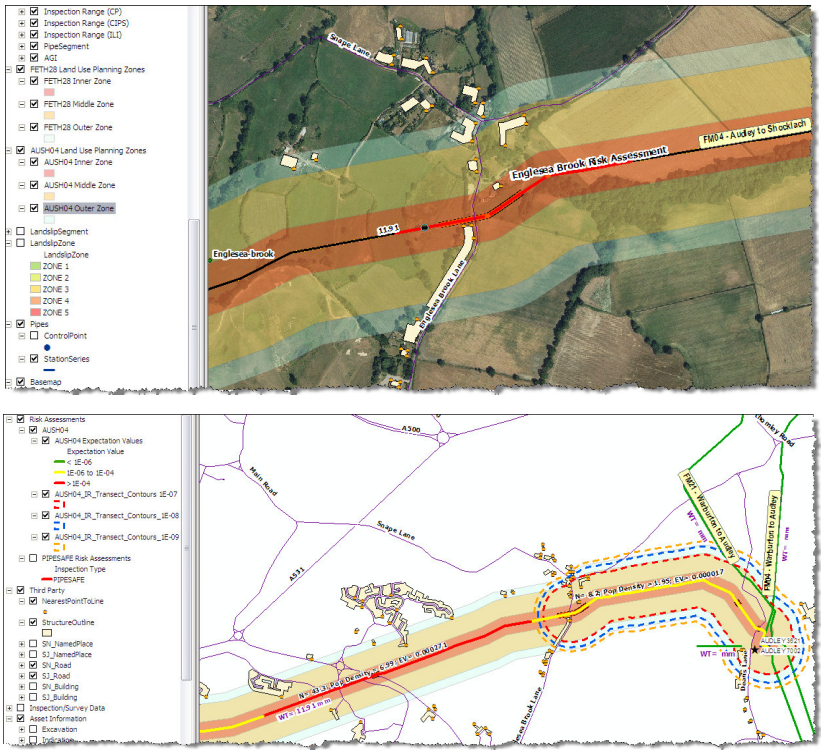
A revised version of the National Grid specification for protective slabs (T/SP/CE/12) was developed to enable the use of PE slabs as an alternative to reinforced concrete slabs, supported by the results of research undertaken as part of the ESM collaborative project into the effectiveness of physical protection for pipelines against external interference damage (see below).

Annual submissions were prepared for industry databases collating the incident experience of pipeline companies in connection with both buried high pressure pipelines and associated installations. The databases are a valuable resource for deriving historical statistics for incident frequencies and ignition probabilities for use in risk assessments

A review of gas release incidents on high pressure pipelines and related installations have been carried out. A report has been prepared to examine trends and to highlight issues. The two reports build on the foundations laid in previous years to provide a valuable key performance indicator to monitor safety performance.

A new version of the ORDER package (for hazard and risk assessments of high pressure gas installations) was delivered in 2012/13 delivered through the ORDER collaboration, including improved functionality and an updated explosion methodology, as well as software modifications.

A failure frequencies report was prepared for use in risk assessments of high pressure gas installations. A range of options were provided, to be used as appropriate depending on the context of the assessment being performed.

	Progress has made with several joint industry collaborations concerned with the safety of high pressure gas pipelines and associated installations. This includes the ongoing ESM (Effectiveness of Safety-improving Measures) project, which is concerned with measuring and improving the effectiveness of safety measures for pipelines; in particular due to external interference. New projects were also initiated, one to develop methodologies for assessing parallel pipelines and another to support companies in managing the threat presented to pipelines by ground movement.
	 **Example of risk information presented in the risk-based asset management tool**
Collaborative partners	**National Grid's partners in the PIPESAFE Group, ORDER Group and related joint industry collaborations on pipeline safety issues sponsored through this project include: GdF Suez (France), Gasunie (Netherlands), Enagas (Spain), Energinet.dk (Denmark), Tokyo Gas (Japan), Osaka Gas (Japan), Fluxys (Belgium), Statoil (Norway), TransCanada PipeLines (Canada), Alliance Pipeline (Canada), Swissgas (Switzerland), BP (UK) and BG Group (UK).**
R&D provider	**GL Noble Denton**

Project title	P9 Semi-Mechanised Hot Tap Welding		
Project Engineer	**Richard Wilkinson**		
Description of project	**Development of contemporary welding and non-destructive examination procedures for heavy wall hot-tap split tee longitudinal seam welds.** **This project aims to deliver project cost efficiencies and savings when welding large diameter, thick wall hot-tap tee connections, along with enhanced levels of weld quality. A reduction in occupational health and environmental risk as a result of shorter working periods is anticipated.**		
Expenditure for financial year	Internal £5k External £21k Total **£26k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£99k**	**Projected 2013/14 costs for National Grid**	**£73k**
Technological area and/or issue addressed by project	**Current methods used by National Grid to weld thick wall minimum hot tap or stopping off connections to a pipeline can result in extended continuous welding times. This has a direct effect on project costs; two teams working in shifts are required to carry out the work.** **From a safety and environmental point of view, shorter working hours help to decrease the risk of occupational health hazards to the work crew. Avoiding instances such as long exposure to arc radiation, fatigue, exposure to atmospheric pollutants, and noise. The longer an operation continues increases the risk of accidental damage to the in-service pipeline and operational constraints to the network when gas flow reduction is necessary to permit welding.** **Under current requirements hot-tap tee welds are inspected by visual and surface magnetic particle testing (MPI) methods only. The new method would reduce risk that embedded weld body and weld root defects are undetected.** **This programme of work will investigate and introduce a new semi-mechanised welding process to complete the split-tee longitudinal seam welds in thick wall tees.** **A suite of welding procedures will be developed for the welding and repair of these welds in the specified materials and in all necessary welding positions. This will reduce welding time required, with a corresponding reduction in resource in operational and construction activity associated with shorter working hours required.** **A new primary method of weld inspection ultrasonic manual phased array testing will be employed in conjunction with the original**		

<table>
<tr><td></td><td colspan="4">methods to inspect the finished welds. This will give a higher probability of defect detection and will provide enhanced confidence in weld quality. Upon completion of this project, the National Grid specifications T/SP/P/9 and T/SP/NDT/2 will be revised to accommodate the new methods of welding and inspection.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Incremental</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>15</td><td>1</td><td>14</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">Cost benefits associated with using a semi-mechanised welding process are expected. By employing a semi-mechanised welding process for the longitudinal seam welds there is the potential to conservatively reduce welding costs by 20% – 25%.

There is an additional benefit of minimising the planned outage window requirement for such operations. On an annual basis, a conservative estimate would be two to three reduced outage windows per year.</td></tr>
<tr><td>Expected timescale of project</td><td>1 year</td><td colspan="2">Duration of benefit once achieved</td><td>5 years</td></tr>
<tr><td>Probability of success</td><td>85%</td><td colspan="2">Project NPV = (PV benefits – PV costs) x probability of success</td><td>£398k</td></tr>
<tr><td>Potential for achieving expected benefits</td><td colspan="4">The likelihood that this research programme will meet with success is relatively high.</td></tr>
<tr><td>Project progress

[Year to End of March 2013]</td><td colspan="4">Since the project began in March 2013, rapid progress has been made with the planning and development of a suitable gas shielded flux cored semi-mechanised welding process for welding thick wall hot-tap tees.</td></tr>
</table>

Simulated longitudinal seam weld for an under pressure hot tap tee

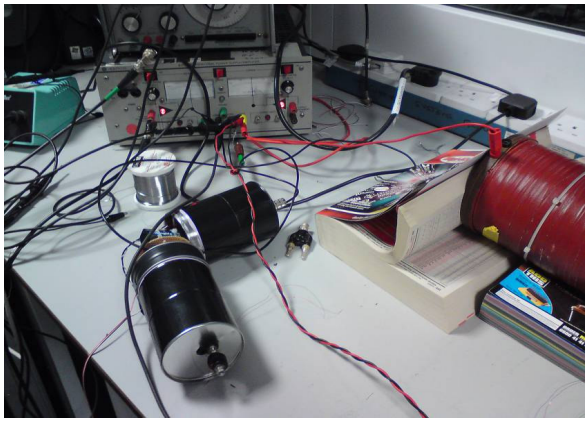
By the end of March appropriate high chemistry plate material has been procured and machined, welding procedures and welding wire selected and tested on 25mm thick sample plates, in all three welding positions, before completing the 50mm thick test plates (see below).

During the trial a small sample of copper (Cu) has been introduced into one of the test welds to simulate accidental Cu contamination. Subsequent investigation will examine whether this can be detected by the ultrasonic Manual Phased Array (PA) weld inspection. This area will also be examined later by macro-section during destructive testing.

The test plates have been examined for defects using a procedure developed specifically for the PA method and they have been delivered to a Mechanical test house to be machined and prepared for destructive testing. The testing, to be witnessed by National Grid, is scheduled to start week commencing May 2013.

Collaborative partners	**None**
R&D provider	**MACAW Engineering Ltd.**

Project title	Development of AC Over Line Survey System				
Project Engineer	**Peter Martin**				
Description of project	**This project will deliver a suitable over line AC survey system that will be used for the initial identification of areas where the levels of AC interference on gas pipelines may require mitigating action. When implemented, the survey system will enable the improved detection and assessment of AC-induced corrosion in gas pipelines, thereby reducing the likelihood of leakage or failure though this particular corrosion process**				
Expenditure for financial year	Internal £6k External £76k Total £81k	**Expenditure in previous (IFI) financial years**	**Internal £14k** **External £180k** **Total £194k**		
Total project costs (collaborative + external + NG)	£323k	**Projected 2013/14 costs for National Grid**	**£48k**		
Technological area and/or issue addressed by project	**AC corrosion has been documented in the UK, mainland Europe and North America. Through-wall failures have been recorded and corrosion rates as high as 1.4 mm/yr calculated. A 2004 report indicates that 24 known cases of AC corrosion were reported in Europe (but likely that this is only a small percentage of the total). These pipelines were not shown to have any defects during conventional DC CIPS surveys. Increasing installation of power lines, rail transit systems and improvements to pipeline coating quality will all continue to increase AC corrosion instances.**				
Type(s) of innovation involved	Radical	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**	
		12	6	**6**	
Expected benefits of project	**The business benefit is attained through developing a clear view of the levels of AC interference along a pipeline, rather than just at the test points (as is presently the case). Through this process, mitigation measures can be applied, if necessary, enabling the issue to be effectively monitored and controlled. The potential order of magnitude of costs 'avoided' are outlined above.**				
Expected timescale of project	4.5 years	**Duration of benefit once achieved**	**5 years**		
Probability of success	90%	**Project NPV = (PV benefits – PV costs) x probability of success**	£42k		

Potential for achieving expected benefits	**Based upon data capture and analyses from the field trials, the cable technology can identify areas of high current density, therefore the potential for this project to achieve expected benefits is high.**
Project progress **[Year to End of March 2013]**	**Following promising results under laboratory conditions for the candidate device (prototype AC Module) and the trailing cable technologies it was decided to test the technologies over a series of field trials.**  ***Figure 1 - Bench testing of cable real shielding*** **Field trials were designed to test 3 cable technologies with the candidate device and the associated prototype AC module. The cables technologies tested were set out in the following three scenarios:** • **Standard MC Miller copper wire as used in a standard CIPS survey for control purposes i.e no shielding from AC inductance** • **Specially designed 0.3mm Coaxial cable – Shielded against electromagnetic (EM) induction** • **2 x MC Miller copper wires in very close proximity combined with a prototype shielding device designed to cancel out any EM inductance / interference**  ***Figure 2 - MC Miller Device, Prototype AC CIPS Module attached*** **During the first field trials in 2011/12 the following were also tested:** • **Usability of the candidate device, and deployment of cable technology** • **Test the draft operational procedures for the device and the trailing cable technologies in the real world.**

	• **Soil resistivity tests** • **Static voltage and current readings** • **Test post voltage and current monitoring** • **Measurement of the EM field generated by the overhead power lines.** **A good data set was collected for each of the 3 scenarios and a series of lessons learned were captured.** **The initial data was processed in accordance with the formula identified in the theoretical physics studies and this initial data was then analysed.**  ***Figure 3 - Connecting AC Voltage & current readings at a test post*** **A set of conclusions and recommendations that came out of the second set of field trails were written into a revised field trial procedure that formed the basis of the subsequent field trials.** **During 2012/13, a method of calculating the true current density from the measured value was developed. The factors that affect the measurement include the length of the wire when deployed and coiled, and the number of turns based on the spool wire resistance.** **A further two field trials were carried out using the standard copper wire and the custom coaxial wire. Prior to the fourth trial, the number of turns and the length of wire where accurately measured. Both of these trials obtained further data used to confirm the validity of the developed correction techniques.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	MTM (Magnetic Tomography Method) Pipeline Inspection System: Evaluation & Validation		
Project Engineer	**Peter Martin**		
Description of project	**Conduct field trials to evaluate this new inspection method's ability to detect significant metal loss features on buried National Grid pipelines and validate the method's output by subsequent selected excavation and physical examinations of the pipelines.**		
Expenditure for financial year	Internal £8k External £230k Total **£238k**	**Expenditure in previous (IFI) financial years**	**Internal £k** **External £0k** **Total £0k**
Total project costs (collaborative + external + NG)	**£393k**	**Projected 2013/14 costs for National Grid**	**£0k**
Technological area and/or issue addressed by project	**Uniqueness of the MTM Technique** **None of the techniques, currently employed above-ground to assess the condition of buried pipelines, are capable of locating coating disbondment. However, the MTM technique is now claimed to be able to locate coating disbondment from above ground, and therefore provide similar information to that generated during an in-line inspection (ILI).** **MTM technology has been developed to be an innovative, non-intrusive and non-contact method of inspection which can provide 100% inspection of a pipeline from above ground. It is said to be capable of locating pipeline material anomalies, characterizing these anomalies and forecasting the need for follow-up actions.** **How it Works** **The MTM inspection technique has recently appeared in the UK market place and is currently being marketed by Transkor Ltd. The technique measures distortions in the earth's magnetic field due to the presence of buried objects such as a pipeline. Areas of high stress in the pipeline cause significant distortion of the earth's magnetic field that surround the pipeline and these areas of distortion can be detected from the surface. Excavation of these areas can then be made to determine the cause of the distortion. The technique is claimed to have the following advantages over other above ground techniques:** ▪ **No need for advanced preparation or change to the pipeline's operating conditions.** ▪ **Suitable for any pipeline regardless of type of construction, type of medium transported and presence of flow.** ▪ **Does not magnetize the pipe.** ▪ **Reveals metal loss features and cracking.** **The technique is claimed to be of particular benefit where metal loss features occur under disbonded coating. Although these features are**		

	detectable using ILI tools, none of the above ground survey techniques, currently employed on pipelines, are capable of locating or sizing metal loss features. **Historical Note** **In 2007/8, the MTM system was trialled in the United States by the NE Gas Alliance of which, National Grid US is a partner. The trial was performed in Manhattan on a number of buried pipelines but, due to problems, the pipes were never excavated to evaluate the MTM results and as a consequence of this the MTM inspection results were not confirmed. Consequently, the MTM system still requires to be evaluated by National Grid to determine the extent of its abilities to detect significant features on National Grid pipelines.**			
Type(s) of innovation involved	Radical	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		11	0	**11**
Expected benefits of project	**If the MTM system can truly detect the magnetic signature created by significant metal loss on a buried pipeline, the biggest benefit will be that it should enable National Grid to tackle a potentially significant problem that is starting to generate concern.** **The potentially significant problem is corrosion, caused by disbondment of the coal-tar coating on buried pipelines (most of the pipeline network is now exceeding its original 40-year design life and coal tar coatings, in particular, are giving rise to concern, because coal-tar is a liquid, albeit a very viscous one). Where disbondment occurs, water tends to seep between the pipeline and its coating by capillary action, where it forms a "closed" corrosion cell. The significance of it being a "closed" corrosion cell is that cathodic protection (CP) does nothing to reduce the rate of corrosion (CP only works to reduce corrosion of exposed defects).** **The standard approach to identifying and controlling corrosion on buried pipelines is to conduct in-line inspection (ILI) surveys every 14 years. Where sub-critical defects are detected by ILI, the level of cathodic protection is increased in conjunction with 'close intervals potential surveys' (CIPS), which are undertaken much more frequently.** **A typical pipeline may have up to 3000 sub-critical defects. 70% of pipelines are coated with coal-tar. International experience suggests that as much as 20% of corrosion defects may be caused by disbondment. However, National Grid has no current method to confirm this. Safety considerations dictate that National Grid cannot afford to wait 14 years to measure corrosion rate of defects over the period between two ILI surveys. CIPS can detect the location of lowest potentials but cannot diagnose the nature of the corrosion and CP will do nothing to halt or delay the corrosion in a "closed" corrosion cell.** **If MTM works, it could be used to conduct surveys from the surface during the 14 year interval between ILI surveys. It may be able to characterise coating disbondment on a single survey. Alternatively, if successive MTM**			

	surveys showed continuing metal loss despite CP levels being raised, this could indicate a corrosion mechanism that is not affected by CP (e.g. a "closed" corrosion cell caused by coating disbondment). The metal loss could then be monitored by MTM until the defect became critical, at which point National Grid would dig down and repair the pipeline. **Without MTM surveys (or a comparable solution), National Grid has no way of knowing how extensive is the problem of "closed" corrosion cells caused by coating disbondment. If coating disbondment is a significant problem, National Grid then has no way of monitoring it during the 14 years between ILI surveys. In order to manage the risk to the public of pipeline failure from this type of corrosion, National Grid would be required to either increase the frequency of ILI surveys or dig down and visually inspect the worst of the 3000 or so sub-critical defects on the typical pipeline. The increased "pig and/or dig" activity would lead to an escalation in maintenance costs that National Grid would be keen to avoid:** ▪ **Typical ILI survey cost for a pipeline (including disruption to network capacity): £80k – £100k.** ▪ **Typical excavation cost: £20k – £30k (occasionally rising to £250k in mountainous areas).** ▪ **Indicative cost of MTM service (equipment hire, plus qualified operator and provision of analysis): £30k /month.** **National Grid is currently part way through an aggressive CIPS survey programme covering a significant percentage of the network. For example, this has highlighted 22 defects that warrant further investigation on one Scottish feeder. If MTM works, it could be used to prioritise any subsequent dig activity. Another example would be a coal tar coated pipeline in a mountainous region, where dig activity would be at a premium.** **If the project is successful, NGG Transmission might reasonably expect in the course of 10 years to delay by an average of 5 years the cost of digging down to further investigate 1% of the current total 38,000 sub-critical defects. The cost of hiring the MTM kit for 4 months each year would be around £120k per year.**		
Expected timescale of project	3 years	**Duration of benefit once achieved**	**5 years**
Probability of success	85%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£26k**
Potential for achieving expected benefits	**The original series of trials, performed in 2011, established that the MTM system had the potential to inspect a buried pipeline from the surface and locate metal loss features. During 2012, a further series of trials were conducted on NG transmission pipelines located in 6 locations in the UK. The aim of these particular trials was to further evaluate the existing MTM system and, additionally, evaluate a new model still undergoing development. This latter system used a technique known as Stress Concentration Tomography (SCT).**		

	Both systems performed very well during the trials. The MTM & SCT results compared very well to ILI indications. Additionally, pipes suffering from ground movement were inspected and a good correlation was obtained between the levels of stress measured in the pipes from strain gauges and the stress values obtained from the MTM & SCT results. **The latest series of trials further demonstrates that the MTM and the new SCT system appear to have great potential for the inspection of buried pipelines for both National Grid and other Oil and Gas majors.** **No further development work is planned for the MTM system as it currently stands in the market place.**
Project progress [Year to End of March 2013]	**The MTM system successfully inspected 6 sections of pipeline in 2011 which had previously been inspected with an In Line Inspection (ILI) tool. Following completion of the onsite trials, an MTM inspection report was produced and the MTM results were overlaid on top of the ILI data using National Grid's Uptime system. This produced a set of pipeline maps that has enabled a direct comparison to be made between the two sets of data. Two of these maps have been provided in this report for reference (see figure 1 & 2).** **Evaluation of the two data sets has shown that there is a good correlation between the locations of the pipeline anomalies.**

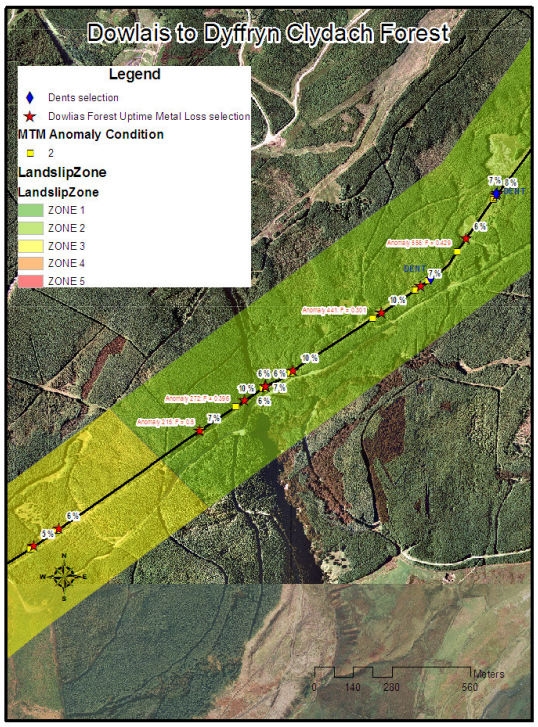


Figure 1: Uptime Map for the Dowlais to Dyffryn Clydach Pipeline-Forest Section.

Figure 2: Uptime Map for the Roundham Heath to Great Wilbraham Pipeline-Forest Section.

Between April and November 2012, the MTM and SCT systems were used to inspect 26.31 kms of NG pipeline at 6 locations within the UK. The inspection results were compared to ILI/P11 results. Additionally, 2 sections of pipeline suffering from ground movement (due to mining) were also inspected, plus a sleeved section of pipe. By overlaying the as original as laid pipeline maps on top of the MTM & SCT Uptime maps, it appears that both systems can also detect features such a pipeline girth welds and pipeline fittings such as bends. Further work is still required to confirm this result.

The SCT system is still undergoing development and the information obtained from the site trials is being fed back into the SCT software programme and tested in the laboratory to produce an accurate analysis algorithm. It is anticipated that the ongoing development work will take another 18 to 24 months before the SCT system has been developed to the point where the level of reporting should be able to provide details of features equal to that of an ILI tool.

Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	Ageing Critical Valve Research			
Project Engineer	**Steve Johnstone**			
Description of project	**This project looks to establish guidelines for prioritising valve replacements and to develop reliable methods for refurbishing valves. In both cases, the ultimate aim is to reduce the potential future annual cost of valve replacements.**			
Expenditure for financial year	Internal £8k External £34k Total £5k	**Expenditure in previous (IFI) financial years**	**Internal £6k** **External £79k** **Total £86k**	
Total project costs (collaborative + external + NG)	£128k	**Projected 2013/14 costs for National Grid**	**£0k**	
Technological area and/or issue addressed by project	**Following an upgrade at Churchover compressor station a number of Cameron ball valves were removed, which provides an opportunity to conduct detailed analysis on the performance and condition of this type of valve. This study complements previous work already carried out on the Cort valves but, importantly, the deterioration/condition assessments will be carried out on a valve type that was not covered by the previous work. Two 36" Cameron ball valves have been identified for the assessment – a 'low duty' Station valve and a 'high duty' unit valve.** **A 36" Cort ball valve at Helpston AGI has also been removed from service due to a leak from its 'Cort' 3-piece bolted closure joint. The leak was subject to attempted remediation by means of 'Furmanite' injection into holes drilled about the circumference of the 3-piece bolted closure joint. This solution has failed over time and the valve was subsequently removed and is currently stored at PMC Ambergate. This valve will be dismantled, examined and compared to previous valve investigations. Dismantling will also allow National Grid and Furmanite the opportunity to conduct a detailed assessment of the earlier attempted remediation.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		20	3	**17**
Expected benefits of project	**The benefits that can be derived by this project stem from identifying ageing Cameron valves that do not need replacement. The number of Cameron ball valves with more than 30 years service on the NTS is approximately 1000 (between 50mm and 1200mm). Revalidation of each Cameron valve back to T/SP/V/6 could cost in the order of £4k for a typical 30" ball valve. Because of its construction, it is not possible to re-life this type of valve. Replacement of each Cameron valve could cost £200k to**			

	£250k per valve. **The number of Cort ball valves with more than 30 years service on the NTS is approximately 700 (between 200mm and 1050mm). Refurbishment / re-life of each Cort valve could cost £100k. Replacement of each Cort valve could cost in a range of £200k to £250k per valve.**		
Expected timescale of project	1.5 years	**Duration of benefit once achieved**	**5 years**
Probability of success	20%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£1,035k**
Potential for achieving expected benefits	**The benefit potential remains high. Work undertaken to date does not indicate any detrimental impact on the original potential for achieving the expected benefits for this project.**		
Project progress [Year to End of March 2013]	**The valves available for this test programme were constructed into test vessels and pressure testing and sealant trials undertaken.**  ***Valve test vessel for pressure testing*** **The two Cameron ball valves were subjected to hydrostatic strength and seat tests. Injection of two different sealant materials demonstrated the improvement in sealing capability which could be achieved by this remedial action. Subsequent internal inspection of the valves showed the propagation of these materials around the seal.** **The Helpston Cort valve was also pressure tested, confirming the leak locations around the body closure joint. The injection capabilities of two different sealant materials were demonstrated, and their propagation around the closure reviewed.**		

	 *Internal surfaces of large ball valve* **External and internal inspections of all valves confirmed the deterioration which had been experienced by various components during service, which helped to focus these and any subsequent activities.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

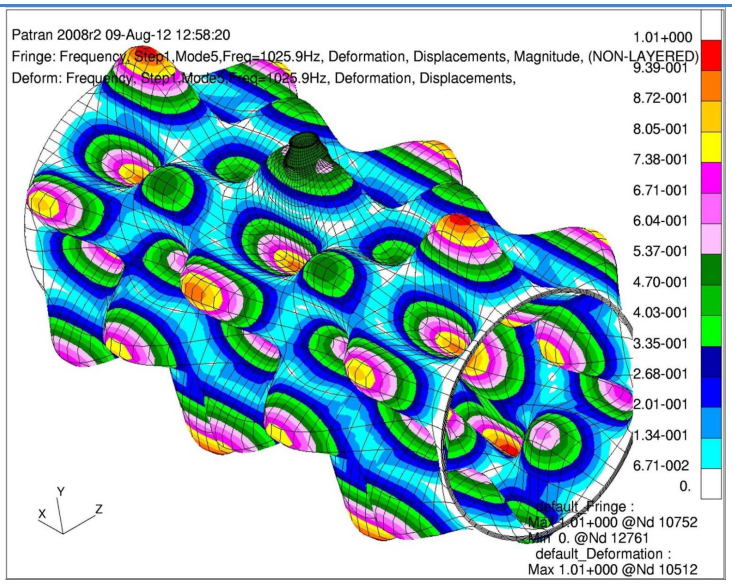
Project title	The Need for Pressure De-rating Prior To In-Service Welding		
Project Engineer	**Brian Woodhouse / Richard Wilkinson**		
Description of project	**This IFI project aims to confirm that hot-tap welding to pipelines operating at pressures above 70 bar can be carried out within sufficient margins of safety to prevent loss of material strength and consequent local bulging due to the effect of high pipe wall temperatures and internal gas pressure acting upon pipe walls.**		
Expenditure for financial year	Internal £4k External £1k Total **£5k**	**Expenditure in previous (IFI) financial years**	**Internal £5k** **External £40k** **Total £45k**
Total project costs (collaborative + external + NG)	**£50k**	**Projected 2013/14 costs for National Grid**	**£32k**
Technological area and/or issue addressed by project	**In-service welding is a common maintenance and installation connection practice which generates both economic and environmental benefits by not removing pipelines from service. The T/SP/P/9 procedure, first published in 1984, specifies pipeline pressure "to be reduced to the minimum practicable". This programme is a benchmark study which looks to address whether elements of the procedure should be amended in light of material and technological developments over the past 20 years.** **Other published standards such as BS 6990 and EEMUA 185 will also be reviewed. The BMT Fleet Technology's hydrogen diffusing modelling tool, along with data collated on variation in material properties with temperature, will be used for this analysis.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating** 15	**Project Residual Risk** -4 / **Overall Project Score** **19**
Expected benefits of project	**The principle driver in this case is safety. When welding on to a live gas pipeline the pipe is preheated up to 250℃ and then welded during the time it takes for the pipe temperature to cool down to 150℃. The preheat and welding cycle is repeated until the joint has been completed. If excessive temperatures are encountered, together with the internal pressure, this could lead to bulging of the pipe. In extreme cases this could even lead to a blow-out. This project looks to determine whether a certain combination of worst-case conditions might lead to a problem, using some simplified analysis to try and predict whether blow-out is likely to be an issue or not.** **Therefore this project has the potential to avoid loss of life, remedial costs, shipper penalties and loss of company reputation in the event of a pipeline failure while carrying out in-service pipeline welding.** **There is a business benefit in establishing whether the following three procedures are consistent and appropriate for current National Grid**		

	operations given the use of new materials and changing network conditions: • **T/SP/P/9** • **BS 6990** • **EEMUA 185** **Hot tap welding is carried out approximately five times per year on the National Transmission System (NTS). There is cost associated with this activity related to pressure constraints (i.e. buyback costs £500,000 /day). In most instances there is a need to reduce gas flow rate to allow P/9 welding to take place, this could result in decreased pressures.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	80%	**Project NPV = (PV benefits – PV costs) x probability of success**	**-£37k**
Potential for achieving expected benefits	**This project ascertained that, for the three line pipes assessed in this work, no pressure reduction is required during hot tap welding, provided the safe guards in the P9 procedure are correctly followed.**		
Project progress [Year to End of March 2013]	**There are two key activities for this project:** **1. A detailed review of the existing safeguards in P9 and a comparison with other published standards, a selection of published papers on work sponsored by Pipeline Research Council International (PRCI) and Australian Pipeline Industry Association (APIA) and a literature search to determine the appropriate strength versus temperature property data for typical line pipe steels.** **2. A welding simulation using finite element analysis (FEA) to assess numerically the requirements for pressure reduction during hot tap welding.**  ***Hot-tap welding to pipelines operating at pressures above 70 bar***		

	Conclusions based on work carried out to date found that the current practice of measuring the actual wall thickness of the run pipe is judged prudent. **Based on the review conducted by 5G Orbital, it was concluded that the scope of application of P9 should be changed to the default minimum pipe wall thickness of 5.0mm to ensure that P9 is consistent with BS6990. However, further validation is required to assess the applicability of P9 on pipe wall thicknesses less than 5.0mm.** **The analyses undertaken using nominal wall thicknesses and recommended elevated temperature tensile properties showed that the following three line pipes tested have sufficient margins against collapse:** ▪ **12" diameter API 5L grade X52 pipe with a wall thickness of 7.1mm and design pressure of 70bar** ▪ **36" diameter API 5L grade X60 pipe with a wall thickness of 12.7mm and design pressure of 85bar** ▪ **48" diameter API 5L grade X80 pipe with a wall thickness of 14.3mm and design pressure of 94bar.** **Recommendations at the close of this phase specify that pressure reduction is not required during hot tap welding for the three line pipes assessed in this work provided the safe guards in the P9 procedure are correctly followed.** **The finite element (FE) results warrant validation in full scale field trials once the FE model has been validated, then similar analyses should be carried out for other line pipe grades and geometries used by National Grid (specified in TS-C4Gas-PIP4 v1.2[18]) to establish the limiting failure pressures. In addition, further tests to measure accurately the back wall temperatures during hot tap welding particularly for pipe wall thicknesses less than 7.1mm are recommended.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	Development of Novel Mitigation Methods for High Frequency Main Pipework Vibration		
Project Engineer	Brian Woodhouse		
Description of project	A review of available techniques associated with mitigation against high frequency pipe wall vibration, and the development of a new concept of a grouted ring solution into a working prototype.		
Expenditure for financial year	Internal £10k External £93k **Total £103k**	**Expenditure in previous (IFI) financial years**	**Internal £5k** **External £21k** **Total £26k**
Total project costs (collaborative + external + NG)	**£15k**	**Projected 2013/14 costs for National Grid**	**£15k**
Technological area and/or issue addressed by project	**High frequency acoustic excitation of main pipework is characterised by excitation of pipe wall 'shell' modes, with local flexing around the circumference and along the length of the pipe section. At high levels this behaviour can lead to acoustic fatigue at welded features such as pipe supports and small bore connections.** **Excitation sources which can give rise to this type of internal pipe noise and vibration include blade passing or other periodic excitation or broadband turbulence from centrifugal compressors, high pressure drops from components such as control or pressure relief valves, and vortex-shedding from an obstruction in the flow. Once created the energy from the source can be amplified by acoustic and mechanical resonances, giving rise to high vibration and noise.** **Problems associated with this type of response include failure of main pipe welds at local stiffening features, such as blank weldolets/small bore connections and welded pipe supports, and excitation of attached impulse pipework. A number of National Grid compressor sites have experienced problems of this nature.** **There are a number of possible mitigation methods which can be used to address this issue depending on the nature of the excitation, including changes to the source such as alteration of compressor impeller clearances or the installation of compressor Helmholtz dampers, installation of acoustic material or a silencer inside the pipe, attachment of external damping material, or welding of stiffening rings to the pipework. The practicality and feasibility of each of these methods depends on what stage in the plant life cycle the problem has been identified.** **A new approach is proposed as a possible mitigation method for this behaviour, consisting of a short metal sleeve or ring which is fixed to the outside of the pipe using epoxy grout. This approach would have the benefits of ease of installation and no immediate integrity issues.**		

Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		16	2	**14**
Expected benefits of project	**Benefits of carrying out the above study include the following:** **1. Reduced risk of vibration-related fatigue failure due to high frequency acoustic noise for compressor station and AGI pipework. Failure of main pipe welds, pipe supports and impulse pipework can be classed as RIDDOR reportable, a serious safety risk as well as potentially leading to large releases of natural gas into the environment.** **2. The failure of compressor discharge process/impulse pipework, caused by high dynamic stresses, is likely to cost in the region of £50,000 (including materials, manpower and nitrogen purging). There is also a high risk of a loss of network flexibility with compressor units on outage. Historically these have generated losses of around £50,000. A grouted ring solution could be installed (retro-fitted) with minimal disruption to site operations and has the potential to provide savings in the order of £100k/year.** **3. There is an increasing need to monitor vibration across the NTS due to changes in national infrastructure relating to gas inputs and the impact this will therefore have on the use of the NTS. This approach benefits from ease of installation and no immediate integrity issues, allowing for the cost savings achieved when using this new approach.** **4. There are the additional environmental benefits of a reduction of radiated noise levels and no requirement to vent the units on installation.**			
Expected timescale of project	1.5 years	**Duration of benefit once achieved**	**5 years**	
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£142k**	
Potential for achieving expected benefits	**The proposed approach has good potential for realisation of the expected benefits, and offers a method for tackling the identified issue with minimal disruption to operational sites.** **Theoretical modelling and experimental testing has confirmed the behaviour to be largely as expected.**			
Project progress **[Year to End of March 2013]**	**The second stage of this project has now been completed, aiming to develop this concept into a working design and to demonstrate its practical realisation through laboratory testing, prior to testing in the field.**			



Prediction of high frequency response of pipe by FE analysis

Extensive theoretical modelling (finite element analysis) has been carried out, demonstrating the potential effectiveness of the use of this type of stiffening ring for high frequency vibration mitigation on pipework (see figure 1). A range of pipe and ring geometries have been assessed, in order to gain an understanding of the design envelope and to optimise their effectiveness.

Installation of stiffening rings around small bore connection

Experimental testing of several different designs (see figure 2) has confirmed the behaviour to be largely in line with theoretical predictions. Furthermore, through installation of the rings in a laboratory setting, key aspects for successful deployment in field applications have been tested and defined.

Collaborative partners	**None**

R&D provider	**GL Noble Denton**

Project title	Feasibility study into the use of epoxy sleeves in place of heavy wall pipe		
Project Engineer	Brian Woodhouse & Tony Jackson		
Description of project	This project will look at the feasibility of using epoxy sleeves in place of thick wall pipe at road crossings. The initial phase of work aims to understand requirements for developing this technique in order to meet all relevant safety criteria, and identify the follow-on scope for a design feasibility study for application of existing technology at National Grid.		
Expenditure for financial year	Internal £4k External £40k Total **£44k**	Expenditure in previous IFI financial years	Internal **£0** External **£0** Total **£0**
Total project costs (collaborative + external + NG)	**£61k**	Projected 2013/14 costs for National Grid	**£17k**
Technological area and/or issue addressed by project	NTS pipelines are constructed in accordance with IGEM/TD/1 Edition 5, and the current edition stipulates the use of heavy wall pipe as protection against third party interference at road crossings. National Grid receives two or three requests a year to divert or install thick wall pipe for a new high density road. For example, planning revisions to the routing of the road scheme will lead to a road crossing a section of the pipeline without reinforcement of heavy walled pipe. The gas transmission system will also be impacted by the planned high speed rail link (HS2) between London and the West Midlands and will involving a number of additional diversions or additional pipeline reinforcement operations. The options for reinforcement are limited to a pipeline diversion and stoppling operation and the inherent risks associated with type of operation and costs in terms of flow reduction and implications of buyback, give a strong case for further investigation into any alternative options. This programme of work will evaluate the use of epoxy sleeves for providing the required level of protection against third party damage as an alternative to heavy wall pipe. An epoxy sleeve consists of two steel half-shells, joined to encircle the damaged area, with the annular space filled with an epoxy grout. A significant amount of research throughout the 1990s has meant that epoxy sleeves are now a common solution for providing repairs to most types of damage including corrosion, gouges, dents, dent-gouge combinations, cracking and girth weld defects. However the research to date has not been directed at assessing the suitability of the technique for impact protection, both from a mechanical engineering and code compliance perspective. The project will therefore look to address		

	issues such as: **1. Does the epoxy clamp arrangement reduce the specified minimum yield stress (SMYS) in the pipe-work system to an appropriate level to allow the crossing of a road/railway?** **2. Does the arrangement introduce excessive stresses on the pipe-work system either side of the reinforcement?** **3. Given that the shell length is restricted by the rolling capability of a mill, will a gap be an issue or stress concentration factor? If so how does this need to be designed out or managed?** **4. Will this extra metalwork put an extra strain on the CP system, especially if it is a significant length of reinforcement? Do we need to manage the potential for corrosion between the shell and carrier pipe-work?** **5. What thickness of shell and what thickness of grout would be required?** **The scope of work will involve the following tasks: a review of the technical development of the epoxy sleeve repair technology to date, a summary of the IGEM/TD/1 requirements for road crossings, and an assessment of the compliance of epoxy sleeves with TD/1 requirements for road crossings. The project will then deliver a technical note presenting the case for compliance with IGEM/TD/1 Edition 5 and the requirements for the design feasibility study for National Grid.** **A second stage of works will then be to identify the scope of work for a design feasibility study for the use of epoxy sleeves to provide protection at a particular road crossing. This is likely to give a more practical emphasis to the work and proposed trial application. The issues identified above may fall within the scope of the technical note or form part of the feasibility design.**			
Type(s) of innovation involved	Significant	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		16	-4	**20**
Expected benefits of project	**If epoxy sleeves can be proven as a viable alternative to thick wall pipe, then reinforcement work could be carried out with a significantly reduced safety risk associated with a diversion using stopple and bypass, and employees working downstream of the stopple fitting. The operation also leaves the stopple fitting on the pipeline with an ongoing maintenance requirement and a long term risk of leakage. An incident in September 2011 with a stopple leaking resulted in flow disruption (both transmission and distribution and LNGS), actions taken to prevent a storage facility bringing gas onto the network and large volumes of gas vented to atmosphere.** **A diversion to install heavy wall pipe requires gas flows to be reduced whilst welding is carried out and the stopples fitted, the installation of an epoxy sleeve could be carried out without**			

	interrupting flows providing a continued service to customers. **Previous number of diversions has been approximately two / three per year, there is an additional impact on National Grid of the High Speed Rail Link (HS2) phase 1 project to link London and the West Midlands. If the HS2 project does go ahead there are five main high pressure pipelines that go underneath the HS2 rail track, which is regarded as a 'high density traffic route' and therefore the installation of heavy wall will be required to protect the pipeline. If Phase two to link with Manchester and Leeds goes ahead there would be more diversions required, and numerous other diversions (fifteen of them high pressure) have already been identified on the distribution system.** **This proposal has a strong link to previous work that looked at the use of composite wraps for this application, and therefore shares many benefits as described above. The technology readiness level (TRL) for composites is at a lower level than epoxy sleeves; this project has potential to deliver an alternative to heavy wall pipe more quickly, whilst longer term both are likely to be valuable additions/alternatives in our approach to safe and efficient asset management.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£217k**
Potential for achieving expected benefits	**There is a high likelihood of the project delivering the stated benefits. There is a possibility that the technical note may indicate the requirement for physical testing of an epoxy sleeve.**		
Project progress **[Year to End of March 2013]**	**The feasibility study phase of this programme of work is complete.** **Following the study, a conceptual design was developed that is largely based on standard design principles and specifications with the addition of linking sleeves together in order to provide integrity and protection to long lengths of pipeline.**		

Epoxy sleeve designed to specification

Evaluation of grout adhesion to Fusion Bonded Epoxy (FBE) coating was undertaken to asses whether application of the grout directly over the FBE coating will adversely affect its adhesion and hence compromise the performance of the grouted repair sleeve. An evaluation programme was also conducted to investigate how water ingress into the FBE coating influences the adhesion between the FBE and the substrate, and the intercoat adhesion between the FBE and the grout material. It is important to understand how the in-service condition of an FBE might affect the performance of the grout and hence the consequence of applying grouted repair sleeves directly over aged FBE.

The concept of using epoxy sleeves as a suitable alternative to thick wall pipe has been reviewed by the IGEM TD1 committee and its methodology has been accepted in principle. Standardisation is subject to being independently reviewed at a later date based on successful real-time trials.

Collaborative partners	**None**
R&D provider	**PIE (Pipeline Integrity Engineers)** **GL Noble Denton**

Project title	Pipeline Risk Ranking Model		
Project Engineer	**Danielle Willett**		
Description of project	**To develop a risk based model for prioritisation of high pressure gas pipeline management and maintenance activities, taking into account the threats posed by different damage mechanisms such as corrosion, third party interference and ground movement on individual pipeline sections. This type of prioritisation system is a new concept and will better enable the prioritisation of resources to the highest risk pipelines.** **This work will determine how National Grid can best make decisions for prioritising maintenance and inspection for high pressure gas pipelines to maintain their availability for use by customers whilst meeting our safety obligations.** **The initial study is designed to scope model development and provide example demonstrations of the risk ranking results produced as a result. The next stage is the development of a fully functional interactive model.**		
Expenditure for financial year	Internal £4k External £24k Total **£28k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£98k**	**Projected 2013/14 costs for National Grid**	**£70k**
Technological area and/or issue addressed by project	**National Grid operates high pressure pipelines across a wide variety of locations from rural and suburban. Whilst the pipelines are all exposed to similar threats, including third party damage, ground movement, fatigue and corrosion, the extent of the threat varies dependant upon the pipeline location and construction standards in place at the time of build.** **The current approach is generally to use standard procedures for all pipelines, which do not take into account specific risks for individual pipeline sections (with the exception of inline inspection).** **National Grid are undertaking a study to develop a model that takes into account the threats posed by different damage mechanisms on individual pipeline sections and ranks the relative risks of failure so that high risk sections can be identified, and inspection, maintenance and mitigation actions applied appropriately.** **The model will include relevant factors such as the location of the pipeline and the likelihood of failure due to:** ▪ **Corrosion - influenced by soil characteristics, wall thickness, coating, whether the pipeline is piggable, inspection findings etc.** ▪ **Ground movement – influenced by local instability, wall**		

<table>
<tr><td></td><td colspan="4">thickness, diameter, operating stress etc.
▪ External Interference – influenced by wall thickness, diameter, operating pressure etc.
▪ Material and construction defects – influenced by age and hydrotest level etc.
▪ Operational errors – influenced by control systems, operating procedures and training.
▪ Prevention and mitigation measures – including pipeline route marking, physical protection, emergency isolation facilities etc.
A risk ranking model uses a points scoring system, and will be used to calculate a total risk score for the pipeline.
Information will be used from around the world including Europe, US and Asia and from research bodies such as EPRG and PRCI to define the appropriate risk profile and consider the various options for pipeline inspection and management.
The model will consider pipeline location, failure mechanism likelihoods for specific sections of pipeline, and the prevention and mitigation measures in place for those pipeline sections.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Significant</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>15</td><td>4</td><td>11</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">Being able to rank pipelines against each other based on their propensity for failure will help National Grid make informed choices for investing funds in maintenance and/or inspection activities for higher risk pipeline sections and ensure that we continue to meet our customer and safety obligations in the most efficient way.
A pipeline failure on the NTS would be an incident with far reaching consequences. This risk ranking model will provide a robust and consistent methodology for undertaking the most appropriate mitigation actions across the National Transmission System (NTS).
National Grid’s overheads on inline inspection, excavations, linewalking, Close Interval Potential Survey (CIPS), third party monitoring is many £m per annum. For example, National Grid spends £400k on TD/1 pipeline inspection surveys, assessing each pipeline every four years.
The new edition of TD1 allows a pipeline operator to extend this to one in six years following authoritative review. If this one-in-six year approach could be adopted, annual expenditure would fall to £267k. This study is the first assessment to establish if this risk ranking approach could be successfully developed for use on the NTS. Investment in a risk ranking tool offers excellent potential for greater efficiencies by targeted inspection and maintenance.</td></tr>
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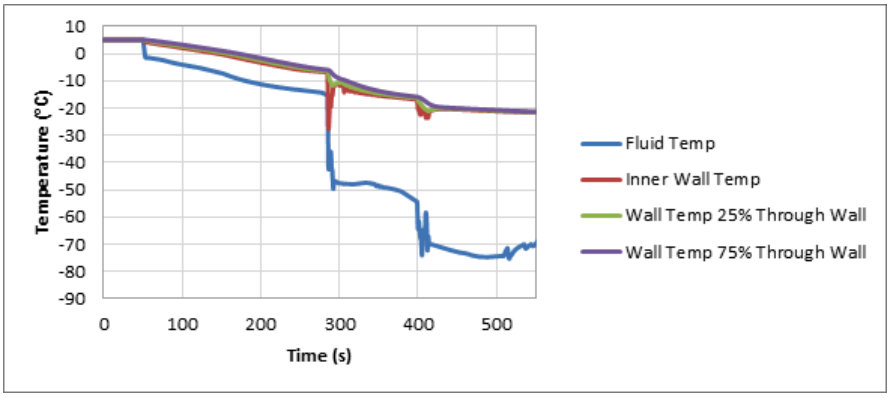
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£40k**
Potential for achieving expected benefits	**The potential for achieving expected benefits is high with the first stage as a simple (non-interactive) version of the model has been developed successfully. Phase two will enable the project to develop a fully functional interactive model.**		
Project progress **[Year to End of March 2013]**	**The simplified, non interactive model has been successfully developed and presented back to National Grid.** **Phase two of this programme of work will focus on the development of a more complex, fully functional, and interactive pipeline risk ranking model. This work is set to commence in 2013/14.**		
Collaborative partners	**None**		
R&D provider	**PIE (Pipeline Integrity Engineers)**		

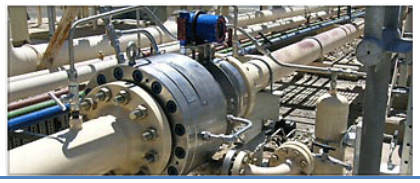
Project title	Toughness of Fittings		
Project Engineer	**Julian Barnett**		
Description of project	**This program of work is being undertaken to rationalize and update the existing suite of National Grid specifications for the toughness of pipeline fittings. This will include explicit definition of the rationale for establishing the design temperature and the associated test temperature for toughness testing. The work will ensure that more expensive, low temperature rated fittings are not specified unnecessarily.**		
Expenditure for financial year	Internal £3k External £11k Total **£14k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£87k**	**Projected 2013/14 costs for National Grid**	**£73k**
Technological area and/or issue addressed by project	**Inconsistencies have been identified in the existing suite of specifications regarding the toughness of fittings for use on natural gas pipelines. The inconsistencies relate to the definition of design temperature, the relationship between the design temperature and the material test temperature. In most cases the requirements are based upon test work carried out in the 1960s for the development of the British Standard for pressure vessels, BS 5500.** **Initial research carried out to determine the material properties required for above ground and buried pipelines and fittings involved the assessment of worst case environmental temperatures, and the application of material toughness research carried out by The Welding Institute (TWI) for application to pressure vessels (and incorporated in the former pressure vessel standard BS 5500, now PD 5500). Since that time, the need to take into account the effect of Joule Thomson (JT) cooling due to pressure reduction during routine and non-routine pipeline operations has arisen. Typically, this means that the assumption applied is that the lowest operational temperature in the fitting is assumed to be that which occurs in the fluid on depressurisation. To avoid this assumption, it is necessary to take account of the transient heat transfer from the pipeline and fittings to obtain a more realistic understanding of minimum temperatures which may occur. The aim of this programme of work is to carry out the research necessary to investigate and develop a generic methodology which builds on and extends the existing methodology. The intent is to demonstrate to all internal and external stakeholders that a fit for purpose material selection process has been adopted.**		

Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		10	0	**10**
Expected benefits of project	**The work is expected to ensure that a more expensive, low temperature rated fittings are not specified unnecessarily to take account of Joule Thomson (JT) cooling effect, as required by current best practice. The cost of low temperature fittings is typically a factor of between 2 and 4 times greater than the cost of carbon steel fittings (depending on size and type).**			
Expected timescale of project	1 year	**Duration of benefit once achieved**	**Lifetime**	
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£43k**	
Potential for achieving expected benefits	**Benefit potentials remain good:** **An initial assessment of the impact of warm pre-stressing, taking account of reducing pressure with reducing temperature indicates the expected benefits will be achieved.**			
Project progress **[Year to End of March 2013]**	**This project is currently in the initial phases of work. During this phase fitting specifications needed to be assessed and have been now identified. These include bends, tees, valves, pig traps, reducers, sweepolets and weldolets. The design and material test temperatures specified in the current versions of the specifications are being collated.**  **The fluid and wall temperatures in the buried section of the pig trap during the CO2 venting at the low point** **The scope for phase 1 thermal analysis was specified and all information required for the thermal analysis was provided to enable simulations to be conducted which will determine likely material temperatures.**			

Collaborative partners	**None**
R&D provider	**PIE (Pipeline Integrity Engineers), GL Noble Denton (GLND)**

Project title	Pipeline Impact Detection System			
Project Engineer	**Aroon Parmar**			
Description of project	**Evaluation of the first use of a Threatscan remote-by-satellite pipeline acoustic monitoring system for the detection of third party interference.**			
Expenditure for financial year	Internal £5k External £36k Total **£41k**	**Expenditure in previous (IFI) financial years**	**Internal £86k** **External £521k** **Total £607k**	
Total project costs (collaborative + external + NG)	**£648k**	**Projected 2013/14 costs for National Grid**	**£0k**	
Technological area and/or issue addressed by project	**The objective of the project is to examine the feasibility of an impact detection system for transmission pipelines. GE has developed a solution which has been tested on an operational pipeline in the USA and Germany. The impact detection system was installed on No 7 feeder for trial.**			
Type(s) of innovation involved	Radical	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		15	2	**13**
Expected benefits of project	**It was hoped that the tool would enable National Grid to identify location of third party plant and equipment working in close proximity to the pipeline prior to physical impact damage taking place. This would allow National Grid to take proactive precautionary measures to safeguard the system integrity before damage occurs.**			
Expected timescale of project	6 years	**Duration of benefit once achieved**	**5 years**	
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£184k**	
Potential for achieving expected benefits	**The trials have shown the system to be effective for detecting actual impacts on the transmission system. However at the current stage of development the GE Threatscan system does not offer a pro-active indication of encroachment near to the pipeline.**			

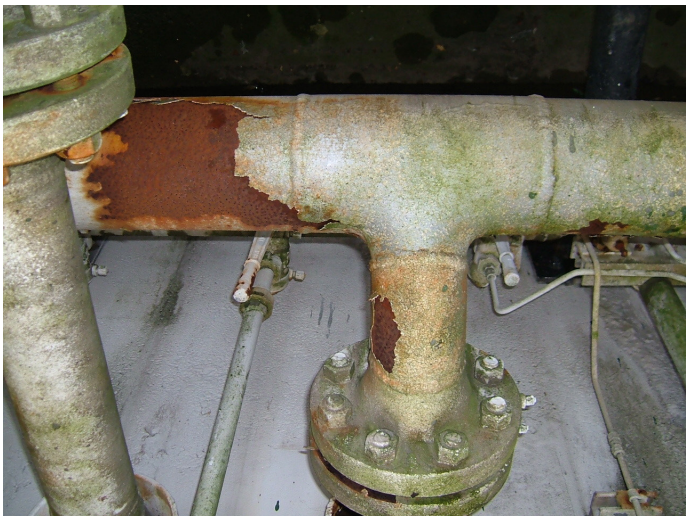
Project progress [Year to End of March 2013]	**In September 2008 the ThreatScan system, developed by GE, was installed on five sites between East Ilsley and Michelmersh to carry out feasibility studies on performance in impact detection on National Grid transmission pipelines.**  **A programme of impact testing was carried out to assess functionality of the ThreatScan hydrophones, with data correlation checks against GE monthly impact reports. Results showed good functionality of the hydrophones, indicating the system is reactive to direct impacts near pipeline.** **Work was then carried out to investigate the development of algorithms that would enable the system to detect encroachment activities on site. It was concluded that the ThreatScan system is not sufficiently developed for proactive detection of encroachment activity and therefore does not offer further advantages over current third party pipeline impact prevention systems. Based on these findings, the ThreatScan systems were decommissioned from the five sites between East Ilsley and Michelmersh.**
Collaborative partners	**None**
R&D provider	**GE Oil & Gas, GL Noble Denton**

Project title	Installation of IRIS separators			
Project Engineer	**Paul Sinclair**			
Description of project	**To install IRIS separators in the fuel gas supplies at Carnforth Compressor Station to trial the removal of liquid contaminants.**			
Expenditure for financial year	Internal £7k External £1k Total **£8k**	**Expenditure in previous (IFI) financial years**	**Internal £35k** **External £238k** **Total £273k**	
Total project costs (collaborative + external + NG)	**£280k**	**Projected 2013/14 costs for National Grid**	**£0**	
Technological area and/or issue addressed by project	**To trial the use of a rotary separator that will easily remove liquid contaminants from the fuel gas supply, thereby increasing the efficiency and life of the gas generators.**			
Type(s) of innovation involved	Technology Transfer	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		11	1	**10**
Expected benefits of project	**There is a requirement from all the Gas Turbine original equipment manufacturers (OEMs) to provide a clean, dry gas supply system within certain limits. If this requirement is not met, the effect is considerable damage to gas generator hot gas path components that cause a loss of efficiency, increased operational, overhaul and repair requirements. Monitoring the amount of liquid removed will determine success of the scheme.**			
Expected timescale of project	6 years	**Duration of benefit once achieved**	**5 years**	
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£27k**	
Potential for achieving expected benefits	**Initial likelihood that IRIS filters will remove liquids if present was expected. Uncertainty related to removal of significant liquid contaminants from fuel lines and potential for detectable reduction in major overhaul frequency for the gas turbine engines remained unconfirmed due to cessation of manufacturer support.**			
Project progress [Year to End of March 2013]	**The installation of two IRIS separators at the Carnforth compressor station during planned station outage was necessarily cancelled in connection** 			

	with the unexpected cessation of support by the IRIS filter manufacture. Field trials at Carnforth station were therefore halted and the project closed. The IRIS separator is not a sustainable option if not supported by the manufacturer.
Collaborative partners	**None**
R&D provider	**Dresser Rand**

Project title	AGI Paint Systems		
Project Engineer	**Peter Martin**		
Description of project	**Development of new painting practices for the National Grid gas transmission system's above ground installations (AGIs) to minimise the costs of future maintenance painting activities.**		
Expenditure for financial year	Internal £4k External £10k Total £14k	**Expenditure in previous (IFI) financial years**	**Internal £18k** **External £216k** **Total £234k**
Total project costs (collaborative + external + NG)	£248k	**Projected 2013/14 costs for National Grid**	**£0k**

Technological area and/or issue addressed by project	**This project will facilitate the development of National Grid's painting policy and practice for its above ground installations to minimise the cost of maintenance painting.** **This objective will be achieved by two key developments** **1. Identification of single coat paint systems that can be used to perform local patch repair on existing paint coatings without the requirement for grit-blasting and will provide temporary protection until the next scheduled maintenance painting programme.** ***2.*** **Identification of over-coating paint systems which can be applied to entire sites to extend the life of the existing coating. This will mitigate having to grit-blast pipe work and structures back to bare metal and re-apply a complete paint system.** **The general condition of the asset is now reaching the stage where a reactive approach to corrosion management is no longer cost effective due to age and previous levels of corrosion investment. It is necessary to improve the corrosion management of these assets, as there is a potential for a significant increase in repair/replacement costs and the potential for corrosion related failures.**			
Type(s) of innovation involved	Technology Transfer	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		13	2	**11**
Expected benefits of project	**In addition to ensuring the integrity of equipment, a pro-active approach to corrosion management has major financial benefits through:** ✓ **Reduced un-scheduled pressure reductions/outages due to corrosion repairs** ✓ **Reduced repair costs** ✓ **Minimisation of problems during application** ✓ **Realisation of performance from a 2-coat compared with a 4-coat system**			

	✓ **Maximisation of asset life**  **Example of asset corrosion** **The outcome of this project will be the identification of two-coat paint systems that are compatible with existing materials. Maintaining the existing coating system, rather than effecting its complete removal and replacement, will provide a more cost effective solution to maintenance painting.**		
Expected timescale of project	5 years	**Expected duration of benefits**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£48k**
Potential for achieving expected benefits	**Based on accelerated corrosion testing a two-coat system has been identified that is reported to provide equivalent performance to the four-coat systems traditionally specified for maintenance painting.** **Information generated from large-scale site trials indicate the two-coat systems have good application properties, can be applied to the required film thickness (in two coats), dry/cure under the extremes of environmental conditions that often prevail on site and have the ability to provide long-term corrosion protection.** **Development of two-coat maintenance systems, rather than the four-coat approach previously employed by National Grid, will potentially reduce paint, application and inspection costs, and minimise the potential for costly problems to occur.**		

Project progress [Year to End of March 2013]

Five large-scale field trials of a two-coat paint system were conducted during the 2010 painting season at National Grid (Gas) above-ground installations (AGIs) located around the UK. At four of these sites (Carlisle, Mickle Trafford, Brisley and Larbert) complete removal and replacement of the paint system was deemed to be necessary. At a further site (Honeybourne) a patch repair programme was considered to be sufficient.

The original purpose of this programme was to identify systems suitable for maintenance where partial paint breakdown had occurred. It is now evident that the successful two-coat systems from the laboratory programme are equally applicable to AGIs where complete removal and replacement is necessary, hence extending the application opportunities for these two-coat systems.

The AGIs identified for the field trials were representative of coastal, industrial and rural sites. This allowed us to capture the range of difficult environmental conditions that prevail, including low temperatures, high relative humidity and condensation.

Application of two-coat system

Short-term performance assessment of the two-coat systems were found to have good application characteristics, were capable of achieving the target (250 microns) thickness in two coats, dried and cured in an acceptable timeframe and gave an aesthetically pleasing finish of the topcoat. Performance assessment was based on:

- **Topcoat appearance, e.g. gloss, colour change and lack of dirt retention.**
- **Intercoat adhesion and adhesion to the substrate.**
- **The degree of degradation, e.g. flaking, delamination and blistering.**
- **Compatibility with existing systems where patch repair has been**

undertaken.

Monitoring continued over a span of two years to assess the performance of the two-coat system. The last round of paint condition assessments was completed in April 2012 and a final report of those findings has been prepared. In addition to the in-service performance of the experimental two coat and the standard four coat system, the ability of a single coat material employed on site to spot repair small areas at which destructive pull-off adhesion testing had exposed the steel substrate, was assessed at the final 24 month inspections. (At the 24 month inspections the repair material had been in-service for approximately 12 months, the first application being at the 12 monthly inspections). National Grid was particularly interested in the short term performance of these spot repair materials for temporary repairs. The repair material employed on site was a rapid curing two pack solvent free polyurethane supplied by Practical Compounds (Versathane 3/1 mastic). This material had performed extremely well during the accelerated corrosion testing.

A high-level summary of the paint condition assessment findings are as follows:

Corrosion protection - All of the experimental two-coat paint systems applied at Carlisle, Mickle Trafford, Brisley and Larbert AGIs are generally providing excellent corrosion protection after 24 months in service. In addition, the single coat spot repair material showed no evidence of breakdown after 12 months service.

Adhesion - All of the experimental two-coat paint systems exhibit excellent adhesion and none show any propensity to fail adhesively from the substrate. In the majority of cases, pull-off adhesion tests fail cohesively through the topcoat or exhibit glue line failure.

Topcoat gloss and colour retention - Aesthetic properties of the paint systems, while not a critical factor, were taken under consideration. Trial topcoats retained a high level of gloss with the exception of the International Paints system applied at Mickle Trafford; lower gloss levels recorded on the International Paints topcoat was attributed to condensation during the curing process. The retention of a high gloss often facilitates a certain degree of self cleaning of the paintwork hence preventing excessive dirt retention.

Colour retention of the topcoats was excellent and in most cases the colour changes would only be perceptible to a trained colour matching chemist.

Coverage - In the majority of cases the experimental two-coat paint systems provided excellent protection when applied to difficult to coat areas including nuts, stud bolts, flange edges, pipe supports etc. No paint breakdown or rust staining was observed in these difficult to coat areas at Mickle Trafford, Brisley and Larbert.

However, there is evidence that some rust staining has started to occur at a few stud bolts on small diameter flanges and pipe supports at Carlisle. Premature paint breakdown on stud bolts was attributable to the limited access to these items (concealed within the bolt holes in flange and pipe supports) and insufficient attention to stripe coating operations.

Comparable corrosion protection - The experimental two-coat paint systems

	applied at Mickle Trafford, Carlisle, Brisley and Larbert provided a comparable level of corrosion protection to the standard four-coat system specified in the National Grid painting specification T/SP/PA/10. **Time & Cost benefit - The use of two-coat paint systems, in place of the four-coat maintenance system currently specified in T/SP/PA/10, incurs significantly less time and hence cost in terms of its application, and minimises the opportunity for problems to occur during the maintenance painting programme, e.g. pressure reductions resulting in condensation. The fewer coats a system requires, the fewer opportunities there are for these types of problems to occur.** **Brush & Spray application guidelines - Where large-scale removal and replacement of paint systems is being planned, two coat systems should only be specified where spray application is being employed. Large scale application by brush may not achieve the total coating thickness (200 – 250 microns) required. As in any painting programme, stripe coating of difficult to protect areas (nuts, stud bolts, flange edges, pipe supports etc.) is essential.** **When patch painting is being conducted, the application of two coat systems, by brush, has been shown to be practical. Stripe coating of difficult to protect areas is critical when brush application is being employed.** **Spot Repair - Spot repair materials have proved their ability to provide short term protection at small area damages, with limited surface preparation, for periods up to 12 months.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

<table>
<tr><th>Project title</th><th colspan="4">High Pressure Metering Uncertainty Calculation Tool</th></tr>
<tr><td>Project Engineer</td><td colspan="4">John Wilson</td></tr>
<tr><td>Description of project</td><td colspan="4">Develop a measurement uncertainty tool for orifice plate meters, turbine meters and ultrasonic meters. The resulting technique will allow error and bias to be monitored against maximum permissible error (MPE) and maximum permissible bias (MPB), to avoid costly annual re-calibrations where these are demonstrated to be unnecessary.</td></tr>
<tr><td>Expenditure for financial year</td><td>Internal £3k
External £16k
Total £19k</td><td>Expenditure in previous (IFI) financial years</td><td colspan="2">Internal £5k
External £8k
Total £14k</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£97k</td><td>Projected 2013/14 costs for National Grid</td><td colspan="2">£20k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">Initially a prototype model was developed for calculating the maximum permissible bias (MPB), maximum permissible error (MPE) and uncertainty in volume and energy of flange-tapped orifice plate meters.

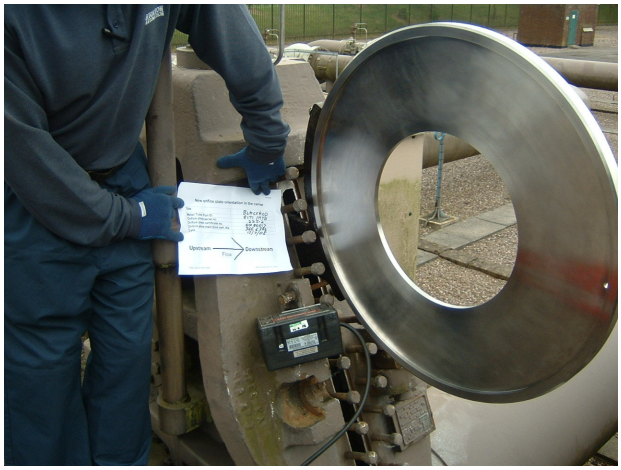
The second stage of the project developed the orifice plate tool further to cover any range of gas composition, pressure, temperature and differential pressure.

Going forward the tool is being used by both National Grid Gas Transmission and Distribution to develop their in-house procedures such as T/PR/ME/1. Work proposed under this project looks to develop the tool further for turbine and ultrasonic meter technologies.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Incremental</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>11</td><td>-8</td><td>19</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">The cost of springing, recalibrating off-site and re-instating a typical ultrasonic meter is £25-30k (including cranes, transport and calibration charge). This cost is getting close to the cost of a new ultrasonic meter, so the ‘fit and forget’ concept and associated cost benefit advantage of selecting an ultrasonic meter could easily disappear unless something is done to improve confidence in longer calibration intervals (e.g. 2 -4 years, instead of 12 months).

This project seeks to reduce the frequency of the above recalibration cost for installed ultrasonic, turbine and orifice plate meters, by increased confidence in the meter accuracy.

By extending the improvement in the calculation of uncertainty, error and bias of volume and energy to cover turbine, ultrasonic and orifice plate meters, the tool will allow National Grid to:

1. Identify, where necessary, where site improvements can be most</td></tr>
</table>

	effective. **2. Demonstrate to Ofgem, third parties and external auditors that the metering is fit for purpose and ensure compliance with contractual obligations.** **3. Separate uncertainties and errors as required by OIML (Organisation Internationale de Métrologie Légale).** **4. Re-assess the tolerances of primary and secondary instrumentation during validation and therefore enable the updating of National Grid policy and procedure documents.**		
Expected timescale of project	2 years	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£16k**
Potential for achieving expected benefits	**The following benefits have been achieved:** **1. Identifying where site improvements will be most effective.** **2. Ability to demonstrate compliance (or otherwise) with contractual obligations.** **3. Separate uncertainties and errors.** **4. Ability to re-assess the tolerances on National Grid policy and procedure documents.**		
Project progress [Year to End of March 2013]	**Development of the orifice plate, turbine and ultrasonic meter uncertainty and error calculation tools have been completed and tested by an independent third party using real flow and validation data from HPMIS (High Pressure Metering Information System).**  ***Orifice plate meter uncertainty tool development*** **Improvements to the models were suggested and these have now been implemented to comply with latest developments at British Standards Institute.** **Inputs to the calculations consist of all on-site measurements which**		

include:

- ✓ **Gas quality**
- ✓ **Pressure**
- ✓ **Temperature**
- ✓ **Differential pressure for orifice plates**
- ✓ **Meter calibrations**
- ✓ **Meter pulse inputs for turbine and ultrasonic meters**
- ✓ **Equation of state**
- ✓ **Barriers**
- ✓ **Analogue to digital conversion**
- ✓ **Calculation of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full (ISO 5167)**

The orifice plate, turbine and ultrasonic tools developed in this project separate out the calculation of uncertainty and error for volume and energy. A finite element option with each tool allows the user to determine the sensitivities of the individual uncertainties and errors to identify the inputs with the greatest impact.

Included in the scope of this project, the independent third party will also be updating a number of National Grid documents from the ME procedure (work procedure for validation of equipment associated with measurement systems for the calculation of mass, volume & energy flowrate of gas) which have an inter-dependency on the calculation methods and results generated from this project.

An option for future work being considered will include using the new tool on a variety of metering sites to determine the levels of maximum permissible error and maximum permissible bias that can typically be achieved by National Grid Gas; these values will then feed into National Grid Gas procedures and specifications.

Turbine and ultrasonic meter uncertainty tool development

Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	Efficacy of Low Flow Differential Pressure Measurement for Orifice Plate Meters		
Project Engineer	Dr. Quentin Mabbutt		
Description of project	This programme will provide experimental evidence as to the uncertainty of low differential pressure measurement. Currently there is limited experimental evidence available to support the industry held view that continued operation of meters at low differential pressures of a few millibar (mBar) is inappropriate tending towards meter under registration.		
Expenditure for financial year	Internal £7k External £25k **Total £32k**	**Expenditure in previous (IFI) financial years**	**Internal £5k** **External £17k** **Total £23k**
Total project costs (collaborative + external + NG)	**£55k**	**Projected 2013/14 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	Despite recent advances in high pressure gas measurement technology, the majority of meter systems on the National Transmission System (NTS) are of the Orifice Plate (OP) design. These systems rely on four key primary measurement components, the orifice plate and carrier assembly, pressure, temperature and differential pressure measurement devices. Usually the meters are operated at flows which are well within the operating range of the respective instruments. However, there has been a tendency to operate at flows where the differential pressure measurement, is below the expected 30-90% range (span) of the instrument. In these cases, the meter system will be operating outside its design envelope. There is a strong body of circumstantial and limited experimental evidence to suggest that low flow and hence low differential pressures, has a propensity for negative measurement bias (under read) to a magnitude of greater than 2% of absolute reading in some instances. Although flow equation is a continuum across the flow range, its proportionality to the square root of the differential pressure ensures that errors in its measurement will dominate at low flow. This is further exacerbated by the measuring instrument's uncertainty at these very low values. This, coupled with the resolution of the differential pressure instrument, and the inability to validate at these low pressure values outside a dedicated calibration laboratory, make experimental validation of these phenomena more relevant. All commercial arrangements that govern off taken gas from the NTS require minimum flow and measurement uncertainties to be adhered to. Most of these meter systems are of the orifice plate design where flow measurement is a function of the differential pressure measurement across the plate. However, due to changing operational and commercial		

	regimes, a number of NTS off takes operate at exceedingly low flows. This coupled, with the resolution of the differential pressure instrument and the inability to validate at these low differential pressures outside a dedicated calibration laboratory, make experimental validation of these phenomena very relevant.			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		15	0	**15**
Expected benefits of project	**Of one hundred and twenty one (121) Distribution Network offtakes that operated in 2011/12, eighteen (18) OP meters recorded continuous flowing differential pressures of less than 15 mBar for periods in excess of twenty (20) percent of their annual throughput. From the evidence presented, the resulting measurement errors are considerable although the absolute system flow is low.** **In 2011/12, 89,015 GWh (8092 mscm) of gas was delivered through meter systems operating at differential pressures below 15 mBar. If a negative weighted bias of 2%[1] is applied to the expected differential pressure measurement the annual gas under registered is potentially 1521 GWh. This constitutes 38% of the assessed NTS Shrinkage Unaccounted for Gas (UAG) component at a cost to the Shrinkage budget of ~ £28 m for the same period.** **There are currently significant efforts expended to ensure customer value and National Grid efficiency. Improving off take operation by reducing extended operation at low differential pressures would significantly improve potential UAG husbandry.** **[1] George, D.L. & Hawley, A.G. (2010) *Extended Low Flow Range Metering Final Report.* SwRI Report No. 1815188, PR-015-09605.**			
Expected timescale of project	2 years	**Duration of benefit once achieved**		**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**		**£28k**
Potential for achieving expected benefits	**The initial low flow trials did indicate that orifice plates operating at low differential pressures exhibited a tendency to under register flow. The magnitude of under registration varies from 1.9% to 0.4% with orifice plates of beta ratios of 0.5 and 0.6 respectively. The results from the 0.7 beta ratio test was inconclusive and require further analysis.** **Additional tests (described in Programme Summary below) allowed for further assessment of the measurement behaviour of OP meter systems at low flows. The full set of National Grid results were consistent with other studies (see George et al 2010, George et al 2009), although the test data at**			

	the largest beta ratio (0.7) are considered unique. **If OP low flow is prevented (meter flows below 30% of flow meter range), the cost benefits when mapped to 2012/13 figures produces the following:** ✓ **The initial estimates of flow through off takes operating at differential pressures below 15 mBar in 2012/13: 75,312 GWh (7,019 mscm).** ✓ **Based on an error envelope approach (see Figure 4) a negative bias of 0.65% is applied, the annual gas under registered by off takes alone is: 489 GWh at a cost of £9.79m to the UAG element of NTS shrinkage budget. This is a direct community saving as it impacts directly on the transportation charging mechanism.** **The completion of the additional analysis confirmed the initial results and these studies will form the central feature of the ongoing meter strategy with all NTS orifice plate asset owners. Some of this articulation strategy has already begun and the reduction in low flow totals for 2012/13 is considered the reflection of the installation of new metering assets and improved flow control of other OP assets. The wider knowledge of meter performance under low flow conditions also assists the detection of UAG and possibly begins to explain its inherent volatility.**
Project progress **[Year to End of March 2013]**	**Programme Summary** **An initial series of low flow trials indicated that OPs operating at low differential pressures exhibited a tendency to under register flow. The magnitude of under registration varied between 1.9% to 0.4% with OPs of beta ratios of 0.5 and 0.6 respectively. The results from the 0.7 beta ratio test was inconclusive and required further analysis.** **To verify the initial flow results, an additional set of low flow tests were conducted again employing 300mm (12") OPs with beta ratios of 0.5, 0.6 and 0.7. These beta ratios being typical of meter systems operated on the NTS. Each individual plate was subjected to an 11 point test procedure whereby flow measurements were made at differential pressures of 5mBar, 10mBar, 15mBar, 20mBar, 80mBar and 90mBar in both ascending and descending flow directions.** **The results proved that the two modes of under and over measurement bias were exhibited but the observed behaviour was very dependent on the beta ratio. As such each respective beta ratio are treated separately below.** **Beta Ratio: 0.5** **All 0.5 beta ratio OP tests (Figure 1) displayed under registered flow when operated at differential pressures below 20mBar. The under registration was parabolic in nature with its magnitude increasing from ≈–0.5% at 20 mBar to ≈–1.75% at 5 mBar.**

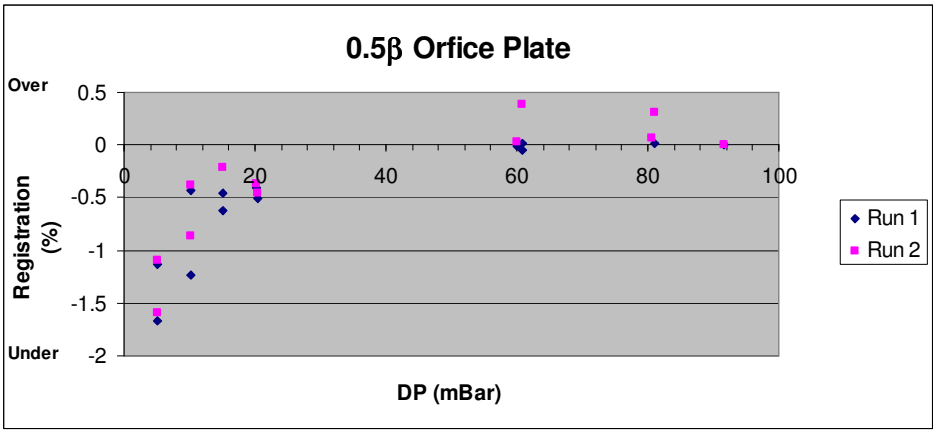


Figure 1. 0.5 β Orifice Plate Low Differential Pressure Test Results.

Beta Ratio: 0.6

The results at 0.6 beta ratios displayed mixed measurement modes from over to under registration (Figure 2) although the measurement bias was consistent for the respective run. Generally, irrespective of measurement mode, there was a weak parabolic relationship between differential pressure and measurement bias. The range of measurement bias was between -1.8% (under) to 1% (over). The over registration observed in Run 2 (square data points) to 4% (over) is considered to define the outer envelope of measurement behaviour but indicates the large variability of measurement performance over these flow ranges for this meter configuration.

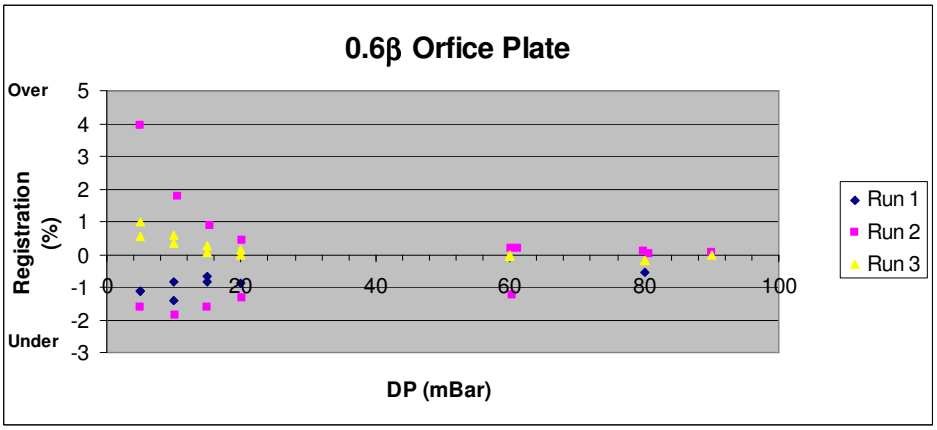


Figure 2. Low Flow Rate Results with 0.6 Beta Ratio Orifice Plate.

Beta Ratio: 0.7

The measurement results at 0.7 beta ratio again exhibited a mixed mode of measurement bias between under and over registration. There was also a parabolic relationship between differential pressure and flow (as indicated by the parallel curves in Figure 3) but the respective flow relationships appeared to be displaced about the zero (error) registration axis.

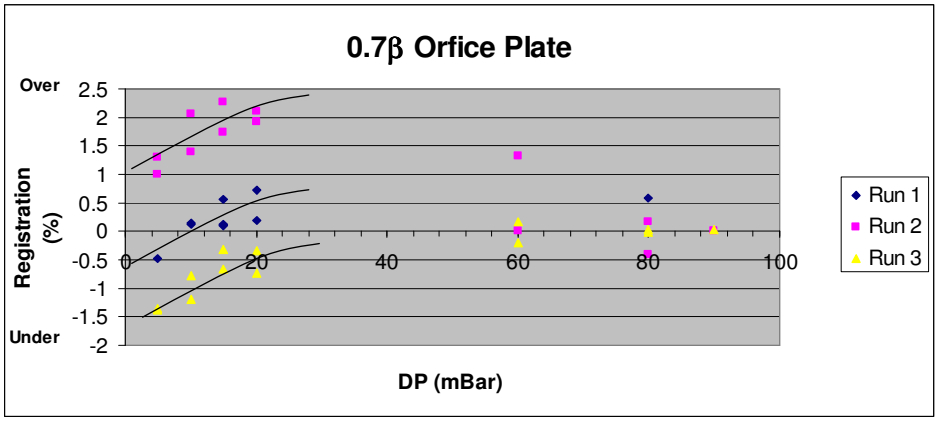


Figure 3. Low Flow Rate Results with 0.7 Beta Ratio Orifice Plate.

Conclusions

- ✓ **The results for the 0.5 beta ratio plate were consistent with earlier work and confirm the view that these orifice plate metering systems have a tendency to under register at low differential pressures (flows). The magnitude of the under registration is between 1.9 and 0.4% and is to be considered a measurement bias.**
- ✓ **The results for both the 0.6 and 0.7 beta ratio plates exhibited both under and over registration. The sense of the measurement bias (under/over) remained consistent within an individual test sequence but it varied between test runs. The 0.6 beta ratio mix mode data is consistent with other studies [1] although there is no corroborative evidence for the 0.7 beta ratio results.**
- ✓ **This mixed sense measurement bias at the large beta ratios was considered the non optimal development of the gas flow downstream of the OP vena contracta. Any asymmetric distortion of the flow pattern in this area would affect the differential pressure measurement and consequently the calculated flow. As the flows increase, the flow patterns would become more developed which is likely to reduce asymmetry improving the 'true' differential pressure in that flow region.**
- ✓ **At 0.5 beta ratio, even at the lowest differential pressures, it is considered that the flow patterns are more fully developed, even at the very lowest differential pressures and possibly exhibit greater symmetry which leads to a more consistent flow performance.**
- ✓ **All the results are presented in Figure 4 and a measurement bias envelope has been defined and is shown as area enclosed between the solid 'trumpet' lines. The dashed upper trumpet line defines the upper measurement bias.**
- ✓ **The defined envelopes when analysed statistically still indicate the propensity for OP meters to exhibit a negative measurement bias (under read) at low flows.**

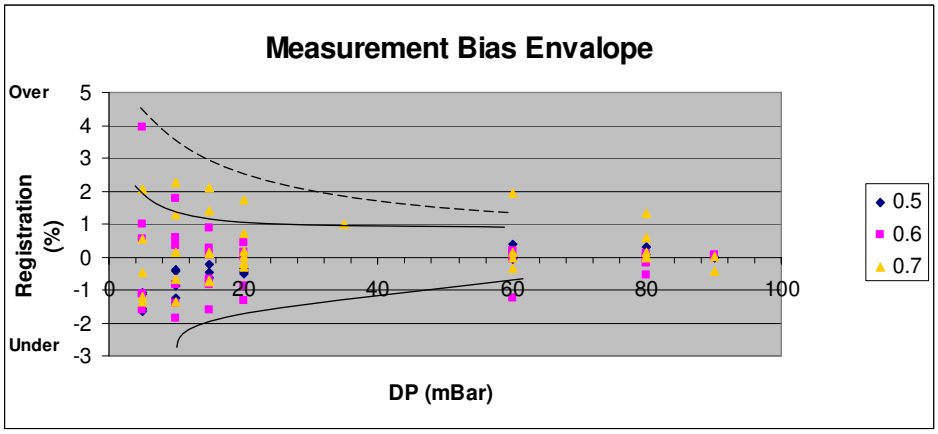
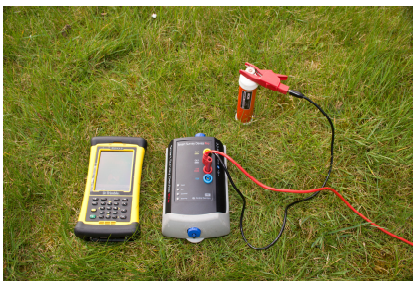


Figure 4. All flow results and the measurement bias trumpets

[1] George, D. L., Jowers, C.W., and Grimley, T. A., ***Assessment of Orifice Plate Flow Measurements with Low Differential Pressures,*** Final Report to Pipeline Research Council International. Contract PR-015-08605. April 2009.

Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	CIPS Box II			
Project Engineer	**Peter Martin**			
Description of project	**The project aims to develop a prototype Smart Survey Device (SSD) capable of supporting a Close Interval Potential Survey (CIPS) and a Test Post Survey. The device will also be uniquely designed to accommodate the hardware required to support an AC CIPS survey and a Pearson's Survey (a coating defect survey).**			
Expenditure for financial year	Internal £5k External £76k Total **£81k**	**Expenditure in previous (IFI) financial years**	**Internal £5** **External £68** **Total £73**	
Total project costs (collaborative + external + NG)	**£155k**	**Projected 2012/13 costs for NG**	**£0k**	
Technological area and/or issue addressed by project	**A cathodic protection (CP) current is induced into a pipeline to prevent corrosion. If this current is switched on and off, the efficiency of the CP and areas of pipeline coating damage can be detected by measuring On and Off potentials between the ground and the pipeline.** **Currently National Grid Gas Transmission has a number of hand held logger devices for capturing cathodic protection (CP) data (moving data and GPS coordinates) as part of maintenance activities at test post facilities (Nomad Loggers). The logger devices currently used do not have the hardware capability to carry out dual channel close interval potential surveys (CIPS). Dual channel close interval potential surveys (CIPS) are conducted as part of maintenance as well as used in fault finding and defect analysis. At present, without a logger device that has CIPS capability, National Grid are dependent upon using contract labour and resources to carry out this work. This results in a considerable financial impact on the business.** **An existing interim solution termed CIPS Box I has provided a rudimentary solution to enable small scale CIPS to be undertaken. However, as the original solution is a bespoke 'prototype project box' with individual elements manually soldered and attached, this solution lacks the facility for upgradable firmware or future improvements. It also suffers from limited reliability. Therefore a more durable solution is required** **The development of the CIPS Box II prototype device therefore looks to provide significant improvements in functionality, flexibility and robustness.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		12	1	**11**
Expected benefits	**Gas Transmission will require approximately 30 units for the necessary**			

of project	**maintenance and fault finding activities. The unreliability inherent in CIPS Box I has significant safety implications associated with correctly identifying any issues associated with pipeline integrity. Hence, assuming business requirement to develop a more suitable device, the proposal to develop CIPS Box II centres around the high degree of flexibility that this particular device could offer and the financial benefits when compared to CIPS Box I or other proprietary devices.** **There are significant differences between the two Smart Survey Device (SSD) solutions (CIPS Box 1 & II) with regard to technical capability and functionality. The CIPS Box II Smart Survey Device solution is also suitable for use with a wide range of data logger, capable of communicating with any device supporting Bluetooth or USB thereby allowing it to be utilised with current and future device and technology, e.g. tablets, tough books, smart phones etc. In addition, the CIPS Box II solution contains a memory card, allowing for the ability to be used as a data logger; this capability provides the singular solution to work with the AC CIPS equipment developed within a parallel IFI project.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	90%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£56k**
Potential for achieving expected benefits	**The first batch of production units now known as the Smart Survey Device (SSD), have been manufactured. Based on CE testing of the samples of the device it is anticipated the final device will achieve the expected benefits.**		
Project progress [Year to End of March 2013]	**The Smart Survey Device (SSD) design has now been completed. Prototypes were built to specifications and underwent a series of successful field trials.**   ***Smart Survey Device (SSD) during field trials*** **The software embedded into the device (firmware) was also completed. A boot-loader system will enable users to install any required future updates by simply inserting an SD card. The CP Logger software has been upgraded allowing it to be used with the SSD.** **Introduction of a diagnostics mode will increase fitness for purpose by providing assessments of problematic CP systems and evaluation of CP interrupters.**		

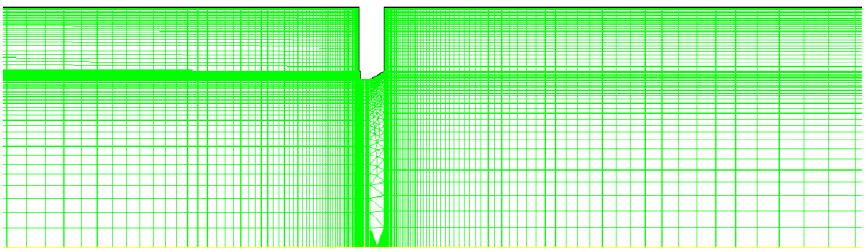
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	Evaluation of Chemical Rock Breaking		
Project Engineer	**Tamsin Kashap**		
Description of project	**This project looks to investigate and evaluate the use of a chemical product, Sylentmite, as a method for cracking rock for a pipeline excavation.**		
Expenditure for financial year	Internal £4k External £16k Total **£20k**	**Expenditure in previous (IFI) financial years**	**Internal £5k** **External £87k** **Total £92k**
Total project costs (collaborative + external + NG)	**£112k**	**Projected 2012/13 costs for NG**	**£0**
Technological area and/or issue addressed by project	**A number of coating defects have been identified on the Feeder 28 pipeline. Part of this pipe-section was installed by a trenchless technique known as Augerbore. The augerbore section was installed through hard rock (compressive strength ranging from 90mpa to 280mpa), making the required excavation for remediation works impossible by hand whilst mechanical picks cannot be used in close proximity to the live pipeline.** **The project therefore looks to use Sylentmite, a chemical product comprised of naturally occurring minerals that cause a reaction resulting in expansion when cold water is added. Once the top of the pipe section is exposed, the Sylentmite mix will be inserted into holes drilled for this purpose. There are both primary and secondary holes, and expansion holes to control the rate of cracking. The intention is to expose a trench of 1200mm plus the removal of rock under the pipeline in ~4m sections.** **The main concerns of this process being imposed stresses, vibration, and temperature. As this is not a technique previously used on the NTS, the review and monitoring process looks to provide reassurance that the integrity of the pipeline is not affected.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating** 18	**Project Residual Risk** -5	**Overall Project Score** **23**
Expected benefits of project	**Safety is the key driver for this project. The isolation of Feeder 28 is not possible and mechanical picks cannot be used through the hard rock in such close proximity to the live pipeline. The review will provide reassurance that the novel methodology proposed will not impact in any way on the integrity of the pipeline. The on site monitoring of pipeline stress, temperature, and vibration will provide this reassurance during the field operation.** **National Grid has been increasingly utilising horizontal directional drilling and other similar boring techniques in laying new pipelines. These techniques were used multiple times in preference to open cut during the**		

	construction of relatively new feeders 24, 28 and 29 for road crossings and in mountainous areas. If corrosion features are discovered over the life cycle of these pipeline sections, the use of chemicals in the breaking up of the overlaying rock will be a very useful technique in addition to the more conventional digging options.		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£1,322k**
Potential for achieving expected benefits	**The conclusion of this work has deemed that the use of chemical product Sylentmite to break rock in close proximity to a high pressure pipeline is acceptable. By following an approved Method Statement, the process would not produce significant levels of stresses, heat or vibration that would pose a threat to the integrity of the pipeline.**		
Project progress [Year to End of March 2013]	**Prior to commencement of the rock breaking activity a Method Statement and Risk Assessment were approved. However, due to the unknown nature of the rock, adjustments to the Method Statement and Risk Assessment were required. During the initial extraction phase it became evident that even with higher strength chemical which were left up to 24 hours or more in holes drilled closer together, only the upper ½ m of rock cracked sufficiently to allow removal.** **Effects of the chemical rock breaking activity on nearby pipeline measured well within safety levels. The maximum stress changes measured are under 80 N/mm^2, well within the acceptance limit of 90% SMYS. There was very little temperature increase measured, a maximum of 22.1℃ was recorded and there were no concerns related to the temperature effect on the pipe coating. The general vibration level was about 20 to 30 mm/s during the work. The maximum measured vibration of 59.8 mm/s was well within the acceptance limit of 75 mm/s**  **Results from the trial show that chemical rock breaking can be safely carried out under strict site inspection with any significant deviation from the existing Method Statement would require monitoring and data capture.**		

	Due to the variance of unique rock properties, the method for applying chemicals to break rock will necessarily vary. Therefore, the findings of this study specify that a standardised rock breaking protocol is not appropriate. **Prior to future use of chemicals to break rock near existing pipelines, advice will be sought from a competent Civil and Structural Engineer to ensure the process doesn't compromise pipeline integrity. Depending on site specific conditions, a monitoring system will be considered, specifically if work is to be carried out close to an older pipeline with a low strength of steel and weld quality.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	CFD Analysis of Bent Orifice Plate Systems		
Project Engineer	**Quentin Mabbutt & John Wilson**		
Description of project	**This programme aims to establish a Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA) benchmark to study orifice plate deformation under normal operating conditions.** **The aims of the study is to improve transporter reputation and knowledge of orifice plate meter performance under service conditions and improve confidence in the efficacy of the orifice plate meter systems.**		
Expenditure for financial year	Internal £4k External £12k Total **£16k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£232k**	**Projected 2013/14 costs for National Grid**	**£18k**
Technological area and/or issue addressed by project	**Current deformation analysis is based on theoretical models; the proposed CFD modelling will provide a good baseline study of the orifice plate and meter system.** **The limited available CFD analysis of orifice plate systems makes this programme important to further understanding of the orifice plate under service conditions. Exact knowledge of the elastic/plastic behaviour of the bore of the orifice plate will significantly improve plate husbandry, particularly with respect to honing or re machining of service plates.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating**: 10	**Project Residual Risk**: 0 / **Overall Project Score**: **10**
Expected benefits of project	**CFD techniques are becoming readily available and their application to model orifice plate meters could potential significantly improve the knowledge of the inner flow patterns of these systems. This will advance the knowledge of these meter types, improving asset owners' operational knowledge whist ensuring high levels of measurement efficiency.**		
Expected timescale of project	2 years	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£17k**

Potential for achieving expected benefits	**The current programme aims to provide CFD analysis by which it will be possible to substantiate the current mechanistic orifice plate bending equations (Jepson & Chipchase). The programme has already provided a set of material data which will improve the audit and consistency of secondary constants used in the ISO 5167 flow equation.**
Project progress **[Year to End of March 2013]**	**The programme had been delayed due to the need to align the aspirations of all the collaborators[1]. The programme has been scheduled in defined phases to allow each collaborator the opportunity to continue with the programme or withdraw.** **Phase 1 was completed in August 2011 and presented clarity with respect to material constants (Bulk Modulus, Young's Modulus and Thermal Expansion coefficients) which are indirectly associated with the ISO 5167 Orifice Plate (OP) flow calculation but not uniquely defined within the standard.** **The report further presented information related to the Jepson & Chipchase 1 equations for OP deformation. These equations are based on a mechanistic approach (summarised in general form by Roark 2). There has been little substantive work since to verify these equations. This is to form the basis of Phase 2. This work commenced in February 2013 and is due to report in March 2014.** **The suitability of CFD for the modelling of orifice plate meters systems has already been established. In 2009, National Grid supported a CFD study [3] into the effects of contaminant on orifice plates and the subsequent flow behaviour. The results were largely in agreement with the earlier large scale experimental programme undertaken by National Grid in 2007/08. While this was a very limited programme the results were encouraging.**  ***CFD Mesh of an orifice place meter system*** **The proposed work in Phase 2 of the programme is expected to add further evidence as to the viability of CFD for orifice plate meter modelling but it is hoped that it will also be able to:** • **Provide some information as to the development of the gas flow paths in the vicinity of the orifice plate. This has considerable significance in establishing the pressure profiles and hence flow measurement. This would help to establish a direct link between**

	CFD and the ISO 5167 flow equation parameters. • **Define the exact nature of the orifice plate surface condition and the effect on the flow measurement. This could reduce asset owners' maintenance costs.** **The knowledge of orifice plate deformation under service conditions is important and Phase 2 of this programme will help provide a set of verifiable criteria by which to validate this phenomena.** [1] **Effect of Plate Buckling on Orifice Meter Accuracy. J. Jepson., R. Chipchase., J. Mech. Eng. Sci. Vol 17 No. 6 1975.** [2] **Roark's Formulas for Stress and Strain, W.C.Young & R.G.Budynas, 7th ed., (2002)** [3] **Analysis of the effects that oil contaminant on the surface of orifice plate meters has on the measurement of high pressure gas flow. Report: 050866777. T. Miller**
Collaborative partners	**The collaborators are Scotia Gas Networks, Northern Gasworks (UUL), National Grid Transmission (UKT) and National Grid Distribution (UKD).**
R&D provider	**GL Noble Denton**

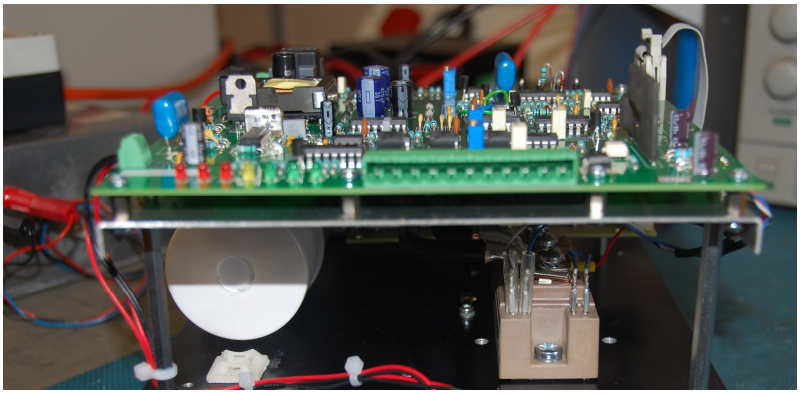
<table>
<tr><th>Project title</th><th colspan="4">Backup DC Drive Electronic Starter</th></tr>
<tr><td>Project Engineer</td><td colspan="4">Mark Allatson & Chris Walton</td></tr>
<tr><td>Description of project</td><td colspan="4">This innovation project aims to develop a safer, more reliable alternative to the resistance type motor starters currently installed on compressor sites. These form part of the emergency backup dc motor drive systems supplying vent fans and lube pumps. The new electronic motor starter system will replace the existing units.</td></tr>
<tr><td>Expenditure for financial year</td><td>Internal £6k
External £71k
Total £77k</td><td>Expenditure in previous IFI financial years</td><td colspan="2">Internal £0
External £0
Total £0</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£105k</td><td>Projected 2013/14 costs for National Grid</td><td colspan="2">£28k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">Most compressor station gas turbine units have a number of battery powered emergency back-up DC motors driving mechanics, such as the vent fans and lube pumps, which are started in the event of a mains power failure. Currently these motors are started from resistor type starters located within each compressor unit’s DC motor control centre.

There have been events where resistor starters have overheated. This causes damage to the control equipment and introduces an increase to fire risk. Therefore this project will develop an appropriate alternative to replace resistor starters; a DC electronic motor starter has been identified has a potential replacement.

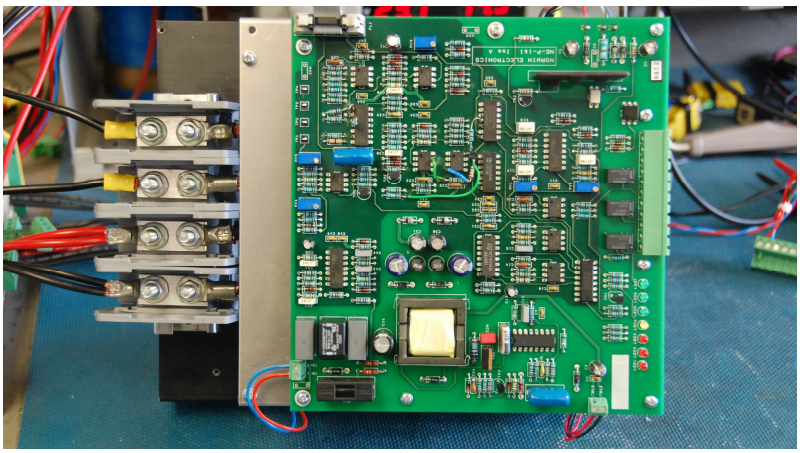
However, DC electronic motor starters are not available as off the shelf products for a DC battery supply and will therefore require design and development. As part of this project, a prototype will be designed, tested and then a working unit will be installed at a compressor station for field trials.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Technology Transfer</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>7</td><td>0</td><td>7</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">The key benefits to the business include safety and system reliability. The resistor starters need to be modified or replaced by a new system because of a fire risk which has been identified in the existing design. Fire risk will be virtually eliminated with the electronic starter system once the resistor has been removed from the starter.

A successful starter design will provide a simplified motor starter with less discrete electro-mechanical components. Electronic components have been proven to have high reliability and low long</td></tr>
</table>

	term maintenance costs. A variable speed drive system is essentially maintenance free and has a higher Mean Time Between Failures (MTBF) than discrete electro-mechanical components. This gives higher availability for the system with less down time. **The cost of the replacement electronic starter is comparable to that of a like for like replacement system, including installation of the new design.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	75%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£4k**
Potential for achieving expected benefits	**It is anticipated that this project will fully meet the expected benefits. Benefits to be confirmed once factory and site tests are complete in 2013**		
Project progress **[Year to End of March 2013]**	**Work on this project has progressed significantly, specifically in the building and testing of the DC drive prototype.** **The design of the electronic DC drive was developed and has been approved. Based on the approved design specifications a prototype of the electronic DC drive was built and has undergone testing.**		



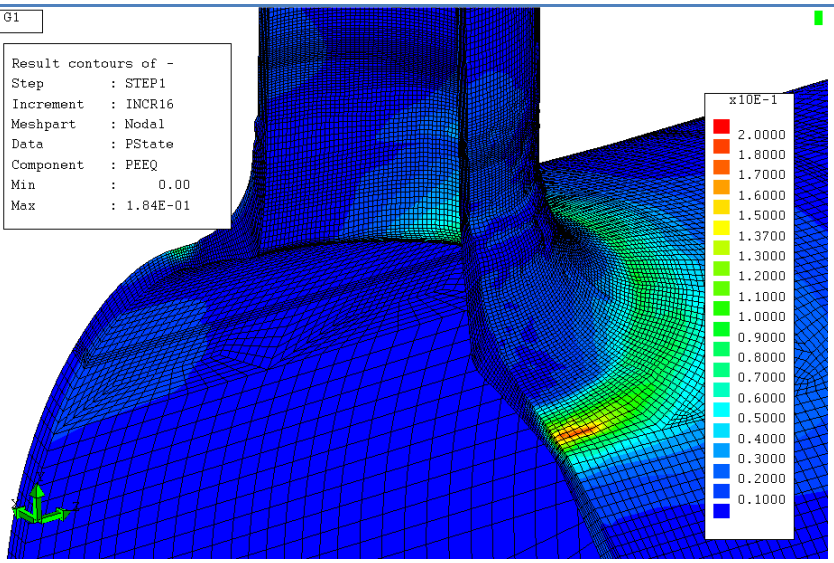
Side view of the electronic DC drive starter prototype



	Top down view of the electronic DC drive starter prototype **Based on the successful testing programme, a full scale electronic DC drive starter unit is being built. Once the build is complete, a full factory acceptance test is scheduled to take place, in the summer 2013.**
Collaborative partners	**None**
R&D provider	**Kim Systems Ltd**

Project title	Modelling and Testing of Corroded Sweepolets		
Project Engineer	**Brian Woodhouse and Steve Johnstone**		
Description of project	**The objective of this innovation project is to deliver a new methodology for assessing damaged pipework based on the use of on-site laser scanning systems and 3D model generation of corroded and un-corroded areas.**		
Expenditure for financial year	Internal £4k External £134k Total **£138k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£138k**	**Projected 2013/14 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	**As certain assets on the National Grid Transmission System reach the end of their design life, it is becoming increasingly critical to understand the condition of these assets and the implication of their continued operation life. There is the opportunity, as specific assets are removed from service to assess integrity and probable failure modes and apply this learning to the operational system.** **The removal of the pipe work and valve assembly on a block valve site was initiated after severe corrosion was discovered under dis-bonded coating at a sweepolet fitting. In addition the coating of the bypass pipe-work appeared very thin.** **The current procedure for assessment of damage in steel pipelines provides methods for measuring damage and assessing its significance. However, pipework on National Grid's installations have a more complex geometry than just straight pipe; added to this are the complexities of pipework loadings. These issues may lead to unsafe or overly conservative decisions when damage is discovered.**   ***Corrosion on pipework*** **This project will provide National Grid with a proof of concept study to generate a surface model of the corroded pipework removed from the block valve site. The output from the 3D model will then be used to create a finite element stress analysis giving a prediction of failure modes and full scale testing will verify the model.**		

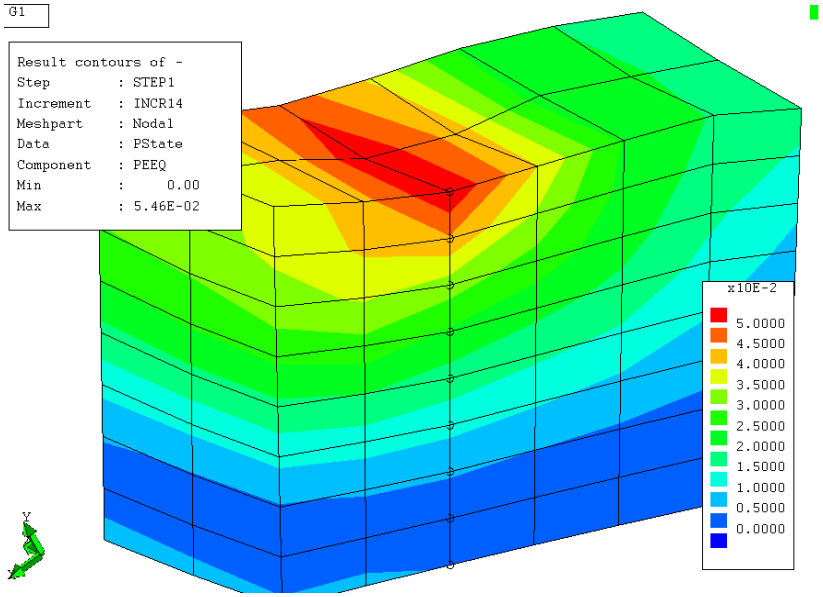
Type(s) of innovation involved	Significant	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		12	4	**8**
Expected benefits of project	**This project offers multiple benefits to National Grid and our customers:** **Safety - Improve knowledge and take preventative steps in the avoidance of any loss of pipeline integrity. Current inspection methods rely on a visual inspection by maintenance staff; which is a relatively subjective process and gives results which are potentially inconsistent and unquantifiable.** **Efficiency - Avoid costly and unnecessary remedial work. The removal of one particular block valve assembly costs over £100k. This particular block valve was removed rather than replaced as it is no longer required for strategic isolation or gas limiting in the event of pipeline failure. However the re-lifeing of the below ground coating, locally actuated valve and pipe supports was estimated at £200k. There are many hundreds of block valve sites on the NTS. If the scanner and model is developed successfully to prevent unnecessary re-lifeing at one or two sites then the project net present value is positive.**			
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**	
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£72k**	
Potential for achieving expected benefits	**The long term project success, to have a scanning tool suitable for use in the field which offers a quantifiable method for corrosion assessment, is high.**			
Project progress **[Year to End of March 2013]**	**The project has considered the condition of two pipework assemblies, both suffering from external corrosion on complex geometry fittings, i.e. a sweepolet. The project has investigated the feasibility of assessing the damaged fittings using modelling software.** **The following activities were undertaken during the scope of this project.** **A non-destructive material characterisation was performed to understand material performance. Then a high resolution site scan of pipework was undertaken to produce a 3D model, including the defective areas. The 3D scan mode was converted into a finite element analysis (FEA) modelling package.**			



3D Model

An FEA assessment was carried out to predict the performance of the pipework assemblies, failure pressure and failure mode, paying particular attention to any defects present in the pipework.

Following on for the assessment, a full scale hydrostatic burst test to verify results of FEA modelling was specified, planned and completed.

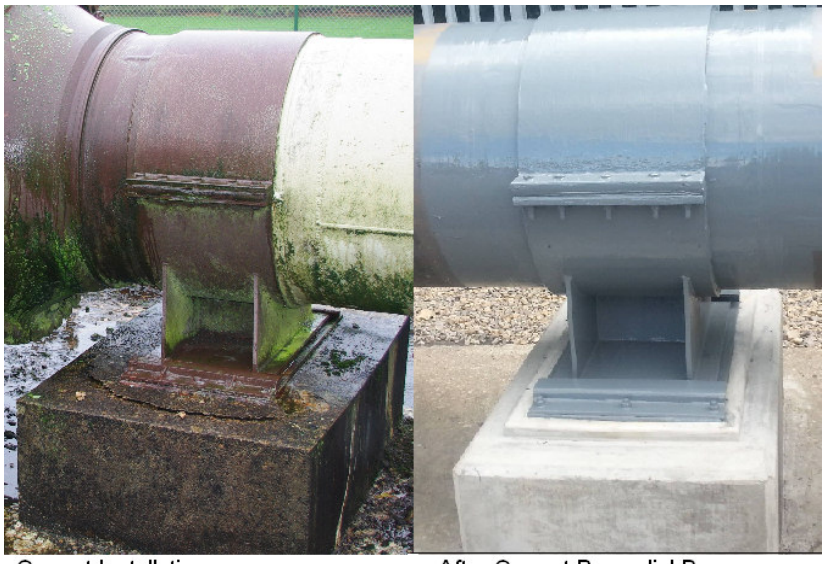


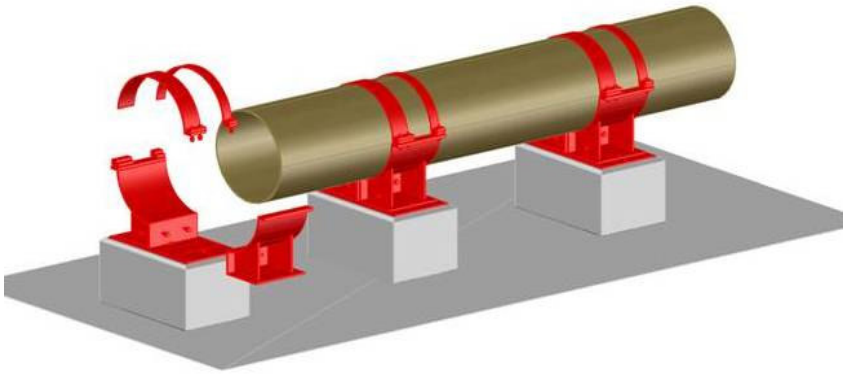
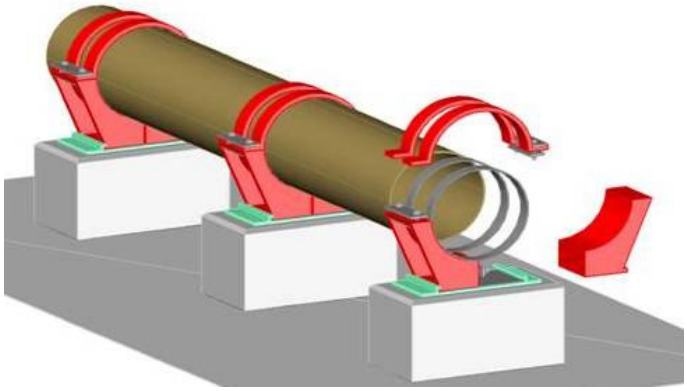
FEA Modelling

Destructive material characterisation of pipework material was undertaken for comparison with estimated non destructive testing (NDT) material characterisation.

	 ***Destructive characterisation*** **Revisions of the FEA model were developed to improve accuracy of modelling using information gathered during full scale hydrostatic burst tests and mechanical testing.**
Collaborative partners	**None**
R&D provider	**Macaw**

Project title	Composite Pipe Supports		
Project Engineer	**Simon Cowling**		
Description of project	**A review of the existing styles of pipe supports in use across the UK gas National Transmission System (NTS) and determination of concepts for trial to remove the existing manual handling issues as identified below and to allow for inspection without the need to damage/break out the associated concrete plinths. The subsequent design would also eliminate the inherent corrosion risk with existing materials.**		
Expenditure for financial year	Internal £5k External £25k Total **£30k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£30k**	**Projected 2013/14 costs for National Grid**	**£48k**
Technological area and/or issue addressed by project	**The existing pipe supports on NTS sites are installed by different means and to different designs. Certain large diameter pipe supports cannot be removed without the breaking out of concrete plinths in order to inspect for corrosion between metallic surfaces underneath them. These steel pipe supports are also very heavy and present a manual handling issue to both remove and replace. Other pipe supports in use are welded to the pipe and as such the sliding mechanisms cannot be maintained without damaging the support and concrete plinth.** **Whilst this initial phase of this project is to research potential solutions, further funding will be required to bring the preferred solution through to full development.** **The current programme of works on the Pipe Supports and Risers Investment Project only includes the repair and replacement of the supports against the original design as per the photos included below. This was a £6m scheme over a 3 year period, 45% of which is allocated to address issues relating to pipe supports. In improving the design of the pipe supports we will be able to reduce the necessity for maintenance schemes such as this one.**		
Type(s) of innovation involved	Significant	**Project Benefits Rating**: 10	**Project Residual Risk**: -1 / **Overall Project Score**: **11**
Expected benefits of project	**This work will allow greater flexibility of inspection under pipe supports without the requirement to break out concrete plinths, hence reducing the associated maintenance and replacement costs.** **Annual site inspections are conducted on all sites on the National**		

	Transmission System (NTS) and any corrosion is identified. T/SP/CM/4 condition surveys are then conducted on sites identified with corrosion; during these surveys it is currently not possible to review the condition of the pipework under the current style of supports as they cannot be moved for inspection. The business benefit of developing pipe supports which can be moved to facilitate these inspections is that the cost of subsequent revisits and the requirement to break out the concrete plinths can be removed. The number of pipe supports per site can range from that of a Block Valve site, where there are 2 large diameter supports and 8 small diameter supports to a Compressor Station and Multi-Junction where there could be in excess of 30 large diameter supports and over 100 small diameter supports. A new design of pipe support could potentially reduce the maintenance cost associated with pipe supports by up to 50% as a result of removing the need to revisit sites or break out and replace the concrete plinths.  Current Installation After Current Remedial Programme **An additional benefit is the reduction of the safety risks associated with manual handling in removing/replacing the pipe supports. It is likely that this solution will also significantly reduce the inspection frequency because the bi-metallic interface will have been removed reducing the likelihood of corrosion.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£17k**
Potential for achieving expected benefits	**Full benefits are expected on the conceptual design of a split support that will facilitate the removal and re-installation during in-service inspections.** **The secondary benefit of reducing component weight has been**		

	partially achieved by virtue of the split design but the use of steel as the structural material results in the largest component, for a 750 diameter support, being approximately 6 kg.
Project progress **[Year to End of March 2013]**	**A conceptual design of a split support has been developed utilising conventional structural steel.** **The support comprises a split lower cradle which provides the primary support and pipe guidance structure. The upper shell(s) duplicate the existing design. The two lower halves can be readily separated and removed from the pipe without disturbing the plinth structure or wear plate.**  **The current development has resulted in a design utilising non-metallic reinforced composite for the structural material.**  **A total design review of the existing support style and mechanism has been conducted resulting in a first stage steel prototype replacement design being available. A Finite Element Analysis (FEA) of that design has demonstrated adequate structural properties. Subsequently a prototype will be constructed.**
Collaborative partners	**None**
R&D provider	**Capita Symonds**

Project title	Evaluation of DC Electromagnets and Water Based Inks for use in Pipeline Inspections (MPI)		
Project Engineer	**Alan Kirkham**		
Description of project	**This programme of work focuses on identifying and developing material improvements to Magnetic Particle Inspection (MPI). Based on the identification of two main areas of concern that relate to the application of MPI in the field, an evaluation of new materials relating to those two areas will be undertaken.** **Details of these two areas and the associated materials evaluated are as follows:** **1. Evaluate the use of DC powered electromagnets for their suitability to inspect welds and fittings and compare the results to the appropriate National Grid and BS-EN specifications. The work will consist of measuring three activities of the electromagnet (field strength, lift capability, and the ability to define a surface breaking defect) at different levels of battery charge.** **2. Investigate the use of 3 water based paints and inks to supplement the use of aerosol oil based paints and inks that are currently used to perform MPI.**		
Expenditure for financial year	Internal £6k External £54k Total **£60k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£60k**	**Projected 2013/14 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	**The Magnetic Particle Inspection (MPI) technique is used to perform inspections on a range of applications that include pipeline welds, pipeline fittings and attachments. MPI is performed by using an 110V AC (Alternating Current) electromagnet in conjunction with white contrast oil based paint and black oil based magnetic ink. It is these two main areas where a concern has been identified.** **1. Provision of AC power supplies in remote areas can be problematic.** **The use of new MPI DC powered electromagnets would alleviate this problem. However, there is concern regarding reliability due to deterioration of battery condition and the effect of battery condition on performance needs to be investigated.** **The UK marketplace has recently seen the introduction of DC (Direct Current) and AC/DC powered electromagnets. The use of DC powered equipment for use in remote onsite applications has obvious advantages in that an AC power supply is not required. DC electromagnets use a 6 volt battery to generate the power and produce a magnetic field in the component under test. National Grid**		

	personnel have raised a number of concerns regarding the use of DC electromagnets, which include battery life and the condition of the battery to produce an adequate magnetic field. **2. Oil based MPI paints and inks are not environmentally friendly.** **This project will review water based paints and inks which may be suitable alternatives that are more environmentally friendly. Current practice when employing MPI is to use an AC electromagnet and oil based white paint and inks, dispensed from aerosol cans. The Control of Substances Hazardous to Health (COSHH) sheets for the paints and inks list a significant number of chemicals that are hazardous to both humans and the environment. As part of the DC electromagnet evaluation, the use of water based paints and inks will be reviewed as a possible alternative to using aerosol oil based paints and inks.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		6	-1	**7**
Expected benefits of project	**The knowledge gained from this project will allow National Grid to make informed decisions around implementing improvements to safety and an environmentally sound application of MPI in the field.** **A reduction in inspection cost is expected following a successful trial. With savings of 2% per project, based on eliminating the need for external power sources or site ventilation equipment at the workplace.** **Health & Safety and Environmental Benefits:** **In addition to cost saving, the project will allow for significant additional benefits relating to Health & Safety such as lighter equipment, lower power sources, ease of operation, less toxic vapours. Once identified and applied, the improvements will permit an environmentally sound practice which will bring the MPI technique inline with our commitment to reduce environmental impacts.** **DC equipment - with 110v powered magnets there is a requirement during remote operations to use mobile generators which have a number of hazards associated with them including their physical size and the fuel needed to power the units; these risks pose hazards to both health, safety and the environment.** **Water based materials - the current oil-based inks and paints have a number of COSHH issues associated with them. As well as the health and safety requirement to use materials in a well-ventilated location. As natural ventilation is not always possible/available, in some situations use of the current products require additional equipment to produce adequate airflow across the work site.**			

Expected timescale of project	0.5 years	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£-41k**
Potential for achieving expected benefits	**From the work carried out, the perceived benefits will be achieved upon implementation, resulting in a lower risk to site personnel carrying out this operation as well as reduced operational costs.** **1) Magnets - From the work carried out it was demonstrated that not all available equipment would meet National Grid requirements and further work is now required to amend National Grid specification to ensure only compliant equipment is used.** **2) Inks - The work showed that there is a viable alternative to the currently used kerosene based products that have potential health hazards associated with their use.**		
Project progress **[Year to End of March 2013]**	**This programme of work assessed two types of magnet; the first being a pure DC magnet and the second included a convertor to produce an AC current. Results showed that although both magnets found the defects, only the converted magnet complied with the standard for carrying out testing.**  ***Figure 1 - battery powered magnet with converter*** **From this work we are now able to recommend a type of portable magnet for site use (figure 1 above), thereby reducing the hazards associated with the 110v equipment and the generators.** **During testing of the alternative water based projects it was identified that all of the products meet requirements for use. Based on this outcome, the water based inks and oils will therefore be recommended for use on future projects as an improvement that will reduce risks to operators on sites.**		
Collaborative	**N/A**		

partners	
R&D provider	**GL Noble Denton**

Project title	Gas Compressor Enclosures – Safe Working Design Study		
Project Engineer	Wayne Lawson		
Description of project	This scope of works aims to deliver a Safety by Design study with a number of leading gas compressor manufacturers who have expressed a formal interest in working with National Grid on future projects involving an innovative approach to compressor design. Each of the manufacturers offers a packaged solution, which is quite different from National Grid's approach historically. These packages that form the basis of this study which, once completed, will supplement National Grid's proposed investment delivery strategy and will support a more detailed feasibility study into the suitability of these packages as an alternative solution to the design and construction of a traditional compressor machinery train enclosure.		
Expenditure for financial year	Internal £68k External £1k Total **£68k**	Expenditure in previous IFI financial years	Internal £0 External £0 Total £0
Total project costs (collaborative + external + NG)	**£68k**	Projected 2013/14 costs for National Grid	£0
Technological area and/or issue addressed by project	This programme has two primary drivers: the first under the Industrial Emissions Directive (IED) due to be transposed into UK law in January 2013, followed by the Pollution Prevention and Control (PPC) regulations, which are driven by the European Integrated Pollution Prevention and Control (IPPC) Directive which has also driven large scale emissions investment on the NTS to date. National Grid has 21 compressor units on the NTS that need to be compliant under the requirements of the IED. In addition, there are a further six units captured under the IPPC emissions reduction programme, increasing the total to 27 units requiring compliant readiness. All of these units at present consist of a traditional compressor enclosure design consisting of a large enclosed building built around the compressor machinery train together with associated ancillary equipment. The first investment driver, the Industrial Emissions Directive (IED) is designed to bring several separate pieces of EU legislation on industrial emissions under one directive. The relevance for National Grid is through the proposed further tightening of emissions limits, in comparison to the Large Combustion Plant Directive (LCPD1), for CO and NO_X and particulate limits that the Directive proposes. Gas turbines for mechanical drives using natural gas as a fuel have new Emission Lower Values (ELV): NOx = 75 mg/Nm3		

	CO = 100 mg/Nm3 **In addition to IED, National Grid also have a legislative requirement to comply with the Pollution Prevention and Control (PPC) regulations which are driven by the European Integrated Pollution Prevention and Control (IPPC). Following discussions with the environment regulators, it was agreed to adopt a fleet approach to emissions investment in order to obtain the greatest environmental benefit at the most efficient cost. To prioritise investment effectively and communicate the strategy, National Grid produces an annual Network Review.** **In recent years the design and installation of the compressor cab, including the building and all associated equipment, would be completed by the main works contractor, and therefore subject to all associated costs including technical prime fees on the direct costs. Under the new delivery strategy the role of informed buyer is to be performed by National Grid, retaining the contractual rights to investigate different solutions without compromising any commercial arrangements that may be in place. In doing this National Grid will be best placed to seek efficiencies within individual unit costs (including whole life value) on a site by site basis.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		12	0	**12**
Expected benefits of project	**Subject to the packages being fit for purpose and suitable for National Grid operation the potential benefits are significant and detailed as follows:** ▪ **Reduced design costs from the main works contractor, the Compressor manufacturer will have included these in the package price.** ▪ **Reduced capital costs of the enclosure, the Compressor manufacturer will have included these in the package price.** ▪ **Reduced capital costs of the additional plant and equipment, the Compressor manufacturer will have included these in the package price.** ▪ **Reduced installation costs.** ▪ **Reduction in testing & commissioning costs; these would have been carried out in the manufacturer's facility prior to shipping to site.** ▪ **Potential reduction in ongoing maintenance costs for the life of the asset.** ▪ **Development of Gas Transmission Asset Management (GTAM) team members, thereby retaining enhanced knowledge in the business.**			

Expected timescale of project	0.5 years	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£28k**
Potential for achieving expected benefits	**The likelihood of success in evaluating the options offered by seven registered manufacturers and their suitability against National Grid's operation and maintenance requirements using a safe working design study approach is high.** **This programme of work included evaluations of a number of different specialists from Gas Transmission Asset Management (GTAM) across different disciplines; mechanical, electrical, control and instrumentation. It is expected that, using the breadth of internal expertise that is currently within GTAM, National Grid will be able to retain the development and knowledge gained during this programme of work within the business.**		
Project progress **[Year to End of March 2013]**	**This programme of work entailed a study designed to draw out the strengths & weaknesses of each package together with any cost options available in order to produce a single bespoke packaged solution from each manufacturer was achieved.**  **A detailed programme of safe working design studies have been produced in association with each of the six (6) identified vendors. Set against National Grid's operation and maintenance requirements, these studies will provide National Grid's investment team engineers an informed approach during the BAT (best available technique) aspect of the investment delivery process.**		
Collaborative	**None**		

partners	
R&D provider	**Internal – National Grid Gas Transmission Asset Management**

Project title	Assessment of Zinc-Nickel Coated Fasteners		
Project Engineer	**Dr. Quentin Mabbutt**		
Description of project	**This business readiness study will enable implementation of the findings from a previous project. The aim is a to assess if electroplated zinc-nickel coated fasteners are fit for purpose on Above Ground Installation (AGI) flanges as a replacement for cadmium fasteners.** **The focus of this study is to understand:** ▪ **Potential interaction between the nickel/zinc coating and the anti-slip lubricant spray currently used by National Grid as a top-coat during application of the fasteners.** ▪ **The effect, if any, on current torque protocol as set out in T/SP/E/55**		
Expenditure for financial year	Internal £4k External £23k Total **£27k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£27k**	**Projected 2013/14 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	**This is a follow-up piece of work on the *Replacements for cadmium plating on fasteners* project (TAO/21109), led by Peter Martin in 2009. During this piece of work it was identified that electroplated zinc-nickel coating is best suited as an alternative to cadmium for corrosion projection of fasteners (nuts and stud bolts).** **The scope of the initial project did not include an assessment of the zinc-nickel coated fasteners as regards fitness for purpose in the field. This project seeks to carry out that work. The aim is to allow the findings of the initial project to be implemented in the business in conjunction with any procedural changes that may be deemed necessary (e.g. torque protocol) based on the information gathered during this brief business preparedness study.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk** / **Overall Project Score**
		12	-4 / **16**
Expected benefits of project	**Risk Reduction – Corrosion & the Environment** **The introduction of an alternative material, such as zinc-nickel coating, will address and potentially remove the serious corrosion and environmental risks associated to the use of cadmium fasteners.** **Historically National Grid UKT has used cadmium coated fasteners on above ground installations (AGI), but has been experiencing**		

	serious corrosion problems with cadmium plated fasteners and therefore require a cost comparable alternative coating that is capable of providing improved corrosion protection. Management of corrosion of fasteners is a major risk to the business, failure to address this issue could result in a security supply or safety risk. **There are clear health and environmental hazards related to the use of cadmium. Cadmium plating is known to give serious health and environmental concerns both during the plating operations and during handling and the disposal of cadmium plated components. Continuing to use cadmium plated fasteners will put National Grid at reputational risk and does not fit into the businesses environmental strategy.** **Cost benefit - Value for money** **There is a significant cost benefit associated with zinc-nickel coated fasteners. National Grid buys thousands of stud bolts and nuts each year, and on average the business could benefit for cost and maintenance savings when moving from cadmium to zinc-nickel coating.**		
Expected timescale of project	6 months	**Duration of benefit once achieved**	**10 years**
Probability of success	70%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£92k**
Potential for achieving expected benefits	**Potential for achieving expected benefits is very high. While this programme provides further evidence as to the viability of Zn-Ni coatings for bolt assemblies, the introduction of coated bolted assemblies would unlikely be universal and are expected to be specified for external applications where good corrosion resistance and ease of maintenance are key factors. The benefit will be derived from:** ▪ **Reduced maintenance time to remove and replace bolting as the need for additional coating (paint/grease) currently used to protect joints will be negated.** ▪ **Reduced bolting replacement.** ▪ **Improved asset condition with a reduction in preferential corrosion due to dissimilar metal interaction.**		
Project progress **[Year to End of March 2013]**	**There is considerable emphasis placed on asset health within National Grid. This concerns all aspects of maintenance and construction, becoming a key factor in through life considerations. Many of these considerations justifiably centre on major asset categories.** **However there are considerable maintenance activities which utilise much smaller component subsets but which are nevertheless very important for the safe and efficient operation of the network.**		

Many routine maintenance concerns the replacement of consumable items such as filter linings, valve or equipment maintenance. Nearly all these activities will involve some form of invasive procedures requiring the removal and reassembly of bolt and nut assemblies.

For most maintenance activities the majority of the cost is usually that of labour and there is much emphasis now being placed on the 'whole life value' chain assessment for asset management.

This is resulting in various maintenance strategies being investigated where the assemblies do not require additional corrosion protection either by painting or cladding.

To enable these strategies to be implemented, it will require the adoption of bolting with improved corrosion resistance. Normally in applications where corrosion is considered an issue, electroplated cadmium coated bolts are specified.

However, the use of cadmium coatings despite their excellent technical performance and low deposition costs, are heavily regulated because both the metal and its cyanide based deposition technologies present serious health and environmental hazards.

The use of cadmium as a coating is usually further compounded by the use of a top coat (passivation) of chromium. Chromium is completely benign in its metallic form. However, the most common deposition process for so-called hard chromium utilises highly toxic hexavalent chromium (Cr VI) solutions based on chromic acid, and is again the subject of strict environmental regulations.

Initial cadmium/hard chromium replacements were pure zinc and trivalent chromium (Cr III). Better performing alternatives are alloys of zinc-nickel (Zn-Ni). These coatings have been widely used in automotive and aerospace applications as a cadmium replacement.

While acceptable Zinc Nickel coating techniques are now well defined in national standards and the performance of a coated bolt/nut assembly has received considerable corrosion (salt spray / mist) evaluation there has been limited assembly and disassembly information.

National Grid commissioned their own corrosion trials in 2010[1] . While these provided clear evidence of the potential of zinc nickel coating substrates under these arduous environments no mechanical bolting performance was provided.

To address this, an IFI programme was commissioned to provide the experimental evidence of the behaviour of the coated bolt/nut assemblies under repeated torque loading.

The programme tested two diameters (0.75", 1.5") of stub and nut assemblies each Zn-Ni coated to the Shell specification ES313 [2].The assemblies were subjected to 10 and 20 repeat torquing cycles respectively. Each torque loading was to that specified in the NG standard (T/SP/E/55) and was performed in the non lubricated and lubricated (Molybdenum based) condition. The lubricant was only

applied once before the torque cycle testing.

Following the test cycle representative samples were examined by scanning electron microscope (SEM) to determine coating performance.

The mechanical test results for the two stud diameters are presented in Figure 1 in terms of the bolting load (tension) and number of torquing cycles. Both the lubricated (green) and non lubricated (blue) behaviour is presented on the same axes at each torque level.

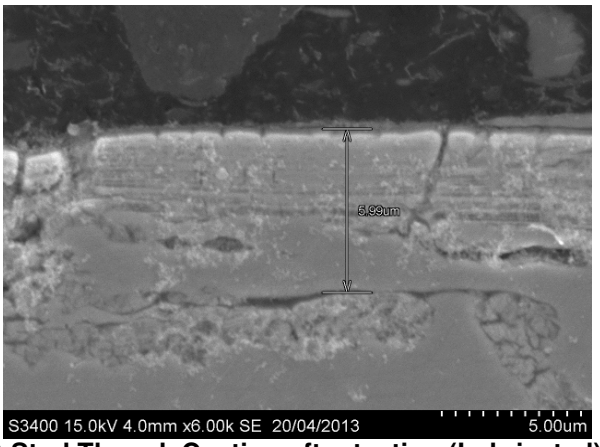
In pure mechanistic terms the lubricated bolts exhibited higher bolting tension (clamping loads) and generally maintained this across the torque cycles. The behaviour was more pronounced at the larger diameter.

The characterising of this behaviour in terms of coating damage during the testing revealed:

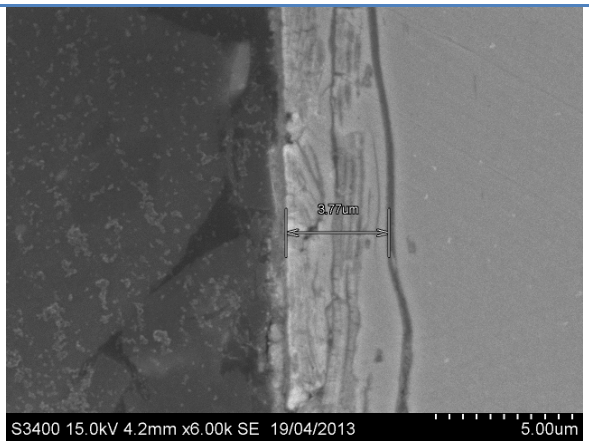
Both lubricated and non lubricated studs exhibited coating removal at the thread roots and crowns after torque testing. Although across the examined threaded regions, the lubricated studs showed less overall coating damage.

The Zn-Ni coating was removed from the threads of the nuts in all cases.

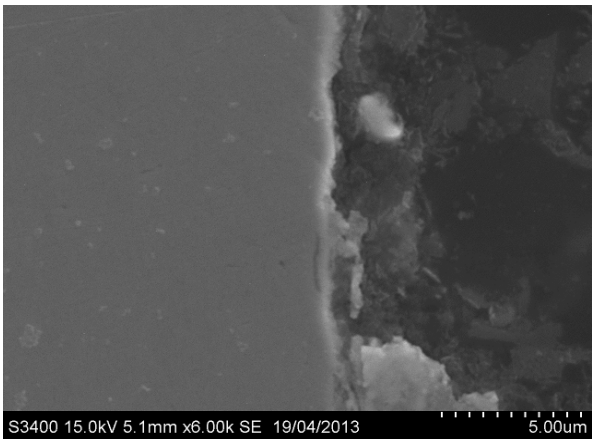
The micrograph montage in Figure 2 presents typical coating morphology for both stud and nut after testing.



a) Stud Thread. Coating after testing (Lubricated).



b) Nut Thread. Coating after testing (Lubricated).



c) Nut Thread. Coating removed in root after testing (Lubricated).

Figure 2. Micrograph montage. Typical SEM images of Zn-Ni coating after testing. All assemblies were tested in the lubricated condition.

The mechanical and physical aspects of Zn-Ni coated bolting assemblies have been evaluated. Results suggest that after repeat torque cycles the the mechanical loading and Zn-Ni coating integrity of stud assemblies is improved by the application of a suitable lubricant. The small coating loss is not considered significant as the removal was purely due to intimate face to face contact.

Other studies of this phenomena have suggested that since the integrity of the remaining coating is intact, when assembled stud/nut is subjected to a corrosive environment the corrosion paths are still very tortuous and thus the loss of protection is not reduced significantly.

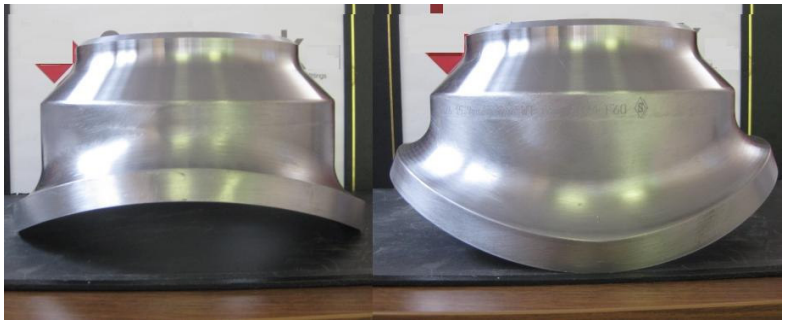
This programme of work is now complete. The zinc-nickel coatings will now be incorporated into the latest National Grid standards and procedures as replacement for cadmium coated fasteners.

[1] Evaluation of Electroplated zinc-nickel, hot dip spun galvanised, PTFE and IVD Aluminium Coatings.

[2] Shell specification ES313 "ES-313 Procurement Specification - Zinc/Nickel

	Electroplated Coatings forFasteners".
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	Study to Determine Stress Concentration Factors (SCF) for Alternative Designs for Branch Connections		
Project Engineer	**Robert Bood**		
Description of project	**This study seeks to establish whether the stress concentration factors (SCF) of a number of alternative designs of branch connections are bounded by those used in the pipework stress analysis code IGEM/TD/12. If confirmed, it will provide National Grid with the ability to utilise a much wider range of potential designs and suppliers than currently available.**		
Expenditure for financial year	Internal £4k External £11k Total **£15k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£30k**	**Projected 2013/14 costs for National Grid**	**£16k**
Technological area and/or issue addressed by project	**One of the principal methods for making branch connections to pipework is to use a fitting generally referred to as a 'Welded-in Contour Insert' (WICI). These come in two distinct forms:** **1. The traditional version, usually called a 'Sweepolet' (although that is a trade name owned by Bonney Forge) which has a smooth swept transition from the edge welded into the carrier pipe through to the branch.** **2. A design sometimes referred to as an 'Insert Branch Outlet' or an 'Insert Weldolet' which is of a more compact and stockier shape, still with a smooth transition but less swept.** **A number of companies are now producing variations on the second design which have the potential to offer a wide range of benefits. However, National Grid is not currently in the position to be able to use these as it has not been determined whether the SCFs given in IGEM/TD/12 (Pipework Stress Analysis for Gas Industry Plant) can be applied to them. It is likely the origin of the SCFs, given in A4.11.7 of TD/12, was developed using the traditional design and therefore further research is required to determine if the SCFs given in TD/12 are conservative for second design.** **This project proposes that a 3D finite element analysis (FEA) be performed to predict the SCFs of two sizes that give the most extreme ratios in header to branch diameter. The results will be compared against the TD/12 SCFs derived using clauses A4.11.7 (Sweepolet and Welded in contour insert) and A4.10.4 (Fabricated tee). If the predicted SCFs are bounded by those for a component already given in TD/12, then a view could be formed on whether TD/12 SCFs could be used for all sizes.**		

<table>
<tr><td>Type(s) of innovation involved</td><td>Incremental</td><td colspan="2">Project Benefits Rating
9</td><td>Project Residual Risk
-3</td><td>Overall Project Score
12</td></tr>
<tr><td>Expected benefits of project</td><td colspan="5">If successful the project will enable National Grid to use the alternative design with confidence, knowing it is fit for purpose and meets required standards. This will allow for increase in potential suppliers which should provide benefits by way of shorter supply time and reduced unit cost.</td></tr>
<tr><td>Expected timescale of project</td><td>1 year</td><td colspan="2">Duration of benefit once achieved</td><td colspan="2">5 years</td></tr>
<tr><td>Probability of success</td><td>80%</td><td colspan="2">Project NPV = (PV benefits – PV costs) x probability of success</td><td colspan="2">£12k</td></tr>
<tr><td>Potential for achieving expected benefits</td><td colspan="5">There is a high probability that the work will enable National Grid to make use of the new sweepolet designs.</td></tr>
<tr><td>Project progress
[Year to End of March 2013]</td><td colspan="5">During the first phase of work on this project, finite element analysis (FEA) was performed on two geometries of Insert Branch Outlet, (762x457mm and 1067x114mm). Based on the FEA results, the stress concentration factors have been determined.
 
A draft report has been prepared detailing the method and results, and compares the results against stress concentration factors determined from industry standard IGEM/TD/12. The results need to be reviewed in detail to determine the conclusions to be drawn from the study, and may require the assessment of one or two geometries.</td></tr>
<tr><td>Collaborative partners</td><td colspan="5">None</td></tr>
<tr><td>R&D provider</td><td colspan="5">GL Noble Denton</td></tr>
</table>

<table>
<tr><th>Project title</th><th colspan="4">Pig trap enclosure door seal study</th></tr>
<tr><td>Project Engineer</td><td colspan="4">Gemma Parkes</td></tr>
<tr><td>Description of project</td><td colspan="4">The goal of this project is to understand the cause of pig trap closure seal failures on the National Transmission System (NTS) and to investigate the fitness of purpose for using elastomer seals in preventing future failures.</td></tr>
<tr><td>Expenditure for financial year</td><td>Internal £5k
External £8k
Total £13k</td><td colspan="2">Expenditure in previous IFI financial years</td><td>Internal £0
External £0
Total £0</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£37k</td><td colspan="2">Projected 2013/14 costs for National Grid</td><td>£24k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">There are 208 pig traps on the NTS all holding a volume of gas at line pressure (between 50 and 75barg) that are compulsory on the network to undergo our legislative requirements for internal inspection of pipelines.

Recently there has been an upwards trend in the number of seals failing per year. The Ringlock type of closure has experienced 95% of failures recorded to date, however a small number on the Bandlock type have also failed. This work is intended to assess the cause of failure and indentify a potentially alternative seal that is fit for purpose.

When the seals fail there is a release of gas to atmosphere. At which point National Grid must isolate the pig trap to stop emissions and repair.

A previous project looking at improving the over-all integrity of pig trap enclosures set the groundwork for this investigation into the elastomer seals' fitness for purpose.

To understand the cause/source of failure, the first phase of work will include a review of existing enclosure and seal details, operating duties and procedures, and seal failure analysis.

To establish fitness for purpose and identify potential alternatives, work will be done to establish likely failure modes and will include possible contributory factors / issue findings. Recommendations will then be identified for alternative seals to avoid future failures.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Incremental</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>17</td><td>-1</td><td>18</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">Addressing the ongoing issue of seal failure by sourcing the problem and finding a suitable alternative to current practice thereby</td></tr>
</table>

	decreasing instance of seal failure will: **1. Reduce cost associated to maintenance. Each seal failure incident requires resource, call out charges if out of hours, travel and multiple visits for each failure.** **2. Realise environmental benefits based on a reduction in the amount of gas emissions to the atmosphere.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**years**
Probability of success	85%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£17k**
Potential for achieving expected benefits	**During this programme of work it is expected that the cause of seal failures will be identified. This learning will provide a very high potential that solutions will then be identified for seal replacement. The unknown factor at this stage of the project is whether the identified solutions will be fit for purpose regarding cost effectiveness and operational standards.**		
Project progress **[Year to End of March 2013]**	**The initial phase of work comprised mainly of sharing information with our R&D provider, Premtech, regarding:** ▪ **Asset data on the National Transmission System (NTS)** ▪ **Outlining historical issues with National Grid pig traps and seal failures, including maintenance and reporting** ▪ **Reviewing manufacturer feedback/responses.** **Manufacturers have been engaged to understand the dimensional impact on the door seal and draft a preliminary list of possible solutions.**  ***Pig trap located in Susworth Trent East*** **Failure trending has been undertaken. Two seal samples have been extracted for seal failure analysis. Following seal analysis, possible theoretical reasons for seal failures have been identified.**		

	 ***Seal failure*** **In addition to the above analysis, the elastomer specialists have explored the functionality of a 30" Ringlock pig trap and collected data regarding how pig traps operate. This information will help to identify and understand if/how pig trap operations may be affecting, or compromising, door seal functionality.**
Collaborative partners	**None**
R&D provider	**Premtech Limited**

Project title	External Contamination Detection and Measurement at Entry Points		
Project Engineer	**John Harris**		
Description of project	**This project will provide recommendations on the device, or array of devices, that would be required to detect liquid contamination at the entry points to the gas transmission system. The project will also evaluate the capability of such devices to provide quantitative measurements, initially targeting "order of magnitude" as a level of uncertainty.**		
Expenditure for financial year	Internal £6k External £101k Total **£107k**	**Expenditure in previous (IFI) financial years**	**Internal £19k** **External £1,083k** **Total £1,101k**
Total project costs (collaborative + ext + National Grid)	**£1,208k**	**Projected 2012/13 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	**Each year there are several serious incidents of liquid contamination within the gas transmission system, some of which have caused damage to equipment owned by either National Grid (compressors) or large industrial customers. The annual bill to repair damage and compensate customers is in excess of £1M.**		

Liquid contamination found during the routine pigging.

There are two main suspected mechanisms for liquid contamination:

Gas producers may accidentally allow liquids produced by process failures to contaminate the gas. Such liquids are glycols, methanol and gas condensates.

Gas that enters the National Transmission System in compliance with Gas Safety (Management) Regulations (GS(M)R) may have a composition which, when certain physical conditions such as temperature, pressure and flow are changed, condenses out as liquid in an unexpected manner.

<table>
<tr><td></td><td colspan="4">The instruments currently used to monitor the gas composition at NTS entry points have the following limitations:

All sample points and measuring instruments are designed to sample and analyse dry gas. Any liquid contamination picked up by the sample probe causes damage to the analysers.

There are no instruments in place to monitor the concentrations of some potential liquid contaminants (glycols and methanol).

The instruments which monitor higher hydrocarbon concentration and calculate hydrocarbon dewpoint do not analyse on a continuous basis; a typical time interval for sampling is every 30 minutes. This may be too infrequent to detect liquid events.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Technology Transfer</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>15</td><td>0</td><td>15</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">Compliance

As a gas transporter, National Grid is responsible for ensuring that the gas they supply complies with GS(M)R.

Financial

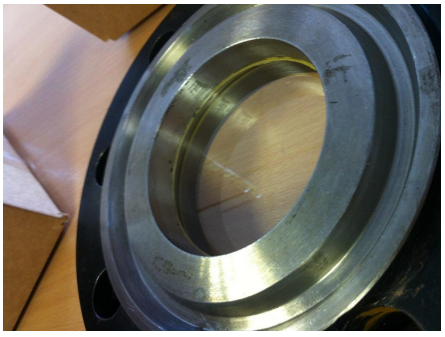
If gas supplied directly by National Grid is proved to cause damage to customer’s equipment, then National Grid are liable for compensation.

NTS equipment is designed to operate or monitor dry gas. Contamination of the gas by liquids causes major damage to expensive items such as compressors.

Whenever liquid events are discovered, they must be resolved immediately by diverting staff from their usual duties.

Knowledge

If a liquid event is caused by a gas producer, National Grid need robust data to justify either terminating gas flow and/or seeking compensation.</td></tr>
<tr><td>Expected timescale of project</td><td>5 years</td><td colspan="2">Duration of benefit once achieved</td><td>5+ years</td></tr>
<tr><td>Probability of success</td><td>50%</td><td colspan="2">Project NPV = (PV benefits – PV costs) x probability of success</td><td>£585k</td></tr>
</table>

Potential for achieving expected benefits	**A prototype laser-based analyser has been built by IMA Ltd. to design parameters. Results from a laboratory testing program have demonstrated that the prototype analyser is extremely sensitive to the presence of any liquid or aerosol (both liquid and particulate).** **Measurement of liquid depth is linear and repeatable for all liquids that are known to be potential NTS contaminants. The analyser can identify specific liquids, performance does not deteriorate if the contaminating liquid contains water.** **Testing on an outdoor high pressure test loop on the Spadeadam Test Facility identified some operational limitations of the analyser. However, it is believed that these limitations can be overcome by specific installation protocol.** **Once this is established, high pressure testing will demonstrate whether the excellent results obtained in the laboratory can be repeated with fast flowing turbulent liquids in a high pressure gas flow.**
Project progress **[Year to End of March 2013]**	**The Prototype Analyser** **The analyser has been designed to detect the presence of liquid contamination and identify it as glycol, gas condensate, compressor oil, methanol or "unidentified". In addition, it is intended that the analyser will detect an increase in the background concentration of aerosols. The detection of liquids and particulates is by laser-based light detection and ranging. Liquid identification is by Raman spectroscopy.** **The prototype analyser is housed in two boxes. The low power laser used for liquid detection is housed in a flameproof (Exp) box, along with the optical systems that access the inside of the gas incomer via a sapphire window and a double block and bleed valve. The high power laser and detector for liquid identification is installed off-pipe in a weather-proof analyser kiosk and connected to the Exp box via optical fibre.** **A preliminary version of the front-end software for user communication has been successfully demonstrated.**  *Figure 1:* *Sapphire window bonded to adaptor*  *Figure 2:* *Window assembly fitted to analyser* **Analyser Performance: Liquid Detection Function** **The prototype analyser is extremely sensitive to the presence of methanol, xylene**

(for gas condensate), monoethylene glycol (MEG) and compressor oil. Although the analyser reacts to the presence of liquid within 1 second, the analyser takes 2.9 seconds to reach 96% of the final response largely due to a curve fitting algorithm. The analyser signal is subsequently updated every second.

Analyser Performance: Liquid Depth Measurement

Calibration response functions for a liquid depth range of 0 -100mm were obtained for all four test liquids. Results show the analyser has a linear depth measurement between 30 and 100 mm for all liquids although the response gradients are liquid-specific. Measurements made using a test spool that replicates Incomer/Analyser geometry gave a parabolic response function at depths below 30mm. This part of the response curve can be defined by a quadratic equation. At very low depths, <5mm, the depth measurement is dependent on the roughness of the internal surface of the pipe. The worst-case practical lower detection limit for measuring liquid depth in a rough-walled pipe will be 3mm. If the interior surface of the Incomer is smooth, this lower limit will reduce. The average standard deviation over the linear portion of the response functions ranged between 1 and 1.4% of the gradient at the mid-point.

The gradients of the response function for each liquid vary with the distance between the analyser and the bottom of the pipe. The intention is for the production model analyser to have auto-focus which should automatically adjust to any differences in distance between factory calibration and its installation on an NTS Incomer.

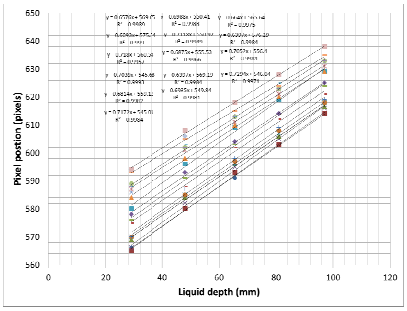


Figure 3: Xylene depth response

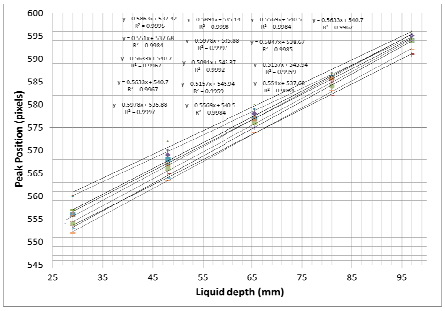


Figure 4: Methanol depth response

Analyser Performance: Liquid Identification

The Raman spectra library within the off-pipe analyser has been populated with spectra collected for MEG, xylene, methanol and compressor oil using two different depths of liquid; 100mm to provide the best possible spectra and 2mm to provide a measure of the minimum amount of liquid required to identify a pure liquid under realistic conditions. Compressor oil returns a fluorescence signal in addition to the Raman signal, however the Raman signal has been successfully extracted from within the fluorescence signal since the two signals are additive. A procedure to allow the analyser to do this automatically is being developed.

It is possible that liquid contamination at an Incomer could contain water due to the failure of upstream dewpoint control. Therefore, Raman spectra were collected from a 2:1 MEG:water mixture to assess the effect of water on the identification of MEG. The Raman analyser only returned MEG spectra since water returns extremely weak spectra; so water contamination in a gas incomer due to failure of

dewpoint control is unlikely to affect the capability of the analyser to detect the other contaminants.

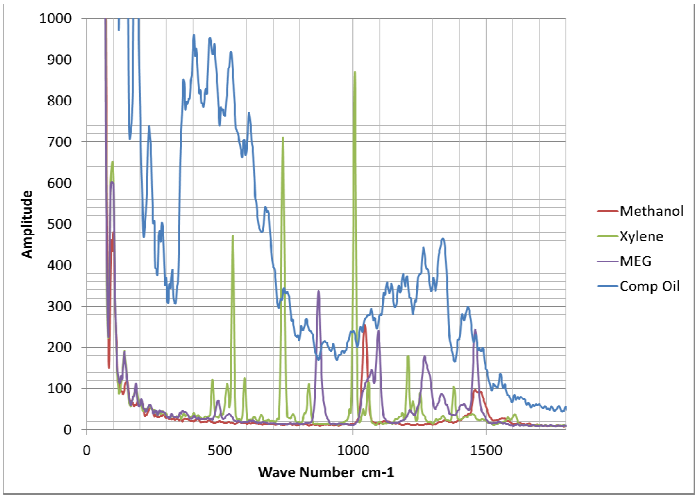


Figure 5: 100mm depth spectra for all liquids

Analyser Performance: Testing at High Pressure

Tests were conducted with the prototype analyser fitted to the high pressure test loop at the GL Spadeadam Test Facility. These showed that the analyser is sufficiently stable for measurements to be made, if pressure and temperature changes are limited to those experienced in the Transmission system. However, rapid fluctuations in pressure or temperature induce instability in the Detect analyser laser; while the Raman analyser laser is unaffected, due to its superior power. The instability is believed to be caused by micro-changes in refraction within the gas column around the laser beam. Insulating the test loop has reduced the instability considerably and it is believed that complete insulation from solar radiation of the vertical spool and the valves between the on-pipe analyser and test loop will eliminate the problem. Full testing can then proceed.

	 ***Figure 7: Compressor oil held inside test spool weirs*** **The prototype has potential to be taken through a full programme of high pressure tests required to finalise the design prior to implementation.**
Collaborative partners	**None.**
R&D provider	**GL Noble Denton**

<table>
<tr><th>Project title</th><th colspan="4">Development of FWACV Capability for New Gas Chromatograph DANINT Software</th></tr>
<tr><td>Project Engineer</td><td colspan="4">Roger Wood</td></tr>
<tr><td>Description of project</td><td colspan="4">This project will research, develop and trial the application of more accurate and reliable management of gas composition, calorific value (CV) and volume data at Ofgem-directed sites to enhance the performance of network.

Followed by implementation of Flow Weighted Average CV (FWACV) onto improved and next generation gas chromatographs via engineering software that complies with Ofgem regulatory requirement; The Gas Calculation of Thermal Energy Regulations.</td></tr>
<tr><td>Expenditure for financial year</td><td>Internal £5k
External £12k
Total £17k</td><td>Expenditure in previous (IFI) financial years</td><td colspan="2">Internal £13k
External £28k
Total £41k</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£1.6m</td><td>Projected 2013/14 costs for National Grid</td><td colspan="2">£13k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">This project provides an opportunity to improve the accuracy and reliability of data provision from these sites in line with regulatory requirements.

In Gas Transmission there are 28 CV gas measurements directed by Ofgem and a further 20 non regulated sites that will benefit from the improved software functionality.

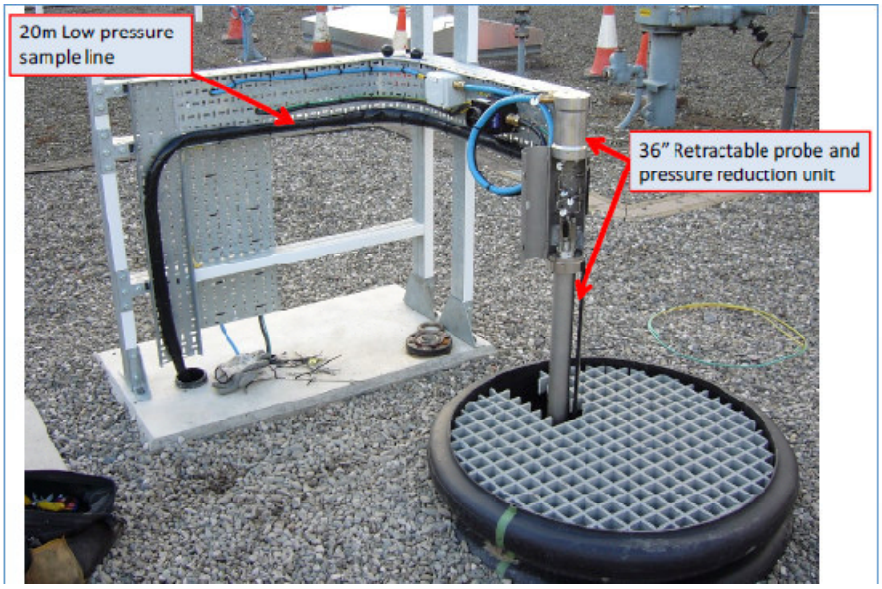
The project will research, develop and seek Ofgem approval of a methodology to be delivered in the next release of DANINT software, build 12c, that can interface with next generation (model 700) Daniels Process Gas Chromatographs and also for use with the Model 500 + New Processor card. (Note that National Grid are currently using build 12a software, so additional £5.6k is required to first upgrade to build 12b software).

The broad project aims are to:
▪ Develop a system solution through information gathering with the supplier of the Ofgem approved analyser.
▪ Develop processes to collect data from the approved CV analyser and flow computer that can be incorporated into DANINT software.
▪ Develop the methodology for creation of secure data files that will be used in the calculation of FWACV.
▪ Support the application to Ofgem for the approval of the software changes, following trials on FWACV system.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Incremental</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>8</td><td>-8</td><td>16</td></tr>
</table>

Expected benefits of project	**This project provides an opportunity to enhance network performance through improving the accuracy and reliability of data provision, in line with regulatory requirements. Environmental benefits are also achieved through the reduction in transport associated with site visits and the reduced use of bottled helium gas.** **If the improvements are successful, there is also an opportunity to reduce operational costs, as the improved system is rolled out onto National Grid's FWACV sites.** **A typical FWACV site consumes bottled helium gas and requires a bottle change approximately once every 8 weeks. This is a one-day job requiring two members of staff on site. A typical visit costs £545 (£500 in labour and £45 for 1 bottle of Helium) and each site will require 6 visits or costs of £3,270 per year.** **If the project is successful, the number of site visits per year is expected to reduce from 6 to 2, resulting in an annual saving of £2,180 per implementation.** **The implementation programme is yet to be finalised for National Grid Transmission, however, we expect two sites will be converted per year over the next five years, starting next year.**		
Expected timescale of project	4.5 years	**Duration of benefit once achieved**	**5 years**
Probability of success	80%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£11k**
Potential for achieving expected benefits	**Benefits will be realised with the provision that the new version/equipment is deployed by each funding party. The main benefits expected from the project to date are an operational efficiency saving per site where deployed and compliance with Ofgem approved equipment.**		
Project progress [Year to End of March 2013]	**Stage 1 of this project included two key deliverables and is now complete.** **Stage 1 - Deliverable 1**  **Produce summary of DANINT module changes required for build 12c. Agree Modbus map with Emerson for DANINT communications with Daniel 2350A controller with new processor card and Danalyzer model 700. Complete software changes and carry out User Acceptance Changes. Support process Ofgem approval of DANINT build 12c. Compile build 12c release CD for GDN's and UKGT to deploy.** **Stage 1 - Deliverable 2** **Development of EOD Module V5.2 to use the difference in the "Offtake**		

	Cumulative Volume Total" between consecutive DAT file records rather than the "Offtake Inst. Volume Flow Rate" as at present. Test software, demonstrate to Ofgem and issue test report. The EOD module is compatible, EOD module will be supplied as part of the DANINT suite and as such will be licensed for use. **Stage 2 of this project is in progress and set for completion in July 2013** **This stage is covering the procurement, installation on a test system, and testing of the developed software; moving on to on site resilience testing of DANINT 12c and 12d, documentation and further specialist development.** **There are seven (7) deliverables for this phase of work, including:** ▪ **Site acceptance testing** ▪ **Hardware install and testing** ▪ **Resilience testing / report** ▪ **Documentation and compliance configuration** ▪ **Specialist investigation and Concept design study** **The scope for stage 3 will be fully determined upon completion of stage. Anticipated deliverables include:** ▪ **Implementation of improvements identified during specialist investigations** ▪ **Development of configurable interface or other suitable solution** ▪ **Training / User Guides** ▪ **Comprehensive documentation; implementation guidance**
Collaborative partners	**Leverage of 5:1 on the IFI costs:** ▪ **National Grid Gas Distribution – 20% (Project Lead)** ▪ **Northern Gas Networks – 20%** ▪ **Scotia Gas Networks – 20%** ▪ **Wales & West Utilities – 20%** ▪ **National Grid Gas Transmission – 20%**
R&D provider	▪ **EIC** ▪ **GL Noble Denton**

Project title	Evaluation of ISO standard gas sampling system		
Project Engineer	**John Harris**		
Description of project	**This project will deliver a report for influencing industry on appropriate gas sampling systems, awareness of performance of existing solutions and lead to an update of ISO 10715 to reflect best practice. It will also validate the use of a new sampling system by National Grid which delivers less venting, faster delivery of a representative gas sample but does not comply to ISO standards.**		
Expenditure for financial year	Internal £4k External £47k Total **£51k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£51k**	**Projected 2013/14 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	**ISO standards are used for the selection of sampling solutions for gas analysers. It has been identified that the use of this standard would typically result is a representative sample of gas taking in excess of 30 minutes to move along the sample line.** **This would prevent management of compliance to GS(M)R1 as the result of a short excursion (whereby the content and characteristics of the gas are not in accordance with the values specified) which would not be indicated or at best will only be known about a considerable time after the incident and the non compliant gas would already be in the Network.** **A new low volume sample system has been introduced and an evaluation is required to demonstrate its ability to deliver a representative sample in less than 90 seconds to a gas analyser, and to incorporate into future revisions of the ISO standard.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating**: 14	**Project Residual Risk**: -3 / **Overall Project Score**: **17**
Expected benefits of project	**The operation of low volume probes and sample lines has only been proven by calculation. This project evaluated and validated the use of these systems by measuring the response of the system using flowing gas and witnessed by an industry recognised body (TUV NEL), providing confidence to the System Operator that measurements from the Gas Analysers at Entry provide appropriate measurements.** **External companies use an ISO standard solution and their measurement results do not give representative answers. For example, H_2S measurement using the current system gives a 3 hour**		

	lag between sample taken and measurement, whilst a low volume solution reduces this to below one minute. Conflict between NG and upstream parties could result in a breach of GS(M)R if non compliant gas enters the system. This could result in a fine. A safety breach could feasibly be of greater magnitude. **The learning from this exercise may mean that it becomes appropriate to change our gas sampling systems, or it may validate the use of existing solutions when risked on the respective use of the gas analyser (i.e. use for measuring H_2S).**  ***Example of new technology during field trials*** **The VE Technology sampling system incorporates a pressure reduction unit at the top of the sample probe that using an orifice plate solution for reducing the pressure. A low pressure sample line then takes the sample gas to the analyser. The use of a low volume solution also reduces the amount of continuous vented gas by about one-third (see TAO\21981).**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£41k**
Potential for achieving expected benefits	**The potential for achieving the benefits and learnings from this project are high.**		
Project progress [Year to End of	**Test Configuration: A gas containing zero Hydrogen Sulphide (H_2S) and test gasses around 3 parts per million volume (ppm/v) H_2S were**		

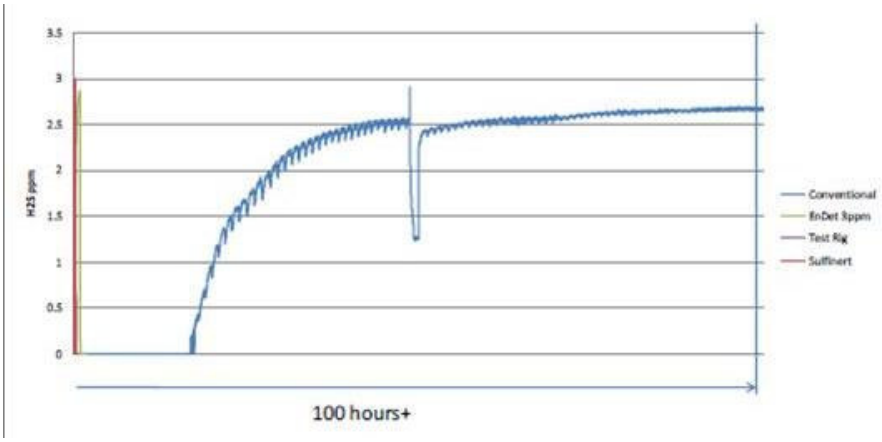
March 2013]

switched into a test rig that simulated a pipeline. Sample probes and sample systems complying with ISO Standards and the new VE Technology system were inserted into the pipeline simulator to take the gas to an analyser that would sample and provided an analysis every 13 seconds.

A second VE Technology system was used that has been treated with Sulfinert coating that reduces the absorption of H_2S into the sample and probe pipe walls.

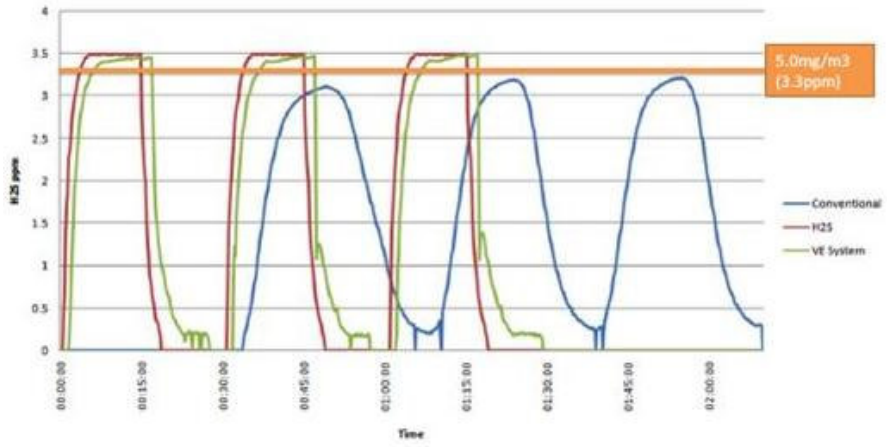
Test Approach: With the test rig installed, it was possible to switch from 0 to 3.0 ppm H_2S and to monitor the length of time to reach at least 90% of the certified value of the gas at the analyser.

Summary: The testing was carried out over a longer period than was expected due to the unexpected results that were produced. The ISO standard 'conventional' solution took in excess of 100 hours to measure up to 90% of the 3ppm H_2S gas value that was injected into the system. As this is such a long period, the results for the VE Technology are masked but can be seen as a red and green line at the left hand end of the graph and represent greater than 90% reading in less than two minutes of the sample injection.



Response to unconditioned conventional system compared to conditioned pipeline simulator

The outcome is that 'conventional' sample systems will not allow a rapid measurement of changes in H_2S composition that could occur due to process failure. This would also lead to disagreements in measurement values between companies using a conventional system and one using the VE Technology solution. There is such a lag in the 'conventional' measurement system, that peaks and troughs in the measurement will be missed and could result in a breech of the Gas Safety (Management) Regulation limit for H_2S being 'under read' as described in the next graph.



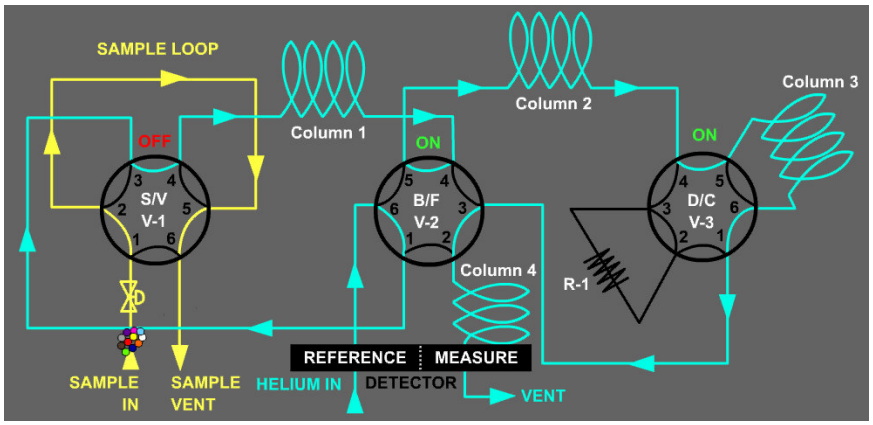
Possible effects of sampling system (Network entry limits)

Tests will be witnessed by the National Physics Laboratory (NPL) to provide support and credence to the evaluation.

Collaborative partners	**None**
R&D provider	**Orbital Gas Systems**

Project title	Liquefied Natural Gas (LNG) Gas Property Measurement		
Project Engineer	Dr. Quentin Mabbutt		
Description of project	This programme undertook a full evaluation on the effects of liquefied natural gas (LNG) on a range of conventional chromatograph types from both a theoretic and experimental standpoint. From this work it is expected that a range of actions may be forthcoming: ▪ Introduction of a new range of chromatograph calibration gases for sites likely to experience LNG. ▪ Improvements to the ISO 10723 standard. ▪ Enable National Grid to manage better customer enquiries related to LNG penetration throughout the NTS. ▪ Remove any unexplained measurement bias thus improving Unaccounted for Gas (UAG) control and monitoring.		
Expenditure for financial year	Internal £5k External £38k Total **£43k**	Expenditure in previous IFI financial years	Internal £0 External £0 Total £0
Total project costs (collaborative + external + NG)	**£43k**	Projected 2013/14 costs for National Grid	£0
Technological area and/or issue addressed by project	There have been dramatic changes to the UK gas supply patterns over the past few years. This is partly due to the natural decline in production from the UK Continental Shelf (UKCS) and the introduction of large quantities of gas from the Norwegian fields. However the major demographic change has been the development of large scale LNG reception facilities in South Wales and increases in the Isle of Grain capacity. LNG supplies can account for 30% of the daily UK demand. Throughout the National Transmission System (NTS), gas composition is determined by gas chromatographs. Chromatographs are calibrated daily and validated annually. In both instances, the calibration gases used are based on traditional natural gas (UKCS) compositions which include both CO_2 and the higher hydrocarbon molecules. LNG will contain no CO_2 and limited levels of higher hydrocarbons, thus a gas chromatograph, which passes both its daily calibration and annual validation, may well be measuring under normal conditions gas outside the calibration limits. Initial review of these phenomena suggests that it potentially introduces a positive measurement bias. The potential effects of mis-measurement across the network impacted by LNG gas, particularly at the reception facilities, is likely to contribute to maintaining the existing positive UAG volumes. In		

	2011/12 UAG contributed £85 million (77%) to NTS Shrinkage. Any sustained diminution of these levels reduces community exposure to these costs.			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		11	2	**9**
Expected benefits of project	**In 2010/11, the LNG terminals delivered 20,365mscm on to the NTS. If there is a negative energy bias of 0.025MJ/m3, the annual over registration of energy would be 141GWh. This would be direct UAG constituting 2.23% of the assessed value for the same period. The attendant increase in calculated density would also have to be taken into account, but this would require further site analysis. The direct community saving would be £2.2M.** **Impacted demand side measurement would also be affected, the further analysis undertaken in this programme enables the overall magnitude to be quantified, whereas previously the effects of comingling and rich LNG mixtures on gas chromatograph (GC) performance were unknown.**			
Expected timescale of project	1 year	**Duration of benefit once achieved**		**Enduring**
Probability of success	10%	**Project NPV = (PV benefits – PV costs) x probability of success**		**£144k**
Potential for achieving expected benefits	**The programme was to provide supporting evidence that the measurement uncertainty of conventional gas chromatographs is not compromised by the large influx of imported Liquefied Natural Gas (LNG).**			
Project progress **[Year to End of March 2013]**	**The current programme, undertaken by EffecTech, was confined to evaluation of the effect of LNG on the measurement response of conventional gas chromatographs that were characterised by back flush or forward elution gas sample handling. Typical gas chromatographs of each sample handling type installed on the NTS were tested.** **All gas chromatographs were tested using three typical LNG gases taken from the main UK LNG import facilities. Each GC measurement of the LNG test gases was compared to a detailed gas analysis determined by dedicated accredited laboratory-based equipment. All the results were evaluated with respect to the statutory uncertainty of calculated calorific value (CV) of 0.1MJ/m^3.** **The respective GC evaluations determined the limits of detection with respect to the respective back flush (see schematic in Figure 1**			

	below) and forward flush gas sampling handling characteristics of each analyser.  ***Figure 1: Typical arrangement of a back flush gas chromatograph*** **Normal levels of detection range between 3 and 50 parts per million (ppm mol/mol) for all the major components found in natural gas.** **For LNG the heavier hydrocarbons (butanes, pentanes, hexanes) are likely to fall below these limits but nevertheless it was expected that each GC type would give measurement errors of -0.008MJ/m^3 (back flush) and -0.012MJ/m^3 (forward flush). In reality the CV measurement errors were lower than these theoretical levels being +/- 0.006 MJ/m^3 with the back flush analyser but slightly higher (-0.019 MJ/m^3) for the forward flush device.** **The measurement discrepancy between the two analyser types was considered to be a function of their respective treatment of propane and butane components within the sample gases.** **Both analyser types gave acceptably small CV measurement errors with the representative LNG samples tested.** **The results from this programme provide strong experimental evidence that large scale penetration of LNG gas across the NTS will not compromise CV determination and thus will not contribute to any misapportionment of costs across the NTS.** **The results also remove another uncertainty in the continued husbandry of NTS Shrinkage.**
Collaborative partners	**None**
R&D provider	**EffecTech**

Project title	Impact of Hydrogen on Portable Gas Detectors			
Project Engineer	**Roger Wood**			
Description of project	**This project is supporting the novel change of carrier gas from helium to hydrogen (H_2) for our gas chromatograph systems, by establishing if our fleet of Gas Detectors are fit for purpose in providing reliable detection of explosive atmospheres.**			
Expenditure for financial year	Internal £4k External £29k Total **£33k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**	
Total project costs (collaborative + external + NG)	**£33k**	**Projected 2013/14 costs for National Grid**	**£0**	
Technological area and/or issue addressed by project	**The supply of helium, used as the carrier gas on most National Grid analysers, is becoming less secure and there are times when our bottle gas supplier is rationing supply; the cost is also increasing.** **National Grid Gas Transmission operates over 80 gas monitoring points around the gas transmission network. Most of the gas monitoring points includes gas chromatographs (GCs) and traditionally these have operated with helium as the carrier gas. As part of the review of the issues associated with changeover to hydrogen from helium, a key aspect of a risk assessment related to the storage and use of hydrogen was gas detection. An on-going programme of changing over the helium supply to hydrogen has been developed as there is a higher risk of rationing and further cost increases. There would also be environmental benefits associated with the changeover.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		11	-3	**14**
Expected benefits of project	**Although the use of these existing gas detectors to detect hydrogen is new and as yet unknown, initial checks on the portable pellistor type sensor show that techniques proposed for testing have a high probability of providing the data required for this evaluation.** **There are some cost savings in the use of hydrogen to replace helium as the carrier gas for flow weighted average calorific value (FWACV), Gas Quality and Metering analysers; but the main benefit to the business comes from cost avoidance in keeping these business critical analyser systems operational by having a secure supply of the carrier gas.** **The FWACV analysers provide data for the calculation of daily LDZ (local distribution zone) CV values used by shippers. The loss of**			

	these systems results in increased CV shrinkage, whereby capping events impact on the calculation of the commodity charge and can range widely in value but typically between £10k to £500k. The use of hydrogen as a carrier gas provides risk mitigation in CV Shrinkage costs. **The Gas Quality analysers are used to police gas entering the network against our legal obligation under the HSE Gas Safety (Management) Regulations GS(M)R regulations and commercial Network Entry Agreements with suppliers. Failure to operate these measurements could result in unsafe gas mixtures entering the network, putting our customers at risk and damaging our assets.** **The metering analysers provide gas composition for the calculation of density to give accurate volume determination. If this analysis is not available, fixed density values are used, resulting in significant volume errors which could result in Meter Error Reconciliation in the fiscal range £100 to £10,000 per gas day. The metering systems are also subject to audit checks by the third party connection.** **Focus on Environmental Benefit** **There is an environmental benefit gained from using hydrogen over helium. Hydrogen is a renewable gas, where as helium is extracted from certain gas producing oil wells using fractional distillation, at a low return, often as low as 0.3% of gas composition so is a finite resource.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£41k**
Potential for achieving expected benefits	**The initial benefit associated with this project has been achieved, in that the existing gas detection equipment used is capable of detecting hydrogen and hydrogen/natural gas mixtures below the LFL (Lower Flammability Limit) and provides appropriate warnings and alarms. The existing equipment provides a similar response to ensure that operators are alerted to any atmospheres that may be hazardous and the output from this work confirms that the existing equipment is still fit-for-purpose.** **At this stage the benefit associated with cost avoidance in keeping the analyser systems operational has not been quantified.**		
Project progress **[Year to End of March 2013]**	**A series of experimental tests have been performed and completed with recommendations given which have been implemented into the business. Trials focused on the response of standard portable and fixed gas detection systems to atmospheres that may contain hydrogen and hydrogen/natural gas mixtures.** **The original project was developed to test portable instruments. The**		

scope was then extended to include testing of fixed gas detection systems that are used in some of the gas analysis installations. This allowed for a more inclusive detector system study.

Examples of gas detectors tested to evaluate the impact of hydrogen

Suitable types of instrument/detectors were identified and led to the purchase of Pellistor-based detectors for flammable gas detection.

- **The fixed gas detectors only had the flammable gas detector head and these were 24V dc powered units.**
- **The portable gas detectors selected had varying functionality.**
- **All the units had pellistors for flammable gas but several of the units also had an electrochemical cell for oxygen detection (used for general atmosphere checks and confined space entry). In addition, four of the units also had carbon monoxide (CO) and Hydrogen Sulphide (H2S) detection capability through separate electrochemical cells.**
- **One of the gas detectors had an internal, integral pump where as the others were all natural diffusion-based detectors.**
- **All the gas detectors were ATEX certified and the grade of this also made them suitable for hydrogen detection (Classification IIc).**
- **All the gas detectors were calibrated by the suppliers/manufacturers using methane to a calibrated level of 5% methane in air, equivalent to 100% LFL.**

The test programme was developed to evaluate the performance of the gas detection equipment with the primary aim of ensuring that it was fit-for-purpose and would provide the necessary warnings and alarms to ensure that the engineer's safety is maintained.

The first test programme involved controlled exposure of the portable gas detectors (individually) in a small test chamber using gas flow rates in accordance with manufacturers' instructions. The fixed gas detectors had a small flow chamber attached over the detector head and again the test gas flow was measured with the design flow rates detailed by the equipment manufacturer.

	The test gases used included methane/air, hydrogen/air and methane/hydrogen/air – at concentrations up to 20% LFL. The response of each gas detection instrument was noted both for the time response of the instrument and the overall LFL indicated concentration. **All the gas detectors showed correct LFL readings for the methane/air readings but with hydrogen present showed an increased reading over that expected. This increased response is a function of the presence of hydrogen and relates to a slightly different response factor for hydrogen compared to methane. The output here highlights that the gas detectors are in effect not giving the correct reading but they are over-reading which is a safer variation. The degree of over-reading is not excessive and it should not lead to false alarms.** **After each test, the gas detector was allowed to recover in fresh air. Each test gas was used three times for each detector. No changes were found to the response of the units to these repeat exposure tests.** **Each gas detector underwent an over-exposure test after the series of test gases had been used. Here, short exposure to 100% hydrogen was used and the instruments all went into immediate alarm and into dormant mode to protect the sensors.** **Although the flammable gas tests were successful, it became apparent that the repeated exposure of the gas detection equipment to hydrogen had a detrimental impact on the CO and H2S sensors. These sensors are cross-sensitive to hydrogen and give high readings when exposed to hydrogen. In the case of two of the instruments this ultimately resulted in permanent failure of the CO sensors.** **The overall recommendation from this study is that the flammable gas detection equipment using pellistors will be fit-for-purpose when used for atmosphere checks when there is the potential for hydrogen or hydrogen/natural gas to be present in kiosks, cabinets and enclosures. However, if the gas detection equipment also has multi-gas detection capability then it must be recognised that the CO and H2S sensors may give false readings as they are cross-sensitive to hydrogen.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

<table>
<tr><th>Project title</th><th colspan="4">Optimisation of Severe Winter Strategy for Pipeline Isolation Valves</th></tr>
<tr><td>Project Engineer</td><td colspan="4">Mick Jarvis & Steve Johnstone</td></tr>
<tr><td>Description of project</td><td colspan="4">This project will develop and combine a risk-based approach for the prioritisation of retrofit measures to address isolation valve reliability during periods of sustained severe winter conditions.

This will be achieved by comparing geographical profiles of severe weather risk, isolation valve functionality and populations of particular valve actuator combinations in a geographic information system (GIS) enabled analysis environment.

A survey of international practice will also be conducted, with a focus on Canada and northern Europe, where sustained severe winter weather is more prevalent.</td></tr>
<tr><td>Expenditure for financial year</td><td>Internal £4k
External £73k
Total £77k</td><td>Expenditure in previous IFI financial years</td><td colspan="2">Internal £0
External £0
Total £0</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£103k</td><td>Projected 2013/14 costs for National Grid</td><td colspan="2">£26k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">During a Reliability Centred Maintenance (RCM) process carried out in November 2011 a potential hidden mode of failure was highlighted associated with the operation of Locally Operated and Remotely Operated Valves (ROVs).

Due to the majority of valve maintenance that takes place during summer months there are a number of possible modes of failure associated with cold winter temperatures (water ingress and freezing conditions) that have previously been unaccounted for.

There are approx 828 ROVs and many hundreds more Locally Operated valves on the network in total, however, the physical testing of each combination of components that make up any one system is unfeasible due to the number of each type of valve, actuator and gearbox combinations.

This project therefore looks to assess the scale of the problem initially, together with physical testing of any components as an option at a later stage and the development of design mitigating modifications.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Significant</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>14</td><td>3</td><td>11</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">This study is innovative in that it will bring together:</td></tr>
</table>

	▪ New approach to visualisation of sustained severe temperature risk ▪ Recent developments in GIS-based Uptime analysis capability ▪ Information sharing from synchronising National Grid's Ellipse database with Uptime ▪ Recent learning from the work to rationalise isolation valves in advance of modernisation. **Bringing these together as a joined-up approach will provide the basis for prioritizing the consideration of severe winter protection measures for a diverse range of different valve actuator combinations on critical Above Ground Instillations (AGIs).** **Knowledge - This is the key area this project will provide benefits.** **The knowledge attained by this study will allow National Grid to make informed decisions on the prioritisation of retrofit design modifications to mitigate the effects of sustained severe winter conditions (development, testing and trial implementation of appropriate design solutions for valve actuator combinations with the highest risk based on their location and susceptibility).** **Safety - In the rare event of a major pipeline failure incident, the reliable and swift operation of remotely operated emergency isolation valves is a key factor in damage limitation, where damage in this case includes loss of life.** **Environmental - In the rare event of a major pipeline failure incident, the reliable operation of isolation valves is a key factor in damage limitation, where damage in this case includes emission of large methane volumes to the environment.** **Network Performance - Some isolation valves are used to control flow through the network (e.g. at multi-junctions and compressor connections) and have an important role during winter to help ensure capacity of the network as supply and demand patterns change.** **External Risks - This project will consider the external risk of sustained severe winter conditions and the external risk of pipeline damage due to third party intervention occurring during a sustained severe winter period.** **Other benefits - Efficient, proactive management of the risk of reputational damage, which could result from protracted attempts to control gas in the event of a major pipeline incident.**		
Expected timescale of project	4 year	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£450k**
Potential for achieving expected	**With most of the risk factors implemented in the GIS-enabled data management environment of Uptime, it has been possible to address**		

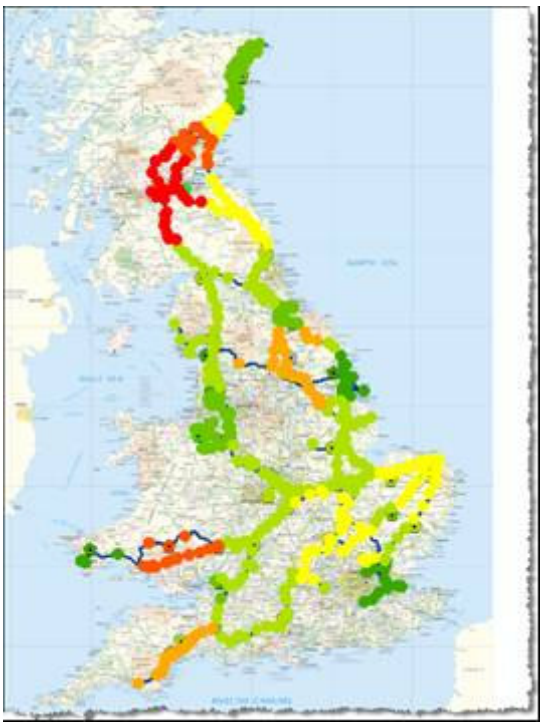
benefits	**the prioritisation of remedial action for protecting key gas network valves against unreliability risk during periods of sustained cold weather.** **The knowledge base of valve actuator and control system cold weather issues has been built up and an action plan is in development with an initial focus on compressor connection valves.** **Some further work will be required to populate the Uptime database with valve and actuator type information on sites where there is more than one key valve. This is especially the case for large multi-junctions, for which the risk of operational need during cold weather is highest.** **Overall, there is a high probability that this project will be able to achieve the expected benefits as the new Uptime functionality is used to prioritise potential remedial actions that are being piloted at compressor stations.**
Project progress **[Year to End of March 2013]**	**Weather station selection:** **The Met Office provided information on the 436 weather stations that were currently open. A combination of logical filters (availability of temperature and humidity data; station open before 1992; within England, Scotland and Wales; within latitude and longitude bounds of the NTS) and initial judgement was used to identify 30 weather stations with even geographical spacing and proximity to the National Transmission System (NTS). The selection was finalised in Uptime, changes were made to the selection to increase the total km of NTS pipe within 20km of the weather stations.** **Weather data quality:** **Some of the 30 selected weather stations had incomplete data sets for the last 20 years. Where the data was <90% complete, the Met Office provided data for the nearest alternate weather station. As a result, 41 data sets were accumulated, 30 of which provided >90% completeness over the preceding 20 years. Some of these datasets use data from two adjacent weather stations.** **Risk of sustained low temperature:** **An algorithm was developed to determine the risk of a severe winter condition at each weather station over the last 20 years. The condition was "3 consecutive days when the minimum daily temperature did not exceed -2℃; and the maximum temperature did not exceed 5℃". This gave a range of risks between 0.02% (about once every 14 years) and 0.08% (about once every 3.5 years).** **Varying the condition changed the magnitude of the risk, but had much less effect on the spread of risk. It was therefore determined that the risk factor could be used to discriminate between geographical areas, as part of a prioritisation scheme for retrofit measures to address isolation valve reliability during periods of**

sustained severe winter conditions.

Uptime (GIS-enabled data management environment):

The 41 weather stations and their "risks of sustained low temperature" were added to the Uptime database; the locations of above-ground installations (AGIs) on the NTS have previously been uploaded.

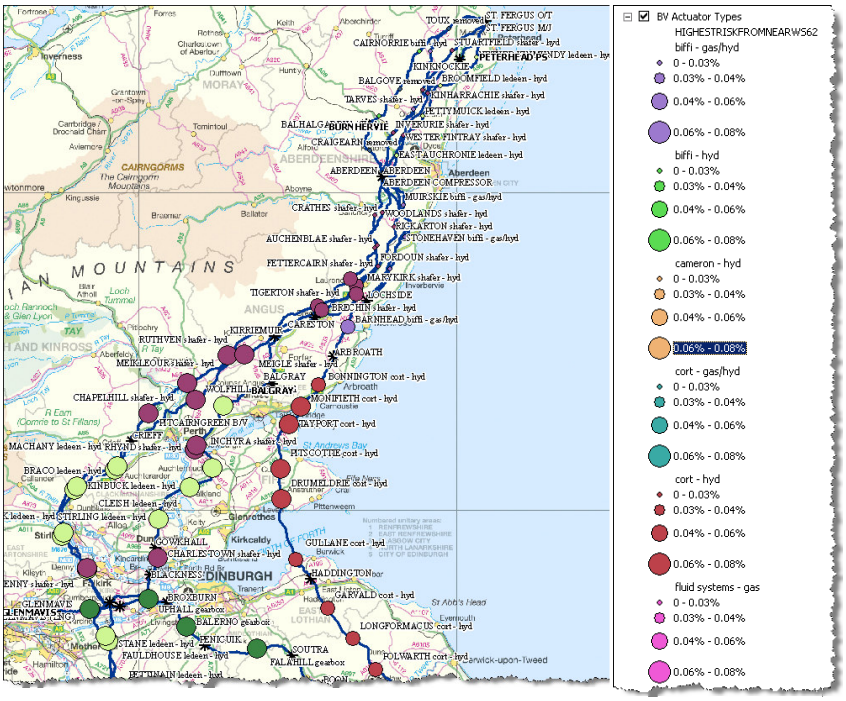
A standard radius was established around each AGI, which included at least one of the 41 weather stations. This standard radius was set at 62km. The highest weather station risk factor within the radius was then applied to each AGI. The below figure shows the result; dark red indicates highest risk; dark green indicates lowest risk:



Other risk factors:

Other risk factors that need to be considered include the susceptibility of different valve actuators and control systems to low temperature; the degree of similarity between adjacent AGIs; and the likelihood of a need to operate in periods of cold weather.

To help establish the means to address these other risk factors along with the risk of sustained cold weather, information on the valves and actuator types was added the AGI function data which already existed in the Uptime database.



The map on the previous page shows an example of how the information can be viewed together using the GIS environment in Uptime. Here, the size of the disc indicates the sustained low temperature risk, while the colour indicates the type of valve actuator:

Severe winter valve issues:

The project has also considered the ways by which valve actuators and control systems can become susceptible to sustained cold weather. These include:

- **Water ingress into valve/actuator transitions, which can freeze and thereby prevent valve operation or completeness of travel**
- **Water ingress into hydraulic actuator systems, which can cause poor performance of the hydraulic oil and ultimately waxing or freezing of the oil**
- **Water ingress into gas controller bleed lines (e.g. condensation or ineffective vent cap), which can freeze and prevent normal control function**
- **Continuous bleeds on gas controllers, where Joule-Thompson cooling can cause freezing of control elements, even at above-zero temperatures.**

Some of these issues are type-dependent, while others are more generic. The project has considered best practice remedial actions for the issues.

These range from targeted measures to reduce the probability of water ingress; design modifications to reduce the need for continuous control gas bleeds; design modifications to improve the integrity of vent caps; and consideration of introducing climate

	control for vulnerable components of the valve system. **AGI function:** **The project considered the different functions of Above Ground Instillations (AGIs) and commented on the likelihood that each type of AGI would be called to "operate in anger" during a period of sustained cold weather.** ▪ **Multi-junction control valves – high likelihood of operational need during severe cold weather, to enable the NTS to respond to peak demand as the patterns of supply and demand change.** ▪ **Compressor connection valves – high likelihood of operational need during severe cold weather, to enhance NTS flow capacity by adding gas compression.** ▪ **Offtake isolation valves – low likelihood of operational need for gas distribution system offtakes, but higher probability for large industrial offtakes, such as combined cycle gas turbine (CCGT) power stations.** ▪ **Emergency block valves – low likelihood of operational need, because the single biggest risk to pipeline integrity is third party damage; and construction activity is not prevalent during periods of severe cold weather.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project title	Variable Envelope Compressors		
Project Engineer	**Owen Ariyo**		
Description of project	**The focus of this research project is investigating methods for varying the performance envelope of centrifugal compressors; primarily adjustable inlet guide vanes.** **The study seeks to establish feasibility of applying nascent technology for varying the performance envelope of single stage centrifugal compressors in the context of National Grid's gas transportation operations. And, where appropriate technology can be established, to assess the feasibility of retrofitting current ageing compressors within the National Grid fleet with variable performance technology.**		
Expenditure for financial year	Internal £9k External £82k Total **£91k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£128k**	**Projected 2013/14 costs for National Grid**	**£38k**
Technological area and/or issue addressed by project	**Pipeline compressors can be put in two categories based on their prime movers; gas turbine driven and electric driven. The gas turbine driven compressor comprises a gas turbine prime mover, the gas turbine, which drives a de-coupled power turbine and process compressor (the "gas compressor"). The electric driven compressor comprises a variable speed electric motor directly coupled to the gas compressor.** **National Grid's fleet of gas compressor trains feature predominantly single stage, centrifugal compressors that do not include any additional technology for varying the envelope of operation besides speed control.** **Compressors are designed to operate within limits known as the "envelope" of operation. When gas flows are stable or predictable, they operate comfortably within these limits. The National Transmission System (NTS) has begun seeing increasing short term changes in gas supply and demand patterns. Hence, some compressors due to their location on the NTS frequently operate around those limits.** **A requirement for the gas compressor to operate around or outside one or more of its limits has traditionally been met by either a re-wheel (changing out the compressor impeller) or by installing a more adequately sized machine (driver plus compressor). Requirements for compressor unit re-wheels have been identified in a few NTS compressor stations in recent years. However, due to the high capital cost, equipment downtime required and the risk posed by supply /**		

<table>
<tr><td></td><td colspan="4">demand volatility few gas compressors have undergone re-wheeling.

The consequence of running the compressor around the limits of its envelope is highly unstable or inefficient operation which could result in:

A. Increased fuel utilisation
B. Reduced machine life due to vibration.
C. Increased risk of equipment breakdown.
D. Difficulty in commissioning and operating new compressor installations.

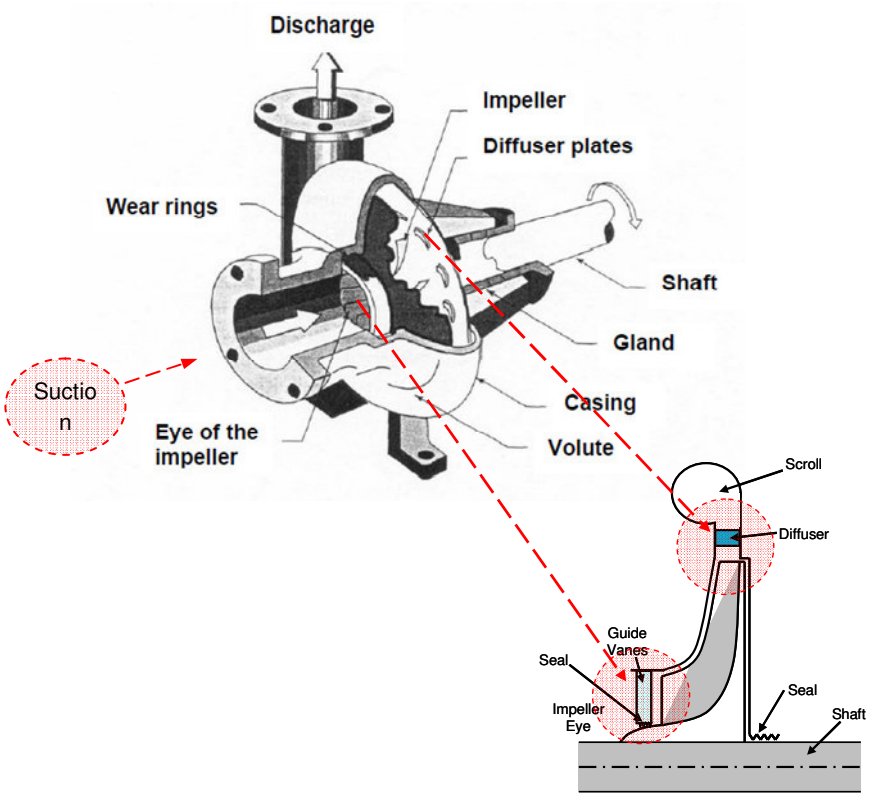
This research and feasibility project investigates the technical and commercial feasibility of installing gas compressors which are capable of varying their performance envelopes to allow efficient and stable operation in response to swings in gas supply and demand.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Significant</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>14</td><td>7</td><td>7</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">Anticipated benefits include:

▪ Reduced fuel cost (from reduced energy consumption and overhaul / maintenance) as compressors operate more efficiently over a wider envelope. Fuel costs could be reduced and, if variable envelope technology could be installed in target gas compressors, and assuming conservative efficiency gains as a result of such technology, significant fuel savings could be realised for high utilisation compressors.

▪ Increased machine life, from reduced requirement for repair, overhaul and maintenance. When the compressor is operated for prolonged periods in choke for instance, this leads to machine vibration which can be reflected to connecting pipework causing early fatigue failure in both machine and pipework. Another possible benefit from ability to operate over a wider range is the use of single machines instead of two machines in parallel, over a wide range of gas process conditions. This benefit would also be reflected in increased machine life.

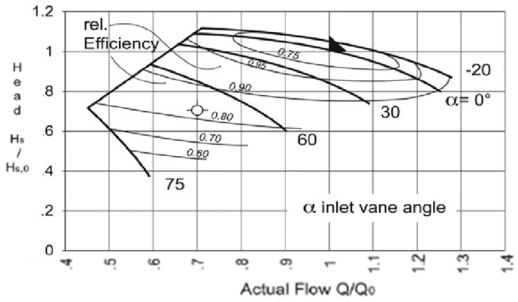
▪ Savings due to avoidance of compressor re-wheel.

▪ Increased unit and station flexibility; compressors would be used effectively and reliably over a wider range of gas process requirements.</td></tr>
<tr><td>Expected timescale of project</td><td>1 year</td><td colspan="2">Duration of benefit once achieved</td><td>5 years</td></tr>
<tr><td>Probability of success</td><td>25%</td><td colspan="2">Project NPV = (PV benefits – PV costs) x probability of success</td><td>£242k</td></tr>
<tr><td>Potential for</td><td colspan="4">The probability that this project will identify suitable solutions to</td></tr>
</table>

achieving expected benefits	**retrofit onto existing units is high based on ongoing work with several key original equipment manufacturers (OEMs).** **The research and development undertaken in this programme of work has identified promising variable envelope technology which could be feasibly applied to compressors on National Grid's fleet. Of particular note is the use of variable inlet guide vanes in combination with speed control.**
Project progress **[Year to End of March 2013]**	**The research project is currently 60% complete. The following are key milestones / deliverables for the project along with an indication of progress to date:** **A. Select and appoint a research partner and outline parameters for the research project.** **This phase of the project is complete. Fraser Nash was selected following an assessment of the competence, knowledge and research capability of three potential research partners.** **B. Research viable methods for varying the performance of compressors.** **Several methods for varying the performance of centrifugal compressors were initially identified. These include use of the following along with speed control. The effect of each individual method, on its own, on the envelope of operation is also illustrated.**  **1. Variable Inlet Guide Vanes. – Varying the angle of the**

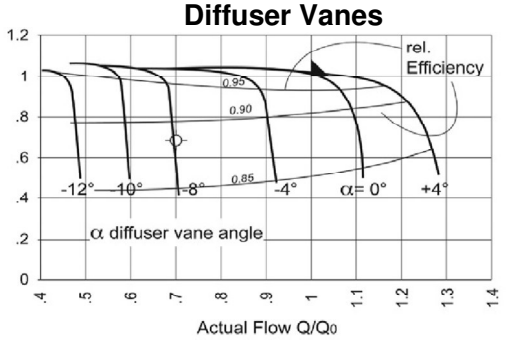
normally fixed inlet guide vane into the impeller during operation:

Variable Inlet Guide Vanes



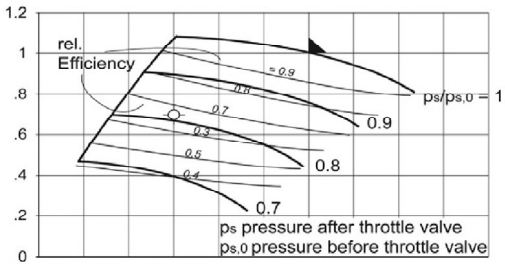
2. **Variable Diffuser Vanes – Installing diffuser vanes and varying the angle during operation:**

Diffuser Vanes

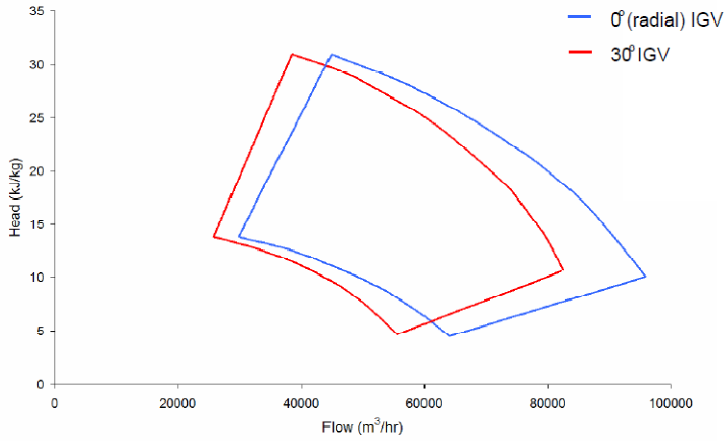


3. **Suction Throttle Control – Varying the suction pressure of the gas flowing through the compressor (using a small regulator) before it reaches the impeller:**

Throttle



The most promising technology is the use of Variable Inlet Guide Vanes (VIGV) in combination with speed control. A measure of the benefit which could be realized is illustrated using a typical compressor envelope below which is based on a prototype design by one of the OEMs. Note that the blue curve is the original speed controlled envelope, while the red curve shows the additional capability realized by varying the VIGV by 30 degrees.



C. Establish theoretical basis for compressor envelope variation techniques – A desktop model that tells why and how envelope variation technologies work. This work is complete.

D. Carry out a high level survey of relevant OEM compressor envelope variation technologies. This work is ongoing (70% complete).

Several OEMs are currently working on implementing variable envelope technologies in their designs while others do not see a market for this technology since most of their customers operate linear gas pipelines or gas production well which experience very little process variation.

The most advanced of these variable envelope technologies currently in the design to prototype stages for new gas pipeline compressors have been developed by Rolls Royce, Dresser Rand, GE and MAN Turbo & Diesel.

E. Carry out an initial high level assessment of the feasibility of a retrofit of a viable compressor envelope variation technology to National Grid's compressor fleet. This work is ongoing *(10% complete)*.

The OEMs have provided an indication of their technological capability to undertake a retrofit of either variable inlet guide vanes or suction throttling on National Grid's compressors. Initial responses are outlined in the table below:

	Dresser-Rand	GE	Siemens	Rolls-Royce	Solar	MAN Turbo
Re-wheel	YES	YES	YES	YES	YES	YES
VIGV	YES (but likely to be expensive and difficult)	NO (due to actuating through HP casing)	POSSIBLE	YES	NO	POSSIBLE (concerns over retrofitting - where used in other applications, they have been designed in from start)
Throttle-valve	?	YES	YES	YES (although dependent on compressor)	?	YES

Collaborative partners	**None**
R&D provider	**Frazer-Nash Ltd.**

Project title	Assessment of Hydrophobic Treatment			
Project Engineer	**Simon Kidd**			
Description of project	**This project will look into the possibility of applying a hydrophobic solution to the metal air intake components on gas turbines, in order to prevent the formation of ice.**			
Expenditure for financial year	Internal £4k External £16k Total **£20k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**	
Total project costs (collaborative + external + NG)	**£35k**	**Projected 2013/14 costs for National Grid**	**£15k**	
Technological area and/or issue addressed by project	**This project will assess the effectiveness of commercial hydrophobic treatments in order to prevent the formation of ice on air intakes. This involves understanding the morphology of hydrophobic treatments and liaising with the turbine manufactures to confirm that the use of the treatments will not cause damage from coating/chemical break-up. Once the hydrophobic treatment has been signed off as safe, a site trial will be carried out over the winter period to test the treatments potential.** **This project aims to reduce greatly the risk of compressor trip (and improve the potential long term availability) due to freezing conditions in order to provide improved reliability and save operational costs associated with unit overhaul, maintenance and potential improvements in long term unit efficiency.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		12	0	**12**
Expected benefits of project	**The primary benefit is the reduction of running trips (i.e. where a pipeline compressor goes offline and is subsequently unavailable) during severe winter conditions. In particular, this project will address unavailability of pipeline compressor units due to freezing fog. Freezing fog is a common failure mode for all compressor units on a compressor site or a common failure mode for a number of compressor sites in an area of the country.** **Part of this study will provide a realistic service review of the technology by conducting field trials of units which have the highest incidence of weather related operational issues. The programme will take a holistic view of the coating not only in terms of ice related build up but also compressor wash cycles and engine efficiency.** **As indicated by the above information on potential business benefits, this project could be expanded beyond the initial scope to tackle the**			

	wider issue of enhanced assurance of compressor reliability during severe winter conditions.		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	90%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£1k**
Potential for achieving expected benefits	**A lab test environment has been established to undertake controlled tests on a variety of aspects of gas turbine air intake material selection and treatment. Compared to the original project scope, this approach has more potential to determine whether the expected benefits can be achieved. The original project scope relied on a field trial site experiencing freak weather for the project to be conclusive.** **Based on initial testing with the lab test environment, the application of hydrophobic solution does show potential to reduce ice formation. However, it is also clear that the type of material and the method of application are also critical to the success of the hydrophobic treatment.** **Because the lab test environment can also be used to evaluate the performance of other materials (e.g. samples from filter components), there is a reasonable chance that its development has increased the potential to realise the expected benefits of the project.**		
Project progress **[Year to End of March 2013]**	**Background research: Recent research by others into the performance of hydrophobic solutions has concluded that the technology is still not yet fully matured and, as such, there is no commercially-available hydrophobic solution that will completely prevent the formation of ice.** **Currently-available hydrophobic solutions are thought to be effective up to a certain set of conditions, beyond which there is a decrease in performance. In addition to this, the method in which the solution is applied to the sample is extremely important.** **The solution must be worked into the sample carefully in order to get the maximum level of performance. Work is also underway to determine whether there are any design features that are likely to contribute to a susceptibility to icing up during periods of freezing fog.**		

A risk assessment conducted on the original project scope determined a high risk of delay in obtaining gas turbine manufacturer support for implementation of hydrophobic coatings to gas turbine intakes.

It also determined a high risk that a field trial would be inconclusive, because of the infrequency of freezing fog events at any selected field trial site. It was also determined that is was likely that hydrophobic solutions might need to be re-evaluated in future years as the technology matures.

The decision was therefore taken to re-focus the project on the development of a lab test environment. This would enable the effectiveness and morphology of hydrophobic coating to be determined on different louver and screen materials under controlled conditions. The controlled conditions would simulate:

- **The range of air flow velocity for typical gas turbine air intakes**
- **The range of air temperature and relative humidity, where freezing fog is most likely to occur.**

Environmental test chamber: Due to the difficulties in obtaining a standard environmental chamber with the capability of simulating high humidity at low temperatures, a test chamber has been designed and constructed to fulfil this purpose. The design incorporates an enclosed space with recirculation pipework and a variable fan. This test chamber will be placed inside a larger environmental chamber in order to control the temperature, while the humidity is provided by a consumer humidifier connected via flexible tubing.

	Inner test chamber that controls air flow and humidity, installed within a standard temperature control cabinet **Testing capability established: With the testing methodology established, it is now possible to test a range of materials, solutions and conditions. Preliminary testing has been conducted in order to ensure the chamber behaves as expected. Samples coated in hydrophobic solution will be tested alongside untreated samples under the same conditions in order to conduct a fair analysis. The susceptibility to ice formation will be determined using mass increase at set time intervals. As well as the testing of hydrophobic solutions, it is possible to test a wide range of materials, such as filter elements in order to assist with validation of manufacturers' claims.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

Project Title	Digital Risk & Security
Project Engineer	Robert Coles
Description of project	**Seconomics FP7** • To complete technical research to understanding the cyber threats affecting National Grid • To undertake economic analysis and modelling of the possible incentives and behaviours of critical national infrastructure (CNI) operators under different regulatory regimes. • To provide an assessment of current and other regulatory framework that could apply to CNI operators in terms of cyber security and obtain consensus of a preferred regulatory regime. **Intentional Electro-Magnetic Pulse Risk Assessment** • To gain a technical understanding of the current capability to generate an intentional electromagnetic pulse that could damage computer equipment and to understand the type and extent of damage that may be caused. • To gain an understanding of the vulnerability of current infrastructure from electromagnetic effects on equipment, systems and infrastructure assets. • To inform the specifications with respect to required infrastructure to withstand such attacks. **Cyber-security Research** • To develop a cyber-security research agenda for National Grid. • To consider what general security research is applicable to National Grid and what National Grid and energy sector-specific requirements must be addressed. • To identify and develop programmes to address these issues. • To identify and develop a group of collaborations and funding mechanisms/sources. • To work with UK/US agencies and the energy sector to develop shared activities and communities with common interests in CNI cyber-security. • To initiate National Grid's position as a thought-leader in energy cyber-security research and place National grid as the natural convener of dialogue in energy sector cyber-security.

Expenditure for financial year	**Internal** Redacted **External Redacted** **Total Redacted**	**Expenditure in previous (IFI) financial years**	**Internal Redacted** **External Redacted** **Total Redacted**
Total project costs (collaborative + external + NG)	**Redacted**	**Projected 2013/14 costs for National Grid**	**Redacted**
Technological area and/or issue addressed by project	**To complete technical research into cyber threats, testing of equipment and infrastructure for UK computer managed assets. Ultimately, to try to provide solutions for managing cyber threats to National Grid assets and systems.**		
Type(s) of innovation involved	Redacted	Project Benefits Rating: Redacted Project Residual Risk: Redacted **Overall Project Score: Redacted**	
Expected benefits of project	**Seconomics FP7** **In the UK National Grid is not subject to mandatory regulation for cyber security. European regulators have mentioned in various forums that regulating CNI operators in terms of cyber security is an option. The purpose of this work is to provide recommendations to the European Regulators of regulatory systems that would incentivise the operator's to be secure.** **Through providing these recommendations the regulatory process can be driven to ensure that onerous regulatory frameworks are not imposed. This allows National Grid to have early engagement and shape the regulatory framework at a European level.** **Without this engagement the European regulator could impose regulatory framework around cyber security that does not incentivise the CNI operators to secure themselves or worse, could be detrimental to the security of the CNI. This could also be very burdensome to the operators themselves and increase the cost of demonstrating compliance to any new regulations in cyber security.** **Intentional Electro-Magnetic Pulse Initial Risk Assessment** **The work once complete will identify vulnerabilities and recommend pragmatic mitigation. This allows National Grid to understand and manage risk effectively to allow the business to operate safely and securely as well as cost effectively.**		

Expected timescale of project	Ongoing	**Duration of benefit once achieved**	**Ongoing**
Probability of success	Redacted	**Project NPV = (PV benefits – PV costs) x probability of success**	**Redacted**
Potential for achieving expected benefits	**Very high based on previous research undertaken and the research collaboration.**		
Project progress **[Year to End of March 2013]**	**Intentional Electro-Magnetic Pulse Risk Assessment** **The scope of the work so far can be organized under three headings:** **Understanding Effects** • **Supporting customers in the development of operational concepts.** • **Providing thought leadership on research priorities.** **Enabling Operations** • **Supporting customers on integration and interoperability issues** • **Research support aimed at addressing the non-equipment defence lines of development (DLODs).** • **Test and Evaluation.** **Assessing Vulnerability** • **Supporting UK Govt. and Infrastructure Owners/Operators.** • **Technical Visual Assessment.** • **Instrumented Technical Survey.** • **Evidence-based hardening consultation.** **The work remaining to be done is the following:** • **Task 1: One additional site pre-survey/Technical Visual.** • **Assessment (TVA) – Gas Compressor Chelmsford.** • **Task 2: Update CPNI Guidance on IEMI to include:** – **General observations from the TVA's conducted**		

so far;

- Data on the intrinsic protection afforded by perimeter fence types and buildings (Task 3, if selected);
- Data on equipment susceptibility (Task 4, if selected);
- Updated information on 'threat' environments.

- Task 3: Intrinsic radio frequency protection of perimeter fences and buildings.
- Task 4: Susceptibility testing of assets.
- Task 5: Gap Analysis of National Grid electromagnetic compatibility specifications.

Seconomics FP7

Digital Risk & Security has appointed Dr. Raminder Ruprai to work 50% on this project, in close co-operation with the University of Aberdeen.

An overview of the implementation mechanisms of policy approaches regarding the question of rules-versus-principles based in enacting policy requirements has been developed. Whilst this is a well-known issue in most public-policy contexts, it has not been studied widely in the area of rule setting in security. This concept will be considered using some specific examples from critical national infrastructure.

Moving on from policy implementation, the needs for security policy in an economic context will be developed by outlining a series of models of security scenarios. In each case, the need for placing constraints on actions (due to incentive incompatibility) of individual agents to maximize the global level of welfare will be illustrated.

A detailed systems modeling framework with explicit representations of relevant systems architecture, and logical methods for reasoning about such models will be considered. A simulation modeling tool (Gnosis) has been outlined that captures the mathematical structures required for systems modelling. The Gnosis modelling tool currently does not include specific representations of economic theory. Part of the work is to illustrate how to use mathematical modeling languages such as MatLab to integrate the necessary mathematical structures and integrate them with notions of utility theory and welfare to encapsulate better the economic interactions inherent in such models.

Specific guidance on integrating economic and systems models in a security problem context have been provided. A worked example of airport security architecture has been outlined. The systems model in this version of the model has a

policy function based on observed metrics that can be used to compare performance of different configurations of the airport security architecture. The core features of the policy function have been derived.

A series of results broadly related to market-based pricing or real options models have been developed. These models are useful when there are exogenous risks, and allow for the calibration of monetized cost benefit analyses. The models typically measure risk next to a known set of benchmarks with easy to value properties (e.g., using an asset pricing model, such as a Geometric Brownian motion value process or a multi factor asset pricing model such as the famous Capital Asset Pricing Model (CAPM)). The objective of these models is to impute discount rates on assets that allow for a) comparison and b) addition of risks. These risks can be converted via a market mechanism to additive costs. This approach is useful when there is at least one easily comparable liquid asset.

A series of micro theory models of externalities and incentives (good when the architecture is simple, intractable to formulate otherwise) useful for under- standing how to build contracts and incentive structures that improve welfare have also developed. This includes principal agent problems, models of externalities and models of public policy, institutional analysis and design. An overview of insurance in this context, again with a view to monetization/or cardinality of preference of the impact of security policies has been presented.

A model that explicitly analyzes the balance between rules- and risk-based regulation is currently being developed. This model will be explored computationally in the context of the NERC CIP regulatory regime.

Cyber-security Research

- **Appointment of Prof. David J. Pym of Aberdeen University as Director of Cyber-security Research for a period of 3.5 yearrs from 1 March 2013.**
- **Projects are being scoped in the following areas:**

  Supply chains/Service level agreements

  Organizational culture

  Bring your own device (BYOD)/mobile devices

  CPNI alignment

The Seconomics FP7 project:

This project is addressing concerns about the design of regulatory regimes and the right balance between rules-based compliance and risk-assessment-based security management.

	Also linked are: • **GCHQ/ESPRC 'Productive Security', with UCL and University of Aberdeen (culture & modelling)** • **New EPSRC project (security modelling/economics) Universities of Aberdeen and Bath, National Grid, HP Labs. This is basic research in security modelling/economics, but is strongly grounded in the intended applications.** • **Seeking further engagement UK funding:** **With CPNI/EPSRC/GCHQ. Pym has been advising CPNI on a new security research institute in industrial control systems.** **Possible Technology Strategy Board engagement with a similar programme.** **There is an opportunity for National Grid to align some innovation funds with CPNI's institute.** **Research Councils: Outline bid submitted to the BACCHUS programme: Minding the Policy-Implementation Gap** **Academic security economics publications in sustainability/resilience and in the need for public policy interventions in information security are in progress.**
Collaborative partners	**National Grid Electricity Transmission, National Grid Gas Transmission** **Seconomics FP7** **University of Aberdeen (primary) and others as above.**
R&D provider	**As above**

Project title	Alternatives to Venting from the National Gas Transmission System (NTS).		
Project Engineer	**Tony Robinson**		
Description of project	**The key objective of this study is to develop practical methods to reduce the emissions of methane that would otherwise occur during venting to the atmosphere from the National Gas Transmission Network (NTS).**		
Expenditure for financial year	Internal £8k External £226k Total **£234k**	**Expenditure in previous (IFI) financial years**	**Internal £29k** **External £1,070k** **Total £1,099k**
Total project costs (collaborative + external + NG)	**£1,436k**	**Projected 2012/13 costs for NG**	**£104k**
Technological area and/or issue addressed by project	**Natural gas, which is typically 85-93% methane, is released to the environment from gas transmission networks in a number of ways, including:** • **Infrastructure containment failures (e.g. elastomer seals, small bore pipework connections, pipework failures)** • **Operational venting for decommission/repair or extension of networks** • **Process venting from equipment (planned and unplanned)** • **Fugitive leakage from pipeline equipment.** **Venting and fugitive leakage constitutes a significant part of the overall methane losses to atmosphere. Fugitive leakage from the NTS has been estimated to be of the order of 4000 tonnes per annum. Although this project will not address fugitive emissions, the figure is given here to compare with operational (planned or necessary) venting of methane.** **Planned venting can arise from a number of sources around the network, including venting at compressor sites and pipeline decommissioning prior to repairs, replacement or modification activity.** **Planned venting at compressor sites is monitored and recorded through the on-line control system. For 2011/12, NTS reported to the Environment Agencies that there had been 2984 tonnes of natural gas emitted from planned venting at compressor stations.** **Pipeline pressure is typically reduced to 7 BarG by recompressing it into an adjacent pipeline. However, the last 7 BarG can not be sensibly recompressed using the available equipment. It is therefore safely vented to atmosphere. Historical trends suggest that in excess of 150,000m^3 of pipework volume is vented to atmosphere in this way each year (about 1000 tonnes of gas).** **Clearly there are sound environmental and energy efficiency reasons for developing methods to reduce the amount of vented natural gas. There are several points that influence the current venting best practice, including**		

	both commercial and operational factors in addition to energy saving and environmental concerns. These concerns include the consideration of: • **Distance between pipeline block valves. These isolation distances are tending to increase and thus lead to increased vented volumes during decommissioning.** • **Installation of Booster Units at Pig Trap or Block Valve Sites to enable better management of the decommissioning activities.** **To improve the environmental performance of the final stages of the decommissioning process several options are available including:** • **Collect the gas and use elsewhere with the network.** • **Flare the gas. Methane is recognised as having a "Global Warming Potential" (GWP) twenty times that of carbon dioxide (CO_2). Thus flaring, which converts the methane to CO_2, is more beneficial environmentally.** • **Use the gas at the decommissioning site.**			
Type(s) of innovation involved	Radical	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		17	-1	**18**
Expected benefits of project	**The benefits from undertaking this work include:** • **Development of new best practice for lowering methane emissions during decommissioning activities prior to maintenance** • **Reduction in National Grid's methane emission inventory** • **Improved energy management.** **A financial benefit can be derived from consideration of reduced methane emissions. The shadow price of carbon is £28.70 CO_2-te and as natural gas emissions are recognised to be twenty times more damaging to the environment than CO_2, this represents a cost of £574/tonne of natural gas vented. No further European Emissions Trading Scheme (EUETS) costs have been considered as the current status of the scheme is uncertain.** **The cost savings breakdown as a consequence of improved vented gas control are:** • **Planned venting down of gas transmission pipelines for maintenance accounts for about 960 tonnes of methane emissions per year. Saving: £551,000/annum** • **Operational venting down of NTS compressor units during emergency scenarios and for maintenance accounts for more than 1800 tonnes (Advantica Report 6446) of methane emissions per year. Saving: £1.03m/annum** • **Recent additional studies have estimated that the amount of natural gas vented from compressors in 2011/12 was 2987 tonnes. Saving: £1.7m/annum** **Real benefits will only accrue if the captured and stored gas can be**			

	efficiently utilised. One such option is to use the stored gas to fuel high efficient micro generators. At an assumed electricity price of 5p per kW-hr the savings are: • **On site micro generation:** **Saving: £505,000/annum** **In reality, the true savings of venting reduction activities will be a composite but not necessarily an aggregate of the savings described above.**		
Expected timescale of project	4 years	**Duration of benefit once achieved**	**Lifetime**
Probability of success	70%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£34k**
Potential for achieving expected benefits	**The financial and environmental benefits that this project can achieve are significant. The initial test results (see below) offer considerable promise that large scale adsorbed gas capture capability is technologically feasible. The design and operation activities have shown that the process is both practical and realisable.** **To achieve the proposed benefits, it will require further integration and implementation of the gas capture with other downstream utilisation technologies. There also needs to be a regulatory and commercial framework to allow the cost savings to be equitably shared across the gas community.**		
Project progress [Year to End to March 2013]	**After the successful completion of the initial technical and economic feasibility phases of the project, the focus has been on developing high rate, near half tonne (400kg), natural gas capture facility. This proof of concept facility has been based on activated carbon technology.** **Following a detailed feasibility study and laboratory scale demonstration of adsorbed natural gas (ANG) storage capability, it was concluded that this technology offered considerable benefits to capture vented gas. These benefits include:** • **Flexibility.** • **Good volume to volume storage ratios.** • **Maintenance of gas quality.** • **High rates of natural gas capture potential.** **The pilot ANG facility has been constructed and commissioned. It consists of a 9.8m^3 activated carbon storage vessel (arrowed in Figure 1) with a 400kg natural gas storage capacity at 30 BarG. The facility shown below in Figure 1 is considered the largest integrated ANG capture and storage system of its type.**		

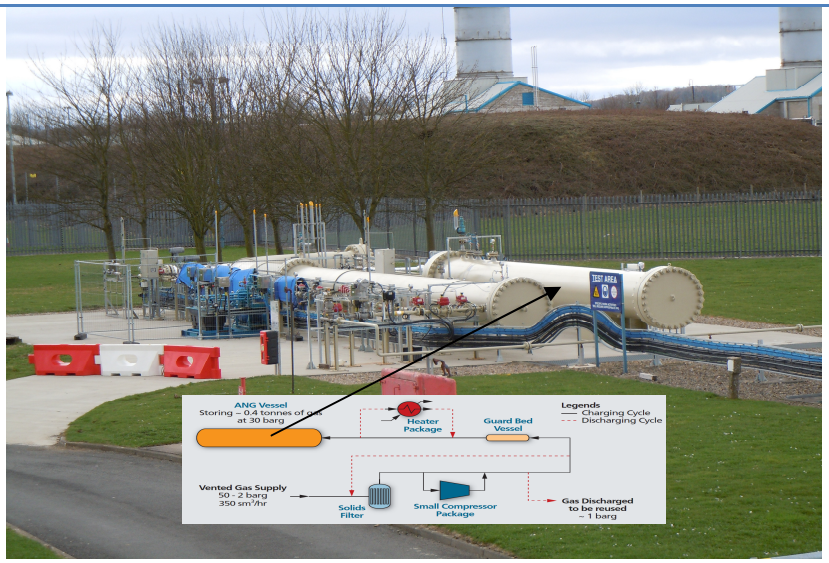


Figure 1. The National Grid ANG natural gas capture facility.

The ANG capture facility has completed its commissioning phase and is now undergoing a comprehensive testing and evaluation programme. This programme is due to complete in the summer of 2013.

Only once this programme has been completed will it be possible to complete a full assessment of the capability of the ANG technology for potential gas capture/storage applications. From the results to date the key highlights are:

- **The activated carbon ANG vessel and Guard Bed (a preliminary activated carbon filled vessel necessary to prevent contamination of the main ANG carbons by large carbon molecules present in natural gas) has shown consistent capture and discharge capacity. (Figure 2) of ≈ 400 kg.**

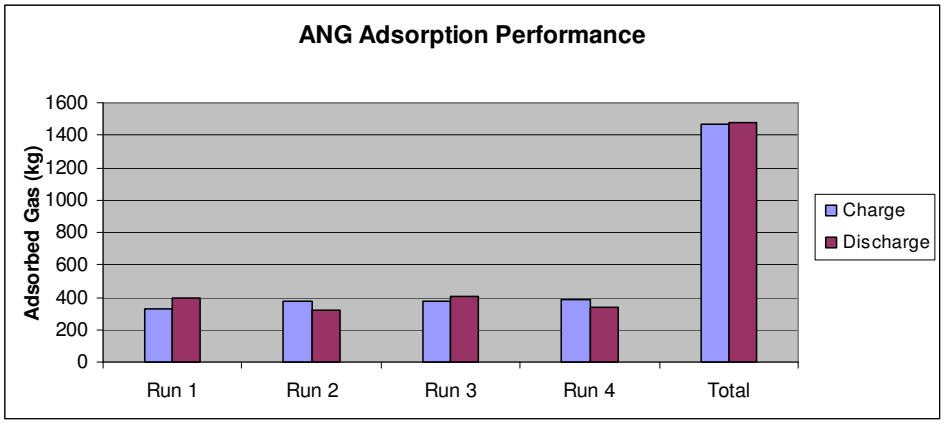


Figure 2. The initial ANG capture and discharge performance in terms of mass (kg) of gas stored per test.

	• **The control of gas quality, within the legal requirements[2] in discharge mode has been demonstrated with good Guard Bed and ANG vessel performance (limited stiction of molecular species on the respective carbon adsorbents)** • **Temperature management of the storage vessels in both charging and discharging modes is well defined and readily controllable.** • **Gas storage capacity is not compromised by charging rates up to 350 scm/h. (Initial discharge rates have been limited to 100 scm/h).** • **The activated carbon material can be regenerated (cleaned of adsorbed resident gas molecules) without any apparent reduction in subsequent methane capture volumes.** **The results to date are highly encouraging and ANG could be a key element in a future coherent emissions reduction strategy.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton**

[2] NTS gas quality is determined by Gas Safety (Management) Regulations 1996. Any gas entering the transmission system has to conform to the limits specified within GS(M)R.

Project title	Clover Groundcover on National Grid Above Ground Installation (AGI) Sites		
Project Engineer	**Gary Haley**		
Description of project	**This innovation project seeks to understand the cost and environmental affects of replacing grass at gas transmission above ground installation (AGI) and block valve sites with clover groundcover, with the long term view of implementing changes to procedures/specifications to ensure the use of clover in place of grass can be implemented at all sites.**		
Expenditure for financial year	Internal £4k External £5k Total **£9k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£9k**	**Projected 2013/14 costs for National Grid**	**£0**
Technological area and/or issue addressed by project	**Historically the use of grass on above ground installation (AGI) and block valve sites has required constant upkeep, with grass being cut up to 6 times per year and the use of weed killers up to three times per year on most sites.** **The planting of a more sustainable clover groundcover that does not require the same level of upkeep and can self propagate will bring efficiency to the business by cutting costs associated with site visits by maintenance contractors almost in half.** **Use of clover in place of grass will also shrink the hidden costs to the environment by reducing National Grid's carbon emissions related to travelling to each site and the use of machinery for cutting grass.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating**: 15	**Project Residual Risk**: -5 / **Overall Project Score**: **20**
Expected benefits of project	**The change of use to clover groundcover is fiscally and environmentally responsible and enduring. It contributes to the reduction of National Grid's carbon footprint whilst promoting beneficial, sustainable impacts on the environment. Most notably, supporting the dwindling bee population by providing a valuable source of food.** **There are several benefits associated with the cost of maintenance. The costs of contractors visiting site, cutting grass with machinery and also travelling to sites would be reduced to the minimum.** **Clover is the right choice for the environment. It is a low growing, flowering perennial plant that stays green year round. This provides the advantage of a similar appearance to grass without the**		

	aforementioned drawbacks of grass. Clover has a dense habit that is tolerant to heavy use and can be planted on coastal sites and steep gradients. It's not inclined to creep or grow onto concrete, tarmac, or chipped or stoned areas and discourages other weed growth. **The added environmental bonus of clover is that clover flowers provide a great food source for the dwindling British bumble bee population during a time of year when food is most needed. Clover is a hardy plant with an almost infinite lifespan and it is hoped that increasing the amount of flowering clover in our urban and rural environments will help aid in the recovery of the bee population that is currently under great threat.** **The financial savings and environmental benefits associated with using clover in place of grass can be increased if this innovative groundcover technique is transferred to other parts of the business (e.g. compressor and electricity transmission sites). The learning from this project could also be shared with other businesses that are equally committed to promoting environmentally friendly practices that make good business sense.** **Therefore, this project aims to implement the required changes to procedures/specifications to ensure this new process is implemented at all new sites.**		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	75%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£158k**
Potential for achieving expected benefits	**The onsite clover cover trials have achieved full expected benefit; as a result of this project the successful identification of clover as a replacement groundcover for grass offers a variety of benefits to the business and the environment.** **Continued benefits gained beyond the conclusion of this project include:** ▪ **Amendments to site maintenance will impact positively National Grid's carbon footprint** ▪ **Reduction in site maintenance costs** ▪ **No fire risk to gas sites** ▪ **Environmentally friendly, sustainable alternative to grass.**		
Project progress **[Year to End of March 2013]**	**The initial phase of this three year project focused on selection of appropriate sites for field trials followed by assessing the best type of groundcover. Bardsey, a typical block valve site of medium size situated in a rural farming community in Yorkshire, hosted the first trial.** **A specialist landscape management contractor inspected the Bardsey site to identify the best plant options. The replacement plant must comply with National Grid's policy on landscape works and maintenance of landscaped sites. Several shrubs identified were**		

	thought to be inappropriate due to potential fire risks and the eventual maintenance needed to keep entry/exits clear. After further discussion, the option that fitted all of the criteria was a mixture of clover.  **The full area of grass was removed at Bardsey and replaced with clover seed. After four months the clover had reached full growth, with only a few empty patches which filled in during the next year of observation. As a mixture of clover types were used, it became apparent that some were not suitable as they grew too high and did not meet the expected requirements.** **Additional trials were undertaken in South Duffield and the Easington Terminal which is a coastal location as well as Wibtoft, which is a small AGI Site in the East Midlands. Implementation of each proceeding trial improved, based on lessons learned from previous trials, including decisions around the best type of clover to use, which is a dwarf strain, and the appropriate technique for complete removal of grass to ensure there is no re-growth and reduction of annual weeds. As a result, subsequent trials met with increasingly successful outcomes.** **At this stage, it is not expected to have to mow the clover. However, results from the field trials indicate that in the event clover groundcover does require mowing, it would be on an annual or biannual basis. Compared to grass, which requires mowing up to six times a year.** **Based on the success of this project, future trials are being outlined in a separate business supported project. Part of this future work will allow National Grid to understand implications of longer term maintenance requirements. Investigating issues such as self-seeding, or manual reseeding if die back of clover occurs.** **To further the learning gained from this project, larger National Grid Gas sites, including several compressor sites, will be part of field trials going forward. Included in this separate piece of work, new plants, such as vetch and other clover strains, will be trialled to continue the development and sustainability as an alternative to the traditional grass ground cover.** **Based on the success of the trials undertaken on multiple sites, it is now understood that replacing grass with a groundcover such as a clover mix will reduce the carbon footprint for National Grid.**
Collaborative partners	**None**
R&D provider	**Blackburn Robinson Ltd**

<table>
<tr><th>Project title</th><th colspan="4">Development of a New Design Vent Silencer</th></tr>
<tr><td>Project Engineer</td><td colspan="4">Russ Nattrass</td></tr>
<tr><td>Description of project</td><td colspan="4">The aim of this project is to carry out the required development and testing of a proposed high pressure venting silencer with the Industrial Noise and Vibration Centre.

The silencer has potential to deliver advantages such as reduced noise levels and health and safety exposure, an improved public perception and the reduction of noise pollution during necessary venting operations.</td></tr>
<tr><td>Expenditure for financial year</td><td>Internal £4k
External £6k
Total £10k</td><td colspan="2">Expenditure in previous IFI financial years</td><td>Internal £0
External £0
Total £0</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£30k</td><td colspan="2">Projected 2013/14 costs for National Grid</td><td>£20k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">The noise implications of National Grid’s venting operations are becoming more highly scrutinised. At the National Grid Tirley pressure reduction installation a planning condition has been imposed.

The planning condition requires a local resident notification process to be agreed with the local planning authority covering any noise event that would be auditable in the immediate vicinity.

It is therefore National Grid’s intention to not only agree a notification process, and, if at all possible, to reduce noise levels during necessary venting operations. Furthermore, it is expected that there will be greater sensitivity around future activities that support further innovation activities that allow us to utilise all available mitigation actions.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Significant</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>8</td><td>-1</td><td>9</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">There is potential that this new vent silencer design will be a low cost, comparatively simple alternative to current practices.

1. Reduction in noise levels

For all venting activity on a national basis. It is expected that such a device may take at least 20 dBA off the current noise level.

2. Reduction in affected/notification zones for venting

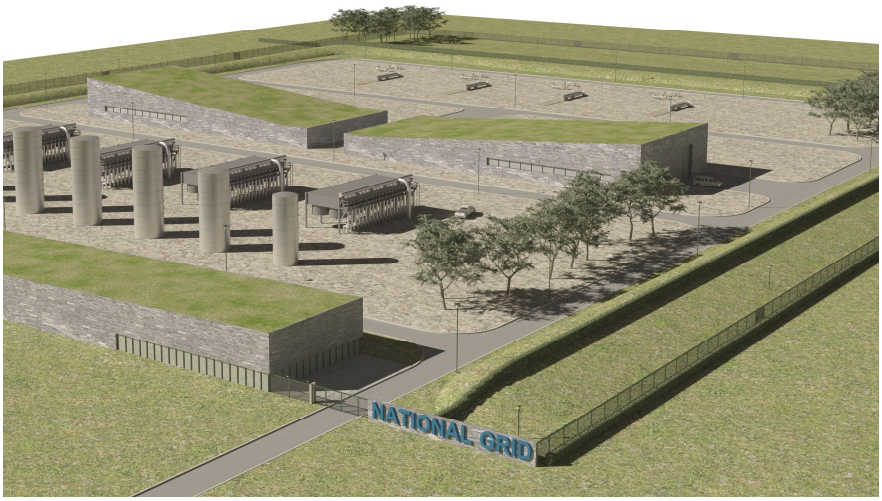
This novel approach in controlling the rate of gas/air mixing</td></tr>
</table>

	has the potential to impact on the assumptions made as part of a risk assessment and the determination of hazardous areas. **3. Reduction in health and safety issues for operatives** **Exposure times and noise levels.** **4. Possible reduction in operations timing** **Greater flows for similar noise outputs.**		
Expected timescale of project	2 years	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£42k**
Potential for achieving expected benefits	**Initial test results indicate there is potential to design a full scale silencing system that will reduce venting noise to within the anticipated levels.**		
Project progress **[Year to End of March 2013]**	**A feasibility study was undertaken to trial the potential use of novel design of silencers to reduce noise generated during the process of blow-down of gas lines. A silencer design that was originally considered to be fit for purpose was found to be cost prohibitive.** **The first phase of work tested a small scale silencer system, once a baseline had been established. Two different nozzles were tested, with adjustable geometry to allow for changes to the flow to be done in a controlled manner.** **Once the minimum noise nozzle geometry was established, the entraining nozzle was fitted with a simple silencer system. Trials found that when using the optimum nozzle configuration, with respect to the best compromise between noise level and flow rate, in combination with the silencer system there was a significant noise reduction.**		

	 ***Entraining nozzle test with a simple silencer design*** **The first phase of testing has concluded that combining an entraining nozzle with a silencer on a small scale test unit has the potential to provide a noise reduction of 95%. It is anticipated that this level of noise reduction can be duplicated on a full scale system, with a potential drop in flow of around 30%.** **Design and testing of a full scale system will be undertaken in 2013.**
Collaborative partners	**None**
R&D provider	**Industrial Noises & Vibration Centre Health & Safety Laboratory (HSL)**

Project title	Architectural Design for Compressor Sites		
Project Engineer	**Michael Jordin**		
Description of project	**This project will deliver an environmentally sensitive design that demonstrates National Grid's commitment to reducing the environmental and resource impacts associated with developing an infrastructure project.**		
Expenditure for financial year	Internal £3k External £26k Total **£29k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£187k**	**Projected 2013/14 costs for National Grid**	**£158k**
Technological area and/or issue addressed by project	**National Grid operates in an ever more stringent planning environment. Implementation of the Planning Act 2008 resulted in the capture of all nationally significant infrastructure projects. This has resulted in increased responsibility for a developer to provide evidence that a full and open engagement has been undertaken with both statutory and non-statutory organisations, particularly the public at large, and to ensure that opinions expressed by third parties have been properly noted and where possible used to influence the final design submitted for consent to the Planning Inspectorate.** **As part of National Grid's commitment to being the industry leader in the implementation of the requirements of the Planning Act, National Grid is required to construct an above ground installation. It is imperative that they investigate fully all alternatives available to minimise the impact of the development on its environment and those who live in that environment.** **Preliminary compressor site design drawings and animations were created for the early stages of the public consultations on the Yorkshire & Humber Cross Country Pipeline project, looking at three design options: Contemporary, Farmstead and Landscaped. The overwhelming preference from the public was for the landscape design i.e. the environmental option.** **Issues this project intends to address include the:** ▪ **increasingly stringent planning consent regime that National Grid has to operate within,** ▪ **need to increase, where possible, public acceptance of major infrastructure projects,** ▪ **need to develop innovative solutions to improve the efficiency of the National Grid Compressor facilities in the future.** **This project engaged an architectural, engineering and**		

	environmental consultancy to investigate the design options for the exterior structure of buildings required to accommodate a typical Compressor site, taking account of the design assumptions identified. The consultancies'' architects will provide options to be incorporated in the design and indicative costs for their options for both capital expenditure and operational savings over the conventional building design for a typical 20 year period. **The designs would be worked up into sufficient detail by the consultancy to produce three dimensional animations and models and construction sequences; with the possibility of National Grid using them for presentations at public meetings etc. where projects are being planned, for submissions to the Planning Inspectorate to gain a Development Consent Order and improve the efficiency of the National Grid Compressor facilities in the future.** **Three hypothetical Compressor site options are being investigated (two based on a medium sized electric drive compressor station); one at a coastal location, a second at an inland greenfield site location and a third based on a small compression site in a coastal environment.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		10	7	**3**
Expected benefits of project	**The benefits to be gained derive from engendering collaborative working between all stakeholders – both within National Grid,and at all interfaces with the general public, interest groups and consultees.** **These are expected to include increased support from local communities regarding the siting/development of above ground assets by engendering collaborative working. This will bring benefits in the form of an associated decrease in project risk; a potential reduction in operating costs through the use of renewable energy sources, reduced maintenance costs and positive environmental impacts on the area surrounding the development.** **By reducing the risks of third party opposition to proposed developments and by utilising renewable technologies and environmental innovation, National Grid has the opportunity to demonstrate its continued commitment to the environment. The investigation of the latest environmentally sustainable technologies throughout the design of the proposed compressor site(s) will provide National Grid with data that will be available for utilisation not only on compressor sites but on all proposed future above ground infrastructure developments across National Grid.** **Additionally, the investigative review should lead to demonstrable reduction in operating costs through the use of renewable energy sources, reduced maintenance costs and positive environmental impacts on the area surrounding the development.**			

	At a more strategic level, the development of architectural options on the three hypothetical sites could be expanded and rolled out to other parts of the National Grid business by developing a Design Guide for all comparable infrastructure developments.		
Expected timescale of project	1 year	**Duration of benefit once achieved**	**5 years**
Probability of success	70%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£112k**
Potential for achieving expected benefits	**The potential for achieving the benefits outlined is excellent with interim project progress reviews having been enthusiastically received across all stakeholders on the project team. However, further investment into subsequent phases will be required to support more detailed follow-up, once the initial Phase 1 tasks are complete. This will ensure the findings are appropriately developed and implemented.**		
Project progress **[Year to End of March 2013]**	 ***Landscape design option that reflects environmentally focused settings such as open landscape and coastal areas*** **Progress to the end of March was approximately 30% of the sanctioned work.** **Visits on site were undertaken to review and compile conceptual design framework case studies. The site reviews include fundamentals for an initial Design Guide.** **The development of a Design Tool has been outlined to facilitate and support project efficiencies, sustainable agendas and cost, and to add value for potential standard facility sites.** **This initial piece of work shows how a step by step guide could help to generate a design quickly and efficiently. The tool demonstrates how an outline cost model can be generated at a very early stage in**		

	the project. **Looking forward, this design tool can be developed to integrate with the BIM (Building Information Modelling) process and building standards.**
Collaborative partners	**None**
R&D provider	**AECOM**

Project title	Automatic Risk-Based Handling Of Plant Enquiries		
Project Engineer	**Nik Wileman**		
Description of project	**Development and trial of an automated web-based response service to advise developers of construction restrictions in the vicinity of National Grid energy transmission assets.**		
Expenditure for financial year	Internal £4k External £89k Total **£93k**	**Expenditure in previous (IFI) financial years**	**Internal £0k** **External £0k** **Total £0k**
Total project costs (collaborative + external + NG)	**£537k**	**Projected 2013/14 costs for National Grid**	**£0k**
Technological area and/or issue addressed by project	**This project looks to evaluate whether the risk of third party interference can be reduced by automatic handling of developers' enquiries relating to critical National Grid assets. Such interference can have consequences for security of energy supply, public safety and the environment, together with the associated operational costs and cost from potential prosecution and/or damages claims.** **Interference damage from third party developers, causing a London energy black-out, is a credible and potentially costly incident. Having a system that gives instant, repeatable, reliable responses to those third parties (including utilities, contractors and local government) involved in development work in the vicinity of National Grid assets should reduce the risk of interference damage.** **Third party interference causing environmental damage is also a credible possibility. Methane released from gas pipelines is 20 times more damaging than carbon dioxide. Oil releases from electrical cables can lead to the risk of prosecution, especially if not discovered by National Grid at the time of damage.**		
Type(s) of innovation involved	Incremental	**Project Benefits Rating** 13	**Project Residual Risk** -6	**Overall Project Score** **19**
Expected benefits of project	**The proposed system is designed to mitigate the risk of third party damage. This system will provide comprehensive, accurate and timely asset information and advice based on agreed plant protection rules.** **Known areas of critical supply and priority/vulnerable customers can be defined in the system and monitored for high risk works. Notification emails can be triggered to plant protection engineers when enquires are received matching criteria setup in the system, such as the examples listed above or when monitoring named users/ organisations that may be causing frequent damage or near misses.**		

	National Grid Transmission Land and Development currently handle plant location enquiries form external organisations on a manual basis, utilising a team of about 7 fulltime employees. With an automated response service in place, this team could focus more time on any exceptions, for example the more difficult enquiries, as well as conducting quality assurance and identifying potential improvements to the automated response service. **The long-term aspiration is for as many third parties as possible to become self-service users of EAGLES, rather than contacting the Plant Protection team by post or email. This not only frees up the Plant Protection team to focus activities that explicitly require intervention, but also removes a layer of interpretation from the process, with third parties defining their activities in their own terms**		
Expected timescale of project	4 years	**Duration of benefit once achieved**	**5 years**
Probability of success	80%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£44k**
Potential for achieving expected benefits	**Confidence that the project will realise the intended benefits is high now the project has reached the final stage. 150 of the external organisations have agreed to participate immediately and there is ongoing work to engage with the remaining groups. Full project benefits can be realised once 100 out of 150 members are participating.**		
Project progress [Year to End of March 2013]	**Full implementation (dependant on total collaborative effort) is expected, including the full external interface, enhancements and the line search interface. A recent demonstration has given good confidence in the final delivery.** **Linesearch functionality: Linesearch is a free to use internet based enquiry system, which allows any 3rd party or private individual to make enquiries on–line against pipeline member assets. A key part of the "self-service model" is the linesearch interface whereby each enquiry submitted to Linesearch is passed in a simplified form to EAGLES for a quick upfront check to see if it may affect any National Grid Transmission apparatus. Any that are adjudged to be "Affected" are submitted to EAGLES in a fuller form, for a more detailed assessment. Linesearch users are notified to contact National Grid and the Linesearch enquiry stored in EAGLES can be retrieved and progressed, by specifying a more accurate location, without having to re-enter all the other details** **Progress Enquiry enhancement: This enhancement allows a submitted enquiry to be effectively "cloned" and a new, related enquiry to be entered based on the original enquiry's original information (e.g. a completed "Proposed Works" enquiry would be cloned to produce a linked "Scheduled Works" enquiry with all the same details except new Enquiry Type and a Start Date for instance).** **There has been good progress with regards to knowledge dissemination and communications in preparation for implementation with both internal**		

	communications and articles for trade magazines. **Realisation of benefits is anticipated over the next twelve months with reduced size of the plant protection team, increased numbers of enquiries straight onto the system, improvements in turn around time for dealing with enquires (six days down to three or four), and critically, reduced strikes to pipelines.**
Collaborative partners	**National Grid Gas Distribution, National Grid Electricity Transmission.**
R&D provider	**GL Industrial Services (UK) Ltd, Fisher German.**

Project title	Daily Gas Demand Forecasting		
Project Engineer	**Chris Aldridge**		
Description of project	**The main aim of the project is to develop new methods for forecasting the daily gas demand from the National Transmission System. The development of new methods will directly improve the demand forecasts provided to the market and used in operational decision-making.**		
Expenditure for financial year	Internal £6k External £62k Total **£68k**	**Expenditure in previous (IFI) financial years**	**Internal £7** **External £101** **Total £108**
Total project costs **(collaborative + external + NG)**	**£296k**	**Projected 2013/14 costs for National Grid**	**£120k**
Technological area and/or issue addressed by project	**National Grid Transmission forecasts the national gas demand for each day over a range of timescales, from a week ahead to within the day, and publishes forecasts to the gas market. This includes the demand from distribution networks, power stations, industrial loads, storage sites and interconnectors.** **Current systems calculate demand forecasts using a "bottom-up" approach, by combining forecasts for individual elements, using regression techniques. The model is complicated and results do not deliver agreed levels of reliability. An extra forecast is done a day ahead using a spreadsheet model; largely based on a "top-down" forecast of the total demand, also using regression, which gives a more accurate prediction. These are used as the basis for the forecasts published and used by the Gas National Control Room.** **This project investigates using local predictor techniques, which automatically identify similar days in history to the forecast day, to make a top-down forecast of total demand. This is a different approach to the fixed regression formula currently used, and initial tests have indicated a significant increase in accuracy over the current models.**		
Type(s) of innovation involved	Technology Transfer	**Project Benefits Rating** 13	**Project Residual Risk** -4	**Overall Project Score** **17**
Expected benefits of project	**National Grid's published demand forecasts ahead of the day are used by the market to aid trading and operational decisions in balancing supply and demand on the day. This work is likely lead to better information provided to National Grid's customers in the gas industry, and potentially reduces gas price distortions.**		

Expected timescale of project	3.5 years	**Duration of benefit once achieved**	**5 years**
Probability of success	60%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£1,069k**
Potential for achieving expected benefits	**There remains good potential for the benefits to be realised. Demand forecasting continues to be challenging, however, this body of work is already revealing the relative merits of different model refinements and input drivers. Provided knowledge transfer is made, and a prototype tool implemented, it is expected that the benefits can be achieved.**		

Project progress

[Year to End of March 2013]

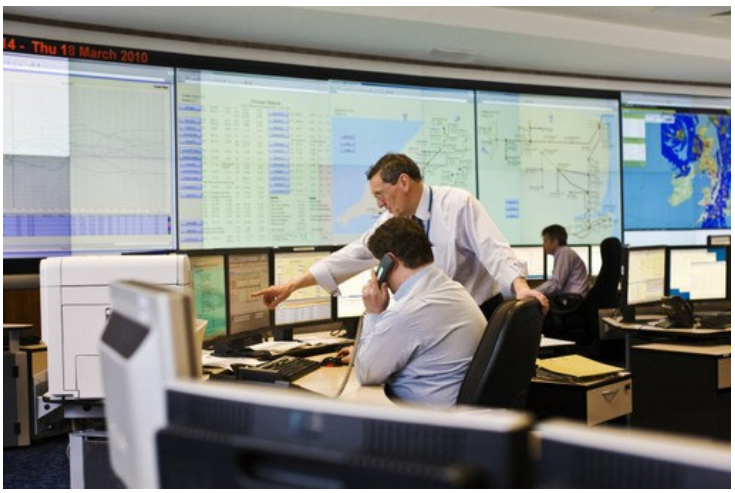


Figure 1 - Trialling new methods of forecasting

Work in 2012/13 initially focussed on improving the weather-based local predictor model for day-ahead demand forecasting. The accuracy of the model, comprising three models dependent on the day of the week, continued to be better than current methods.

Two improvements were investigated.

1. **Gas market prices were introduced as an input in order to model the commercially driven component of interconnector demand. Historical analysis indicated a small increase in overall accuracy was achievable**
2. **The local search algorithm was refined using a method of removing "false neighbours". Historical analysis has indicated significant improvement**

Following the positive outcomes of the project to date, and based on the potential for similar further improvements, this project was extended for a further two years. Demand forecasting continues to be more challenging, therefore a refinement called the promising "false-neighbour" was built into a live trial that was run in late Autumn and early Winter. This trial demonstrated the worth of the model which continued to be run daily while analysis focussed on a new area of demand forecasting on earlier timescales several days ahead of the gas day.

Research showed the multiple model approach identified for day-ahead

	timescales wasn't optimal for earlier forecasts. In response, a single model, including the "false neighbour" refinement of local search, was found to give the best results based on historical data. Again, the merit of the approach was tested in a live trial; creating forecasts every day using only data available at the time. Results showed reasonable accuracy in the near term but with performance tailing off with longer forecasting timescales. The next phase will seek performance improvements through additional inputs.
Collaborative partners	**None**
R&D provider	**Liverpool University**

Project title	2050 Energy Infrastructure Outlook
Project Engineer	David Fidler
Description of project	This Project will deliver data for the UK on different types of fixed energy infrastructure from now until 2050. The cost and performance data will enable evaluation of different energy scenarios as well as allow for the option of undertaking optimisation analysis. The Project will gather cost and performance data on different types of infrastructure associated with specific energy vectors. The energy vectors under consideration are: • Electricity • Gas • Hydrogen • Heat The degree to which the above parameters can change due to the impact of certain variations will also be captured by this project. The variations in question are: Time – this will provide the variation in the above parameters every 5 years from 2010 – 2050, i.e. 2010 (historic), 2015, 2020, 2025, 2030, 2035, 2040, 2045 and 2050. All cost data will be in real terms relative to 2010. Distance or scale – will provide a measure of the variation in the parameters as a result of distance or scale. A variation in terms of distance is relevant only for transmission and distribution infrastructure, whilst a variation in terms of scale is only relevant for storage. If appropriate, scaling factors are sufficient to represent these variations. Variations to conversions and connections are excluded from this. Overall volume of deployment – the variation in the parameters in relation to the level of overall deployment of the infrastructure, e.g. the variation in cost through economies of scale. UK region – how the parameters would vary within different parts of the UK. Twelve onshore regions are specified (East, East Midlands, London, North East, North West, Northern Ireland, Scotland, South East, South West, Wales, West Midlands and Yorkshire & Humber) as well as nine offshore

<table>
<tr><td></td><td colspan="4">regions for transmission (Channel Islands, Dogger Bank, East Scotland, Hebrides, Irish Sea, Lundy, Norfolk, Pentland, Shetlands) and two regions for offshore storage (North Sea and Humber).</td></tr>
<tr><td>Expenditure for financial year 12/13</td><td>Internal £1k
External £8k
Total £9k</td><td colspan="2">Expenditure in previous (IFI) financial years</td><td>Internal £0k
External £0k
Total £0k</td></tr>
<tr><td>Total project costs (collaborative + external + NG)</td><td>£9k</td><td colspan="2">Projected 2013/14 costs</td><td>£9k</td></tr>
<tr><td>Technological area and/or issue addressed by project</td><td colspan="4">Develop a data set for future project use that will be consistent with DECC, the Energy Technology Institute (ETI) and other ETI members (E.ON, EDF, BP, Shell, DECC, Defra, etc)

Outlook scenarios that provide an overview of timescales of infrastructure deployment – this would indicate the costs and timing of alternative infrastructure to gas networks and inform the business to the realistic long-term transition required to switch from gas heating to other networked heating solutions.</td></tr>
<tr><td>Type(s) of innovation involved</td><td>Incremental</td><td>Project Benefits Rating</td><td>Project Residual Risk</td><td>Overall Project Score</td></tr>
<tr><td></td><td></td><td>5</td><td>-3</td><td>8</td></tr>
<tr><td>Expected benefits of project</td><td colspan="4">This project will lead to an improved knowledge of other network infrastructure – hydrogen, District Heat, electric -, increase the understanding of infrastructure deployment capabilities and overall cost constraints

It will work towards the determination of policy changes needed to transition / identify which milestones are indicative of strategic change,</td></tr>
<tr><td>Expected timescale of project</td><td>5 years</td><td colspan="2">Duration of benefit once achieved</td><td>ongoing</td></tr>
<tr><td>Probability of success</td><td>40%</td><td colspan="2">Project NPV = (PV benefits – PV costs) x probability</td><td>-23,226</td></tr>
</table>

	of success
Potential for achieving expected benefits	**There is a medium-low likelihood of success of achieving expected benefits due to the fact that commercially sensitive information would be required to realise the expected benefit of the project. However due to licence conditions, information in the public domain has had to be used reducing the expected benefits.**
Project progress **[Year to End of March 2013]**	**Four reports have been issued throughout the year outlining the progress of the project, the last one being titled "IWP4 Final Submission" March 2013, the report was submitted in full but there has been some difficulty in obtaining data on Hydrogen networks which is still outstanding from the original scope.** **The tool for calculating the cost of networks has been created but not validated. The approach is a simplified version of the network which has some regionally variations in costs but does not take into considerations for MVARS or the equipment required to operate the Electricity system as this requires complex system modelling.** **National Grid will continue to work with BuroHappold and the ETI to check and validate the tool through a series of tests yet to be determined in the upcoming year.**
Collaborative partners	**National Grid Electricity Transmission, National Grid Gas Transmission**
R&D provider	**ETI, Buro Happold, University of Cambridge and Cryil Sweett.**

Project title	Research into Requirements for Gaseous Phase CO_2 Transmission		
Project Engineer	**Russell Cooper**		
Description of project	**National Grid is considering the change of use of existing natural gas National Transmission System (NTS) transmission pipelines so that they can be capable of transporting anthropogenic Carbon Dioxide (CO_2) from large industrial emitters, such as power stations, to a location where the CO_2 can be safely stored. This will require full demonstration, through preparation of a safety justification that the activity can be carried out safely.** **The project involves a range of research and development activities to be undertaken in order that a robust safety justification for the design and operation of gaseous phase CO_2 pipelines can be prepared.**		
Expenditure for financial year	Internal £15k External £425k Total **£440k**	**Expenditure in previous (IFI) financial years**	**Internal £68k** **External £2,187k** **Total £2,255k**
Total project costs (collaborative + external + NG)	**£2,696k**	**Projected 2012/13 costs for NG**	**£0k**
Technological area and/or issue addressed by project	**CO_2 poses potential safety risks to people and the complex phase characteristics of the fluid require specialist modelling to assess the hydraulic behaviour on pipeline design and operation.** **The nature of pure CO_2 changes from the gaseous condition to a dense phase condition at the critical point. In the gaseous phase, CO_2 behaves as a heavy gas, but in the dense phase, the "*fluid*" has the viscosity of a gas and the density of a liquid. While transportation of dense phase CO_2 offers efficiencies due to the properties of the fluid, National Grid's immediate interests are in the transportation of gaseous phase CO_2.** **The heavy gas behaviour of the gaseous phase CO_2 affects the dispersion of the gas and therefore the distances over which it disperses pose a hazard to people. Anthropogenic CO_2 contains impurities, and the effects of these impurities on the phase boundary, hydraulic behaviour, hazard distance and pipe integrity need to be investigated and understood in order that pipeline design and pipeline operation can be carried out safely.**		
Type(s) of innovation involved	Radical	**Project Benefits Rating** 19	**Project Residual Risk** 5	**Overall Project Score** **14**

Expected benefits of project	**This research provides a benefit to gas consumers as it enables CO_2 networks to be developed through the reuse of existing natural gas pipeline assets.** **This change of use will enable natural gas consumers to be protected against the decommissioning costs and associated liabilities that would otherwise be required if a natural gas pipeline is no longer required for natural gas transmission. Further value can be captured for gas consumers by reusing existing pipelines for other applications. The value in question may well be underpinned by calculations of residual asset value.** **Wider energy consumers, including electricity consumers, stand to benefit if the research enables the development of CO_2 networks to support carbon capture from coal fired generators.** **It is possible that without this technology there will be a much diminished role for coal in the UK energy mix, leading potentially to higher electricity prices and an impaired outlook for electricity security of supply.** **Consumers will also benefit from the clear environmental benefits that will be delivered to the UK through the effective mitigation of CO_2 emissions.** **The UK Government and European Union both believe that Carbon Capture and Storage (CCS) present an important opportunity for reducing CO_2 emissions.** **This research can be aligned with the environmental policies of both national and supra-national bodies, potentially presenting real opportunities to re-deploy existing natural gas assets efficiently in the service of mitigating climate change.**		
Expected timescale of project	5 years	**Duration of benefit once achieved**	**Lifetime**
Probability of success	30%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£2,816k**
Potential for achieving expected benefits	**Benefit potentials remain good:** **CO_2 transportation through pipelines has been in operation in the United States since the 1970's. These activities have been mainly focussed on the transport of naturally occurring CO_2 from the source to various oil fields for the purposes of delivering Enhanced Oil Recovery (EOR). It is noted though that the CO_2 pipelines in the United States are laid in remote areas and very little research work has been carried out relating to the safety aspects of pipeline operation. However, the knowledge that these pipelines exist and have been in operation for a substantial period of time provides a high degree of confidence that a successful CO_2 transportation network can be developed in Europe.** **Similar Research and Development (R&D) work was carried out for natural gas in the 1970s and 1980s and forms the basis of the safety justification for National Grid's high pressure natural gas transmission network. The results of the work are not directly relevant to the transportation of CO_2, but**		

	the logic applied and learning obtained will be applied as appropriate assisting in minimising timescales by the application of "*lessons learnt*". **National Grid is utilising a range of service providers who have a wealth of experience with this type of R&D work and knowledge of CO_2 systems, therefore increasing confidence in success.** **Progress to date has been good for the R&D work and National Grid continues to monitor and review the R&D programme.**
Project progress [Year to End of March 2013]	**Progress Summary** **Coal will continue to provide a significant percentage of the electricity generated in the UK and around the world as it is reliable, low cost, there are abundant reserves available and coal fired generation can easily respond to fluctuations in energy demand. However, coal is also the fuel with the highest carbon emissions and generates significant quantities of CO_2.** **The use of CCS has the potential to reduce CO_2 emissions from fossil fuel power stations by up to 90%.** **The Government believes that CCS is an important way of reducing CO_2 emissions given that a significant proportion of the increase in world energy demand is expected to be met by fossil fuels, in particular from coal. CCS can help to meet the UK's increasing energy needs whilst maintaining the security of the energy supply by making coal a more viable option, and assists in reducing dependence on natural gas imports.** **CCS is a critical part of the UK's decarbonisation strategy and it facilitates the transition to a low carbon economy.** **Ongoing R&D work develops upon previous work and continues to develop information on CO_2 systems. Knowledge gaps are being investigated whilst facilitating the implementation of CCS through the utilisation of existing pipeline assets which supports the Government's objectives.** **R&D work conducted for gaseous phase CO_2 covered the following four main work areas:** **A. Corrosion testing utilising gaseous phase CO_2.** **B. Venting of gaseous phase CO_2.** **C. Dispersion of gaseous phase CO_2 from craters.** **D. Metering.** **A - Corrosion testing utilising gaseous phase CO_2** **A1 Introduction** **MACAW Engineering Limited previously conducted a series of tests for National Grid to assess the corrosion potential of transporting anthropogenic CO_2 gas mixtures from industrial emitters in carbon steel pipelines.** **The current work expands and develops the test work previously conducted and has the objective of assessing potential corrosion rates in conventional**

pipeline materials which could result from an unintentional release of water into a pipeline transporting gaseous phase anthropogenic CO_2.

The work is split into the following four main tasks:

1. **Task 1 - Modify the existing test rig MACAW have to demonstrate the corrosion rates obtained in test work conducted by MACAW's correlate with published test results.**
2. **Task 2 - Conduct a literature review of all available published data on corrosion in CO_2 pipelines.**
3. **Task 3 - Using a gas mixture, derived from the National Grid worst case pipeline transportation specification, investigate the corrosion mechanisms and rates over short durations using different linepipe materials.**
4. **Task 4 - Conduct an additional test matrix (similar to Task 3) including further testing to cover different operational scenarios and different gas mixes based on the findings of Task 3.**

The following sections provide further information on each of the tasks.

A2 Task 1

The objective was to demonstrate that the MACAW test facility can replicate the results of published data. In particular, the tests carried out by Yoon-Seok Choi and Srdjan Nesic in their paper "*Determining the corrosive potential of CO_2 transport pipeline in high pressure CO_2 water environments*".

Corrosion test weight loss coupons after 24 hour exposure

Task 1 has been completed and concluded:

- **MACAW Engineering's test rig produces results similar to those published by Choi and Nesic. However, it is not possible to replicate the results exactly, due to the published papers not providing sufficient details on all of the test parameters. (Noting that most published data in this area do not fully detail the test parameters. As a result, it is difficult to replicate the results of experimental work**

precisely.)

- The tests also confirmed that higher corrosion rates were observed in the CO_2 saturated water solution than in the water saturated gaseous CO_2 phase.

A3 Task 2

The review considered published papers, conference proceedings and relevant standards. The review also discussed how published data compared with the testing which has already been conducted and advised on what further work is required to understand corrosion risks to pipelines from the transportation of anthropogenic CO_2 in both the gaseous and dense phase.

The review considered experimental techniques used in published work when testing with CO_2 and gave recommendations on what techniques are the most suitable for the purposes of assessing the corrosion in CO_2 pipelines.

Task 2 has been completed and the literature review concluded:

- Negligible corrosion rates are expected in CO2 free of impurities as long as water remains dissolved in the CO2 fluid.
- In the presence of impurities water solubility in CO2 can be lowered and corrosion may occur.
- In high pressure CO2 environments, it has been clearly confirmed that carbon steel materials exposed to free liquid water will suffer high sweet corrosion rates. However, there are clear discrepancies between the different corrosion rates reported and, equally significant, the trend of corrosion rates with CO2 pressure has not been found to be consistent. Confidence in data can only be achieved if the test procedure and parameters are clearly documented and sufficient tests are carried out to demonstrate repeatability.
- In the presence of impurities, corrosion in pipelines in the presence of an aqueous phase will be dependent on the types of impurities and their concentration in the CO2 stream and on the partitioning behaviour of these impurities between the different CO2 and water phases.
- Corrosion inhibitor injection could prove to be beneficial when water is present in the pipeline at high CO2 pressures but further testing is required.
- At high CO2 pressures, high grade stainless steels may be satisfactory for service, even in the presence of free liquid water at temperatures below 30 degrees Celsius. The effect of impurities remains to be tested.

A4 Task 3

It is believed that the gas components that would have the greatest effect on corrosion were CO2, Nitrogen Dioxide (NO2) and Sulphur Dioxide (SO2). Therefore the following four test gas compositions were considered and tested to evaluate their effects on the corrosion mechanisms:

- Pure CO_2.
- CO_2 + NO_2.

- **CO_2 + SO_2.**
- **CO_2 + NO_2 + SO_2.**

The corrosion mechanisms observed during the earlier test work showed sensitivity to the steel's microstructure. So the testing includes three different types of materials to understand the effect that microstructure sensitive corrosion has on corrosion rates.

The tests were carried out on material from an existing high pressure natural gas pipeline (constructed circa 1975), material that is representative of a new section of pipeline and material from an existing older pipeline system (material from around the 1968 era).

Figure 3 Test Cells located inside the incubator

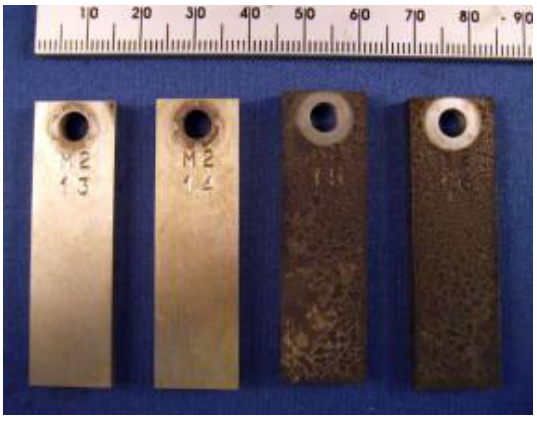


Figure 4 Test 4, Test Cell A, CO_2 + 100ppm vol. SO_2, weight loss coupon after testing prior to cleaning

The key conclusions from Task 3 are:

- **Small additions of NO2 appear to only have a small effect on corrosion rates, typical values in the CO2 saturated water solution are 3.36 to 7.45mm per year compared with 1.63 to 7.20mm/year (averaging 4.24mm/year) in a pure CO2 saturated water solution.**
- **Small additions of SO2 appear to increase corrosion rates to 5.6 to 8.3 mm/year compared with 1.63 to 7.20mm/year (averaging 4.24mm/year) in a pure CO2 saturated water solution.**
- **The higher corrosion rates for pure CO2 monitored in Task 1, 8.3 to 13.6mm/year, are considered consistent with the lower corrosion rates monitored in Task 3, 1.63 to 7.20mm/year (averaging 4.24mm/year), which were tested at a lower temperature and pressure.**
- **Corrosion in the water saturated gaseous phase is consistently 0.1 to 0.3mm/year for all gas mixtures and materials tested.**
- **The Task 3 test results indicate that variations between materials of similar grades and chemistries types are likely to be subtle.**
- **In tests where SO2 was present, a significant number (75%) of the weight loss coupons exposed in the CO2 saturated water produced low corrosion rates (below 1mm/year).**
- **In tests where SO2 and NO2 were present, all weight loss coupons exposed in the CO2 saturated water produced low corrosion rates (below 1mm/ year).**
- **No significant difference was observed between pre saturating the solution at atmospheric pressure and at the test pressure.**

A5 Task 4

This was additional test work (similar in nature to Task 3) to consider new operational scenarios and different gas mixes. The objective of Task 4 was to assess potential corrosion rates in convention pipeline materials, i.e. low carbon manganese steel, which could result from an unintentional release of water into a pipeline transporting gaseous phase anthropogenic CO2. This was to be achieved by investigating the effect that small additions of impurities would have on corrosion rates on different pipeline materials. The impurities considered were Sulphur Dioxide (SO2) and Nitrogen Dioxide (NO2).

The gas mixtures tested were:

- **Pure CO_2.**
- **CO_2 + 1000ppm vol. SO_2.**
- **CO_2 + 1000ppm vol. NO_2.**

Figure 5 Weight loss coupon prior to testing

The results for Task 4 are currently being assessed, however the initial conclusions are as follows:

- **Weight loss coupons tested in a CO2 saturated + 1000ppm vol. SO2 water solution produced low corrosion rates ranging between 0.33 to 3.24mm per year at 30°C and 1.44 to 4.59mm per year at 50°C.**
- **Weight loss coupons tested in a CO2 saturated + 1000ppm vol. NO2 water solution produced low corrosion rates ranging between 0.02 to 0.75mm per year at 30°C.**
- **Weight loss coupons tested in a pure CO2 saturated water solution at 30°C and 34 barg produced corrosion ranging between 4.23 to 5.00mm per year. Tests performed at 40°C and 50°C did not show any significant change to corrosion rates, ranging between 1.22 to 6.13 and 3.31 to 8.15mm per year respectively.**
- **Weight loss coupons tested in a pure CO2 saturated water solution at 50°C and 40 barg did show an increase of corrosion rates, ranging between 4.65 to 6.67 mm per year.**
- **A large amount of localised corrosion pitting has been observed on Weight loss coupons exposed to a CO2 saturated + 1000ppm vol. SO2 water solution, with some pit rates over 20mm per year being recorded in several locations. Weight loss coupons exposed to pure CO2 and CO2 saturated + 1000ppm vol. NO2 produced far fewer corrosion pits.**

B - Venting of gaseous phase CO2

B1 Introduction

As part of its ongoing research programme into the behaviour of CO2, National Grid commissioned a series of experiments to vent CO2 from a storage vessel to the atmosphere. In order to carry out the programme of work, two separate test arrangements were constructed using existing test rigs in order to reduce costs and minimise timescales. One test arrangement examined a release at a steady rate through a vertically upwards pointing vent and the second examined the gradual venting of a section of pipeline through a smaller diameter horizontal vent.

The purpose of the experiments were to obtain data on the dispersion of the releases in the atmosphere and to record the changing conditions in the CO2 vessel or the section of pipeline during the venting process. The work carried out in this study examined the data collected during the experiments to seek out trends in the data and compared the behaviour of CO2 during the experiments with pragmatic models of the type typically used in carrying out risk assessments. This study has been completed.

B2 Findings

In particular, the temperature, pressure and changes of phase that occurred as the CO2 depressurised on approach to the vent exit were examined and the outflow rate was compared with predictions.

The measurements of the temperature within the first 5 meters of the atmospheric plume formed by the vertical vent were analysed and it was

shown that a consistent set of data had been obtained, with the results following the expectations for a jet like flow.

The trajectory of the plume was compared with the predictions of a dispersion model. It was noted in the experiments that, unlike some of the views that had been expressed prior to the experiments, no CO2 was observed to 'rain out' of the plume close to the source and in many of the experiments, the plume dispersed entirely whilst above ground level.

The influence of wind speed and mass flow rate on trajectory was examined and it was noted that the concentrations that were recorded downwind of the release close to the ground were always below the level that would cause immediate harm to people. Interestingly, the experiments revealed that large differences in behaviour were produced depending on whether the venting took place from the bottom or top of the length of horizontal pipework.

The information obtained should help in the safe design and conduct of any venting operations.

B3 Knowledge sharing

Reference has been made to the work in a paper presented by GLND at the 23rd Hazards international symposium arranged by the Institution of Chemical Engineers (I.Chem.E.) in November 2012.

C - Dispersion of gaseous phase CO2 from craters

C1 Introduction

This work area incorporates a full scale puncture and a scaled rupture test using gaseous phase CO2. The puncture test was successfully completed on Friday 4th November 2011 and the rupture test on Thursday 28th March 2013.

In order to reduce costs and minimise timescales, test arrangements incorporated in another National Grid research programme were utilised.

C2 Puncture test work

There have been many studies carried out to understand how a puncture of a buried natural gas transmission pipeline would behave. However, there is no similar, reported work on how a puncture in a gaseous phase CO2 pipeline would behave. Hence, an experiment was carried out at full scale in order to observe the behaviour and to collect data that would be of use in the development or validation of mathematical models for gas outflow and dispersion.

An existing section of buried, instrumented, 914 mm outside diameter pipeline was used to provide a source for the release. The pipeline was fitted with a 50.8 mm diameter bursting disk that was selected to fail when the pressure was raised above about 35 barg.

The bursting disk was located in a horizontal position, on the side of the buried pipe, simulating a release from a puncture at this location. The

pressure and temperature of the CO2 in the vessel were monitored, as was the temperature on the walls of the pipeline, especially close to the point of release. The release was allowed to form its own pathway through the surrounding soil to the surface. The dispersion in the atmosphere of the resulting CO2 cloud was monitored using an array of oxygen cells, located close to ground level in the nominal downwind direction.

Video records of the cloud that was formed were taken. In addition, temperature measurements were taken alongside the oxygen cells. The ambient wind speed and direction, atmospheric humidity and temperature were all logged during the experiment.

C2.1 Findings

The observations showed that an open crater was not formed by this below ground release. Rather, the soil surface rose up slightly ('up-welling') and the ground surface was cracked in numerous places. Evidence was found for a number of 'blow holes' in the soil, through which the CO2 flow made its way to the atmosphere. The equivalent free area of the 'blow holes' was measured and found to be approximately 2.4 m2.

The plume that was formed by the releases through the 'blow holes' was observed to return to close to ground level and subsequently dispersed downwind under the influence of the wind. The maximum value of the recorded CO2 concentration, using 5 second moving averages, on each downwind arc has been plotted against the downwind and statistics on how the concentration varies with time have been obtained.

The experiment gave direct evidence of the importance at full scale of the source conditions, the density of the release in determining the dispersion behaviour and the results compared with the predictions of a number of mathematical models, to help improve the risk assessments for such releases.

C2.2 Knowledge sharing

Reference has been made to this test work in a paper presented by GLND at the 23rd Hazards international symposium arranged by the Institution of Chemical Engineers (I.Chem.E.) in November 2012.

C3 Rupture test work

The experiment was carried out to study how a rupture in a below ground pipeline would behave. A length of 150 mm (6 inch) diameter pipeline was used as a 'test section'.

The section was joined by a flange connection to separate lengths of approximately horizontal pipeline of 150 mm (6 inch) diameter. The 150 mm (6 inch) diameter pipelines were then connected to reservoirs which had previously been used in two fracture propagation experiments for National Grid.

The test section was buried at a depth of 0.3 m to the top of the pipe, simulating a length of a 610 mm (24 inch) outside diameter pipeline at a reduced scale of approximately 1 to 4.

The reservoirs and connecting pipework, including the rupture section,

were filled with gaseous phase CO2. The central part of the test section was fitted externally with an explosive charge. Once the desired pressure and temperature had been achieved in the test rig and the preparations completed, the explosive charge was fired to rupture the 150 mm (6 inch) diameter pipe, opening it out horizontally along a 3 m length, leaving two opposed, full bore, open pipe ends.

Initially, this produced a rapidly decaying release as the gas in the pipeline depressurised, followed by a more slowly decaying period as the reservoirs depressurised. The central pipeline and the reservoirs were monitored to record the fluid temperature and pressure, as well as selected external wall temperatures. Oxygen cells were set out in an array close to ground level around and nominally downwind of the test section to detect any presence of CO2 in a dispersing cloud.

The atmospheric conditions were monitored immediately before and during the release. Fluid pressure and temperatures were recorded along the length of the 150 mm (6 inch) diameter pipeline sections as well as pipe wall surface temperatures.

C3.1 Findings

The temperature and pressure of the fluid in the pipeline fell rapidly immediately following the start of the release (first one or two seconds). This was followed by a period in which they partially recovered until about 5 seconds. After this time, the pressure and temperature both fall more slowly in the pipeline as the fluid expands and is accelerated towards the open ends of the pipe, as the pipeline continues to depressurise.

his occurs during the first 60 seconds in the western end and 120 seconds in the eastern end as the CO2 expands and flows towards the open ends of the ruptured pipe.

Although the pressure continues to fall throughout the pipe, there is some temperature recovery after this time when the majority of the pressure drop has occurred, with a more marked change in temperature seen on the western end than the eastern end. This is because the positive heat transfer from the pipe wall to the fluid becomes apparent, as the fluid warms up over the next 200 seconds.

Analysis of the concentration data shows that the CO2 is first detected some 200m downwind at about 33 seconds to 50 seconds after the release starts, corresponding to a mean cloud speed of about 6.6 m/s to 4 m/s in the downwind direction, compared with an average wind speed prior to the test of about 5 m/s at the 5m elevation.

This suggests that the CO2 cloud moved downwind at about the average local wind speed, in agreement with the modelling assumptions made to date.

The earlier detection times suggest parts of the CO2 cloud moved more quickly, perhaps because the plume has risen to such a height that it has entrained air that is moving downwind more quickly, causing the plume to move more quickly in that direction after it had returned to ground level. The size and shape of the crater formed immediately after the release commenced was recorded.

In conclusion, the experiment has provided valuable information on the behaviour of a different release type (rupture) to extend the available database on gaseous phase releases.

D - Metering

D1 Introduction

For the development of CCS it is important to understand the unique properties and characteristics of CO2 rich mixtures and the impacts they have on flow metering systems. In addition to determining the feasibility, CO2 metering must also satisfy the same standards of uncertainty and error as natural gas applications however the challenges are very different. These include working at higher and lower pressures, avoiding the two phase and critical regions of the phase diagram, using different sampling and analysis systems and the selection of the most reliable equations of state.

In November 2011 National Grid employed the services of TUV SUD NEL Limited (NEL) and Germanischer Lloyd Noble Denton (GLND) to carry out a programme of work to investigate and overcome the challenges of CO2 flow metering.

D2 Metering of CO2 - Work Packages

This work area was led by NEL who develop and maintain part of the National Measurement System on behalf of the UK National Measurement Office. NEL is a global centre of excellence for flow measurement and fluid flow systems and was therefore very well placed to lead this programme of work for National Grid.

GLND provide technical consultancy to National Grid on custody transfer metering both in their transmission and distribution businesses; this includes meter design, validations, procedures, meter error reporting as well as uncertainty and error calculations to ensure metering compliance with contractual obligations.

This joint NEL/GLND proposal develops further work previously conducted by GLND on metering for National Grid and draws on the strengths of both providers.

This work area is split into the following Work Packages:

1. **Work Package 1 - Flow meter testing.**
2. **Work Package 2 - Orifice plate diagnostic systems.**
3. **Work Package 3 - Equations of state.**
4. **Work Package 4 - Sampler and chromatograph testing.**
5. **Work Package 5 - Project management.**

Further information on each of the Work Packages is detailed below.

D3 Work Package 1: Flow meter testing

Work package 1 was formulated to investigate the performance of various types of flow meters in gaseous phase CO2 specifically orifice plate, Coriolis and ultrasonic meter technologies.

The tests were carried out in the NEL gas flow calibration loop. This calibration loop is normally configured for the calibration and testing of dry and wet gas flow meters using nitrogen as the test gas and, for wet gas testing, water or kerosene as the liquid.

The loop is constructed to operate at pressures of up to 60 bar. Test meters are normally tested using a reference ultrasonic meter which, like all the other instrumentation, is calibrated and traceable to national standards. For this project a calibrated orifice plate was used as the 'nominal' reference device.

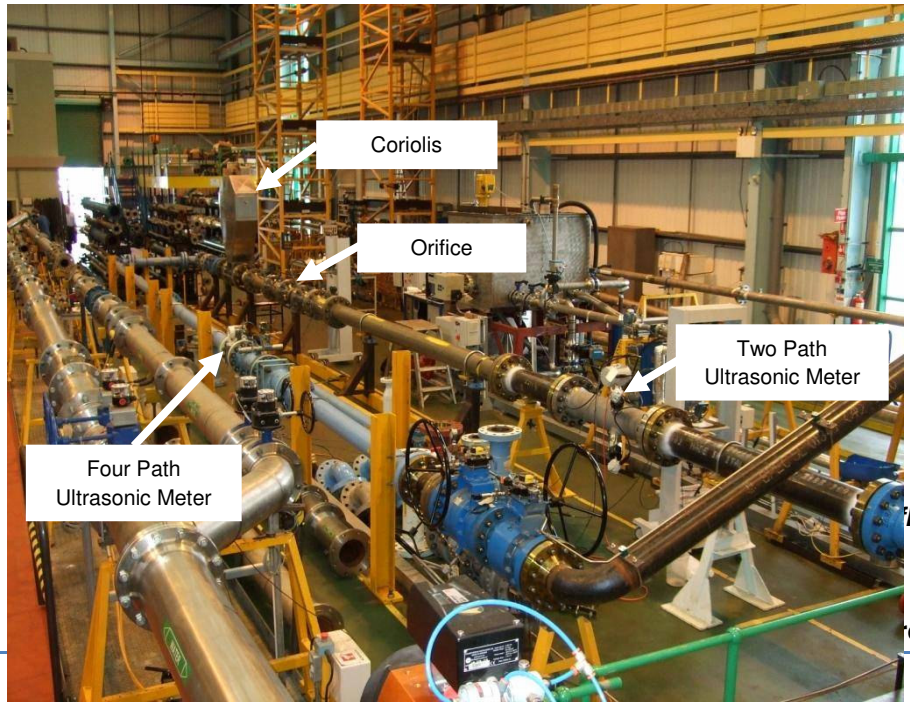
Comparative tests of a 150 mm (6 inch) diameter, four-path ultrasonic meter, a 200 mm (8 inch) diameter, two-path ultrasonic meter and a 200 mm (8 inch) diameter Coriolis meter were carried out using gaseous phase CO2 as the fluid. A 200 mm (8 inch) diameter orifice plate assembly, with a beta ratio of 0.4, was used as the reference meter.

The ultrasonic meters were provided on loan to NEL and were fitted with transducers chosen to operate at frequencies reducing the absorption of ultrasound in gaseous phase CO2. The Coriolis meter was on loan from National Grid and had previously been used in the measurement of high pressure, liquid phase CO2. The orifice plate was manufactured and fitted to be fully compliant with ISO 5167.

The assembly was calibrated in water using the NEL water flow test facilities. Flange tappings, with additional downstream tappings for diagnostics, were utilised.

The test loop was filled with nitrogen, evacuated and then filled with CO2 giving an estimated composition of 99.6% CO2 by mol. Testing was carried out at 20 barg and 15 barg with additional test points at 12 barg.

Figure 6 shows a photograph of the NEL gaseous phase flow loop which contains the orifice plate, Coriolis and ultrasonic flow metering systems. The CO2 in the flow loop flows in an anti clockwise direction.



low

round

0.2% lower than the orifice plate reference meter, linearity with ±0.1% and repeatability within ±0.05%.

The two-path ultrasonic meter did not perform as well as the other ultrasonic meter with linearity of 1.5% and repeatability of up to ±0.2%.

The Coriolis meter was purchased by National Grid for monitoring the flow rate of high pressure, liquid phase CO2 on some other test work. It was decided to make the meter available for testing in low pressure, gaseous phase CO2 to evaluate the operational range despite it being oversized for these particular operating conditions. The Coriolis meter did operate across most of the flow range although, as expected from a 200 mm (8 inch) diameter meter, it was rather non-linear.

At the lower pressures it stopped working at the lowest flow rates as the meter was oversized for the duty. The meter had been designed to measure high pressure, liquid phase CO2 therefore the piping within the Coriolis meter was thicker than required for lower pressure applications. Unfortunately this meant that the flow meter was less sensitive since the Coriolis forces that occur at the lower flow rates were not detected leading to higher errors than expected. Had a Coriolis meter designed to operate under these test conditions been used, it would have performed better.

D4 Work Package 2: Orifice plate diagnostic systems

Ultrasonic meters, unlike orifice plate metering systems, have a continuous diagnostic monitoring system which, if used correctly, provides a reduction in measurement risk, an increase in recalibration intervals and a reduction in operational costs. This feature gives ultrasonic meters an advantage over orifice plates however for a variety of operational and technical reasons, orifice plates still provide the first choice meter for CCS metering arrangements.

Work Package 2 looked to test the performance of a commercially available monitoring system which recently came onto the market that allows condition monitoring to be undertaken on differential pressure meters such as orifice plates. The system was developed by utilising a third tapping downstream of the meter body to read three differential pressure measurements (reference Figure 7) to determine the uncertainty of the meter.

Testing of the diagnostic system was conducted to see if it was capable of reducing measurement risk for differential pressure meters and improve confidence in their performance in CO2 and natural gas applications.

Orifice Plate

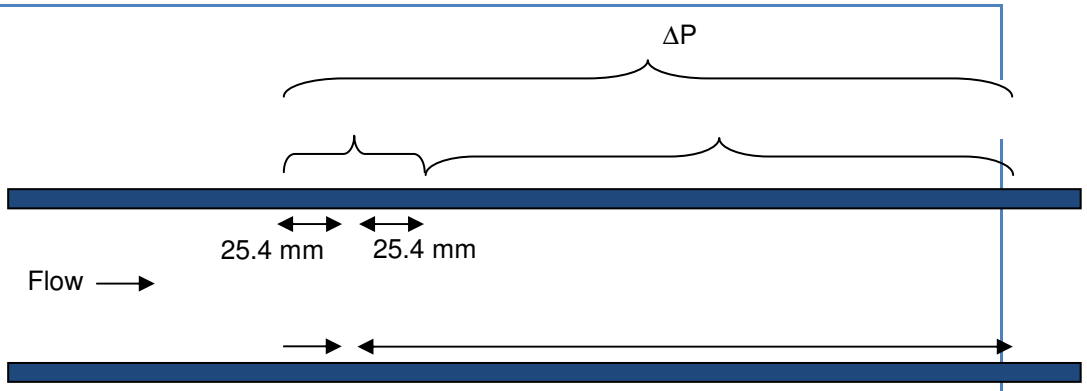


Figure 7 Arrangement of the pressure tappings for the diagnostic system

From these measurements three diagnostic ratios are computed:

1. **Pressure Loss Ratio (PLR) = Ratio of PL to ΔP.**
2. **Pressure Recovery Ratio (PRR) = Ratio of PR to ΔP.**
3. **Pressure Recovery to Pressure Loss (PRL) = Ratio of PR to PL.**

The aim of the test work was to:

- **Study the theoretical basis and the potential capabilities of the system;**
- **Examine the sensitivity to disturbances to flow conditions which may occur in pipeline transportation; and**
- **Investigate potential additional functionality of the diagnostic system to meet National Grid's requirements.**

An orifice plate metering stream fitted with the diagnostic system was inserted into NEL's water flow loop. The system was then tested in normal flow conditions and with a series of fault conditions such as:

- **An error in orifice plate or pipe diameter.**
- **A drift in the differential pressure transmitter.**
- **An incorrectly positioned orifice plate.**
- **A rounded orifice plate edge.**
- **A drain hole present but not included in the calculation.**
- **A deposit on the upstream face of the orifice plate (simulating face contamination).**
- **Two-phase flow (with bubbles added to the water).**
- **The orifice plate installed backwards.**
- **Downstream of a partially closed gate valve (simulating a partially blocked flow conditioner).**
- **A buckled orifice plate.**

Based on differential pressure readings the diagnostic system identifies when the flow rate error exceeds the limit specified by the user. The limit is denoted by a green box as shown in Figure 8. The system has proven to

alert the operator of most common metering issues causing the meter to produce an error of 1% or more in the resultant flow measurement.

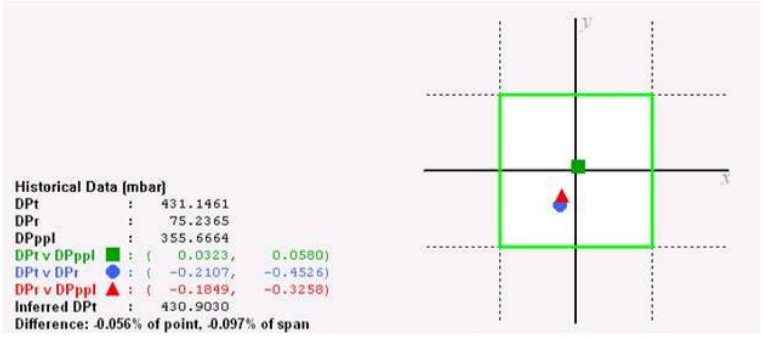


Figure 8 Output from the diagnostic system showing the flow rate uncertainty limit (green box) and the measured differential pressure readings from the flange tappings

The work in this project has shown that a diagnostic method using an additional downstream pressure tapping is feasible. The simple diagnostic of summing the measured pressure loss (PL) and the measured pressure recovery (PR) and comparing with the measured differential pressure (ΔP) seems to be surprisingly powerful.

D5 Work Package 3: Equations of state

For flow rates to be calculated certain properties of the fluid being transported are required such as density, viscosity, isentropic index etc. This information is supplied using an equation of state which provides the thermodynamic characteristics of fluids and fluid mixtures. Currently there is no commercially available equation of state specifically developed for CO2 rich mixtures.

Figure 9 compares the phase diagram of pure CO2 with the phase diagram of a CO2 rich mixture. Given the significant impact impurities have on the thermodynamic characteristics of the CO2 it is essential for the purposes of flow metering that an equation of state which accurately determines the fluid properties is used.

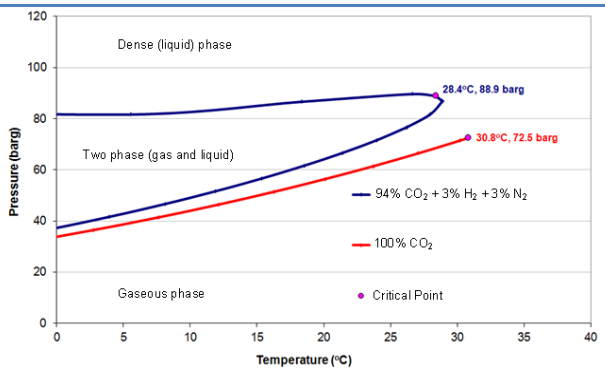


Figure 9 Phase diagram of pure CO_2 and a CO_2 rich mixture containing Hydrogen (H_2) and Nitrogen (N_2)

The aim of Work Package 3 was to ascertain which equation of state is most reliable and accurate for the metering of CO2 rich mixtures and for the calculation of 'line pack' in the pipeline system. This was achieved through:

- **An uncertainty sensitivity analysis on mass and volume flow calculations in gaseous and liquid phase CO2. This determines the uncertainty limits that any equation of state or other calculation procedure must achieve.**
- **Summarising current research knowledge (experimental data, model developments, research projects) relevant to equations of state for CO2 and CO2 mixtures.**
- **Assessing existing experimental data, and the suitability for inclusion, on CO2 and CO2 rich mixtures including the impact of any gaps on the accuracy of existing equations of state and the determination of density for metering.**
- **Investigating the use of simplified correlations for CO2 density calculations and verifying against the GLND GasVLe software package and the Physical Property Data Service (PPDS) software packages to assess their performance and determine valid operating limits.**

The findings from this work package are that the GERG-2008 equation of state is currently the best equation of state for high CO2 content mixtures although it was developed for natural gas applications and is not specifically designed for CCS. Work is on-going by Professors Wagner and Span at Ruhr University, Bochum, Germany (by Johannes Gernert and others) at improving GERG-2008 for use with CCS.

Experimental measurements of density in CO2 rich mixtures are in short supply. As these experiments are expensive and time consuming an alternative approach may be to use computer simulations. The major components expected to be present in the CCS stream are simple molecules and their intermolecular potential energy can be accurately estimated, and hence computer 'experiments' can be a reliable and a quick way to estimate mixture properties.

At present there is no known commercially available flow computer that implements the GERG-2008 equation of state although the equation is

available as a separate computer application. The NIST-14 equation of state that was developed in the 1980s for EOR applications is not currently supported or recommended by NIST for CCS although it is available in some flow computers.

D6 Work Package 4: Sampler and chromatograph testing

In order to obtain the necessary fluid properties from the equation of state and to ensure that the fluid being transported meets the pipeline entry specification quality requirements an accurate, continuous sampling and analysis system is required. Inaccurate measurement of the composition will lead directly to errors in the CO2 metering.

The aim of Work Package 4 was to examine the performance of a sampling system in the presence of CO2 and common contaminants at various pressures and temperatures across the range of conditions expected in the field.

For natural gas systems National Grid currently uses sampling systems and process gas chromatographs to determine the composition. Once the composition is known the volume and energy of natural gas is calculated. The sampling and analysis of CO2 for custody transfer CCS metering will present new challenges.

Any error in the analysis of the fluid composition could result in:

- **An error in determining the fluid properties leading to an error in the flow calculation.**
- **A CO2 mixture entering the transportation system which does not conform to the pipeline entry specification.**
- **Venting of CO2 to atmosphere.**

The sample extracted from the pipeline fluid will need to be depressurised to typically 2 bar before being analysed by a gas chromatograph. One of the key challenges with analysing CO_2 rich mixtures is developing a continuous sampling system that depressurises the fluid from a liquid to a gas without altering the composition of the fluid.

When crossing the liquid-gas phase boundary the more volatile constituents in the liquid (such as Nitrogen and Hydrogen) tend to evaporate quicker than the less volatile components. As a result the composition across the resulting gas mixture is inconsistent and not representative of the fluid being transported in the pipeline.

As part of this work package GLND facilitated the development of a sample probe that heats the CO2 rich mixture before depressurising it into a gas whilst avoiding the liquid-gas phase boundary. The sampling system is then able to supply a sample of CO2 to the gas chromatograph at the required pressure of 2 bar. As the phase boundary was avoided the composition of the gas sample is representative of the composition of the liquid in the pipeline.

The performance of the sample probe was validated at GLND's test facility

at Spadeadam using a small flow loop containing a mixture of CO2 and N2 (Figures 10 and 11). A more detailed test programme was then carried out in the static CO_2 test facility at NEL's premises in East Kilbride to test the sampling system with three known compositions containing CO_2 rich mixtures with common contaminants.

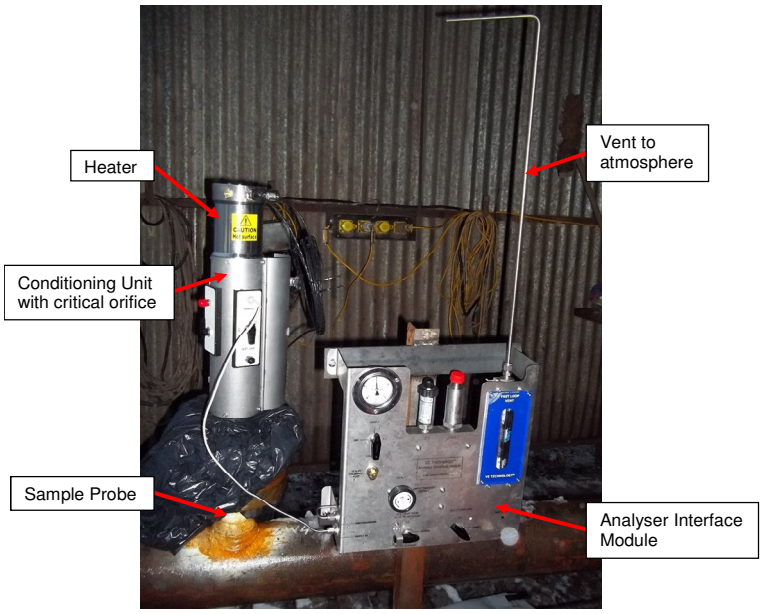


Figure 10 - the sample probe system being tested in the flow loop

Figure 11- the sample probe section which is inserted into the pipe

The sampling system was tested over a range of pressures and temperatures from 34 barg to 150 barg and from 5℃ to 40℃. This enabled test points to be taken in the gaseous and liquid phase regions. The samples were then analysed by gas chromatographs to see how well the readings compared with the actual compositions.

The agreement between the composition readings in the gas chromatographs and the actual composition was within 0.2% for the majority of the test points. The sampling system tested appears to be suitable for use within the CCS industry across the full range of conditions

	expected. The gas chromatographs tested also appear to be suitable for measuring common contaminants to an acceptable level of uncertainty. **D7 Work Package 5: Project management** **Throughout this programme of work NEL provided the project management service. This included the development of an extensive programme to deliver a series of work packages within the given budget and timescales, procuring the services of GLND and providing monthly progress updates to National Grid. Whenever any issues arose which impacted the timescales NEL were responsible for developing a programme of recovery to ensure the work would be completed on time.**
Collaborative partners	**None**
R&D provider	**GL Noble Denton (GLND), MACAW Engineering Limited, TUV SUD NEL Limited**

Project title	Leveraged International Research Programmes for Gas Pipelines and Above Ground Facilities		
Project Engineer	**Tony Stonehewer**		
Description of project	**Pipeline Research Council International (PRCI)** **The PRCI facilitates a collaborative R&D programme, with funding based on the total length of pipelines operated by each member company. This is a global organisation managed out of the USA with a combination of membership and associate membership from America, Europe, Asia and Australia. Each member company contributes to the projects that most closely address their needs, but all member companies have access to the output of the complete programme.** **European Pipeline Research Group (EPRG)** **EPRG is a cooperation of European pipe manufacturers and gas transmission companies. EPRG undertakes a wide range of research directed to increase integrity and safety of gas transmission pipelines.** **European Turbine Network (ETN)** **The European Turbine Network (ETN) is a non-profit European association which brings together the gas turbine technology community for power generation and mechanical drive applications in Europe, representing 79 members from 17 European countries.**		
Expenditure for financial year	Internal £25k External £189k Total **£214k**	**Expenditure in previous (IFI) financial years**	**Internal £60k** **External £247k** **Total £307k**
Total project costs (collaborative + external + NG)	**£2.7m**	**Projected 2013/14 costs for National Grid**	**£136k**
Technological area and/or issue addressed by project	**PRCI** **The PRCI aims to conduct a collaboratively-funded research & development programme that enables energy pipeline companies around the world to provide safe, reliable, environmentally compatible, cost-efficient service to meet customer energy requirements.** **The areas covered by the PRCI programme in the 2013 ballot that were supported by National Grid included the following:** ✓ **Design, Materials & Construction: 7% of National Grid subscription** ✓ **Operations & Integrity: 79% of National Grid subscription** ✓ **Compressor and pump station 6% of National Grid subscription** ✓ **Measurement: 3% of National Grid subscription** ✓ **Corrosion 5% of National Grid subscription** **ETN**		

	Cycle Efficiency - Improved performance of gas turbine components and intelligent system integration will enhance fuel efficiency and environmental performance. **Fuel Flexibility & Emissions - Gas turbines capable of operating in an efficient, safe and reliable manner utilising a wide range of fuels whilst minimising polluting emissions such as NOx and aiming at zero CO_2 emissions.** **Materials Degradation & Repair Technologies - Extending the ultimate life and repair interval for hot section components.** **Condition Monitoring, Instrumentation & Control - Aiming for 25,000 hours of gas turbine operation without intervention.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		21	0	**21**
Expected benefits of project	**PRCI** **PRCI's value proposition: "Formal cost / benefit studies of member participation show a consistently positive ratio of 4:1 to 7:1 from reduced costs of operations and maintenance, inspection, materials, design, construction and testing"** **National Grid Transmission and National Grid Gas Distribution this year used their combined annual contribution of $159k to help launch 19 PRCI projects with a total cost of $2.7m. This represents an average leverage of 17:1 on National Grid supported projects.** **EPRG** **Benefits include improved system integrity knowledge, improved corrosion protection, reduced 3rd party incidents leading to less supply disruptions, networking opportunity with other pipeline operators, sharing information and best practice. It is very difficult to articulate the exact benefits of these high level benefits until the output of each individual project is known.** **Significant research leverage benefits of about 15:1, based on a National Grid contribution of €20k.** **ETN** **ETN promotes environmentally sound gas transmission technology with reliable and low cost operation. Besides facilitating and coordinating research effort of different parties, bringing together key stakeholders in the gas turbine community, ETN also presents extensive networking opportunities and acts as a solid platform for exchange of knowledge and experiences. ETN identifies research gaps and influences the EU research agenda and policy-making at an early stage.**			

Expected timescale of project	Ongoing: reviewed annually	**Duration of benefit once achieved**	**Ongoing**
Probability of success	70%	**Project NPV = (PV benefits – PV costs) x probability of success**	**>£1m**
Potential for achieving expected benefits	**The PRCI collaborative programme gives National Grid the opportunity to benefit from a significant number of highly leveraged projects which complement much of the work on the overall IFI programme. It also provides a link with PRCI global pipeline operator membership and benefits of identifying emerging threats and opportunities.** **The programme of work within EPRG has potential for achieving the expected benefits for National Grid due to the collaborative nature of the projects. The R&D leverage ratio of 15:1 and the shared knowledge on best practice and incidents are the main benefits and a consistency between the Distribution and Transmission businesses.** **National Grid predominantly uses ETN as a forum to help identify emerging issues and opportunities with gas turbine mechanical drives.**		
Project progress [Year to End of March 2013]	**PRCI** **The following PRCI projects were supported by National Grid this year:** **Design, Materials & Construction** • **Program to Evaluate the Long-term Performance of Composite Repair Systems** • **Update of PRCI Seismic Guidelines** • **Sleeve End Fillet Weld Stress Intensity Factor Solutions** • **NASA TecFusion** **Operations and Integrity** • **Right of Way Automated Monitoring** • **Right of Way Monitoring and Surveillance by Satellite** • **ILI Technology Improvements** • **Develop an Optimized Set of Safety Factors or Response Criteria for Use With ILI Results** • **EMIT technology development for longitudinal and circumferential crack detection in dry gas applications** • **Tools to detect and discriminate mechanical damage** • **Mechanical damage assessment** **Corrosion** • **Evaluation of Current Practices and Equipment Used for Assessing the Integrity of the Coating System as the Pipe Comes Out of a Horizontal or Micro Tunneled Thrust Bored Pipelines Road Crossings** • **Develop an Alternate Method for Potential Measurement to Satisfy the Cathodic Protection Criteria** **Compressor and Pump Station** • **Collecting Cold Ambient Emissions Field Data on Solar's Titan 130**		

SoLoNOx Gas Turbine

- **Leak Prevention in CO2 Pipeline Valves**

Measurement

- **Effect of Upstream Piping Configurations on Ultrasonic Meter Bias**

Recent output from the PRCI programme of interest to National Grid includes:

- **Human factors Analysis - Contol Room Operations. Work under PRCI has resulted in cost avoidance for National Grid, as research would otherwise have been fully funded without the opportunities for leverage**
- **Third Party Interference - Threatscan pipeline monitoring system was trialled on our network. The project was unsuccessful in developing the tool to work in a proactive manner, though some useful learning has been documented.**
- **Extended Low Flow Range Metering - The PRCI report outcomes have been used in the scope for further test work at the flow centre at Bishop Auckland, UK. Testing is still ongoing.**

Other highlights from the year include

- **Attendance at the PRCI technical committee meetings, including chairing of a workshop session on unpiggable pipelines. The workshop also included demonstrations of inspection techniques.**
- **A meeting of European PRCI members was attended, which is helping to promote European interests in PRCI.**
- **Output from the long term performance of composite repairs project continues to complement the delivery of the gas distribution IFI:43 High Pressure Temporary Repairs project.**
- **Networking within PRCI is helping to inform on latest technology on In-Line Inspection.**
- **Knowledge of the PRCI Stress Corrosion Cracking (SCC) programme is influencing the scope of the future IFI project to be commissioned to review potential risks to National Grid from external SCC following the Enbridge, Michigan rupture due to disbonded coatings.**

EPRG

Meetings of the EPRG Corrosion, Materials and Design Committee were attended. A large number of projects are currently ongoing. Of particular interest to National Grid are:

Materials

- **Fracture propagation for high strength steels, high toughness levels and rich gas mixtures**
- **Drop weight tear test (DWTT) requirements for seamless pipe and generally increased understanding**
- **CO_2 pipeline requirements relating to fracture propagation**
- **High frequency induction pipe bond line Charpy toughness testing**

Corrosion

- **Sensitivity of damaged pipe to cathodic over-protection**

	• Long term behaviour of 3 layer polyethylene coatings **Design** • Fitness for Purpose of X80 pipelines • Dent and gouge damage testing • Wrinkles due to bending • State of the art review of seismic assessment methods • Ground movement • EPRG weld defect guidelines **In terms of deliverables the X80 fitness for purpose report has provided additional data for X80 damage assessment to support National Grid's T/PM/P/11 procedure. There has been a workshop briefing given to National Grid staff on mechanised pipeline welding and a review of strain based design.** **Joint workshops held between transmission and distribution help to share awareness of the EPRG/PRCI programmes of work.** **ETN** **Ongoing European Turbine Network projects include:** **Cycle Efficiency, Fuel Flexibility and Emissions** • CFD Validation Study • Dynamics of Combustion Instabilities • EC Work on Interoperability - Harmonisation of Gas Quality • Shale Gas Study • Virtual testing **Materials Degradation & Repair Technologies and Condition Monitoring, Instrumentation & Control** • Advanced sensor technology for gas turbines • Benefits of emission reduction retrofits • Creep – fatigue database • Hot boroscoping project • Life limiting mechanisms database • Filtration technology project **Asset Management** • Condition Monitoring • Esreda collaboration • Risk based decision making project
Collaborative partners	**PRCI is a collaboration with National Grid Gas Distribution (UK) and 72 other companies, pipeline operators, industry bodies and associate members.** **EPRG is a collaboration with National Grid Gas Distribution and 17 other**

	European pipe manufacturers and gas transmission companies **ETN has 78 other members from 17 European countries**
R&D provider	**PRCI (which uses a selection of Research Contractors, including large, multi-discipline corporations, non-profit institutions, small pipeline niche firms, major colleges and universities).** **EPRG (which uses a range of European Research Contractors)** **GL Noble Denton** **ETN**

Project title	Strategic R&D		
Project Engineer	**Quentin Mabbutt & Andy Lees**		
Description of project	**This project is a combination of strategic projects being carried out by university groups as part of major strategic collaborations. Projects are supported under Engineering and Physical Sciences Research Council (EPSRC) funding. The projects focus on understanding the potential of techniques or technologies to impact the gas Transmission network.** **This research and development programme consists of three i-CASE awards at Manchester University:** **1. Economic and reliability analysis of integrated electricity and gas transmission network operation** **2. Wireless energy harvesting sensor arrays based on photonic interrogation of sensitised optical fibres** **3. Time and frequency domain analytics for distributed sensors embedded in plastic optical fibres.**		
Expenditure for financial year	Internal £5k External £32k Total **£37k**	**Expenditure in previous IFI financial years**	**Internal £0** **External £0** **Total £0**
Total project costs (collaborative + external + NG)	**£64k**	**Projected 2013/14 costs for National Grid**	**£32k**
Technological area and/or issue addressed by project	**Economic and reliability analysis of integrated electricity and gas transmission network operation:** **This programme of study aims to extend classical power system models to an integrated network operation model that takes into account the tighter interaction of electricity and gas systems and the impact of such interaction in terms of flexibility, adequacy, reliability, and resilience of the overall energy system under future uncertain scenarios** **Wireless energy harvesting sensor arrays based on photonic interrogation of sensitised optical fibres:** **Wireless Energy harvesting sensor systems implementations are fast becoming an established technique for developing environmental awareness of the functionality of processes and systems. They can be retrofitted and function in a decoupled manner to the functionality of the monitored or assessed systems and have a small footprint. A capability which independently assesses the environmental conditions in the immediate vicinity of a given process greatly enhances operational safety, reliability, and awareness of the ongoing environmental processes. The objectives of the programme are to investigate current technologies involving energy harvesting**		

	and their integration into photonic systems **Time and frequency domain analytics for distributed sensors embedded in plastic optical fibres:** **This undertaking would then provide a new development allowing for a novel integration of optically interrogated fibre sensors into wireless energy harvesting systems.**			
Type(s) of innovation involved	Incremental	**Project Benefits Rating**	**Project Residual Risk**	**Overall Project Score**
		4	4	**0**
Expected benefits of project	**Off grid, remote monitoring of asset integrity capability has considerable potential for National Grid. The iCASE award with Manchester University makes this programme highly appropriate.** **The applied use of the latest range of Energy Harvesting (EH) techniques will enable National Grid to benefit from the development of an array of self contained specific asset monitoring hubs. Implementation of EH hubs across the network, without the need to develop a local power infrastructure, increases monitoring coverage and flexibility as sensor hubs can be easily relocated.** **The increased asset information derived from EH sensor hubs has considerable potential to greatly improve maintenance response and general network husbandry. The partnership with Manchester University through this iCASE award, will draw on their experience and EH capability to develop a series of industry ready solutions.**			
Expected timescale of project	3 year	**Duration of benefit once achieved**	**5 years**	
Probability of success	50%	**Project NPV = (PV benefits – PV costs) x probability of success**	**£60k**	
Potential for achieving expected benefits	**The scope of this project starts with research (low Technology Readiness Level), however, initial work to date has been promising and is therefore expected to provide recommendations for implementation.**			
Project progress **[Year to End of March 2013]**	**This research and development programme of study is in the initial stages of work. Meetings between the university students and National Grid will be held in Spring 2013.** **The initial pilot works are expected to provide a broad, generic level of information, focused primarily on photonic energy harvesting using the gas pipeline marker post and the development of robust energy harvesting devices that can be attached to them.** **Energy harvesting extends development on the IFI third party pipeline interference 'camera in the post' concept which is currently under review. Energy harvesting techniques provide potential for**			

	aggregate of future intelligence, such as image processing, to be applied to this activity to prevent false alarms using on board image processing. **The marker post gives a robust platform to develop an external pipe based sensor network or monitoring hub that could even utilise other energy harvesting opportunities, such as wind and thermal. Therefore the integration of a photonic energy harvesting unit using an NTS gas marker post is being investigated.** **Energy harvesting technology has considerable potential and the initial concepts and ideas are intended to gather field based experience, and to stimulate other relevant, nascent innovative opportunities.**
Collaborative partners	**National Grid Electricity Transmission**
R&D provider	**University of Manchester**