Project Code/Version No | SSET204/Non conf

Low Carbon Networks Fund
Full Submission Pro-forma

Section 1: Project Summary

1.1 Project title

PATHS: Powering Agriculture, Transport and Heat Sustainably

1.2 Funding DNO

Scottish Hydro Electric Power Distribution

1.3 Project Summary

PATHS is a collaborative, stakeholder driven project demonstrating an integrated approach to energy management which will:

- Improve distribution network access for renewable generation by actively managing local energy flows and transferring energy to other systems.
- Unconstrain highly congested electricity networks and help decarbonise wider energy provision by transferring renewable energy to gas networks, transport systems and agricultural energy systems.

To achieve this, PATHS will harvest excess renewable energy which will be converted by an electrolyser into hydrogen; this will act as the energy vector for this project. The hydrogen produced will be used to meet stakeholders' requirements in two ways: for injection into the gas network by the gas distribution network operator, helping to decarbonise heat while continuing to use the existing gas infrastructure; and to fuel a fleet of fuel cell buses being introduced by the local Council, helping to decarbonise transport.

1.4 Funding

Second Tier Funding request (£k)	15,587

DNO extra contribution (k)	0	**External Funding (£k)**	6,414

1.5 List of Project Partners, External Funders and Project Supporters

Project partners include:
Aberdeen City and Aberdeenshire Councils; Aberdeen Renewable Energy Group; Scotia Gas Networks; Stagecoach; First Group; Wood Group; BOC Linde; Element Energy; Robert Gordon University

External funders include:
the Scottish Government; Scottish Enterprise; the Technology Strategy Board

1.6 Timescale

Project Start Date	December 2012	**Project End Date**	December 2017

1.7 Project Manager contact details

Contact name & Job title

Frank Clifton, Project Development Manager

Telephone Number

01738 456237

Email Address

frank.clifton@sse.com

Contact Address

Scottish Hydro Electric Power Distribution
Inveralmond House
200 Dunkeld Road
Perth
PH1 3AQ

Section 2: Project Description

AIMS

PATHS aims to demonstrate the benefits that can arise from developing integrated technical solutions for power, heat, transport and agriculture in the UK. It also provides an opportunity to test the existing legal, commercial and regulatory frameworks to establish what if any changes are needed to encourage utilisation of integrated solutions in future.

PATHS aims to quantify benefits including faster and lower cost connections for renewable generation, avoided network reinforcement, increased network utilisation and the adoption of low carbon solutions for transport, agriculture and heat. Similar to previous SSEPD projects PATHS looks for synergies and solutions which resolve problems across a number of sectors and stakeholders. It will also share learning to ensure opportunities and benefits are maximised.

In summary, PATHS aims to demonstrate how integrated network solutions can:

- Facilitate the timely and efficient connection of large scale renewable generation on the electricity distribution network
- Reduce the cost of connection to the electricity network in the UK
- Reduce reinforcement costs for the electricity distribution network operator
- Provide a cost effective means of dealing with constraints on the electricity distribution network
- Reduce downstream network losses by capturing and utilising energy locally, where and when it is needed
- Bring sustainable low carbon benefits to other sectors such as transport, heat and agriculture
- Provide an evaluation of hydrogen production as an alternative energy storage and constraint management tool

PATHS has been developed in response to requests from a range of local and national stakeholders. It has also been developed to deliver learning that will be used to assess whether the approach can be replicated in other situations in future. It also consolidates learning from the Aberdeen Hydrogen Bus trial and other related trials throughout the UK including the Isle of Wight Ecoisland and other hydrogen based projects.

OBJECTIVES

The project will be delivered using a range of innovative solutions and will achieve the following

- Identify, test and address the technical, commercial and operational issues associated with electrolysis and production of hydrogen, including their interaction with renewable generation
- Development and testing of commercial arrangements and technical solutions required for distribution network operators to use an energy vector (hydrogen produced by electrolysis)
- Develop and test robust economic arrangements for the integration of energy networks by the transfer of energy between multiple systems
- Provide full life cycle cost models to inform further implementation of similar solutions on other networks under RIIO ED1
- Create a blueprint for integrating multiple energy networks, applicable anywhere in the UK

2: Project Description cont.

THE PROBLEM

The electricity distribution network in Aberdeenshire is a typical of urban and semi-rural areas elsewhere in the UK. It has been developed to support the distribution of energy from the electricity transmission system through a relatively small number of grid substations.

Traditional network design and planning standards (such as Engineering Recommendation P2/6) mean the network is designed and managed to meet maximum or 'peak' output. This can often result in renewable developments needing to be connected to higher voltage tiers, including transmission. This will potentially result in higher cost and involve significant lead times for network development to accommodate the output. This will delay decarbonising the network and at the most extreme it could result in particular developments not proceeding.

We believe alternative integrated solutions may provide an opportunity to maximise value for the developer and for current and future distribution customers, who will be liable for a proportion of the cost of most reinforcement required through increased use of system charges. This will be achieved through lower cost connection solutions, greater utilisation of existing network assets and avoided reinforcement.

As is widely expected, levels of demand for new connections for renewable energy developments continue to grow, the value associated with more efficient methods of connection will increase. PATHS offers a solution which offers a low cost solution for connections and also helps address other issues identified in the Carbon Plan, such as decarbonising agriculture, transport and heat.

In Aberdeenshire, as in many areas of the UK, there is a high demand for connections for renewable energy generation developments, ranging in size from small scale domestic projects (kilowatts) to large scale commercial projects (hundreds of megawatts). In many distribution networks, under utilised capacity could accommodate much of the output of these wind farms, but would require a managed connection agreement. There are many proposed renewable energy developments in Great Britain which could be accommodated if the potentially constrained output could be `harvested' by new controllable demand.

The PATHS proposal

PATHS will harvest excess renewable energy which will be converted by an electrolyser into hydrogen; this will act as the energy vector for this project. The hydrogen produced will be used to meet stakeholders' requirements in two ways: for injection into the gas network by the gas distribution network operator, helping to decarbonise heat while continuing to use the existing gas infrastructure; and to fuel a fleet of fuel cell buses being introduced by the local Council, helping to decarbonise transport.

Driven by stakeholder demand

The PATHS project has been designed to meet the immediate requirements of a number of stakeholders.

A 70MW windfarm is currently being developed offshore from Aberdeen by a consortium led by Vattenfall. In common with many windfarms, the project is currently seeking a commercially viable connection agreement.

Aberdeen City Council has ambitions to reduce the city's carbon footprint, as well as it reliance on the oil and gas sector. The city has specific environmental challenges; air quality issues in the city centre, where petrol and diesel fuelled vehicles contribute to unacceptable levels of pollution. In addition two of the UK's largest transport operators, Stagecoach and First Group, both of whom operate services in Aberdeen, are keen to find ways of reducing their carbon footprint of their operations.

2: Project Description cont.

Transport challenges

In the transport sector interest has been growing in electric vehicles of all types and automotive manufacturers are increasingly investing in hydrogen powered fuel cell vehicles. This interest has been recognised by the UK Government in the form of the UKH_2Mobility scheme. At its launch, Business Minister Mark Prisk said “Hydrogen fuel cell electric vehicles are increasingly being recognised as one of the viable options as we move to a lower carbon motoring future”. Similar projects are appearing in other parts of the UK including Isle of Wight Ecoisland and the Western Isles, initiatives all instigated by non DNO organisations.

PATHS will provide clean hydrogen fuel for a 10 bus project in Aberdeen, as well as providing learning on the impacts and benefits of electrolysers embedded in the distribution system - a key hydrogen generation technology.

Heat challenges

The Government's Carbon Plan recognises the need to eradicate greenhouse gas emissions from heat and buildings by 2050. This is a significant challenge as the vast majority of our heat currently comes from fossil fuels and over 80% from gas. Decarbonising heat is a significant challenge; electrification of heat is one possibility but will require significant network investment and development to accommodate new loads and a shift change in consumer behaviour. We believe this would also leave an existing well developed gas network underutilised. We do not believe this is necessarily the most efficient solution. The PATHS project will help inform the debate on the way forward, exploring opportunities to decarbonise gas and the existing heat supply using hydrogen. Scotland Gas Networks operates the gas network in Aberdeen area and is keen to work with us to explore ways to reduce the carbon emissions, and increase the sustainability of the gas distribution network. The lessons learned from this element of the project could then be shared across other industry sectors.

Agriculture challenges

Similarly, the agricultural sector is committed to reducing the environmental impact of its operations and is exploring opportunities for reducing its energy related carbon footprint whilst optimising the potential offered by their land.

Integrating energy systems

As explained above, there could be substantial benefits from integrating energy solutions and systems. PATHS proposes to do just this by moving renewable energy from the electricity network to other less constrained energy systems, where there is increasing demand for low carbon energy solutions.

METHODS

PATHS proposes to integrate energy infrastructures and end use sectors to unlock capacity of electricity networks, decarbonise hard to treat sectors, and lower the cost and reduce timescales associated with the connection of renewables onto networks. This will be achieved by introducing electrolysers to manage load and facilitate the transfer of renewable energy to the transport and heat sectors. This will be controlled by an active network management system. The Methods used are as follows:

Method 1

Improving access for renewable generation on the distribution network by active local energy management and energy transfer

This will be facilitated by the introduction of a local active network management scheme. SHEPD will lead on the design of the scheme, building on learning from earlier projects. The system will be monitored and data on performance will be analysed, so that longer term performance trends can be measured in a full scale fully operational trial. The costs and value associated with the use of hydrogen as a constraint management solution will be assessed.

2: Project Description cont.

This will be facilitated by the introduction of a local active network management scheme. SHEPD will lead on the design of the scheme, building on learning from earlier projects. The system will be monitored and data on performance will be analysed, so that longer term performance trends can be measured in a full scale fully operational trial. The costs and value associated with the use of hydrogen as a constraint management solution will be assessed.

PATHS will establish new commercial arrangements to capture and monetise the value of the PATHS system, which will have a number of potential revenue streams. Building on earlier work carried in DSM, we will gather data to inform and test the operation of a number of market models. Robert Gordon University will lead on this element of the work.

Analysis of the system performance and benefits will be linked to other projects such as EcoIsland to evaluate learning in the context of the different geographical locations, with different generation mixes and local hydrogen markets.

Method 2
Unconstraining highly congested electricity networks by the transfer of energy to the gas networks

The project will facilitate the delivery and integration of hydrogen production and storage facilities in the Aberdeen area. This will include an assessment of the safety, technical and operational considerations. SHEPD will provide the electrical infrastructure required and BOC Linde will lead on the hydrogen element of the works.

Scotland Gas Networks (SGN) will install and operate a network entry plant which will allow hydrogen produced by the electrolyser to be mixed with methane from the gas grid. This methane-hydrogen mix will then be re-injected into the gas mains. The trial will generate important learning on the technical feasibility and regulatory environment for the injection of H_2 into the gas grid.

This method will demonstrate how existing capacity on gas distribution networks can be utilised as a sink for the removal of energy from congested electricity networks. The potential to utilise latent energy storage potential in gas network assets will be measured in a fully operational trial, and the data gathered from the trial will be used to validate the estimated number of locations in which this solution would be applicable throughout the GB. The benefits of this method of decarbonising the gas grid will be evaluated as part of this trial and compared to other methods of decarbonising the domestic heat sector.

Method 3
Unconstraining highly congested electricity networks by the transfer of energy to the transport sector

The electrolysers will generate hydrogen from renewable energy for use as a fuel for 10 hydrogen fuel cell buses being introduced by the local Council. The potential of the electrolyser to convert electrical energy to potentially higher value revenue streams such as transport fuel will be analysed and assessed. The data gathered from the trial will be used to evaluate the applicability of this solution throughout Great Britain.

PATHS will provide the electrical infrastructure for the installation of an electrolyser which will convert electricity to hydrogen. The electrolyser, which will be operated by the project partner BOC, will be situated close to Aberdeen. SSEPD will develop a related active network management (ANM) system.

An integrated model

The methods described above are linked by a common vector: hydrogen. To understand the methods' interactions and interdependencies, we will develop models which consider all three methods. The models will inform the operation of such energy transfer systems, building on standards and learning established in previous UK and European projects. Robert Gordon University will lead on this element of the work.

2: Project Description cont.

SOLUTIONS

Via the methods set out above, PATHS will develop the following solutions to the problem of accommodating peak outputs from intermittent renewable generation sources:

- Introducing active local energy management and energy transfer which improves access for renewable generation to the distribution network
- Energy will be transferred from the highly constrained electricity networks to less constrained networks
- Heat and transport sectors will be partially decarbonised by the provision of a sustainable fuel
- Models will developed to optimise the value of integrated energy systems

Technical Description

In **Phase 1** of the project, the first electrolyser will be installed and will connect to a small wind farm. A simple ANM system will be developed to connect the wind farm to the grid, and to the electrolyser. The renewably generated hydrogen produced by this electrolyser will be used to power a fleet of 10 fuel cell buses, which are being introduced by Aberdeen City Council. Once generated, the hydrogen will be stored in a number of tube trailers, which are used to transport the fuel to a state of the art refuelling station. This first phase of the project will allow the network operator and the electrolyser operator to understand the potential for an electrolyser to provide network management services.

In **Phase 2** of the project, electrolysers coupled with an ANM system will facilitate the connection to the distribution network of an approximately 70MW wind farm which is being developed offshore from Aberdeen. An initial study suggests that a 3MW electrolyser is the optimum size to help manage the output of the wind farm and provide hydrogen for the likely demands from the gas grid and merchant hydrogen. The 1MW system from Phase 1 will be moved to the site of the Phase 2 electrolyser, with 2MW of electrolysis being added in Phase 2.

Phase 2 will trial the injection of hydrogen into the local gas distribution system. Hydrogen will be stored in gas storage tanks before injection into the gas grid via a network entry plant, which will mix the hydrogen and methane, analyse and meter the gas mix before reinjection into the gas grid (note funding for the gas part of this Phase is not being sought from LCNF - see further details below).

Further detail on the technical description of the project can be found in Appendix B.

The methods being deployed are innovative in that this is the first time in the UK an electrolyser will be used as a dynamic load to facilitate the connection of a large renewable generator to the distribution network, rather than connecting to the transmission network. The components of the whole system have been demonstrated in isolation but have never been integrated to work together at scale within a project which aims to ensure the integration of transport and energy systems. The electrolyser technology is mature and proven, and there have been a number of trials linked to wind farm outputs (eg the US National Renewable Energy Laboratory's Wind2H_2 project (2007 - present day).

DESCRIPTION OF THE DESIGN OF TRIALS

The location for the trial and its replication potential

This part of the network, just to the north of Aberdeen, has been chosen to trial these methods for the following reasons.

- the project is designed to meet local stakeholder demands, meaning there is a strong collaboration for this novel project
- the distribution network is constrained and could not accommodate the full output of the new offshore wind farm; conventionally, a connection to the transmission system would be required
- the network is representative of many urban and semi-rural networks in Great Britain

2: Project Description cont.

Replication potential

There is potential for replication across Great Britain. As evidenced (Appendix A(i)), this method is likely to be applicable for up to one in five new generation developments of 15MW and above in the years until 2020. These projects will comprise those generation whose size and location mean that connecting to the higher voltage system may be prohibitively expensive, but connecting to the distribution system would involve a constrained output. Replicability of the PATHS approach is considered in more detail in Section 3.

Trialling the technical effectiveness of energy transfer systems

The project will determine the effectiveness of the PATHS approach in delivering the solutions. A phased approach is used to de-risk the project by gaining early learning on technology performance, before full capacity is developed.

Phase 1

Phase 1 will investigate how an electrolyser operates as a form of controllable demand on the network.

As set out above, PATHS does not seek to investigate the concept of electrolysation *per se*. Rather, the trials will evaluate the technology's system management and optimisation capabilities. The aim is to determine the potential of the system to flex as an actively managed load on the distribution network in response to generation intermittency. The Phase 1 system will be producing hydrogen for a fleet of buses, and so its ability to produce fuel on a regular basis will be trialled.

Phase 1 one will provide the learning required to develop Phase 2. The phased approach of PATHS helps manage the risks associated with the novel application of proven technology. Phase 1 will in itself deliver learning which will be of value, but should initial learning indicate that this application of the technology does not provide the expected operational capability, it allows informed decisions to be made about whether Phase 2 should be implemented.

Phase 2

As noted above, Phase 2 will only proceed if learning from Phase 1 proves the concept to be sound. Phase 2 will trial a larger scale system (3MW in total) which will facilitate the connection of the wind farm with a constraint level which allows the wind farm to operate at an economically acceptable level. The trial will gather further data on the ability of the larger system to flex as an actively managed load on the distribution network. The Phase 2 system will also inject hydrogen into the gas grid and hence will have to respond to more signals than the Phase 1 system. The project will show how effective the system is in transferring energy to other networks including the heat network and the transport sector.

Technology Readiness

Whilst all the technologies proposed for PATHS have been proven in different markets or industries, they have not been applied to distribution networks in the UK before. The present DPCR5 business plan, as agreed with Ofgem, does not support the technologies identified for use in PATHS. There is no scientific uncertainty associated with injecting hydrogen into the gas grid but again there are technical uncertainties. Scotland Gas Networks have an ongoing project funded by IFI to investigate this aspect of the project.

Stakeholder requirements

Network management and energy storage have been a key area in the portfolio of LCNF projects developed by SSEPD. We are keen to further expand on these areas by including new technologies, stakeholders and energy systems, whilst building on the knowledge gained in our earlier work. PATHS represents the next step in this innovation process. Previous projects evolved to include both generation and customer demand in managing flows on our distribution network; in PATHS we are now expanding beyond the electrical energy system to involve other energy systems: transport, heat, and assessing the feasibility for agriculture (see Figure 3b).PATHS originated from discussions with local Councils, Scotland Gas Networks, Agricultural organisations and a renewable energy developer, Vattenfall, as described in the `Problems' section.

2: Project Description cont.

This extensive consultation allowed SSEPD to develop a proposal which aims to optimise the use of renewable energy by integrating energy infrastructures and systems to unconstrain electricity networks, decarbonise hard to treat sectors, and lower the cost and reduce timescales associated with connection of renewables.

STAKEHOLDER MEDIATED FUNDING

The value of PATHS to its stakeholders is evident in the amount of funding our various partners are bringing to PATHS. One of the key roles of PATHS is to help provide low carbon transport fuel. Aberdeen City Council has secured a combination of funding from two EU Projects, First Group, Stagecoach and BOC Linde to provide up to 10 hydrogen buses for the City. This has been supported by funding from Scottish Government, Aberdeen City Council, Scottish Enterprise, Scotia Gas Networks and the Technology Strategy Board to deliver the initial hydrogen production and storage elements of the project. This amounts to almost £20m of external funding and meets the full cost of the provision of the buses and associated hydrogen station. Some of this funding is also covering the costs of developing the 1MW electrolyser.

Further contributions from partners such as Wood Group, Element Energy, Robert Gordon University and Aberdeen Renewable Energy Group will help manage the project delivery, safety and compliance aspects as well as many of the learning and dissemination activities. PATHS has also attracted interest from other players in the energy supply chain. Discussions have been initiated with a number of potential energy supply partners; for reasons of commercial confidentiality, they have asked not to be identified at present, but it is anticipated that one or more energy suppliers will become involved in PATHS as it develops.

Partner contributions to PATHS amount to approximately £6.2m, which, for clarity is in addition to the £20m bus-related funding described above. The £6.2m is brought to the project from a number of diverse sources to reflect the multi sector elements of the project.

FUNDING

We recognise, and agree, that the LCNF should not fund transport projects. In line with this, the bus components of PATHS are being funded from other sources as detailed above. Accordingly, these are not listed in the project costs. Initial work relating to the 1MW electrolyser has been partially funded by the sources detailed above which include Scotland Gas Networks' Innovation Funding Incentive and the Technology Strategy Board. SHEPD's contribution to the first year's work on the infrastructure for the 1MW electrolyser is being funded from Tier 1 of the LCNF.

This bid seeks funding for: the remaining work on the 1MW system infrastructure and associated simple Active Network Management scheme (Phase1); the infrastructure for the 2MW electrolyser to complete the 3MW system, and the associated advanced Active Network Management scheme (Phase2). The funding will also be used for knowledge dissemination, project management and project safety.

Funding for gas injection

We are not seeking funding from LCNF for the innovative gas injection parts of the project. However, in order that PATHS can meet our stakeholder, Vattenfall's, need for a timely connection, we must proceed with developing the related infrastructure now.

The project is phased such that it is possible to proceed with much of the works in advance of this element whilst still gaining significant learning. However, PATHS aims to secure funding for the gas injection aspect of the project from one or more of the following sources:

- The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) - this is a €1 billion public private initiative to foster development of hydrogen sector. The partnership is backed by approximately €500 million of European funding. The FCH JU issues annual calls for proposals. The next 2013 call will be open early in 2013 and has approximately €70 million of funding available. The call is expected to suit hydrogen production and gas injection technologies.

2: Project Description cont.

- The Technology Strategy Board (TSB) has recently completed a £9m hydrogen call and is now scoping support for the technology next year, which is expected to be of a similar magnitude. The TSB is currently funding gas injection feasibility work, and assuming the results are favourable, would be expected to support a gas injection bid.
- The proposed Network Innovation Competition which is being considered by Ofgem for inclusion in RIIO-GD1 and as such may be available to Scotland Gas Networks.

TIMESCALES

The project will run for five years, from the beginning of 2013 to the end of 2017. The selected duration is necessary to allow a phased approach to trial a 1MW electrolyser (which will be in place by the end of 2013 to provide hydrogen for the buses), and then put in place a further 2MW electrolyser at the end of 2014. The wind farm connection is expected at the end of 2015. This gives the 3MW system as a whole one year to run on a test basis before it is required by the network to accommodate the wind farm output. The 3MW system will then run with a wind farm connection for 2 years as part of the LCNF Tier 2 project. Subject to demand for hydrogen from the transport operators and gas grid, the electrolysers will operate on a commercial basis from 2018. The managed connection for the large wind farm will continue; should the electrolysers not be available, SHEPD will use other forms of system management to provide a managed connection in line with the connection agreement.

CHANGES SINCE THE INITIAL SUBMISSION PROFORMA

We have refined the detail of the PATHS project since the ISP. The learning we expect to derive from PATHS remains the same, however the physical location of some aspects of the projects has changed, and the phasing of the work has been improved.

PATHS will now comprise two phases, rather than the three proposed in the ISP.

Phase 1

Facilitating the development of an electrolyser at an approximately 1MW rural windfarm, with the hydrogen output used to fuel hydrogen buses. This differs from the original Phase 1 only in terms of the size of the wind farm and its precise location. Learning gained through the development of PATHS has included an appreciation that electrolyser operators require highly controlled sites for the installation of their technology. Primary requirements included controlled access and 24 hour security. In order to meet these requirements, sites other than farms were investigated, with a suitable site being identified at a rural quarry, where permission was already being sought for a single wind turbine.

Phase 2

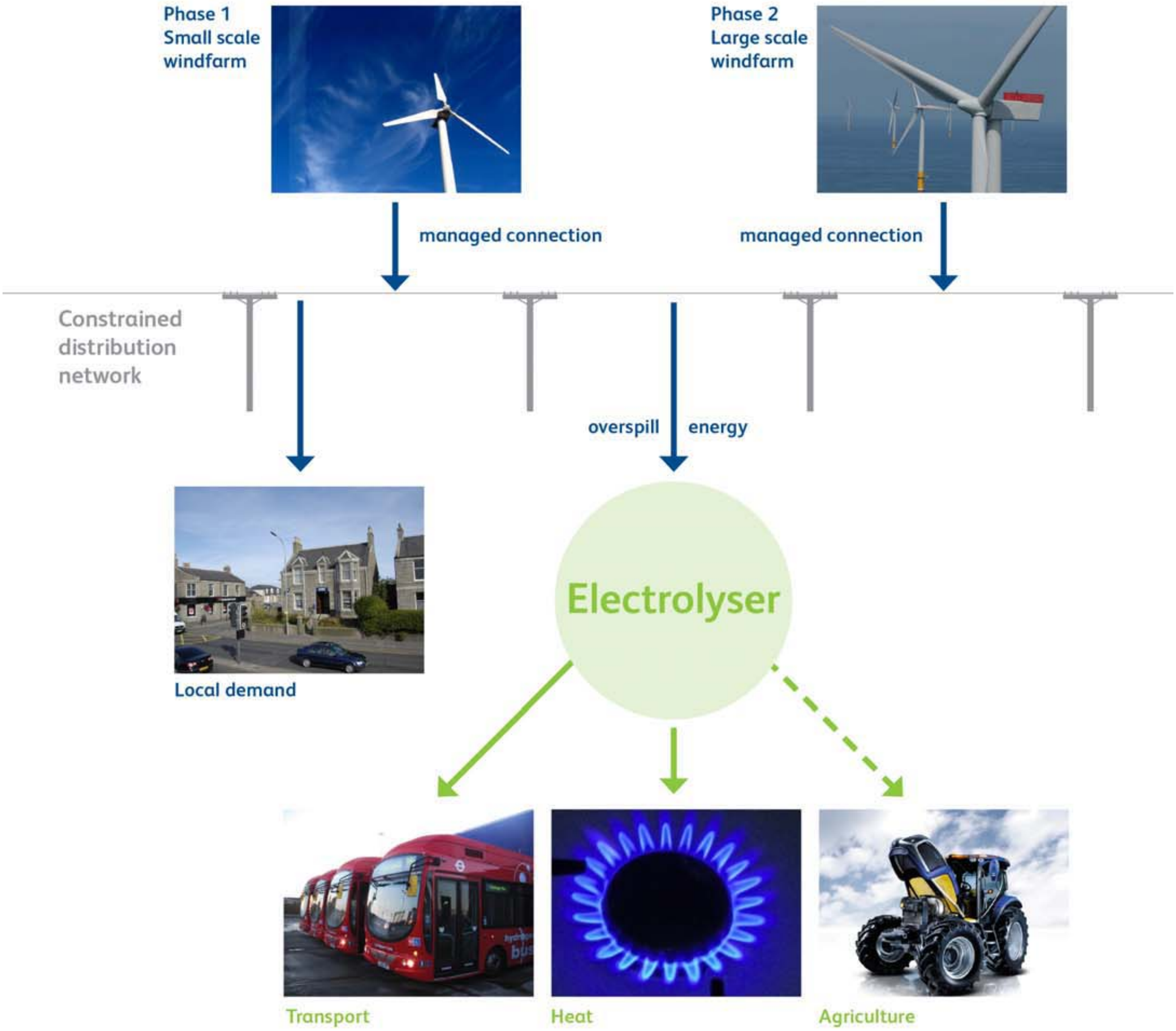
Phase 2 will trial a larger scale system (3MW in total). 1MW of this capacity will be provided by relocating the equipment from the Phase 1 site. This will allow us to apply the learning from Phase 1 to facilitate the connection of a larger wind farm. The Phase 2 system will continue to supply hydrogen for the bus fleet and will provide hydrogen for injection to the gas grid.

Funding developments

Since we submitted the ISP, we have received confirmation of funding from sources including the Technology Strategy Board, the Scottish Government and Scottish Enterprise. This provides the match funding necessary for the release of funds from HyVLoCity and HyTransit European funds, which allows the commencement of the Aberdeen City Council project to bring ten fuel cell buses to the City, providing a confirmed hydrogen demand which can be met via PATHS.

2: Project Description Images, Charts and tables.

Project Summary



	PATHS Phase 1	PATHS Phase 2
SSE Undertakings	Simple ANM scheme Electrical infrastructure for 1MW electrolyser at Site 1	Advanced ANM scheme Electrical infrastructure for 3MW electrolyser at Site 2
Partner Undertakings	Install 1MW wind turbine at Site 1 Introduce 10 hydrogen fuel cell buses 1MW electrolyser and hydrogen storage Develop bus refuelling station and hydrogen storage facilities	Build 60MW offshore wind farm Injection of hydrogen into gas network Install 3MW electrolyser at Site 2 incorporating relocated 1MW unit Create additional hydrogen storage facilities

Project Description images

Section 3: Project Business Case

Background

PATHS proposes to demonstrate and quantify the benefits arising from integrating the electricity network with other energy systems (natural gas and transport fuels). The concept will provide faster and lower cost connections for renewable developers whilst removing the requirement in many cases for traditional network reinforcement. It aims to demonstrate a new way of making the most of distribution assets and to exhibit resource efficiency by permanently removing the need for many system upgrades. This will provide benefits to DNOs across GB by generating evidence on how to manage the challenges the low carbon economy will bring to the electricity network.

Ofgem has estimated a need for up to £55bn of network investment by 2050, significantly greater than the rate of investment over the last 20 years. In order that the level of investment anticipated is reduced, and its impact on consumers minimised, investment needs to be smarter, drawing on a range of new, innovative intervention techniques as an alternative, or supplement, to conventional reinforcement

As the demand for renewable connections continues to grow, the number of circumstances where reinforcement is required will also grow. Traditional design philosophies for these projects are based around the peak demand/output of the developments. These `traditional' solutions will largely be based on installing additional assets on the network to add capacity. These solutions are typically deployed on a `fit and forget' basis, providing a reliable, secure and low risk investment, even though the cost and delivery times can be high. Furthermore, these solutions can result in very low rates of asset utilisation, given the intermittent nature of renewable generators.

This project offers alternative methods which look beyond the traditional network boundaries to exploit existing network capacity and storage in the gas grid, whilst supporting and benefiting from emerging markets for low carbon transport.

The project is designed to align with the RIIO-ED1 incentives. It will:

- Provide a clearer understanding of the applicability and costs of alternatives to conventional reinforcement
- Allow network investment decisions to be based on a broader range of criteria including energy transfer potential, active network management and managed connections to optimise system utilisation
- Allow investment decisions to be made with a broader understanding of energy systems and timescales
- Enable addition of new criteria (energy transfer potential or percentage of network utilisation, for example) as required to allow PATHS to evolve with RIIO and ED1 incentives

Project Description and Context

The traditional method of providing increased system capacity for both demand and generation is investment in assets like new substations, upgrading transformers and the installation of new cables. The industry is very familiar with these techniques and they offer a reliable low risk solution. However, they can be expensive and time consuming to construct, with the potential for inefficient network utilisation when combined with intermittent renewable generation. PATHS aims to generate learning on alternatives to traditional reinforcement by implementing a novel solution to a situation the north east of Scotland which is representative of similar situations across Great Britain.

3: Project Business Case contd.

Drivers for Alternative Solutions

The industry is beginning to bring alternative smarter solutions to bear, where generators in particular are being offered `managed connections' controlled by an Active Network Management (ANM) scheme which constrain or curtail output within network limitations to avoid reinforcement. These solutions offer a significant step forward and PATHS looks to build and expand on these solutions by better utilising the constrained energy.

Solutions being investigated by SHEPD and other DNOs involve a range of energy storage technologies, each with its own particular characteristics such as technical constraints and storage timescale. (See attached diagram- the Storage Continuum) For example, battery systems are more cost effective over short storage durations; but for storing wind energy, with high output events sustained over days and weeks, batteries are an expensive solution. The PATHS approach to this will explore how hydrogen can provide energy storage by acting as a vector for transferring energy to other systems. Used in this way, hydrogen can accommodate demand and generation profiles with long time constants. This will help further develop the industry's understanding of the most appropriate energy storage technologies for high renewables penetration.

The PATHS approach would allow the new wind farm to connect to the distribution system, rather than at higher voltage tiers. Distribution level connection generally offers a less disruptive solution and has a lower cost and is expected to deliver that for the EOWDC. In addition it will offer the potential for a quicker connection than the traditional option, as it is less reliant on consents which are a key contributor to the long timescales associated with traditional connections. The PATHS project should allow the generator to connect 12 months earlier than using a traditional connection.

THE EOWDC connection proposal is the first proposed application of this approach. Looking at the wider context, combining under-utilised distribution capacity with additional demand and storage using variable loads such as electrolysers may allow many developers - perhaps one in five - to connect in advance of upstream transmission upgrades. Looking further forward these types of solution may be particularly useful when existing wind farms are repowered using upgraded machines.

Unlike current managed connection arrangements where constrained energy is lost, linking to alternative energy sectors via the PATHS approach will allow much more of the energy to be usefully harvested.

Project Benefits

Benefits for Customers

- **All customers** will benefit from lower than predicted DUoS charges as a result of the use of alternatives to conventional network investment

    - **New customers wishing to connect to the network** will benefit if their project would normally trigger reinforcement which can be avoided by using the PATHS technique. For these customers, connection will be quicker and /or lower cost

    - **All customers** could potentially benefit from lower cost balancing services as the electrolyser can be used as a low cost dynamic load, reducing the cost of providing balancing on the network

3: Project Business Case contd.

Benefits for DNOs

The PATHS project will generate the following learning for distribution network operators:

- What are the benefits of actively managed demands with energy transfer to other sectors? The project will characterise and quantify the benefits of active demand management and energy transfer.
- What services can a dispatchable electrolyser provide to electricity networks? The operational characterisation will be compared to other technologies using common metrics to ensure DNOs apply appropriate technologies.
- What are the regulatory and market implications for actively managed demands? The project will provide real world learning on the way an actively managed load interacts with today's regulatory and market framework and make recommendations for how this might be improved to facilitate more applications of this type.
- What is the potential for energy transfer to supply transport, heat and agricultural demand? The project will generate a quantitative assessment of the potential demand for hydrogen and identify the conditions where energy transfer is viable.
- How can the integration of energy networks be structured to allow replication? Development of a `tool kit/blue print'. PATHS will look to trial a model for the management and economic operation of the system proposed.

Environmental benefits directly attributable to PATHS

The initial phase of PATHS will fuel the replacement of 10 conventional diesel buses with hydrogen fuel cell buses. By using renewably generated hydrogen to replace a hydrocarbon in an inefficient process (internal combustion), PATHS will save over 800tCO_2/year.

Replacing 5% of the methane in the medium pressure gas grid close to the electrolyser site with hydrogen gives savings of 125tCO_2/year.

It is possible under PATHS to allow the connection of the offshore wind farm one year earlier than with a traditional connection. This however is dependant on factors not under SSEPD's control, in particular the granting of planning consent. If the earlier connection were to be achieved, this would facilitate one year's worth of early wind farm generation, equivalent to carbon savings of approximately 74,000tCO_2.

Environmental benefits possible for Great Britain

Heat

The analysis shown in Appendix A (i) suggests that the PATHS solution will avoid up to 40,000 heat pump installations if it were replicated across GB by 2030. The carbon savings associated with this have been established by offsetting the methane requirements for heating these homes. This could save 57,000t CO_2/ annum from 2020.

3: Project Business Case contd.

Transport
As identified in Appendix G hydrogen fuel cell vehicles are increasingly being recognised as one of the viable options for sustainable transport in the future. If vehicle numbers reach the anticipated levels, then there will be significant demand for hydrogen as a transport fuel. If it is assumed that up to fifty per cent of these vehicles could be fuelled from wind powered electrolysers then this could see carbon savings rise to 420,000tCO2 / annually in 2030. Obviously, this benefit cannot be solely attributed to PATHS but the solution will contribute to enabling these savings to be realised.

Agriculture
The Carbon Plan identifies agriculture as a hard to treat sector which represents 8% of UK CO_2 emissions. PATHS can contribute to CO_2 emission reductions here. Key objectives include the reduction in the consumption of diesel in farming (3.6Mt CO_2), which constitutes a significant portion of farming cost (as well as exposure to fuel price fluctuation), and in the production of fertiliser (1Mt CO_2). PATHS will work with the farming community to use the learning outcomes to identify applications where there is a need and economic imperative. (See appendix G.)

Financial benefits for DNOs
Direct financial benefits
If PATHS were replicated across GB, the net benefit of deploying Method 1 (improving access for renewable generation on the distribution network by active local energy management and energy transfer) by 2020 could be about £304m. This is the difference between the avoided costs of network investment, and the costs of adding a PATHS system to help a generator connect to the distribution network (details in Appendix Ai). We have undertaken a sensitivity exercise on PATHS inputs (including factoring in cost reductions as the PATHS approach moves to business as usual) which gives a range of benefits from £176m to £498m. Estimation of this benefit relates only to the period to 2020 as only limited data is available beyond that date; beyond that time, according to National Grid's Gone Green scenario, there is expected to be a levelling out of demand for connections from onshore, and therefore benefits from PATHS would be expected to level out too.

Furthermore, if demand for hydrogen into transport increases in line with current projections, the number of electrolyser systems on the network would be far larger. Learning from PATHS will be extremely valuable in supporting this.

Additional financial benefits for DNOs
The following benefits cannot be attributed solely to PATHS but a PATHS type solution will be an enabler to yielding these benefits. By introducing a renewable fuel into the gas system, this decarbonisation of gas can offset a number of heat-pump systems. We have estimated that the value of avoiding heat pump systems in terms of avoided network reinforcement, is £558m by 2050.

PATHS could generate significant net savings from transport. Within the Ofgem Smart Grid Forum project, the DECC central scenario projected around one million electric vehicles (EVs) in GB by 2020, rising to around seven million EVs by 2030. Analysis shown in Appendix G , suggests that if the UK is an early adopter of fuel cell electric vehicles there may be up to of 50,000 vehicles by 2020, rising to over one million H2 cars in the early 2030s. It is reasonable to assume that the H_2 cars will net off against and hence reduce EV demand, as H_2 vehicles are also ultra-low carbon. Research (See Appendix A(i)) suggests that the net benefit arising from avoided EV-related distribution network reinforcements, will be over £2bn (discounted) out to 2050.

Turning a challenge into a network benefit
If electrolysers utilised are used in the way that PATHS proposes, they can reduce the need for demand-led network investment. If, however, they are connected simply as a new demand, this could compound the challenges

3: Project Business Case contd.

posed by the widespread adoption of other low carbon technologies. There is a need for the right mechanism to ensure that this demand is connected in appropriate circumstances, to act as a benefit to the network as opposed to a burden.

Wider benefits

It is also worth considering the business case for the operator of the electrolyser, and other stakeholders, as this will ultimately dictate whether these systems can be installed in future. In PATHS, there are a number of ways in which shareholders may benefit:

Benefits to renewable generation

As outlined previously, renewable developers will benefit from potentially reduced connection costs and timescales by adopting a PATHS type solution. The PATHS project will develop models which will assist developers in this process.

Other Benefits for Electrolyser Operators

There are other potential markets which may be available to electrolyser operators in the future. These, when combined constraint management (network services) services will determine long term viability.

Provision of response services: the electrolyser is a dynamic and controllable load with a response time of less than 1 second. This means it could provide STOR and Frequency Response services to National Grid.

Sale of energy to other sectors: hydrogen can be sold into the transport, industrial gas and natural gas sectors. The potential return will differ by sector (eg the transport sector is currently likely to command a higher value per kWh than the natural gas grid) and will also vary through time.

A number of system operating scenarios will be modelled. There is a wide spectrum of operating configurations which will be assessed in PATHS, providing a qualitative assessment of the potential benefits for stakeholders. Initial assessment of the potential revenues suggest that the PATHS project could not operate without the support of the LCNF. However, the cost of the technology is projected to fall and the value of response and network services is expected to rise; it is estimated that systems of this type could be commercially viable by 2020.

Additional benefits

PATHS will also provide:

- Accelerated low carbon technology connection for developers
- Methods to optimise use of renewable energy which may have otherwise been `lost'
- Evidence on the potential to link previously separate energy sectors
- Informed business plans going into RIIO-ED1 with the ability to consider alternative energy sectors
- An improved understanding for stakeholders of how to self-mitigate network issues through links to other energy systems
- Evaluation of resource and skill requirements
- Training and learning dissemination
- A no-customer minutes lost (CML) impact implementation strategy

3: Project Business Case contd.

Alternatives

In developing PATHS we have considered the implications of the main alternative to the project, which is to reinforce the network.

Reliance on traditional design techniques which largely rely on peak output figures would trigger solutions which would necessitate significant network reinforcement. This would extend connection timescales, increase connection costs and reduce asset utilisation. In some cases this could result in potentially viable renewable developments failing to proceed as they would be required to connect at points in the system which will become increasingly remote from their location.This comes at a time when the industry already has a significant challenge in managing the upgrade programme to meet the needs of the low carbon economy. Instead, PATHS helps to de-risk the transition to a low carbon economy by diverting energy at times of peak output to other energy sectors.

Converting innovation into business as usual

DNOs in Great Britain are working to deliver improvements in networks and operational efficiency in response to the decarbonisation of energy.

PATHS has been designed to feed into the business plans of the GB DNOs in the following ways:

- Provide an evaluation of how network management and energy storage techniques can be used to defer or potentially permanently avoid the need for network reinforcement by removing `surplus' energy from the electrical system
- To benchmark the use of hydrogen production and storage using electrolysers as an energy storage device for managing network constraints
- To develop short, medium and long term models to consider the potential for using hydrogen as an energy vector for diverting energy to alternative energy sectors
- Provide an evaluation of the techno-economic considerations for moving energy between currently unconnected energy sectors
- To generate new processes, standards and procedures that are required to implement the PATHS approach

We believe that this technology has the potential to become business as usual towards the end of RIIO ED1, with adoption at this time limited to areas with forward thinking stakeholders promoting the use of hydrogen or other chemicals as an energy vector.

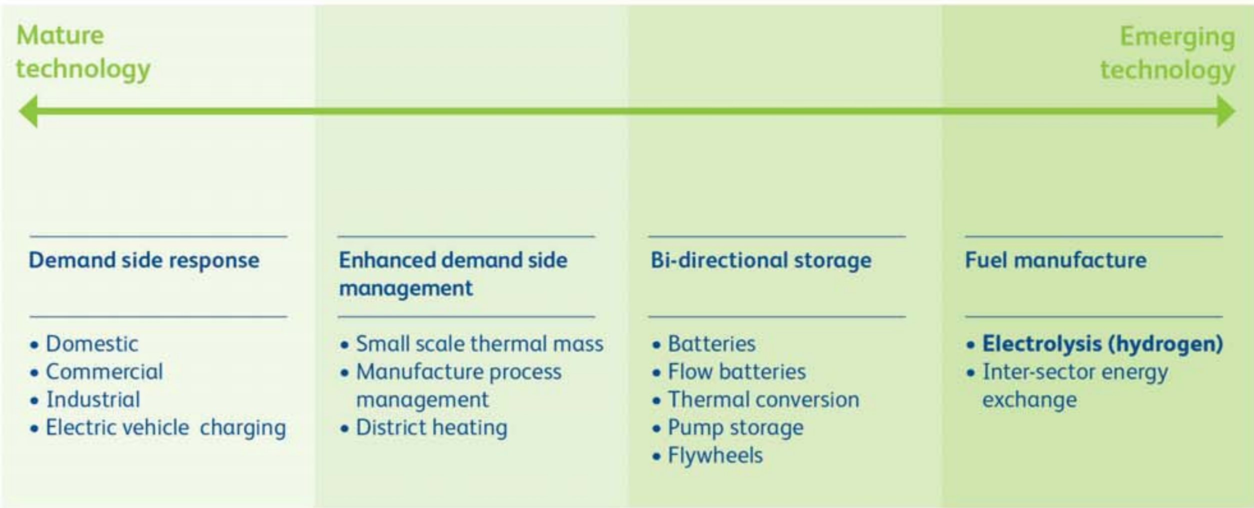
Conclusion

PATHS will provide important evidence needed to inform decisions on the routes to a low-carbon economy. This will include learning about the ability of electrolysers to perform as planned; the level of customer uptake for the hydrogen produced; the value of the demand management achieved; how hydrogen can be used to provide solutions on both sides of the meter. PATHS will also influence relevant policy, economics and design decisions in the future.

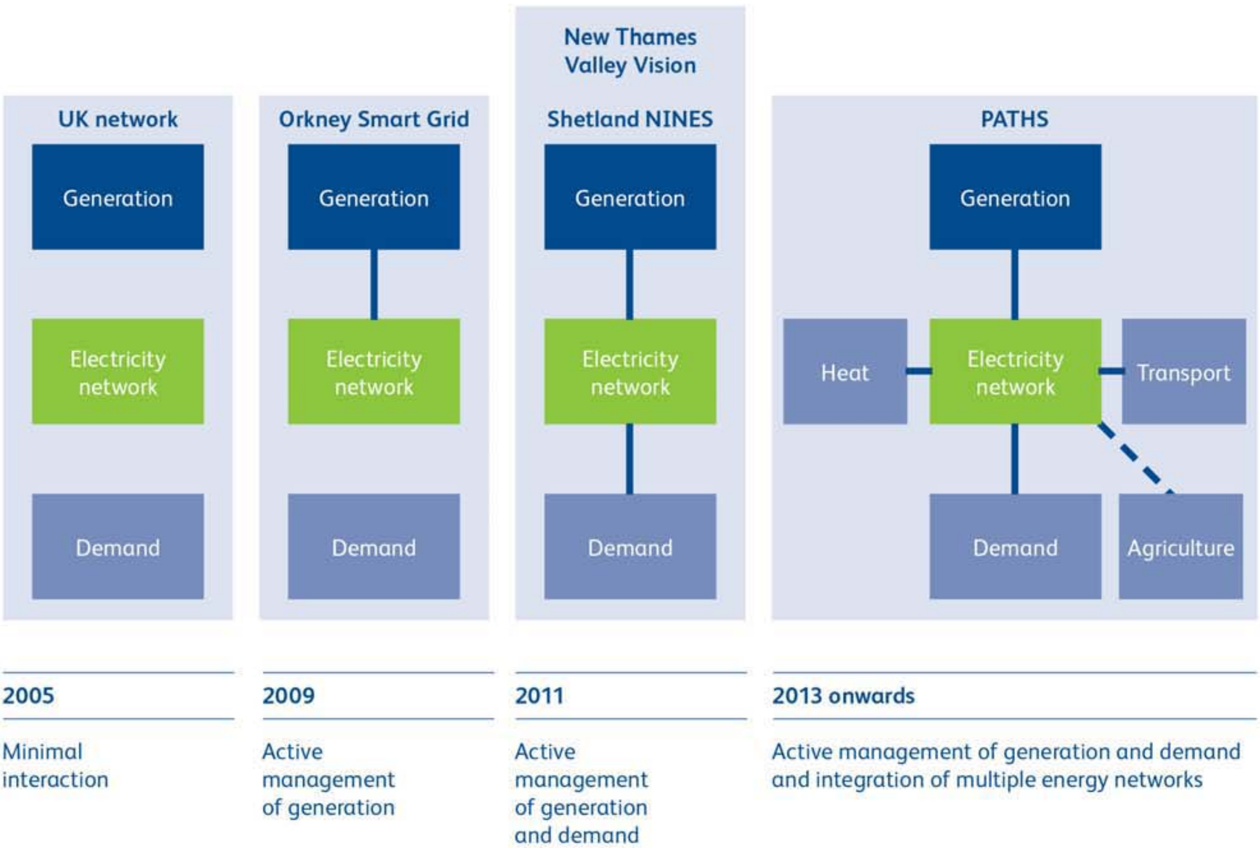
The alternative, of continuing to build increasingly expensive and lengthy fully rated connections, is not sustainable if renewables are to become a much greater proportion of the generation mix. This option is not acceptable from a financial and customer service perspective, and is not compatible with our aim of providing the energy people need in a sustainable way. The challenges faced by the electricity network in moving toward a low carbon economy will require a much more flexible and responsive approach. PATHS will further build on the portfolio of work carried out by SSEPD, but will also seek to demonstrate that solutions outside the formal network boundaries could offer better alternatives to the traditional solutions.

3: Project Business Case images, charts and tables.

Energy Storage Continuum



Project Evolution



Project Business Case images

Section 4: Evaluation Criteria

ACCELERATES THE DEVELOPMENT OF THE LOW CARBON ENERGY SECTOR AND HAS THE POTENTIAL TO DELIVER NET FINANCIAL BENEFITS TO FUTURE AND/OR EXISTING CUSTOMERS

A PATHS solution facilitates the following objectives of the Government's Carbon Plan:

- Increase electricity generation from renewable sources.
- Larger, stronger, smarter grid to reflect quantity, geography and intermittency of power generation.
- More flexible electricity system to cope with fluctuations in supply and demand.
- Buildings obtain heating from low-carbon sources.
- Sustainable transport

Actively managing the local energy system

Currently, network connections must be sized to accommodate the peak output of the new generation development. With load factors typically less than 35%, this can lead to very low utilisation levels on new infrastructure. PATHS aims to make more efficient use of capacity in the distribution system by managing output from generators, using techniques including using existing demand and transfer of energy to other systems, such that sufficient output can be accommodated on the existing distribution network to make the development economic.

This could provide a quicker, lower cost way of connecting new low carbon generation to the grid and accommodating the effects of its intermittency.

Decarbonising 'hard to treat' transport sectors with a renewably generated fuel

PATHS will demonstrate how otherwise constrained renewable electricity can harvested for use as a fuel for zero carbon vehicles. A fleet of hydrogen fuel cell buses is to be deployed in Aberdeen; these (and their refuelling infrastructure) are funded separately from LCNF. PATHS ensures these buses have near zero well-to-wheel emissions. Analysis undertaken in PATHS will also demonstrate the applicability of PATHS renewable energy supply chain for mobile agricultural machinery utilising hydrogen fuel cell drive trains and for fertiliser production via ammonia to decarbonise agriculture. (See Appendix G.)

Managing peak loads by utilising the latent capacity of the gas network

This helps to unconstrain the highly congested electricity network in the Aberdeen region, resulting in a stronger and smarter grid, which is better able to cope with the fluctuations in electricity supply. A dynamic simulation of PATHS has indicated the good correlation between high wind events in winter, and high heating demands.

Optimising value in the system by using demand management

The energy management system can be used to help the National Grid to balance electricity demand and supply. This smarter system could be switched off when demands elsewhere are high, and switched on when supply outstrips demand Under the National Grid `Gone Green' scenario with 20GW of wind on the network, National Grid estimates that the demand for strategic response will double, leading to an annual market worth £600million-£1billion per year in 2020. (Source: Operating the Electricity Transmission Networks in 2020, National Grid)

4: Evaluation Criteria contd.

HOW DOES THE ROLL OUT OF THE METHODS ACROSS GB DELIVER THE SOLUTIONS MORE QUICKLY THAN THE MOST EFFICIENT METHOD CURRENTLY IN OPERATION ON THE GB GRID?

SHEPD has developed PATHS as an alternative to current business as usual options for connection of new generation. PATHS could improve upon the business as usual solution in the following ways:

1) Improve access for renewable generation on the distribution network by active local energy management and energy transfer.

- Approximately 21% of GB total wind farm capacity is from wind farms between 30 and 80MW, and 14% lie between 40 and 70MW. PATHS could cost effectively improve the economics of wind farms connecting to the distribution network, and accelerate connection agreements.
- Therefore the addressable market for this system is up to 20% of GB wind electricity production (and a significantly greater number of individual wind farms). PATHS increases the load factor and potential revenues for the wind farm.
- The net benefits of PATHS systems (relative to a counterfactual grid extension) has been calculated at £304m in the period until 2020.

2) Unconstrain highly congested electricity networks by the transfer of energy to other end uses, and to the gas networks

- A geographic information system (GIS) study has estimated GB replication potential for PATHS, by overlaying the EHV system in both the SEPD and SHEPD areas on the gas networks in the Scotland and Southern Gas Networks areas, and plotting wind farm locations thereon. This showed that 50% of wind farms are within 1km of the gas network in Southern England, reducing to 13% in Scotland. In future, the replication potential could be greater, if PATHS shows that proximity to the gas grid can improve wind farm viability. A more detailed constraints and opportunities study will be undertaken by PATHS.

3) Integrate energy networks and end uses to decarbonise the `hard to treat' heat and transport sectors

- This method has significant potential across GB to decarbonise transport. There are increasing concerns that battery electric vehicles will remain niche. An issue with plug-in hybrids is the expected correlation between charging times and high loads on the network (ie after the evening rush hour).
- A hydrogen based system such as that trialled by PATHS responds to both of these concerns and the growing sentiment amongst vehicle manufacturers that hydrogen fuelled vehicles offer greater long-term cost-reduction viability relative to plug-in electric vehicles (see Appendix G). Although we do not believe we can estimate uptake of these technologies or EVs what we do know from our stakeholders including DECC is that there is a genuine move towards hydrogen as a viable option for transport.
- Hydrogen electrolysers can respond to fluctuation in renewable energy generation and only produce fuel when electricity supply is greater than demand. Electrolysers will connect at higher voltage levels than individual electric cars so adverse network impacts will be less.
- A PATHS solution, fuelling clean hydrogen vehicles, replacing EVs could avoid EV related network reinforcement. The benefit of this could be over £2bn in the period to 2050.

4: Evaluation Criteria contd.

4) Develop the commercial arrangements required to optimise the value of the system.

- The PATHS system has the potential to add value in several ways: to the wind farm owner (reducing cost of connection); the DNO (in terms of network management); the transport system operator (zero carbon fuel) and potentially to grid operators (in terms of ancillary services). PATHS will identify how to operate the system to deliver maximum value to these stakeholders, and the commercial arrangements necessary to ensure that value can be distributed equitably.
- These commercial arrangements will integrate previously separate markets

CARBON SAVINGS

The potential carbon savings that PATHS could instigate the roll out of across the energy sector are detailed in Section 3 . In summary, savings could rise to 422,000tCO_2 annually from transport applications from 2030; 57,000tCO_2 per annum from heat applications from 2020; and PATHS will contribute to reducing CO_2 emissions related to agriculture, including those from diesel and fertiliser.

Financial benefits to existing and future customers

Value is provided to customers through:

- Increasing the load factor/reducing constrained generation restrictions on wind farms.
- Allow more renewables to connect sooner, by providing simpler and less costly connections
- Generating a zero carbon, high value transport fuel.
- Reducing connection costs for new wind farms

If PATHS is successful and adopted nationally, it is estimated that the project will deliver £2.4bn of financial benefits over the period 2018 - 2050. These benefits are derived as described below.

Potential for replication across GB

To determine the replication potential for a PATHS-style solution to facilitating connection of distributed generation, a sample of real SHEPD connection case studies have been examined. These have then been extrapolated to GB level using projections of onshore wind from National Grid's Future Energy Scenarios document (November 2011) and generation datasets available from RenewableUK of the blend of onshore wind farms currently in the planning process. This process has determined that PATHS technical replication potential varies with wind farm size and headroom capacity in the network. The analysis indicated that up up 23% were suitable for a PATHS solution.

Quantitative assessment of benefits

Improve access for renewable generation on the distribution network by active local energy management and energy transfer.

The base case for the PATHS wind farm is a connection to the transmission system which is not financially viable. The local distribution network has around 45MW of capacity overhead, with another 7MW available due to variable demand. The distribution network cannot accommodate the wind farm output without uneconomic generation constraints.

4: Evaluation Criteria contd.

The PATHS system increases the effective capacity on the network, permitting wind farm operation with a higher and therefore economic load factor.

Building on the GB wide replication methodology described above, PATHS costs were estimated and compared to the counterfactual of a network upgrade. This has determined a potential GB wide benefits case of £304m by the 2020s from wind connections alone. Owing to the multiple variables in the costs of electrolysers and operating models, several sensitivities have been developed. These have been shown to vary the GB wide benefits case from £176m to £498m.

These are classed direct benefits, as are likely to result from the PATHS project. It is the intention to refine this benefits case further as results are yielded from the PATHS project.

Integrate energy networks and end uses to decarbonise the 'hard to treat' heat and transport sectors with a renewably generated fuel.

The potential benefit of having increased numbers of hydrogen fuelled vehicles as against electric vehicles (EVs) has been considered. This work was carried out using the Smart Grid Forum WS3 model, replacing some EVs between 2012 and 2050 with the equivalent number which could be PATHS fuelled. Savings would accrue through avoided network reinforcement for accommodating EVs. The results of this analysis is shown to be a significant £2.04bn.

If heating was provided by a decarbonised form of gas (eg through H_2 injection to the gas grids), rather than via the larger volumes of heat pumps, GB could continue to deliver its carbon targets, but without the need of significant LV network reinforcement.

In order to quantify this, a reduced set of heat pump volumes have been developed and input to the SGF WS3 model. Despite the number of heat pump installations avoided being conservatively estimated at around 40,000 in 2020 and just 2-3 times this figure in 2040, the benefits are a significant £241m by 2030.

PROVIDES VALUE FOR MONEY TO DISTRIBUTION CUSTOMERS

Benefits accruing to the distribution network vs. elsewhere

Benefits accrue to the distribution customers due to the avoided cost of network reinforcement to accommodate new renewable generation. As identified above, a GB wide rollout of PATHS could yield about £304m of net direct benefits by the 2020s, with significant upside to this if wind penetration increases further.

PATHS also brings significant indirect benefits, which do accrue to distribution customers. By providing an alternative means of decarbonising heating, PATHS could generate £241m in net benefits by 2030. By developing an ultra-low carbon transport option, and thereby avoiding some network upgrades associated with battery electric vehicles, PATHS could contribute to saving over £2bn by 2050. PATHS could increase security of energy supply through use of indigenous renewable energy sources. The majority of the project learning is applicable to the distribution network. Learning outcomes, of which three out of four relate directly to the distribution network, are covered in detail in the following sections. To summarise, the key learning relevant to the distribution network is:

4: Evaluation Criteria contd.

- Understanding the impact of active demand management with an energy transfer asset on distribution system utilisation, the total cost of providing connections, and total time for provision of connections
- Characterising the technical constraints and opportunities for using electrolysers as dispatchable demand
- Evaluating methods for energy storage; allowing DNOs to understand which technologies will be relevant to solving specific grid constraints
- Defining appropriate management and economic operation of energy storage and transfer systems, transferable to all DNOs

LCNF funding only DNO-targeted learning

The one Learning Outcome which does not apply directly to the distribution network focuses on transferring energy from constrained electricity networks to supply heat, transport and agriculture demands. The funding for these aspects of this project are not being sought from the LCNF - funding for the transport part of the project is in place, and Scotland Gas Networks will apply to the IFI for gas network elements of PATHS.

Procurement

PATHS aims to provide the maximum possible learning for the lowest possible cost. Accordingly, where it is feasible to conduct a competitive tender process, we will do so. This is in line with our Large Capital Project Governance Framework. Aspects to which this is likely to apply include the active network management scheme, cabling, civil and electrical works.

The information from the early modelling and analysis will define system requirements. This will inform the tender specifications, allowing us to conduct more effective procurement processes. In order that other DNOS may benefit from our learning in this area, we will share our experiences with other DNOs.

GENERATES KNOWLEDGE THAT CAN BE SHARED AMONGST ALL DNOs

While PATHS is an innovative solution to a network challenge in Aberdeen, the methods are transferable to all distribution networks. PATHS explores solutions to capacity constraints; improving the cost effectiveness of renewable connections; using dispatchable demand to manage networks; and using storage capacity in energy networks.

PATHS categorises learning into four Learning Outcomes:

Learning Outcome 1

What are the network benefits of actively managed loads?

Learning Outcome 2

What services can dispatching electrolyser systems provide to electricity networks?

Learning Outcome 3

What is the potential for energy transfer to supply transport, heat and agricultural energy demand?

Learning Outcome 4

How can the integration of multiple energy networks be replicated in locations across Great Britain?

4: Evaluation Criteria contd.

Learning Outcome 1
What are the network benefits of actively managed loads?
Actively managed loads take many forms: batteries, thermal stores and electrolysers, for instance. PATHS aims to characterise the different forms of actively managed load to allow distribution network operators and other industry participants to make informed decisions as the most appropriate technology for their particular need.

PATHS will quantify:

- The key characteristics of actively managed loads, with parameterisation of load capacity; response time; and duration etc
- The benefits of actively managed loads to generators; the extent of wind farm load factor improvement, economic and environmental benefits
- The effect of active demand management with an energy transfer asset on distribution network utilisation, the total cost of providing connections, and the total time for provision of connections

Learning Outcome 2
What services can dispatching electrolyser systems provide to electricity networks?
PATHS proposes hydrogen as an energy vector, exploring the technical constraints and opportunities around the use of electrolysers as a dispatchable demand. This Learning Outcome can be reapplied to other electrolyser installations and to energy storage technologies more broadly. This will enable comparison of energy storage solutions in terms of standard parameters for network services. This helps DNOs understand which, from a spectrum of technologies, will be relevant to solving specific grid constraints.

PATHS will define:

- The load profiles electrolysers can accommodate; interactions between system cycling, response times and ramp rates and their impact on electrolyser lifetime.
- The dispatching algorithms to optimise the utility and economics of the system.

This operational characterisation will be compared to other technologies such as utility batteries using common metrics to ensure DNOs apply appropriate technologies.

Learning Outcome 3
What is the potential for energy transfer to supply transport, heat and agricultural energy demand?
By generating operational data on PATHS system performance, this project will provide an evidence-based assessment of the replication potential of the approach. The project will identify the range of opportunities for energy transfer via hydrogen to meet current and future demand, as well as economic viability. PATHS will generate a method of identifying the conditions where energy transfer may be a viable option to decarbonise transport, heat and agricultural activities.

This will include an evaluation and assessment of a range of factors including potential market requirements, consider the needs of the full range of stakeholders, and consider the relevant safety and regulatory issues. This will be used to inform the development of a template for future standards and commercial arrangements.

a) Transport
Some vehicle manufacturers are investing in hydrogen fuel cell vehicles, suggesting that they may view them as alternative in some circumstances to plug-in electric vehicles.

4: Evaluation Criteria contd.

See (Appendix G) for more information and references. The learning from PATHS will be valuable when, as anticipated in the cross industry/UK government UKH_2Mobility study, a H_2 refuelling infrastructure is required from 2015 onwards. Electrolysis offers a very scalable and flexible way to generate hydrogen, and these characteristics will be vital in the early period when demand is small but growing. Wind electrolysis is also identified as the lowest carbon intensity source of hydrogen.

b) Heating via gas/electricity grid integration for load management

This project will explore the use of the significant unused capacity in the gas network infrastructure to alleviate peak capacity problems endemic in the electricity system. When electricity capacity issues are caused by wind energy, the benefits are potentially very significant indeed. This is because of the close correlation between high wind generation and high gas demand for heating.

PATHS proposes to take excess electricity off the network permanently, rather than, as with batteries, storing it for electricity regeneration. Transferable learning includes:

- The extent to which hydrogen can be injected into the gas grid
- The extent to which capacity in the gas grid can act as a store for renewable electricity
- Assessing the replication potential for the method by examining the juxtaposition of the gas and electricity networks
- A feasibility study of methanisation (using the Sabatier process to generate pure methane from hydrogen and CO_2); an alternative energy vector to hydrogen, it could result in a simpler lower cost gas injection infrastructure

c) Agriculture

PATHS will explore the use of renewable hydrogen for agricultural applications. Transferable Learning Outcomes in this area include:

- Potential for PATHS to supply mobile agricultural applications (such as tractors, harvesters, mowers, sprayers and balers); learning will be generated and shared with the agricultural sector to enable more effective use of farm-based renewables and reduced connection costs
- Technoeconomic feasibility of an ammonia production facility (utilising the Haber-Bosch process to combine renewable hydrogen with nitrogen using renewable power) within the PATHS infrastructure.
- Practical and health and safety implications of the use of PATHS in agriculture.

Learning Outcome 4
How can the integration of multiple energy networks be replicated in locations across Great Britain?

PATHS will trial a model for the management and economic operation of the systems proposed. In doing so, it will create learning on a range of issues, many of which are highly transferable to DNOs deploying a range of technologies to more efficiently manage their networks. The trial will also identify practical considerations associated with development and deployment of energy transfer systems, enabling the creation of an Energy Network Integration Toolkit, including guidelines for dealing with issues under the following categories: safety; technical; contractual; commercial; regulatory; environmental; stakeholders.

4: Evaluation Criteria contd.

In particular, PATHS will determine a range of practical economic and commercial opportunities for deployment of active demand management and energy storage systems. The toolkit will include a blueprint for deployment of the methods detailing:

- The network balancing revenue streams which can be monetised and serviced by the PATHS system
- Prioritisation of the system dispatching to maximise the beneficial outcomes from each of the system 'customers' including

- the wind farm (increasing the load factor)

- the electricity grid (provision of balancing and services)

- hydrogen end users (transport applications)

- the gas grid (for decarbonising this hard to treat sector)

- Business and ownership models which will need to be in place to support the deployment of such systems.
- Inform market development both short term `zonal' markets and longer term GB wide market reviews

INVOLVEMENT OF OTHER PARTNERS AND EXTERNAL FUNDING

Responding to Stakeholder Requests

The PATHS project responds to direct requests from distribution customers. In recent months, we have received requests from Aberdeen, the Isle of Wight, Shetland and the Western Isles for SSEPD to become involved in projects based around the production of hydrogen from renewable sources, generated from renewable energy. Given the co-funding already won for its key transport application PATHS - based in and around Aberdeen - appeared the most advanced. Further discussions with communities, local authorities, NGOs, government bodies, gas companies and technology firms across the country led to final scope of the project.

Strong Industry Partners - Playing to strengths

By involving a range of industry-leading partners, PATHS allows its collaborators to play to their strengths - transport companies operating buses, industrial gas companies operating and producing hydrogen, project management specialist managing the project integration - while SHEPD focuses on creating an electricity network that allows these technologies to operate.

The project involves UK industry, contributing £6.2m from across the entire energy system from generation to end use, each expert in their own field with:

- **BOC Linde** are responsible for the hydrogen generation, delivery and fuel retail equipment;
- **Wood Group** will provide overall project management for the H_2 system
- **Element Energy** and **Aberdeen Renewable Energy Group (AREG)** will be responsible for reporting and disseminating project results focussing on the transport and supply chain development elements of the project

4: Evaluation Criteria contd.

- **Robert Gordon University** will be responsible for providing much of the detailed techno-economic modelling required to understand the transfer of energy between sectors.
- **Vattenfall** are developing the European Offshore Wind Deployment Centre a short distance offshore to the north of Aberdeen
- **Scotland Gas Networks** will be responsible for the integration with the gas network and injecting the hydrogen gas into the network. SGN will apply for funding from the IFI to undertake the gas aspects of this project.
- **Landowners** are keen to support lower connection costs and timescales for renewables and to reduce reliance on fossil fuels.
- **Suppliers** are keen to understand the potential benefits of this approach

Leveraging National and European Funding

- £2.4m from the Technology Strategy Board's Fuel Cells and Hydrogen: Whole System Integration call. This funding has already been secured with the aim of signing a formal Collaboration Agreement in October 2012.
- £5.6m from HyTransit, a Fuel Cells and Hydrogen Joint Undertaking project which will fund seven Van Hool buses. This funding was secured by Aberdeen City Council and the project will be co-ordinated by BOC Linde.
- £2.7m High V.LoCity, a joint project led by Aberdeen City council with Stagecoach to operate three hydrogen fuel cell buses in Aberdeen.

Match funding comes from a range of sources including Scottish Government, Scottish Enterprise, Aberdeen City Council and industry partners. For clarity we have kept these outside the PATHS funding request.

- **Scottish Government:** (£1.65m contribution) are keen to support renewable energy and low carbon projects to capitalise on expertise in this area to support jobs and attract further investment.(See Appendix J)
- **Scottish Enterprise**: (£1.65m contribution) wish to further develop the hydrogen economy in North East Scotland as well as looking at the overall supply chain potential
- **Aberdeenshire Council**: Aberdeenshire is home to some of the richest renewable resources in Great Britain. The council are supporting the project to develop this industry but also to understand how this can support to the agricultural sector.
- **Aberdeen City Council:** (£2m contribution) will be overseeing the bus aspects of the project, which will be operated by First Group and Stagecoach.

Relevance
PATHS meets a number of distribution customer needs, and addresses strategic issues expected to impact GB distribution networks in the medium and long term. It is also a natural extension of the projects SHEPD, SEPD and other DNOs have undertaken through the LCNF.

Supporting future low carbon hydrogen transport requirements
Responding to the poor take-up of battery electric vehicles most automotive manufacturers are supporting billion dollar programmes focused on hydrogen and fuel cell (H_2FC) technology.There is consensus that fuel cells have a better near term opportunity to deliver an affordable, ultra-low carbon car. Proactive public authorities, including Aberdeen City council, are committed to H_2FC in public transport buses, and a number (eg Transport for London) have deployed small fleets of H_2FC buses.

4: Evaluation Criteria contd.

UKH_2Mobility, a cross industry/government initiative sees H_2 vehicle refuelling beginning in 2015. If it is assumed that around half of the hydrogen fuel will be supplied by electrolysis, it is clear that this will have a significant impact on the distribution network. PATHS will deliver the learning DNOs need to understand electrolyser impacts and contributes towards solving the hydrogen infrastructure challenge.

Costly network improvements associated with significant increase in wind capacity
RenewableUK has identified that network connectivity is one of four major reasons for the limited growth in wind farm capacity (State of the Industry Report Onshore and Offshore Wind: A Progress Update, October 2011). Over time, this situation can only worsen as sites with good grid access are used up. Wind farm connections will become more expensive and take longer to plan and deploy. PATHS responds to this by delivering a connection to the distribution system, at a lower cost and over shorter timescales.

A diversity of technologies for utility scale energy storage
Electrochemical energy storage in batteries, at a utility scale, offers significant promise for network support and supply/demand matching. But costs remain high and recent experience has shown that efficiencies and reliability may not meet expectations.

Regeneration of grid electricity is not proposed by PATHS, due to system inefficiencies. However future higher temperature, high efficiency, and reversible fuel cell/electrolysers could result in a favourable comparison against battery storage. Hydrogen systems are more appropriate for long duration storage (in the order of a day or more).

Project start date and duration
PATHS is a five year project, beginning in 2013, a timescale driven by commercial imperatives. A potential transmission connection requires Vattenfall to commit to the connection by the end of 2012, for access to the grid in 2015. PATHS would allow a connection 12 months earlier (2014).Timing is also driven by PATHS support from two European Projects under FP7, and a Technology Strategy Board project (operation of H_2 buses and refuelling infrastructure).

PATHS has two major technology deployments. A 1MW electrolyser will be commissioned, providing the fuelling requirements for the vehicle fleet, permitting testing of electrolysis as active demand management. Following trials and derisking, a further 2MW of capacity will be commissioned.

Parallel works are being carried out by SGN on gas injection. A feasibility study (due Q3 2012) will identify the maximum level of hydrogen which can be blended with natural gas. A gas blending and injection site will begin construction in 2013. Should PATHS not receive LCNF funding in 2012, the potential for managing constraints on the electricity network though the transfer of energy between networks will be lost.

Strategic relevance of PATHS and the project timing

PATHS can proceed now with low technical uncertainty, as the component technologies are mature. But to date, none of these systems have been deployed together, to deliver the integrated benefits we believe are possible with PATHS.

PATHS is required now so that knowledge of the performance operation and commercialisation of the methods is available in the period 2015-2020 to allow the technologies and methods to be characterised and deployed in the subsequent RIIO period.

4: Evaluation Criteria images, charts and tables.

Evaluation Criteria Images

Section 5: Knowledge dissemination

☐ Put a cross in the box if the DNO does not intend to conform to the default IPR requirements

GENERATING BOTH BROAD AND SPECIFIC LEARNING

As described in Section 4, PATHS is driven by four Learning Outcomes, which culminate in the creation of a blueprint for the integration of multiple energy networks applicable to locations across the UK. A subset of the learning will be specific to the systems deployed, and the design, implementation and operation of those systems; however most of the learning, such as the network benefits of actively managed loads, will be independent of the actual systems used, and so will be more broadly applicable to different types of energy storage and transfer systems.

Broad learning applicable to many types of energy storage and transfer systems:

Learning Outcome 1

What are the network benefits of actively managed loads?

This is about understanding the network benefits of actively managed loads. The project will develop a better understanding of the parameters for estimating the benefits of active demand management for stressed networks, and will therefore have widespread applicability for all DNOs. PATHS will also provide a detailed assessment of the effectiveness of an ANM scheme with an energy transfer asset to increase distribution system utilisation factors, reduce the total cost of connections and accelerate the provision of connections.

Learning Outcome 2
What services can dispatching electrolyser systems provide to electricity networks?
This is about exploring the technical constraints and opportunities around the use of electrolysers as a form of dispatchable demand. The evaluation methods developed as part of this LO will be transferable to other energy storage technologies. This will ultimately enable comparison of energy storage solutions in terms of standard parameters for network services.

Learning Outcome 4
How can the integration of multiple energy networks be replicated in locations across Great Britain?
This is about exploring practical considerations associated with development and deployment of energy transfer systems, enabling the creation of an Energy Network Integration Toolkit, including guidelines for dealing with issues such as contractual, commercial, regulatory, and the technical and economic optimisation of such systems.

Learning specific to the PATHS approach:

Learning Outcome 3
What is the potential for energy transfer to supply transport, heat and agricultural energy demand?

This is about the potential for energy transfer to supply transport, heat, and agricultural energy demand. This project will enable a quantitative assessment of the potential demand for hydrogen, the energy vector for this project, in each of these three sectors. The learning from the trials carried out in this project will inform identification of range of theoretical opportunities for energy transfer via hydrogen to meet current and future demand, as well as evaluation of their economic viability. This will provide a method of identifying temporal and spatial conditions where energy transfer may be a viable option to decarbonise energy consumption for heating, transport and agricultural activities.

5: Knowledge dissemination contd.

Targeted dissemination

Key stakeholders are listed below, along with the learning points that are likely to be of the greatest value to each group.

Distribution Network Operators

PATHS-derived learning will help DNOs consider the applicability of multiple energy network integration in their own areas, and help them understand how it could remove the need for significant system reinforcement. The non-technology specific learning will allow DNOs to assess the benefits and opportunities provided by energy storage and transfer systems, in particular in terms of better utilisation of existing network assets and the ability to connect more renewable generation. The toolkit on integrating energy systems will have information and guidance on the contractual, commercial, management and regulatory arrangements for putting in place such systems. There will also be technology specific learning which will allow DNOs to assess whether hydrogen production is the right energy transfer system for their needs.

UK Government, UK regulator, System Operator, and Transmission Owners

The outputs from the PATHS project will help all of these stakeholders to understand the potential to integrate energy networks, and whether these methods can achieve an increase in utilisation of distribution assets, reducing the need for transmission upgrades to accommodate new generation. This information will be important in informing investment decisions for the network, supporting future development of the network, and informing RIIO ED1 decisions. DECC's Heat Strategy calls for the need for evidence on the potential for hydrogen to contribute to decarbonising heat, and this project will have a practical demonstration of the potential for hydrogen to be added to the gas grid.

Electricity Generators

Electricity generators will gain an awareness of the possible alternatives to high-cost, long-timescale transmission connections for medium scale generation development.

Gas distribution network operators

Learning from PATHS will allow gas distribution operators to understand how the current gas supply could be decarbonised by injecting hydrogen into the existing gas grid. The injection of hydrogen into existing gas streams is novel in the UK, and hence the practical details of injecting hydrogen will be of significant value to gas distribution network operators.

Agricultural organisations

Agricultural organisations will understand the potential to decarbonise their operations through the use of hydrogen, as well as the potential to derive value from agricultural land by coupling small scale wind generation with local hydrogen production and use.

Technology suppliers and technical service providers

Technology suppliers will be able to gain an insight into the opportunities that could arise from the wider adoption of hydrogen-mediated transfer of energy between networks. Technical service providers will gain a real understanding of the opportunities and challenges in offering energy network integration services, and in particular services to the distribution network via running energy storage and transfer systems. This will aid them in developing new technical services to meet future demands.

Academics

Energy is one of the fastest growing research topics in UK universities; accordingly learning from PATHS will be of interest. In addition to departments involved in engineering and power studies, a wide range of

5: Knowledge dissemination contd.

academic groups will find PATHS learning useful, including social scientists, environmental experts, chemical engineers and economists.

Local authorities
As local authorities face ever more stringent environmental regulation, they will be interested in new developments which can help them tackle multiple environmental challenges.

Dissemination techniques
The diagram at the end of this section shows the knowledge dissemination plan for PATHS. Interactive learning events will form the core of the learning dissemination strategy for PATHS, supported by the provision of detailed supporting material shared in a number of ways. Industry conferences, in particular the LCNF conference, will be an important vehicle for dissemination. A website will be established, and project videos, learning updates, and papers published in relevant journals will be available here. Over the course of the project, the value of learning will be maximised by appropriate use of social media. The materials will include, but will not be limited to:a toolkit covering learning on key issues such as safety, technical, contractual, commercial, regulatory and environmental;papers published in relevant journals; training manuals; and Enterprise Architect models.

Interactive learning events
In May 2011, SSEPD ran an interactive learning event to share some of the key learning generated by the company's Orkney Smart Grid, Britain's first operational smart grid.The first of its kind in the UK smart grid industry, the event, which was created as a learning event, as opposed to a conference, involved over 60 industry and community representatives, including attendees from each DNO. Each delegate attended three full group sessions and three small group interactive learning sessions, during which a specific aspect of learning generated by the Orkney Smart was shared, and contributions from delegates gathered.

Analysis of responses to a post-event survey shows that events of this nature are an extremely effective way of disseminating learning gained from LCNF projects.

SSEPD's approach to knowledge dissemination
The dissemination of knowledge generated by PATHS will be undertaken in line with SSEPD's knowledge management and dissemination policies.

United by the statement `Sharing Adds Value', the policies set out how the company will share the learning derived from its LCNF and IFI projects, and from other innovative work such as the NINES project in Shetland.

Continual Learning Capture
SSEPD colleagues recognise the scale and value of the knowledge that will be created by PATHS and an important part of their job is to ensure that they record their learning as the project progresses. Job descriptions and personal targets reflect this and systems are in place to facilitate effective knowledge capture. Project personnel will be assisted in this work by the company's dedicated Knowledge Management Team.

Reapplication of Experience
Colleagues are aware of the need to learn from previous research and literature reviews are part of the development of LCNF projects. This will help ensure that the team focuses on new learning.

IPR status
This project will conform with the LCNF default IPR principles. It is not anticipated that the project will develop foreground IPR that will fall outside of the default IPR requirements.

5: Knowledge dissemination images, charts and tables.

Knowledge Dissemination Summary

	Primary events	Conference, presentations including, but not limited to:	Publications	Online/Video
YEAR 1	LCNF Conference		Six Monthly Project Progress Reports	Video: 'Introduction to PATHS' video posted online Online: PATHS web presence created
YEAR 2	PATHS Year 2 Knowledge Sharing Event LCNF Conference	ALL Energy Scottish Renewables Annual Conference	Six Monthly Project Progress Reports Year 1 PATHS Annual Report Minimum of one paper published in relevant journals	
YEAR 3	PATHS Year 3 Knowledge Sharing Event LCNF Conference	ALL Energy Scottish Renewables Annual Conference	Six Monthly Project Progress Reports Year 2 PATHS Annual Report Minimum of two papers published in relevant journals	Online: PATHS learning updates published online Online: Outputs from events and published papers made available online
YEAR 4	PATHS Year 4 Knowledge Sharing Event LCNF Conference	ALL Energy Scottish Renewables Annual Conference	Six Monthly Project Progress Reports Year 3 PATHS Annual Report Minimum of three papers published in relevant journals	Online: PATHS learning updates published online Online: Outputs from events and published papers made available online
YEAR 5	PATHS Year 5 Knowledge Sharing Event LCNF Conference	ALL Energy Scottish Renewables Annual Conference	Six Monthly Project Progress Reports Final PATHS Annual Report Minimum of four papers published in relevant journals	Online: PATHS learning updates published online Online: Outputs from events and published papers made available online Video: 'PATHS overview' video posted online

Over the course of the project, the value of learning will be maximised by appropriate use of social media.

There will also be a range of learning outputs including training manuals, Enterprise Architect models and relevant datasets.

Knowledge dissemination images

Section 6: Project readiness

Requested level of protection require against cost over-runs (%).	5%
Requested level of protection against Direct Benefits that they wish to apply for (%).	Zero

WHY THE PROJECT CAN START IN A TIMELY MANNER

The PATHS project is supported at every level within SHEPD. The project board includes the senior management team, each of whom is actively committed to the successful delivery of the project. We have considered the issues which have impacted other LCNF projects and factored those into the development of PATHS. The project is meeting the needs of stakeholders and is driven by clearly defined Learning Outcomes. Key roles within the delivery team have already been filled and we are fully prepared for transition to full project delivery upon award of LCNF Tier 2 funding.

Building on existing projects

Orkney Smart Grid

This provided the UK with the first experience of building and operating smart grid technology. The learning from this project was transferred to the NINES project and has been equally applicable to developing PATHS.

NINES (Northern Isles New Energy Solutions)

Many of the ideas and themes explored in the NINES project have been built upon for PATHS. The complete integration of customers and generators with the power systems network is now being expanded to integrate other energy systems; this is shown in the project evolution diagram, fig.3b. The modelling based approach to project development is now our default and will allow for re-use and maximum learning transfer to PATHS.

NTVV (New Thames Valley Vision)

From this project we have been able to transfer a number of valuable project development and delivery techniques. In particular the work on stakeholder engagement and knowledge capture has been very beneficial.

Orkney Storage Park

Our experience on Orkney is central to the overall project delivery plan for PATHS. This provides us with assurance in a number of the key areas identified as project risks. Having begun in autumn 2011, it is already delivering useful learning through the UK-first experience of contracting energy storage as a network service and the associated ancillary service markets that it can operate in.

Other LCNF projects

The learning produced by other LCNF projects has had significant bearing on the development of the PATHS project. In particular the learning events held by Northern Power Grid and Western Power Distribution held in July 2012 were an opportunity for us to take onboard the key learning messages. The six monthly reports submitted by all projects have also been extremely useful, particularly for us to identify project risks and opportunities.

The experience gained from these projects has provided us - and other industry participants - with a wealth of technical learning.It has also taught us that early mobilisation of a strong, experienced team is vital to

6: Project readiness contd.

the successful launch of a project and for the maximum learning opportunity.

SSE at a corporate level is involved in UKH_2Mobility and Ecoisland ensuring that learning is co-ordinated and leveraged across a number of projects bringing depth to the derived learning.

Learning from international initiatives

While the complete PATHS proposal is relatively novel, the individual components - active network management, hydrogen generation from renewable sources, hydrogen use in transport, hydrogen in gas grids - have been implemented previously and are relatively well understood. There have been a number of international projects in this area, summarised in the Appendix B. PATHS will build on the technical de-risking that those projects provide, to determine the interplay between system components, optimised operational strategies, commercial arrangements, and replication potential of the methods.

A strong team

PATHS is led by a strong, diverse and experienced team, all current SSEPD colleagues with experience of delivering LCNF projects. Key appointments have already been made and a strategy for the recruitment of additional colleagues has been agreed to ensure the resource plan can be fully met. We have considered the feedback from other LCNF projects regarding the timescales required to adequately resource projects and have factored this into our plans accordingly. The project has been phased to ensure that we can transition resource from the first phase to the second and therefore have maximum continuity and development of experience.

Project Development Manager: Appointed to the project in September 2011. 25 years industry experience, including previous LCNF project development, business development and operations.

Project Delivery Manager: Appointed in May 2012. Eight years industry experience, including delivery of major transmission works, the NaS battery on Shetland and several key parts of the NINES project.

Communications Manager: Appointed to the project in October 2011. 15 years experience in industry communications, including work on NINES, NTVV and numerous Tier 1 and IFI projects.

Knowledge Manager: Appointed to the project in May 2012, five years of industry experience, including working on NINES, NTVV and numerous Tier 1 and IFI projects.

The SHEPD project team will also draw on the knowledge and experience of colleagues throughout the company, including experts in project analysis, commercial connections and power systems modelling.

Consultant support

Element Energy has been integral to the development of the project. Element Energy is an independent consultancy focused on providing objective technical and strategic advice on low carbon energy technologies. Working at the intersection of low carbon power, transport and consumer demand, Element is a recognised leader in energy storage, all forms of low carbon transport including battery electric and fuel cell technologies. Element is currently engaged on the multi-stakeholder UKH_2Mobility project, a cross government/industry partnership to determine the potential role for fuel cells and hydrogen in future UK energy systems.

Technical consultancy

EA Technology was brought into the project to ensure we maximised the opportunity for a scalable project and for the delivery of maximum benefits to domestic customer. EA technology has a long standing reputation for power systems technical consultancy and they have provided invaluable input to the formation of the project.

6: Project readiness contd.

PROJECT PARTNERS

PATHS partners include experts in their fields who are committed to delivering the project effectively and efficiently.

BOC

Committed project partners, with essential experience in the safe generation and use of hydrogen both as an industrial gas and more recently, as a low carbon fuel. As part of the Linde Group, BOC have developed a large number of hydrogen energy projects and refuelling stations, including a significant new facility in Swindon. BOC have committed four staff to this initiative. BOC have formally signed as a project partner for the PATHS project and also for the successful TSB funding application which co-funds a significant portion of the initial 1MWe phase of PATHS. They are fully committed to and are actively working on the successful delivery of this project.

Wood Group

Committed project partners, providing oversight and excellence in the area of safety and environment. With a wealth of experience in the oil and gas sector they are ideally positioned to ensure we have a fully robust mechanism in place for the manufacture, storage and handling of hydrogen gas. This has been identified as a key project risk and Wood Groups involvement as a key mitigation measure.

Robert Gordon University

A committed project partner, providing academic research, analysis and learning. Research within the school of Engineering is graded as `world leading' for 5% and `international level' for 80%. RGU will provide invaluable knowledge from the academic environment to support the delivery of the project and will also provide a crucial role in the production and dissemination of learning. In particular RGU has developed some innovative and valuable methods of researching the benefits to agriculture. RGU has worked with us to develop the scope and scale of the project and are fully committed to the successful delivery of learning.

Stakeholder support

PATHS was conceived from a desire to meet stakeholder needs, and support their ambitions, for more sustainable energy solutions. PATHS directly supports a number of stakeholder priorities and as such has their full support. SSEPD believes that stakeholders - many of whom are partners - have a shared interest in PATHS succeeding; this is a key factor in why we can confidently say the project can begin without delay.

Funding

The PATHS project has already secured funding from all required sources other than LCNF. As stated previously we have not looked to secure funding from LCNF for the gas element of the works; we intend to seek further funding for this elements of the works. The staged nature of the project allows time for this funding to be secured; if this is not forthcoming then it should be possible to review the project and assess the impacts. This will obviously take place prior to committing to the expenditure for the second stage of the project. This would reduce the potential benefits, however the project will still deliver substantial learning for distribution network operators.

The full details of committed funding are explained further in appendix A. The secured funding gives a unique opportunity for us to explore the potential benefits to the distribution customers. It also means that upon securing the Tier 2 funding decision we can transition to project delivery without delay. The staged nature of the project ensures that expenditure can be managed to minimise expenditure on the gas injection elements of the project until the matched funding is in place.

6: Project readiness contd.

Maturity of technology
The focus of this project is to achieve the Learning Outcomes around developing and understanding the commercial models and markets which will support the effective transfer of energy from the electricity distribution network and hence a net reduction in reinforcement costs. Each of the key components in the project have been demonstrated at this scale previously, through the novel integration of these we can achieve valuable learning all network operators.

Distribution Networks
We will utilise existing infrastructure on both the gas and electricity networks, including well established monitoring and control systems.

Generation
Although the generation proposed for the second phase of the project is an offshore wind turbine demonstration site, there will be no functional difference to the network or this project. We can treat this as any other 70MW generation connection.

ANM
This will be the fifth ANM scheme on the SSEPD network and the technology is in transition towards business as usual status. Although the level of complexity should be greater than previously demonstrated (due to the commercial and contractual factors) the underlying component technologies and processes are now well proven.

Electrolysers and hydrogen storage
Hydrogen production via electrolysis is a very mature industry, with over 5% of industrial hydrogen worldwide produced via this method (most of the rest is industrially produced by the energy-intensive process of extracting hydrogen from methane using high pressure, high temperature steam). In this project the key development is the use of electrolysers to manage network constraints. While technically feasible - electrolyser response times can be very short and ramp rates high; nevertheless there would be some expectation of reduced electrolyser lifetimes. This techno-economic issue is addressed by using a mature, proven technology from a supplier confident about the robustness of their designs under variable loads.

Refuelling station and transport
There are over one hundred hydrogen filling stations in operation worldwide. Hydrogen as a transport fuel is still a nascent technology, but many automotive companies, aware of the consumer resistance to battery electric technologies, are investing many billions of dollars into series production hydrogen vehicles. The technology for hydrogen storage and refuelling is readily available, but the greatest barrier to widespread deployment is the lack of appropriate codes and standards, leading to bespoke and high cost systems. Independent authoritative studies (including those referenced in Appendix G) show that the cost of hydrogen supply and refuelling can drop significantly, while it is generally agreed that fuel cell vehicles offer much greater potential for cost reductions and affordability, when compared to battery electric.

Gas injection
For an extended period of time many gas grids relied on coal derived `town gas', which contained very high levels (between 10-50%) of hydrogen, before converting to natural gas. The HongKong and China Gas Company continues to distribute a H_2-CH_4 mixture with 49% hydrogen. Similarly, The Gas Company, in Hawaii, supplies a mixture with 11% hydrogen concentration through metal and polyethylene pipes.

More recently, a number of projects have demonstrated the widespread technical feasibility of injecting small concentrations of hydrogen into natural gas streams, without any impact either on pipelines, or consumer gas products. Generally, 20% hydrogen mixtures are deemed to be safe, but this project is proceeding with a much more cautious assumption of a lower concentration, to ensure it is technically viable.

6: Project readiness contd.

Project development

As with our other LCNF projects, we have developed the PATHS project using analysis and modelling tools. The overview project use case has been developed to illustrate the fundamental arrangement of the project. Through the use of our models we can maximise the project learning and our understanding of business change. The project delivery is focussed on achieving the maximum learning and these tools will be central to achieving this.

Work to date

The PATHS project has been in development since 2011. We have clear working arrangements with all project partners in place and all other funding for Phase 1. By working with both Councils we have a number of potential sites for Phase 1 of the project and are currently carrying out survey works to establish which is most suitable. We have established the key governance documents for the project and are holding frequent steering groups with the project partners. We have the core project delivery team in place and a resourcing plan for the duration of the project. In the time between bid submission and decision, we will continue with full commitment to the delivery of the project.

Project planning

A key element of the project delivery is maintaining a co-ordinated project plan. Our project partners have committed to the programme and the depth of learning which it will provide. The summary plan can be found in Appendix C(i), with the key areas described here.

June 2012 - December 2012

Here we lay the project foundations, having identified the key learning objectives and project partners. We formalise these relationships and agree our delivery approach. The first phase of the project is in active development, with site selection a priority. We clearly define the learning strategy and map out the business as usual processes and systems we will be working with.

December 2012 - June 2013

Having secured funding, in this phase we will transition fully from development to delivery and will build the full PATHS team. The first phase of the project will enter construction and the second phase site selection. Learning will be effectively transitioned between phases and work packs and formal learning documents will be produced for wider dissemination.

June 2013 - December 2013

The first phase system will enter into operation and the full contractual relationships will be in place to support the transfer of energy between systems and will have generated much of the learning to support the first iteration of Learning Outcome 4, `How can the integration of multiple energy networks be replicated in locations across Great Britain?'

December 2013 - December 2014

With a full year of operational data we will be able to provide initial dissemination of learning on all outcomes. The second phase of the project will have proceeded through building and commission and we will be able to confirm the timescale and cost benefits of the distribution phase.

January 2015 onwards

We will continue to gather operational data on the performance of the systems and also the wider commercial positions. The full system will be iterated and refined to maximise commercial opportunities, including entering ancillary services markets. The Learning Outcomes will be refined over this period and a final version of the combined learning issues at the conclusion of the project.

6: Project readiness contd.

Estimating costs and benefits
We have used established costing tools and methods to ensure that we have a fully robust project cost estimate. We have utilised existing framework contracts for the electrical, civil and cabling works. Through other projects within the business we have established a robust cost estimate for the ANM scheme and we will source the Phase 2 system through a competitive tender process. Costs for dissemination and learning are based on our experience on other LCNF projects, with suitable estimates for the new methods we will be trialling in this project. Electrolyser technology is mature, and the costs for electrolyser technology are based on standard packages, with quotes from a number of potential providers , who have been supplying hydrogen production equipment for over 60 years. The costs of the other plant required for the electrolyser (compression and storage), as well as engineering costs are based on estimates from BOC, an experienced gas specialist and one of the world's largest hydrogen providers.

Minimising the possibility of cost overruns or shortfalls in Direct Benefits
PATHS is managed in accordance with the SSE's Large Capital Project Governance Framework (LCP). LCP is a whole-lifecycle tool designed to ensure projects are governed, developed, approved and executed in a consistent and effective manner, with consideration of best practice in project delivery. The framework is applied across all projects valued at over £10m within SSE and the strength of its application demonstrated by ongoing project successes such as Clyde Windfarm - which at £500m is one of Europe's largest onshore wind farms - and the Ferrybridge carbon capture and storage project.The governance framework is phased with six gates at appropriate decision points, with clear, consistent deliverables for each gate. Project governance rules are established and defined for each phase, with standard project organisational structures and key roles.

As PATHS moves through the development and refinement stages it will continue to be subjected to stage gate reviews. The initial reviews consider project readiness and the underlying needs case in order to allow the project to proceed, or if further re-working is required. Similarly, as the project enters the execution and operation stages the project will continue to be reviewed to assess the cost and completion of deliverables.

The governance framework requires increasing cost accuracy as projects pass stage gate reviews. The costing information used in this proposal represents the best available information from SHEPD and the PATHS project partners.

Our project has been constructed as an integrated whole, and any scope changes (if required) by Ofgem prior to project award will require a period of re-planning and possible re-negotiation with collaborators/ suppliers which would delay commencement, and possibly impact on some critical path elements.

Risk management
Risk management will be conducted under the auspices of the SSE Large Capital Project Governance Framework Manual 'Project Risk Management Plan'. The PATHS Project Manager has identified technical, commercial and engineering risks, and will continually review progress on a regular basis, following the reporting and escalation process already in place. The Initial Risk Register is included in Appendix C(ii).

Contingency planning
The project put forward is the optimum physical and commercial arrangement to achieve the Learning Outcomes. There are however a number of alternative paths which the project can take should any issues arise, as detailed in Appendix C (iii).

Assured delivery of learning
Through the combination of effective risk management and contingency planning we can be assured of achieving the PATHS Learning Outcomes. Achieving these is not dependant on any one aspect of the works, and in particular through our phased approach we will deliver initial and then iterated Learning Outcomes. We have strong project management governance in place and full commitment of the senior management team, ensuring that issues are escalated and resolved quickly.

6: Project readiness contd.

Verifying information
Information in this proposal has been developed in conjunction with all project partners and has been subject to checks and analysis to ensure its validity.

Structure of bid
We have worked with our project partners to develop and agree our Learning Outcomes approach. Taking this methodology as the core project principle, the individual deliverables and technologies have been tested to ensure they are relevant. Likewise, the same individual deliverables have been considered in the context of overall technologies and have been similarly tested to ensure they are achievable and effective. Learning Outcomes have facilitated both a bottom-up and a top-down appraisal of the deliverables and technologies as both individuals and in combination.

Carbon and financial benefits cases
The carbon and financial benefits cases have been assessed using a detailed and robust methodology. EA Technology and Element Energy have undertaken a technical and economic analysis to identify the extent of the benefits case, and the sensitivities around this.

Project costs
Cost and technology information has been developed directly by project partners. Project partners are experts in the industry and independent of each other and the electricity distribution industry. As required by SSE's Large Capital Project Governance Framework process we will continue to refine the costs estimates throughout the project development period.

Project management and governance
Overall project rigour and review is in accordance with the SSE Large Capital Project Governance Framework which provides a whole-life cycle stage-gate review process and assess the project viability, delivery and safety with an independent steering group and review bodies. The LCP review process has been applied to verify this bid submission. The project plan has been developed following input from our project partners, to ensure the timescales are both achievable and robust.

Regulatory matters and customer impacts
There are no requirements for derogations to deliver the PATHS project and there are no negative impacts on distribution network customers.

Successful Delivery Reward Criteria

This has been developed in conjunction with our project plan to ensure the criteria put forward is SMART (see Section 9 for more detail).

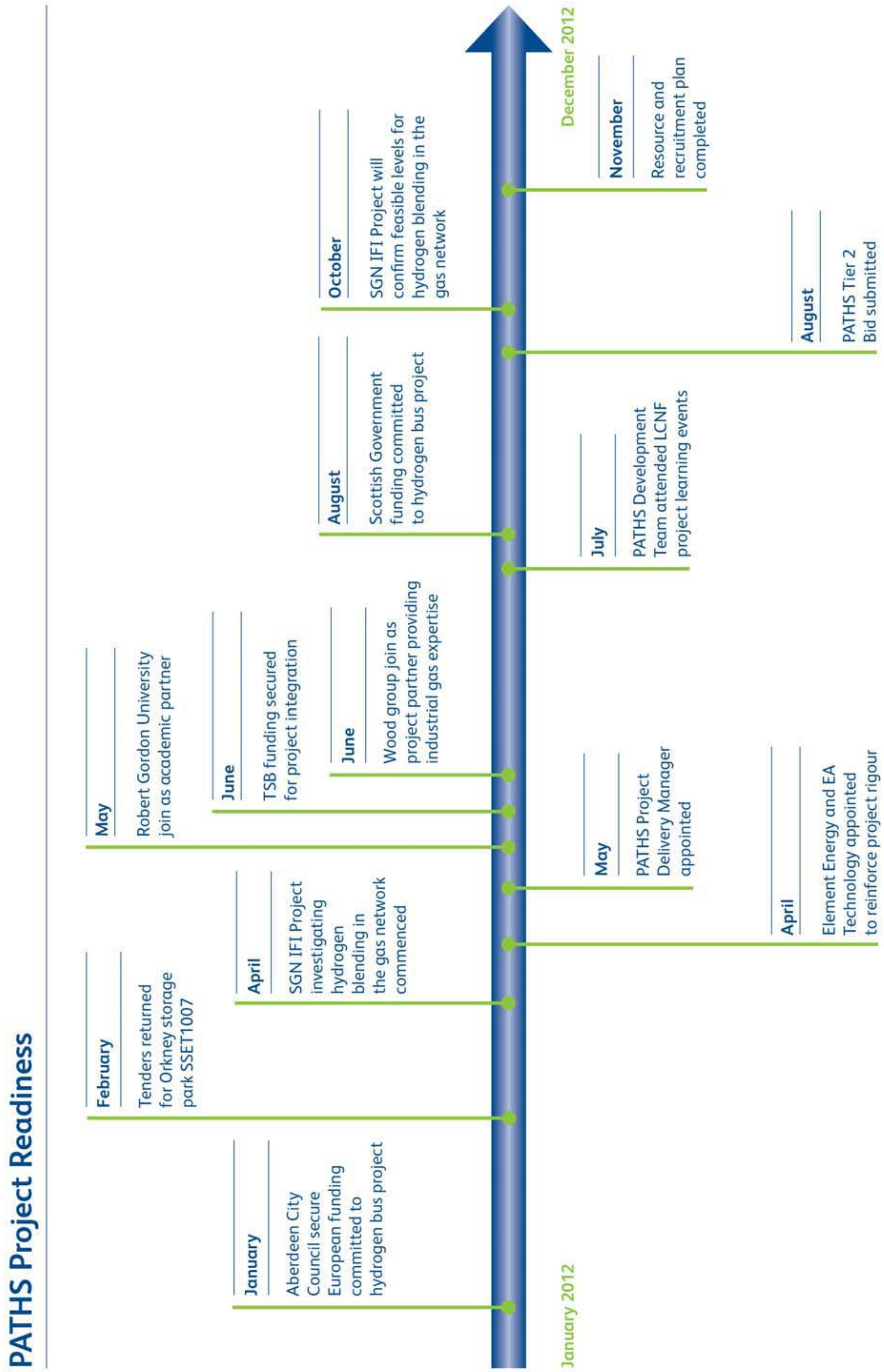
Partner Support
Our project partners are fully committed to the successful delivery of the project and achieving the learning objectives. Details of the project partners can be found in Appendix D.

Identifying when suspension may be appropriate

Risk monitoring procedures will be in accordance with SSE's Large Capital Project Governance Framework. Our project's risk monitoring procedures will be supported by the establishment of a project partner steering group; the Project Director will report on a regular basis to the project board. This is reflected in the Project Organogram detailed in Appendix C(iv).

The members of the project partner steering group are drawn from relevant SHEPD personnel and the key partners (SGN, BOC, Wood Group, Aberdeen City and Aberdeenshire Councils and Element Energy). Our Programme Management Office will be responsible for the co-ordination of relevant project materials via risk/issue registers; planning; document control; finance control and project status reporting. Our Delivery Manager and project partners/suppliers will be responsible for preparing progress control reports, and the Programme Management Office will be responsible for preparing materials for the monthly project board. The responsibility for the decision as to whether the project is to be suspended resides with the project board.

6: Project readiness images



Project readiness Images

Section 7: Regulatory issues

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

The changes expected in the energy sector have resulted in a change to the regulatory framework with Ofgem introducing the new RIIO framework in October 2011. RIIO allows Ofgem to set **Revenue** using **Incentives** to deliver **Innovation** and **Outputs**. The framework is designed to ensure networks play their part in delivering a sustainable energy sector and value for current and future customers. Under this framework we will be required to submit well justified business plans for ED1 that reflect the views, priorities and expectations of all our stakeholders and that will clearly set out deliverables that will provide value for our current and future customers. Innovation is expected to play a central role in our future business plans and we welcome this new approach. We plan to apply the principles set out under the RIIO framework in the PATHS project to help us meet current requirements on the network but also to learn from this project and further test and develop innovative and integrated solutions to meet potential future challenges in the most economic and efficient manner for all customers.

Stakeholder engagement

The PATHS project involves several sectors eg electricity generation, electricity distribution, gas distribution, energy storage and transport and explores the opportunities for a truly integrated approach to energy and transport needs. As such it will require extensive engagement, co-ordination and co-operation across a broad range of stakeholders such as wind farm developers, consumers, and transport bodies. local council, gas distribution network operator, electricity transmission network operator, technology providers and other third parties.

Third party involvement

The project will inform the industry's understanding of the potential opportunities for third party participation in the development and delivery of **integrated low carbon networks**, allowing interested stakeholders to understand the challenges, opportunities, barriers and changes required to the commercial and regulatory framework to facilitate the delivery of economic, efficient and sustainable solutions to some of the challenges it is exploring.

Efficient operation

Alternative network and demand management techniques will be explored to determine the extent to which capital investment may be avoided or deferred while allowing timely connection of low carbon generation and the extent to which this may impact on network operation and costs.

We anticipate the move towards a more integrated and dynamic low carbon network will require increased monitoring and control of the networks. There is a cost associated with this in terms of capital expenditure for the deployment of appropriate equipment and operational costs to process the data collected and turn it into meaningful information. This project will explore the extent to which monitoring and active management is required and the extent to which this can be supported by statistical modelling to minimise capital and operational expenditure.

Impact on incentive regulation and outputs

The project will explore the potential impact and consequences for incentives and output measures under the regulatory framework. It will help us understand the potential need for change to remove barriers or obstacles to change and provide appropriate rewards for flexible, efficient and integrated approaches.

7: Regulatory issues contd.

Charging methodologies

Charging methodologies have evolved over recent years with the introduction of the Common Distribution Charging Methodology (CDCM). The PATHS project will allow us to better understand the behaviours of customers, particularly those who are connecting under managed connections, and the potential need to amend such methodologies in future to provide appropriate cost and value signals to customers connecting. There will be no changes to charging methodologies required in order to implement the PATHS trial.

Commercial arrangements for demand side response / load

The project will collect and review data on customer demand and output patterns and the impact of load management to establish the level of compliance with instructions or requests from the DNO and the potential consequences or impact on the network. It will also explore the levels or type of engagement required to facilitate such services and the financial value attached to such services by customers to inform the development of appropriate commercial arrangements.

Details of derogations required from regulatory or commercial arrangements

At this stage in the project the only requirement for a derogation which may be required is in relation to Engineering Recommendation P.2/6 under Standard Condition 24 of the Electricity Distribution Licence: Distribution System planning standard and quality of performance reporting. This is required to allow the project to explore and demonstrate the value of using Load Management / Demand Side Response as an appropriate means of avoiding or deferring investment and network reinforcement, while maintaining security and reliability of supply. We will work with Ofgem, customers and where relevant other industry participants to develop such derogation, building on the approach adopted in other projects such as the Thames Valley Vision project.

As Load Management/Demand Side Response services will be procured as network services on a voluntary bilateral basis with the relevant customer, no further change is required to any other connection or use of system arrangements or obligations. Power flows will continue to be measured and recorded through the settlement system and be subject to normal CDCM charges, charges and invoicing arrangements. Separate invoices or credit notes will be issued for any commercial network services procured on a bilateral basis for Load Management / Demand Side Response services. The cost of these payments is included in the project's budget. Commercial arrangements for Load Management / Demand Side Response services will provide for:

- A lump sum reward for participation
- A payment or credit against unit rates for avoided consumption / constrained generation during times when the network may otherwise be stressed
- A credit against standing charges or unit rates in exchange for allowing the network operator to install monitoring or control equipment on a switched circuit controlled by SHEPD.
- Credits/ or rewards in exchange for acceptance of special restrictions on new connections (eg maximum export/import capacities subject to change depending on the time of day or the operational status

Collaboration with Gas Distribution Network Operator

This is the first project to involve collaboration with a gas distribution network operator. It is intended that funding will be sought by SGN through the mechanisms , to be introduced under RIIO-GD1. Funding would be used to facilitate the production and entry of hydrogen on the Scotland Gas Network at a later stage in the project. This will allow the project to truly test and develop innovative approaches to integrated system solutions covering electricity, gas and transport. As the NIC is a competitive process and will not take place until the early part of ED1, project finances for this element of the project have been shown separately. As described earlier other potential funding sources have been identified.

7: Regulatory issues images, charts and tables

Regulatory issues images

Regulatory issues images

Section 8: Customer impacts

Energy supply customers

Customers will not experience any planned supply interruptions as a result of PATHS-related work, and the risk of any unplanned interruptions is no different from that associated with `business as usual' operations. PATHS project plans do not involve any direct impact on supply customers and specifically does not require access to customers' premises for any purpose. The customers participating in PATHS, have all done so on a voluntary basis, in order to gain from the project's learning.

PATHS does, however, have the potential to deliver longer term benefits for supply customers and other network customers, including those planning renewable energy developments.

Stakeholder driven

Perhaps the clearest indication that the PATHS project will have a range of positive impacts on stakeholders is the fact that PATHS has been created in response to stakeholder demand. In recent years, SSEPD has been approached on several occasions to become involved in projects which use hydrogen to transfer renewable energy to different energy systems. Through SSEPD's engagement with stakeholders, we considered proposals from Shetland, the Western Isles, the Isle of Wight and Aberdeenshire. Following consideration of the potential for learning offered and the benefits for customers that could be derived from the various projects, SSEPD identified the Aberdeen proposal as the most appropriate project on which to base an LCNF Tier 2 project.

All communities wishing to develop projects involving hydrogen recognised the benefits that the technology could bring to their areas - harnessing of renewable energy sources in cost effective ways and the greening of a range of energy networks, along with the potential for economic development. These are all features of the PATHS project, but the benefits of PATHS will also flow through to customers across Great Britain. Whilst the scale and technical details of the projects may differ, the learning achieved from PATHS will be complimentary to objectives of these projects; this is evidenced in a letter of support received from ITM, a company involved in a number of hydrogen-related projects, including Ecoisland Appendix I.

Direct Customer Involvement

The PATHS trial sites only involve a relatively small number of customers,

- The Phase 1 wind farm operator
- Phase 2 wind farm developer
- Hydrogen Producer

All of the customers listed above are key stakeholders involved in the projects which complement PATHS. For example BOC is providing the hydrogen production, storage and refuelling systems for the proposed bus project. Given the integrated nature of the project it would have been very difficult to open up this approach to a wider customer group at this stage.

Keeping energy bills down

A key aim of PATHS is to develop approaches which will minimise the overall cost of connecting new sources of intermittent generation to the electricity network. As the costs of providing such connections is ultimately met through energy bills, whether through direct charges associated with distribution and transmission costs, or contributing to wholesale energy costs, introducing new, lower cost ways of connecting generation will help minimise electricity bills.

8: Customer impacts contd.

The project benefits described previously only consider the cost of avoided network investment directly associated with new renewable connections. We have not considered, how the PATHS solution could impact on constraints further at higher voltage tiers, for example those triggered by multiple new energy developments in a particular area.

Future Energy scenarios such as National Grids `Gone Green' predict an increase in electricity demand due to the electrification of domestic heating. There are particular references to the increase demand and associated LV network reinforcement caused by the increased deployment of heat pumps. PATHS offers the potential to prolong the life of the existing gas infrastructure whilst facilitating the continued development of a new indigenous UK fuel source. This will serve to avoid future electricity network costs and will also improve utilisation of an existing asset.

In a similar fashion, the future demand growth associated with plug-in electric vehicles will have a significant impact on the distribution network and the LV network in particular. If a proportion of these vehicles are replaced with hydrogen fuelled vehicles (as suggested in UKH_2Mobility), then the impact on the network will be reduced.

In both cases it can be seen that taking a more integrated systems based approach could bring significant additional benefits. The learning and experience gained from PATHS will help the industry better understand the technical and commercial issues associated with an integrated project. Whilst PATHS uses hydrogen as an energy vector, the models developed could be applied to other technologies, such as methanisation.

In addition to minimising the costs of generation connections, PATHS also aims to reduce the time required to provide connections for larger intermittent generation schemes. The PATHS approach is based upon releasing previously inaccessible network capacity within the existing infrastructure.

Accelerating the pace at which new renewable energy schemes connect to the system will reduce uncertainty about future energy provision and accelerate the reduction of reliance on imported fuel.

Generation customers

In preparing this bid, we commissioned a study to understand potential for the application of PATHS-type solutions for new renewable energy developments in Great Britain. The main considerations in establishing whether the solution may work for an individual development include the degree to which the development would overload the distribution network if connected without an associated demand and the capital cost of appropriately sized electrolyser equipment. PATHS would not be applicable in some situations, for example where there is very little capacity available on the distribution network, or where the `overload' from a development would be so small that a traditional connection would be possible at very low cost.

However, the study identified that up to a quarter of wind farms currently in the planning process could potentially benefit from the PATHS approach.

Reducing constraint management costs

PATHS will provide an alternative to paying generators to stop generating in times where supply outstrips demand. In addition to reducing the costs of this aspect of system management, PATHS will also ensure that the maximum amount of renewable energy is captured from Great Britain's renewable energy sources.

8: Customer impacts contd.

Project development - stakeholder relationship

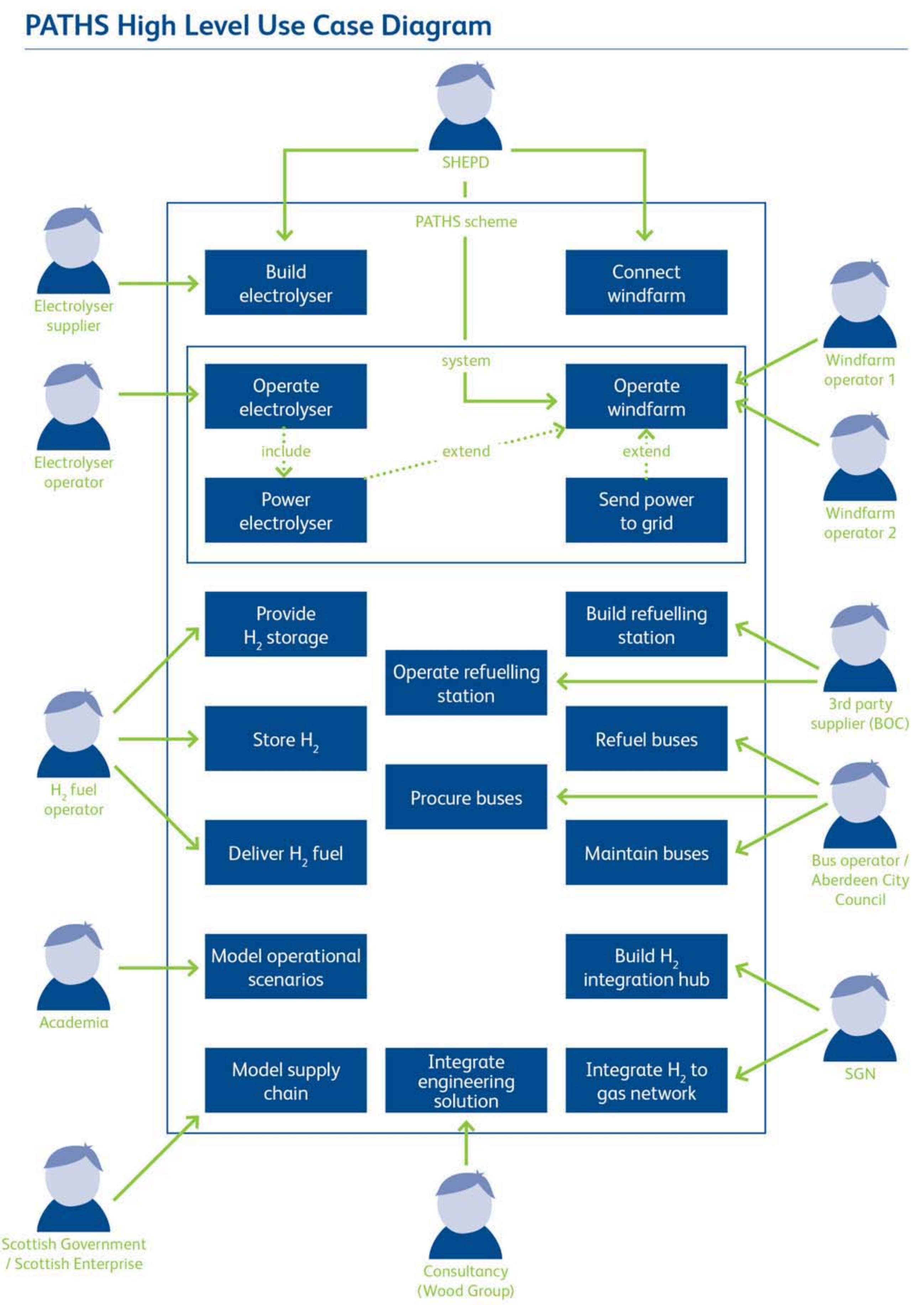
As with our other LCNF projects, we have developed the PATHS project using analysis and modelling tools. The overview project use case has been developed to illustrate the fundamental arrangement of the project, and begin to have an understanding the role of each of the stakeholders - see attached diagram. Through the use of our models we can maximise the project learning and our understanding of business change. The project delivery is focussed on achieving the maximum learning and these tools will be central to achieving this.

Complementary Projects

In line with SSEPD's approach to developing projects in line with stakeholder ambitions, SSEPD has engaged with the community on the Isle of Wight to support the EcoIsland initiative. This will involve the development of a small electrolyser (250kW), the hydrogen generated by which will fuel a range of light commercial vehicles on the Island and may in future feed into other aspects of the island's energy needs. This project complements PATHS by providing learning from the use of an electrolyser of a much smaller scale on non-constrained network, where the intention is not to provide network support services, but to explore how hydrogen can provide other benefits on an island network.

8: Customer impacts contd.

8: Customer impacts images, charts and tables



Customer Impacts images

Section 9: Succesful Delivery Reward Criteria

Criterion (9.1)

Publish key learning from Phase 1: delivery and integration of a 1MWe electrolyser

1) Safety and environmental requirements for electrolyser and hydrogen systems

2) Site selection considerations - particularly in the context of agricultural applications

3) Systems integration - requirements for an active network management scheme to coordinate operation

4) Building and commissioning of the system

5) Testing and initial operational analysis

Evidence (9.1)

1) An outline good practice guide on the design, siting and operation of electrolyser systems.

2) Use cases and business processes detailing the operation of the system

3) Report on the integration and testing of the 1MWe system

4) Publish analysis of the initial operation of the system

Completion date: April 2014

Criterion (9.2)

Publish key learning from Phase 2: integration of 3MWe electrolyser to remove network constraint

1) Update of the areas covered in 9.1

2) The modelling and analysis to support the operation of the system and the ANM rules.

3) Integration with the heat and transport network

4) Network automation to increase demand

Evidence (9.2)

1) Finalised good practice guide on the design, siting and operation of electrolyser systems.

2) Academic paper published.

3) Use cases and business processes detailing the operation of the system

4) Report on the integration and testing of the fully integrated system

5) Published analysis of the system operation

6) Dissemination of the learning at learning events

Completion date: April 2015

9: Succesful delivery reward criteria contd.

Criterion (9.3)

Publish key learning on technical performance of electrolysers as dispatchable load

1) Physical capabilities, eg ramp rates and response times

2) Contractual considerations, eg suitability for the specific application

3) Availability

4) Actual operation in relation to technical specification

Evidence (9.3)

1) Publish a technically robust report covering each of these areas.

2) Academic paper published

3) Develop the necessary tools and methods to incorporate electrolysers into electrical modelling practices

Completion date: June 2016

Criterion (9.4)

Report on the market possibilities which will arise from integrating agriculture, heat and transport with the distribution network.

Agriculture: Forecasts of use of electrolysers on farms and estates and their association with embedded generation, their expected rate of growth, and their effect on the distribution network.

Transport: Forecasts of hydrogen vehicle numbers, their expected rate of growth, application (domestic or commercial) and scenarios for the associated refuelling infrastructure.

Heat: Forecasts of the scale of the markets for application of hydrogen as a means of decarbonising gas (mains gas, LPG conversions, islanded gas grids)

Evidence (9.4)

1) Publish a detailed report covering each of these areas.

2) Publish academic paper on the market opportunities.

Completion date: April 2015

9: Succesful delivery reward criteria contd.

Criterion (9.5)

Develop the methods and tools to establish the physical replication potential for this method across the rest of the UK distribution network

1) Provide a technically robust estimation of the number of locations on the SSEPD distribution networks where the PATHS method could be applied - ie those where electrolysers could provide a benefit for the distribution system

2) Estimate the potential impact of the SSEPD distribution networks of future installation of electrolysers which are not associated with on-site generation - ie those where electrolysers could be challenging for the distribution system

Evidence (9.5)

1) Publish report using an overlay of data from the SSEPD electricity distribution networks, generator sites and identified sources of demand for hydrogen (Agriculture, Heat and Transport) to identify locations where the PATHS method could be applied.

2) Publish report using an overlay of data from the SSEPD distribution networks and identified sources of demand for hydrogen (Agriculture, Heat and Transport) to identify locations where electrolysers may pose challenges for distribution networks.

3) Develop the tools and methods which could be applied to other UK distribution networks to allow all DNOs to investigate the opportunities and challenges that electrolysers could present on their networks.
Completion date: September 2015

Criterion (9.6)

Report on commercial arrangements and models which would support the deployment of the PATHS solution across the rest of the GB distribution network, covering:

1) Revenue streams and operating costs

2) Projected future capital costs of the PATHS solution and the baseline alternative

3) The commercial relationships and operators required to support the deployment of the PATHS solution.

4) Generation connection offers

Evidence (9.6)

1) Publish a detailed report covering each of these areas.

2) Produce use cases and business processes to help develop commercial arrangements for the Great Britain-wide adoption of the PATHS method.

Completion date: September 2015

9: Succesful delivery reward criteria contd.

Criterion (9.7)

Physically complete the infrastructure works to accommodate the full system:

Provide:

1) the physical and electrical infrastructure for the installation of a 3MWe electrolyser; and

2) the advanced active network management system required for the integration of the electrolyser and associated renewable energy scheme with the local distribution network.

Evidence (9.7)

Provision of:

1) Design specifications, schematics and safety documentation

2) Commissioning and completion documentation

3) Photographs of the completed work

There will also be opportunities for stakeholder site visits.

Completion date: February 2015

Criterion (9.8)

PATHS solution toolkit:

Provide the physical, commercial, contractual and stakeholder elements required for the roll out of the PATHS method to the whole of Great Britain.

Evidence (9.8)

Publishing of a collated set of guides, specifications, methods, models, use cases, rules and recommendations which can be used to identify and implement the PATHS solution across all distribution networks.

Completion date: Initial toolkit will be available in 2015, with a full version issued by **September 2016**

Section 10: List of Appendices

Appendix A(i): Business case

Executive Summary

The PATHS solution, if proven, has been shown to give significant GB wide benefits. For the three Methods, there is one direct benefits case and two indirect benefits case.

Table 1 Overview of anticipated financial benefits from PATHS

Method	Type of Benefit	Benefit to 2030	Benefit to 2050
1	Direct	£304m	£304m
2	Indirect	£241m	£558m
3	Indirect	£187m	£2,300m
Total		**£732m**	**£3,162m**

NB. The benefits case for Method 1 has been curtailed at 2030 based on limited data availability

Method 1 – Improve access for renewables generation on the distribution network by active local energy management and energy transfer

Generation connections tend to be bespoke to the network they are connecting into - this is especially true for larger windfarm connections onto the 33kV or 132kV networks. In order to evaluate the business case for a connection with a PATHS-style system, a sample of real SSEPD case studies have been examined. These have then been extrapolated to GB level using projections of onshore wind from National Grid's Future Energy Scenarios document, Nov 2011 and generation datasets available on the blend of onshore windfarms currently in the planning process[2]. This suggests that there is the potential to replicate the solution in up to 25% of all onshore wind connections, 67% by MW capacity by 2030. Using this methodology, a benefits case of **£304m** has been shown[1]. PATHS system sensitivities indicate benefits range from £176m to £498m. These are direct benefits, as they are likely to result from the PATHS project. It is the intention to refine this benefits case further as results are yielded from the PATHS project.

NOTE – impact of PATHS on cumulative constraints, or upstream issues at BSPs and on the Transmission system are outside of this analysis. The benefits from widespread electrolysis for automotive applications could have much greater benefit.

Method 2 – Unconstrain highly congested electricity networks by the transfer of energy to the gas network

To meet GB's carbon targets out to 2050, heat must be decarbonised. In DECC Carbon Plan[2] scenarios, Heat Pumps (HPs) have a prominent effect. HPs are challenging to distribution networks, as the load tends to swamp the conventional diversified demand of a household. This alters the principles upon which the networks are designed, triggering significant investment on the LV networks. If heating was provided by a decarbonised form of gas (e.g. through H_2 injection to the gas grids), rather than via the larger volumes of HPs, GB could continue to

[1] Based on today's prices (i.e. undiscounted and uninflated [i.e. no account for increases in commodity prices and the rising costs of circuit components / transformers])
[2] Source: RenewableUK
[2] These scenarios were also provided in WS1 of the GB Smart Grids Forum

deliver its carbon targets. This can be achieved by using the existing gas infrastructure, reducing the need for significant LV network reinforcement.

A set of HP volumes have been developed and input to the SGF WS3 model. Despite the number of heat pump installations avoided being only ca. 40,000 in 2020 with an estimate of 2-3 times this figure in 2040, the benefits are **£241m** by 2030 and **£558m** by 2050.

This is an indirect benefit of the project, as it cannot be attributed solely to PATHS, but the PATHS type solution would be an enabler in yielding this benefit.

Method 3 – Integrate energy networks and end uses to decarbonise the 'hard to treat' heat and transport sectors with a renewably generated fuel

The potential benefit of having increased numbers of hydrogen fuelled vehicles as against electric vehicles (EVs) has been considered. This work is being carried out using the model developed under SGF WS3 and substituting the uptake levels of EVs between 2012 and 2050 with revised figures accounting for a reduction in EV uptake brought about by a number of hydrogen-fuelled vehicles emerging instead. The results of this analysis (in terms of the reduction in network investment required to allow the connection of an appropriate number of EVs) is shown to be **£187m**[3] by 2030 and upwards of **£2.3bn** by 2050. This is also an indirect benefit of the project, as the PATHS type solution would assist in yielding this benefit.

Further detail to support the PATHS GB Business Case

Method 1 – Improve access for renewables generation on the distribution network by active local energy management and energy transfer

To calculate the business case for PATHS, sample case studies have been examined, representing actual Distributed Generation (DG) connections from SHEPD and SEPD, and some information from the SHETL 132kV network. The thermal overload that the proposed connection introduces to the network, was evaluated. In some instances network reinforcement is required to facilitate such connections, in which case we analyse whether a PATHS-style solution would have been superior to traditional reinforcement. PATHS applicability for larger connections is then assessed to represent the growth in DG connections and the trend for repowering to large turbines

Electrolyser sizes

A range of PATHS and electrolyser sizes was specified by Element Energy. The potential overload size on a network, with the generator load factor, informed the economic threshold for these systems. (Overloads here refer to situations when the demand placed on an asset exceeds its rating; however it should be noted that this can take the form of an excess of generation causing an overload via reverse power flow as there is insufficient local demand to absorb the generation). For example, if an overload were of the order of 100kW, it is

[3] Discounted totex out to 2050 based on WS3's Scenario 1 [High Heat, Medium Transport] when applied to the Business-As-Usual (Conventional solutions only) Investment Strategy

unlikely that a solution involving an electrolyser would be deemed to be financially viable, while an overload in excess of 50MW is likely to require wholesale reinforcement. Table 2 summarises the standard electrolyser sizes used, and the instances in which they would be considered.

PATHS capacity scales to the network constraint and the size of generator to be connected. Based on other LCN Fund projects and applications of smart solutions a figure of 10% or larger has been deemed to be sufficiently useful for DNOs in addressing network constraints. The maximum size has been capped at 5MW. While the use of 5MW electrolysers may seem unlikely at present, this has been included in the analysis as it may be the case that in the next 20 years as uptake of hydrogen-fuelled vehicles increases, the demand for this type of technology could increase, making it a more attractive option.

Table 2: Electrolyser sizes considered in analysis

Overload size (MW)	PATHS applicability
<0.5	Manage connection through alternative means
0.5 – 2	Consider use of 0.5MW electrolyser
2 – 4	Consider use of 0.5MW or 1MW electrolyser
4 – 6	Consider use of 1MW electrolyser
6 – 10	Consider use of 1MW or 3MW electrolyser
10 – 30	Consider use of 3MW electrolyser
30 – 50	Consider use of 3MW or 5MW electrolyser
>50	Consider use of 5MW electrolyser, or wholesale reinforcement of the network to facilitate connection

Analysis results

Table 3 shows the results of the analysis. For each generator, the potential applicability of a PATHS-style solution is indicated for a range of generator sizes. The cells are shaded where the use of an electrolyser was deemed to be worthy of consideration.

Table 3: Analysis of applicability of an electrolyser to generation connections[4]

Gen ref	Generator size (MW)	Generator type	Voltage of connection (kV)	Case for PATHS - possible electrolyser size (MW)			
				x1	x1.5	x2	x4
1	12.5	Wind Farm	33	3	3	3-5	5
2	4.6	Wind Farm	33	0	0	0	0
3	52.5	Wind Farm	33	0	0.5	1-3	5
4	4.6	Wind Farm	33	0	0	0	0
5	2.3	Wind Farm	33	0	0	0	0
6	6.9	Wind Farm	33	0	0	0	0.5
7	7.5	Hydro	33	0	0.5-1	1-3	3
8	18.4	Wind Farm	33	0	0.5	1	3
9	9.949	Wind Farm	33	0	0	0	0.5-1
10	6.9	Wind Farm	33	0	0	0	0.5

[4] This analysis was based on real case studies provided by SSE (15 from SHEDL, 3 from SHETL and 4 from SEPD)

11	10	Tidal	33	0.5	0.5-1	1	3
12	8.3	Biomass	33	0	0	0	0.5-1
13	9.9	Wind Farm	33	0	0	0	0.5-1
14	4.6	Wind Farm	33	0	0	0	0.5-1
15	3.5 extension (17MW total)	Wind Farm	33	0.5-1	1	1	1
16	108	Wind Farm	132	0	5	5	5
17	81	Wind Farm	132	3	5	5	5
18	66	Wind Farm	132	3	5	5	5
19	10	PV Farm	33	0	0	0	1
20	14	PV Farm	33	0	0	0	1
21	5	PV Farm	33	0	0	0	0
22	6	PV Farm	33	0	0	0	0.5-1

Out of the 22 considered, 5 generators could be suitable for PATHS. With a size factor of 4 applied, this rises to 18. (It is acknowledged that 4 is extreme multiplier for this analysis, but it demonstrates that PATHS is not viable for some of the largest generators. Key points on the 5 identified generators are provided:

- **Generator 1:** Seeking to connect into a network saturated with capacity. Reinforcement is necessary by way of transformer replacement. A 3MW electrolyser here is a large proportion of the export capacity, but nevertheless is helpful in connection ahead of (or instead of) replacing a transformer.
- **Generator 11**: This would result in a small potential overload of a transformer (1MW) and a larger circuit overload (up to 3MW). Replacement of the transformer may well be avoidable through the use of a small electrolyser.
- **Generator 15:** Strengthening would be required to increase export capacity, which would be the generators cost.
- **Generator 17:** An ANM solution would be required to connect the generator. A PATHS system could have benefits in permitting generation to occur.
- **Generator 18:** Similar to Generator 17; a PATHS system could reduce the amount of power reverse flowing up to the 275kV system which would negate a reinforcement requirement and accelerate connection.

Wider applicability

In all cases with a PATHS system, an ANM solution would also be required. All of the above cases are for connections at 33kV and 132kV. There is no reason, in principle, why a PATHS-type solution could not be deployed at 11kV, economics are likely to be better at higher voltages.

Table 4: Number of generator connections forecast in RIIO-ED1

	SEPD	SHEDL	Total
Number of HV generators connecting in RIIO-ED1 (2015-23)	64	368	432
Number of EHV generators connecting in RIIO-ED1 (2015-23)	16	11	27

The above table shows the generator forecast for RIIO-ED1. These do not include 132kV connected generation - two of the five generators identified as PATHS suitable were at 132kV. A conservative estimate is that 3 of the 22 (14%) of EHV generator connections may be suitable for PATHS. From Table 4, this amounts to 4 of the 27 EHV generators identified for SSEPD in the RIIO-ED1 period.

Cost-benefit analysis

Base Case

The cost of a PATHS solution must be weighed against the counterfactual (conventional reinforcement to facilitate connection of generation). For the 22 cases above, the counterfactual cost of underground cable, overhead line and switchgear for a connection, is costed. Five categories of generator were defined (small, small-medium, medium, medium-large and large) and the average cost of connection of each was calculated from the sample, making use of DPCR5 unit costs, knowledge gained from the SGF WS3 activity and input from SSEPD. All counterfactual costs have been calculated using the above method. Outputs are given in Table 5, noting that these are indicative and that a larger and more detailed sample would improve accuracy. These costs, based on real connections are, by definition, cost effective. To account for the complexities that are likely to result from multiple generation connections and limited network capacity a further multiplier of 1.5x has been applied to represent costs in a 2020+ network.

Table 5: Calculated average costs for electrical connection of generators of differing sizes (counterfactual case)

Generator class	Size (MW)	Average cost of connection (£k)	Average connection costs x1.5 (£k)
Small	<5	391	**587**
Small-Medium	5 to 15	1,439	**2,159**
Medium	15 to 30	2,878	**4,317**
Medium-Large	30 to 45	4,316	**6,474**
Large	>45	6,189	**9,284**

Due to limited data costs for the medium and Medium-Large generators are interpolated between the data for Small-Medium and Large. As generators increase in size the costs are shown below. Shaded cells are deemed **technically** suitable for PATHS.

Table 6: Counterfactual costs for connecting generators as size increases

Generator reference	Initial Generator size (MW)	Counterfactual cost of connection for varying size (£k)			
		x1	x1.5	x2	x4
1	12.5	2,158	4,316	4,316	9,284
2	4.6	586	2,158	2,158	4,316
3	52.5	9,284	9,284	9,284	9,284
4	4.6	586	2,158	2,158	4,316
5	2.3	586	586	586	2,158
6	6.9	2,158	2,158	2,158	4,316

7	7.5	2,158	2,158	4,316	6,474
8	18.4	4,316	4,316	6,474	9,284
9	9.949	2,158	2,158	4,316	6,474
10	6.9	2,158	2,158	2,158	4,316
11	10	2,158	4,316	4,316	6,474
12	8.3	2,158	2,158	4,316	6,474
13	9.9	2,158	2,158	4,316	6,474
14	4.6	586	2,158	2,158	4,316
15	3.5 extension (17 MW total)	2,158	2,158	4,316	6,474
16	108	9,284	9,284	9,284	9,284
17	81	9,284	9,284	9,284	9,284
18	66	9,284	9,284	9,284	9,284
19	10	2,158	4,316	4,316	6,474
20	14	2,158	4,316	4,316	9,284
21	5	2,158	2,158	2,158	4,316
22	6	2,158	2,158	2,158	4,316

Smart Solution Case

Deployed totex costs (capital plus annual opex, less any annual revenue) for electrolyser sizes have been provided by Element Energy and are shown below.

Table 7: PATHS totex costs for connecting generators as size increases

Generator reference	Initial Generator size (MW)	PATHS electrolyser cost for varying size (£k)			
		x1	x1.5	x2	x4
1	12.5	6,263	6,263	8,338	10,413
2	4.6	0	0	0	0
3	52.5	0	1,076	4,189	10,413
4	4.6	0	0	0	0
5	2.3	0	0	0	0
6	6.9	0	0	0	1,076
7	7.5	0	1,595	4,189	6,263
8	18.4	0	1,076	2,114	6,263
9	9.949	0	0	0	1,595
10	6.9	0	0	0	1,076
11	10	1,076	1,595	2,114	6,263
12	8.3	0	0	0	1,595
13	9.9	0	0	0	1,595
14	4.6	0	0	0	1,595
15	3.5 extension (17 MW total)	1,595	2,114	2,114	2,114
16	108	0	10,413	10,413	10,413

17	81	6,263	10,413	10,413	10,413
18	66	6,263	10,413	10,413	10,413
19	10	0	0	0	2,114
20	14	0	0	0	2,114
21	5	0	0	0	0
22	6	0	0	0	1,595

Shaded cells indicate **technically** suitable for PATHS. Looking forward, new generation connections are likely to be larger, hence the "x2" size multiplier is used – it also reflects that connection will be more difficult, making constrained connections, or those requiring some sort of additional management more likely.At the "x2" level, 4 of the 22 generators are classified as large, 1 is classified as medium-large, 9 are medium, 7 are small-medium with only 1 being small.

From the "x2" column, 9 out of 22 generators that could be technically eligible for an electrolyser. Of these 9, four of them are classified as "medium", one is "medium-large", while the remaining 4 are "large".

By comparing the results of Table 6 with Table 7, it is possible to ascertain which of the technically suitable sites are economically viable (i.e. where the costs of the PATHS solution is cheaper than the counterfactual). The results of this (and the benefits) are shown below.

Table 8: Cost saving arising through the use of an electrolyser as opposed to the counterfactual connection

Generator reference	Initial Generator size (MW)	PATHS economically valid cases (benefits £k)			
		x1	x1.5	x2	x4
1	12.5	-	-	-	-
2	4.6	-	-	-	-
3	52.5	-	8,208	5,095	-
4	4.6	-	-	-	-
5	2.3	-	-	-	-
6	6.9	-	-	-	3,240
7	7.5	-	563	128	211
8	18.4	-	3,240	4,361	3,020
9	9.949	-	-	-	4,880
10	6.9	-	-	-	3,240
11	10	1,082	2,721	2,203	211
12	8.3	-	-	-	4,880
13	9.9	-	-	-	4,880
14	4.6	-	-	-	2,721
15	3.5 extension (17 MW total)	563	45	2,203	4,361

16	108	-	-	-	-
17	81	3,020	-	-	-
18	66	3,020	-	-	-
19	10	-	-	-	4,361
20	14	-	-	-	7,170
21	5	-	-	-	-
22	6	-	-	-	2,721

For Table 8 the **technically** suitable generators are shaded, and the **economically** suitable generators are shown by their £ benefit. For the "x2" column there are 5 of 22 generators that could be economically eligible for an electrolyser. Of these 5, three of them are classified as "medium", one is "medium-large", while the remaining one is "large".

Table 9: Average benefit realised through using electrolyser to facilitate connection, split by generator size

Generator classification	Average benefit of PATHS over counterfactual at x2 multiplier (£k)
Small	0
Small-Medium	0
Medium	1,165
Medium-Large	3,282
Large	5,095

Scaling of benefits to GB

In order to scale this to a GB level, data from RenewableUK showing wind generation currently in planning has been considered[5]. The RenewableUK website has information on the mix of generation:

- **Connected** – Sites generating electricity onto the network today
- **In construction** – Generation currently being built
- **Consented** – Projects with design approval and awaiting commencement of construction
- **In planning** – Projects currently in the design process

[5] http://www.bwea.com/ukwed/planning.asp

Table 10: Breakdown of wind farms as taken from RenewablesUK (http://bwea.com/statistics/ extracted 8th August 2012)

Operational wind farms

Onshore			Offshore		
England	125	993.26 MW	England	13	1,698.20 MW
Northern Ireland	34	440.43 MW	Scotland	1	10.00 MW
Scotland	139	3,122.11 MW	Wales	2	150.00 MW
Wales	38	423.40 MW		**16**	**1,858.20 MW**
	336	**4,979.20 MW**			

Total operational wind farms: 352 (6,837.40 MW)

Wind farms currently under construction

Onshore			Offshore		
England	30	530.55 MW	England	5	1,782.90 MW
Northern Ireland	4	59.30 MW	Wales	1	576.00 MW
Scotland	29	1,094.50 MW		**6**	**2,358.90 MW**
Wales	5	111.00 MW			
	68	**1,795.35 MW**			

Total wind farms currently under construction: 74 (4,154.25 MW)

Consented projects

Onshore			Offshore		
England	104	904.93 MW	England	7	2,370.00 MW
Northern Ireland	32	476.50 MW	Scotland	1	7.00 MW
Scotland	113	2,261.12 MW		**8**	**2,377.00 MW**
Wales	14	448.90 MW			
	263	**4,091.45 MW**			

Total consented projects: 271 (6,468.45 MW)

Projects in planning

Onshore			Offshore		
England	95	1,052.25 MW	England	4	1,854.90 MW
Northern Ireland	33	552.40 MW	Scotland	3	1,450.00 MW
Scotland	184	4,776.89 MW		**7**	**3,304.90 MW**
Wales	36	1,190.26 MW			
	348	**7,571.80 MW**			

Total projects in planning: 355 (10,876.70 MW)

Here, generation in-planning has been used to scale the SSEPD datasets, based on the assumption that it is too late to apply a PATHS solution to the generation under construction or consented. Whilst it is expected that not all of the generators currently in planning will commence, the total figures strongly correlate to the total amounts of onshore wind that National Grid are expecting under their Gone Green and Slow Progression scenarios as part of their UK Future Energy Scenarios work.

Table 11: Wind projections taken from National Grid's UK Future Energy Scenarios, Nov 2011

Wind Capacity	2010		2020		2030	
	Offshore	Onshore	Offshore	Onshore	Offshore	Onshore
Gone Green	1.3GW	4GW	17GW	11GW	38GW	13GW
Slow Progression	1.3GW	4GW	10GW	11GW	17GW	12GW

The projects on the RenewableUK site are an accurate illustration of the likely sizes of generation to be expected in years to come. Based on this dataset, the split of generation connections by the sizes described earlier is shown in Figure 1.

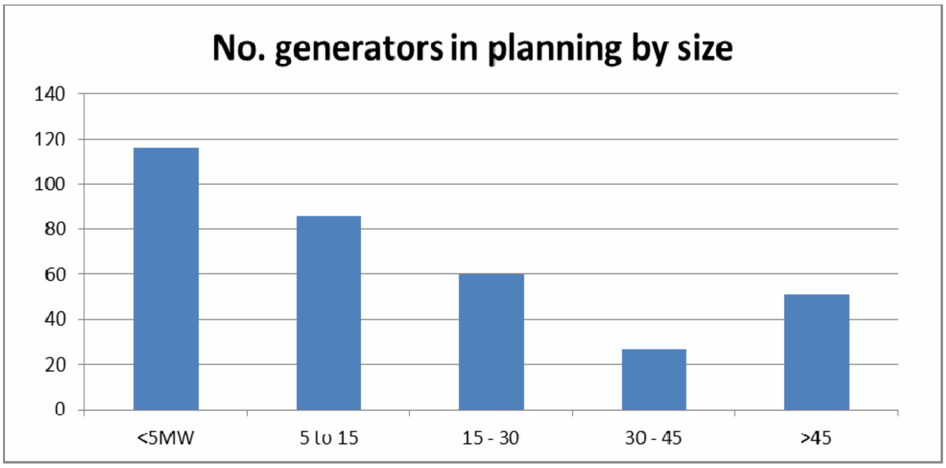


Figure 1: Number of renewable generators currently in planning split by size (source: RenewablesUK)

This data shows that there are 51 large generators, 27 medium-large and 60 medium generators. The previous analysis showed that 100% of the generators classed as large and 100% of the generators classed as medium-large, could be eligible for a PATHS-type solution, while 44% of the generators classes as medium may be suitable. Scaling to a GB level, all generators classes as large and medium-large may be suitable (51 and 27 respectively). Of the medium generators, 44% are envisaged to be suitable, equating to a further 27 generators from the RenewableUK figures.

Table 12: Scaling of the SSE dataset to GB levels

Capacity (MW)	S <5	MS 5-15	M 15-30	ML 30-45	L >45	Totals
Count of generators in planning	116	86	60	27	51	**340**
Total windfarm generation capacity (MW)	190	868	2,202	3,160	7,381	**13,801**
Average windfarm size (MW/site)	2	10	37	117	145	**n/a**
Percentage of windfarm sites applicable for PATHS	0	0	44%	100%	100%	**49%**
Numbers of windfarm sites applicable for PATHS	-	-	27	27	51	**105**
Optimism bias applied to scale down PATHS volumes (x 0.8)	-	-	21	22	41	**84**
PATHS case based on volume x average (MW)	-	-	783	2,528	5,905	**9,215**

Thus, overall there could be some 105 generators across GB, for which PATHS could be considered as a viable solution. This has then been scaled by a 0.8x optimism bias to suppress the benefits in the PATHS business case to account for other unknowns. The total benefit across GB is calculated as shown below.

Table 13: Total benefit across GB of using electrolysers to aid in connection of renewable generation

Gen size	Average PATHS benefit (£k)	Number of GB WF applications	PATHS NPV (£k)
S	0	0	0
MS	0	0	0
M	1,165	21	24,888
ML	3,282	22	70,885
L	5,095	41	207,890
Total			**303,663**

Method 2 – Unconstrain highly congested electricity networks by the transfer of energy to the gas network

To decarbonise heat out to 2050, within the DECC carbon plan Heat Pumps (HPs) have a prominent role, with deployment between 2m and 8m units to 2030 extrapolated to 5m to 15m by 2050. HPs loads swamp the conventional diversified demand of a household triggering significant investment on the LV networks. The Smart Grids Forum WS3 report, published August 2012, reflected this. PATHS provides an additional means of decarbonisation of heating, potentially reducing the need for HPs and associated LV network reinforcement. In order to quantify this, a reduced set of HP volumes have been developed and input to the WS3 model. These are based on the number of predicted PATHS systems from method 1 above, with the associated gas volumes offsetting a number of HP systems in houses and therefore is a very conservative figure as additional systems could be developed. Despite the number of heat pump installations avoided being only ca. 40,000 in 2020 with an estimate of 2-3 times this figure in 2040, the ES3 model predicts benefits are **£241m**[6] by 2030 and **£558m** by 2050. This is an indirect benefit of the project, as it cannot be attributed solely to PATHS, but the PATHS type solution would assist in yielding this benefit.

Table 14: Benefits of a reduced number of heat pumps on the network as a potential result of H_2 injection into the gas grid

	Average Benefit (discounted totex, cumulative)	Average benefit (totex, cumulative)
2012-2020	£ -	£ -
2021-2030	£ 241,401,934	£ 416,941,898
2031-2040	£ 491,749,388	£ 875,992,963
2041-2050	£ 557,661,648	£ 937,840,617

NB. average figures have been used to smooth the results of the model, which are inherently 'lumpy' for the Business-As-Usual Investment case

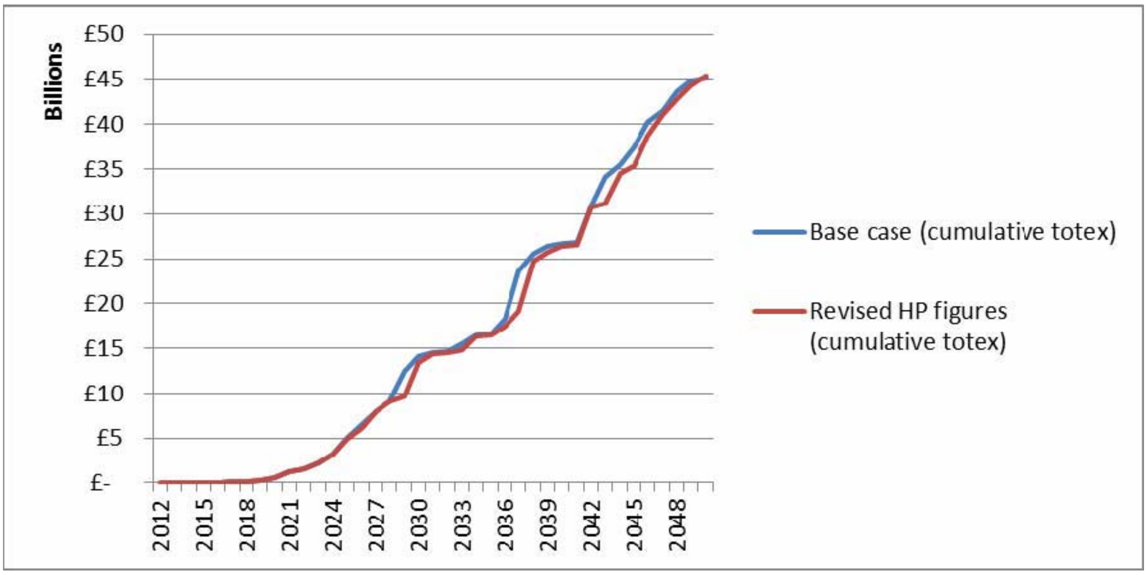


Figure 2: Cumulative investment profiles (gross, non discounted) for the Base Case and the Reduced HP numbers

[6] Discounted totex based on WS3's Scenario 1 [High Heat, Medium Transport] when applied to the Business-As-Usual (Conventional solutions only) Investment Strategy

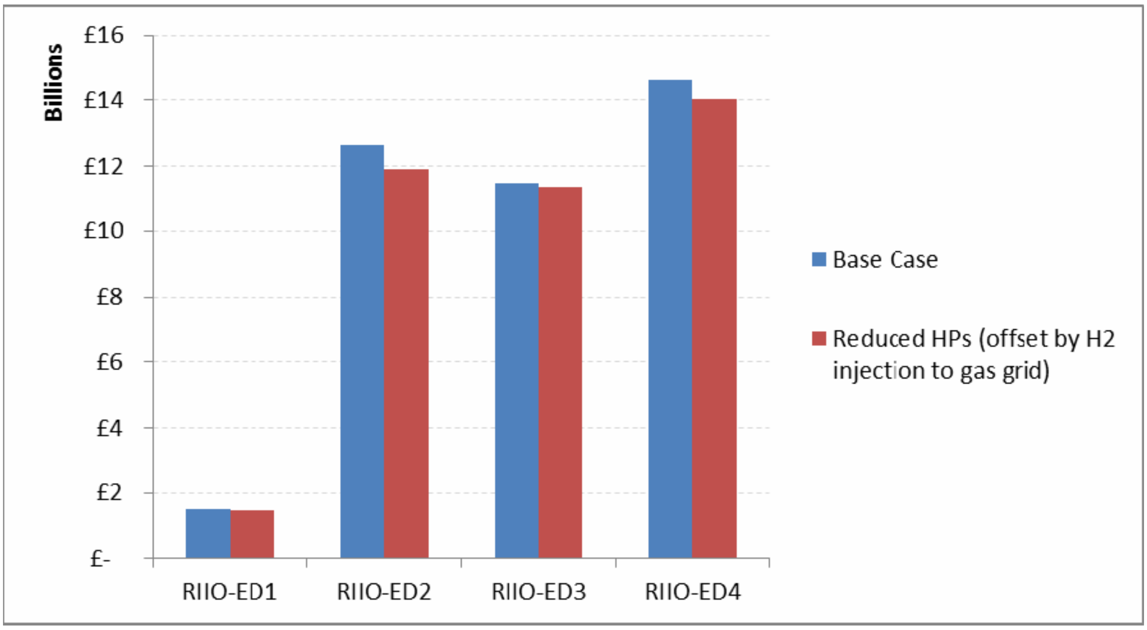


Figure 3: Impact of spend profiles the lower HP volumes have by RIIO price control periods (Gross totex costs, non-discounted based on Scenario 1, Business-As-Usual Investment Strategy)

Method 3 – Integrate energy networks and end uses to decarbonise the 'hard to treat' heat and transport sectors with a renewably generated fuel

The potential benefit of having increased numbers of hydrogen fuelled vehicles as against electric vehicles (EVs) has been considered to support Method 3. This work is being carried out using the model developed under SGF WS3 and substituting the uptake levels of EVs between 2012 and 2050 with revised figures accounting for a reduction in EV uptake brought about by a number of hydrogen-fuelled vehicles emerging instead.

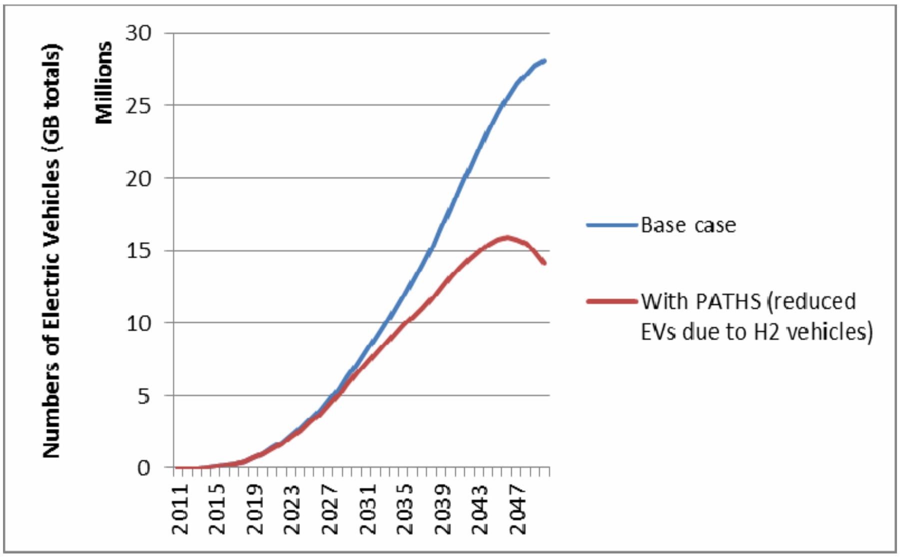


Figure 4: Base case and revised numbers of Electric Vehicles showing the potential reduction with an increase in H_2 vehicles – used as an input in the WS3 model (source: Element Energy)

Key points on the 'With PATHS' scenario:

- Up to 2040; H2 vehicles are taking a small proportion of the EV new sales.
- After 2040; the DECC baseline assumes no more EV growth – i.e. the market is saturated with EV's. So H2 vehicles start to eat into the EV stock after 2040.
- The slowing in growth of EV numbers in the DECC scenario is due to an
- assumption that the car stock has become saturated with EVs (rather than any existing assumption that the EV market is being eroded by a competitor technology), so if a competitor technology were to come along a sharp drop in EV numbers, as shown, is plausible.

An increase in the number of electrolysers could be advantageous in helping to drive such an increase in hydrogen-fuelled vehicles and could be a second order benefit to PATHS-type solutions being deployed more widely.

The results of this analysis (in terms of the reduction in network investment required to allow the connection of an appropriate number of EVs) is shown to be **£187m**[7] by 2030 and upwards of **£2.3bn** by 2050.

Table 15: Benefits of a reduced number of EVs on the network as a potential result of H_2 vehicle deployment

	Average Benefit (discounted totex, cumulative)	Average benefit (totex, cumulative)
2012-2020	£ -	£ -
2021-2030	£ 186,941,295	£ 323,713,409
2031-2040	£ 736,216,577	£ 1,511,853,250
2041-2050	£ 2,294,029,416	£ 6,020,926,923

Figure 5: Cumulative investment profiles (gross, non discounted) for the Base Case and the Reduced EV numbers

Figure 6: Impact of spend profiles the lower HP volumes have by RIIO price control periods (Gross totex costs, non-discounted based on Scenario 1, Business-As-Usual Investment Strategy)

As for Method 2, this is an indirect benefit of the project, as it cannot be attributed solely to PATHS, but the PATHS type solution would assist in yielding this benefit.

EA Technology Ltd
09-08-12

[7] Discounted totex out to 2050 based on WS3's Scenario 1 [High Heat, Medium Transport] when applied to the Business-As-Usual (Conventional solutions only) Investment Strategy

Appendix A(ii): Explanation of method costs

Introduction
The method costs for replicating method 1 have been estimated assuming that the PATHS project is proven a success. The method costs show reductions compared to the PATHS project from 2 main sources;

1) Work packages included in PATHS on knowledge, training, learning and dissemination will not be required once PATHS is proven a success.
2) In some cases cost reductions in components are expected over the coming few years, and these reductions are independent of the success of the PATHS project.

Method costs have been estimated for a range of PATHS sized solutions which relate to electrolyser sizes required for replication as set out in Table 2 in Appendix Ai. Reflecting uncertainty in some capital equipment, ongoing costs and revenues, and operational modes, a variety of PATHS costs have been estimated. A baseline scenario has been used to calculate the benefits of replicating the PATHS project. Pages 2-3 of this Appendix sets out the other scenarios for the method costs.

The baseline method costs
The method cost for method 1 set out in the full submission spread sheet is for an electrolyser system at 1MW, and for the baseline scenario. The costs along with the assumptions for the baseline scenario are set out below:

Components of capex costs:
The Electrolyser: Whilst electrolysis is a mature technology, it is not yet a widespread technology and improvements in costs are expected over the next 8 years. We have assumed a cost of £800/kw in 2020 compared to £1300/kw today[1]. The electrolyser efficiency is assumed to remain the same as for PATHS. This is a conservative assumption, as in practice improvements in efficiency are expected.

Balance of plant and engineering costs: This includes compression and storage costs, as well as installation (engineering). These costs are assumed to be mature and will not reduce significantly if PATHS is proven a success. This is a conservative assumption, as in practice storage costs are likely to reduce as hydrogen production increases. These costs will scale with the size of the electrolyser system.

Grid connection costs and civil engineering costs: These costs are unlikely to reduce once PATHS is proven a success, and the main variation will be due to site specific factors. Therefore these costs are assumed to be the same as for the PATHS project and to scale with electrolyser capacity.

The ANM system: ANM systems are relatively novel and are expected to decrease in cost in the coming years, when systems will be relatively centralised and the main cost components are likely to be software licences. We have assumed the cost of an 11kV ANM system based on the Smart Grid Forum Workstream 3 results, with a capital cost of £50k.

Opex costs:

These comprise maintenance of the electrolysers, project management costs and electricity costs. The maintenance of the electrolyser system is 3% of the cost of the electrolyser system, and so costs will reduce in future because electrolyser

[1] Portfolio of Powertrains for Europe, McKinsey et al. 2010

costs are expected to reduce (see above). Project management is estimated at 3% of the total project cost. Electricity costs are predicted to rise, and the current wholesale market prices of 5p/kWh have been scaled using the scaling factors from DECC estimates of future wholesale prices, resulting in an electricity price of 7p/kWh. DUoS charges have been included, but these have not been increased above the rate of inflation.

Revenues:

Revenue streams come from the sale of hydrogen and from grid balancing services. We have assumed a price of £4.50/kg for hydrogen to transport fuel. This is the price before distribution to a refilling station, and generates a cost equivalent to diesel. We have assumed 50% of the hydrogen is sold into the transport market, and the remainder is sold into the merchant hydrogen market at a price of £3/kg.

In the baseline method costs we do not assume any hydrogen is sold to the gas grid, given the uncertainty about the future regulatory regime (see scenario 4 gas injection below for the results and assumptions when hydrogen is sold into the gas grid).

Grid balancing services are assumed to hold the same value as today, and we have assumed revenues based on a value for STOR of £29k/MW/year capacity payment and £6k/MW/year for utilisation payments. This is a conservative assumption as the value of the market is expected to double by 2020[2].

Scenarios

A number of scenarios for the method costs were considered, and their costs are set out in the graph below. A brief explanation of each scenario follows:

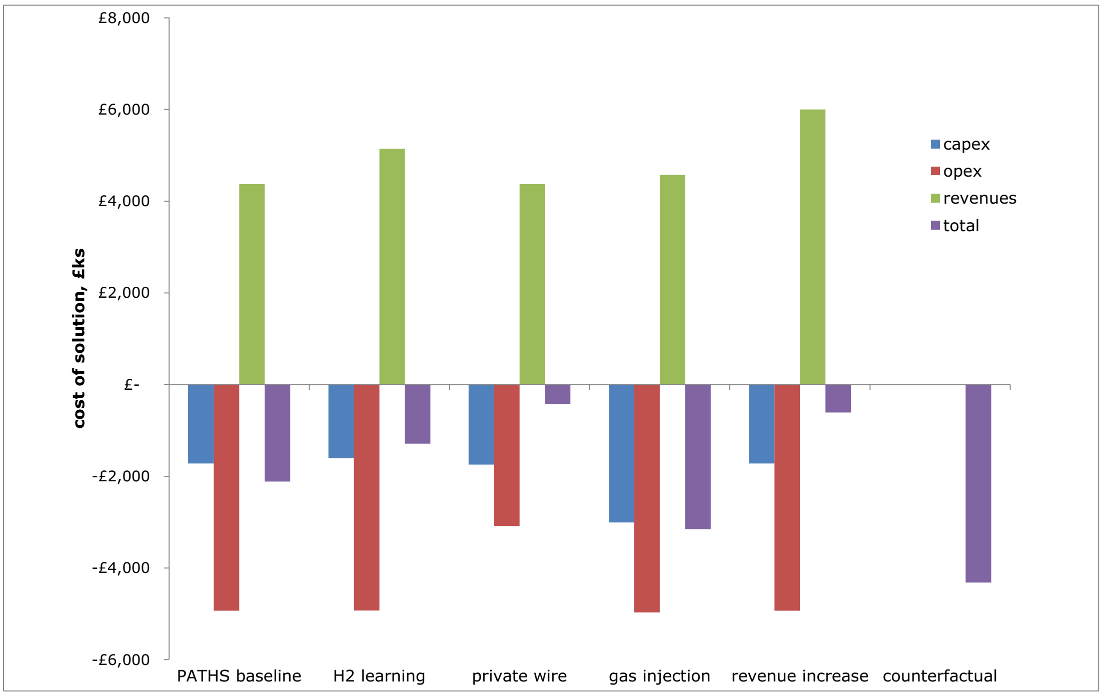


Figure 1 Scenarios for the method costs, based on NPVs in 2020. Total costs compared to the counterfactual are presented, along with a breakdown for each method scenario of capex, opex and revenues.

[2] National Grid, Operating the Electricity Transmission Networks in 2020

PATHS baseline: as set out above

H2 learning: this assumes some reduction in compression and storage costs, and improvements in electrolyser efficiency from 64% currently to 78%[3] which lead to an increase in revenues.

Private wire: this considers the case where the electrolyser is connected directly to the renewable generator via a private wire arrangement, and thus is able to access cheaper electricity prices (5p/kWh as opposed to 7p/kWh), and no DuoS charges.

Gas injection: this includes the cost of the network entry plant for hydrogen gas injection (£775k in 2020), and that the 50% of hydrogen that is sold as merchant hydrogen in the baseline scenario is instead sold into the gas grid. The price of hydrogen to the gas grid is £3.36/kg, which is based on 3.3p/kWh (the projected price of wholesale gas in 2020, DECC) and the current Renewable Heat Incentive rate for biogas of 6.8p/kWh is assumed. Note that, for a 1MW system, the increased price of hydrogen to the gas grid compared to merchant hydrogen is not enough to recoup the capex costs of the network entry plant. However at larger electrolyser sizes of 5MW, the revenues are nearly enough to recoup the cost of the network entry plant (see Table 1 below). Although there is significant uncertainty around the value of hydrogen to the gas grid once the method is proven successful, this result implies that hydrogen gas injection will only be economic for relatively large electrolyser systems.

Revenue increase: this assumes that the value of hydrogen to transport is higher than the conservative assumption (£5/kg compared to £4.50/kg) and that there is a demand for all of the hydrogen produced. This also assumes that the revenues from providing balancing services double from £35k/MW/year to £70k/MW/year.

Table 1: method costs of different scenarios, at difference system sizes NPV £ks.

MW of system	PATHS baseline	H2 learning	private wire	gas injection	revenue increase
0.5	-1076	-663	-230	-2211	-323
0.75	-1595	-975	-327	-2683	-466
1	-2114	-1287	-425	-3156	-608
2	-4189	-2535	-815	-5046	-1177
3	-6263	-3784	-1205	-6936	-1746
4	-8338	-5032	-1595	-8826	-2315
5	-10413	-6281	-1985	-10717	-2885

[3] Summary of Electrolytic hydrogen production, NREL, 2004.

Appendix B: Technical description

Introduction

UK Government modelling suggests that around 60–80 GW of new electricity capacity will need to be built by 2030, and of this around 40–70 GW will need to come from low carbon technologies, such as nuclear, renewables and fossil fuel stations with CCS[1]. By 2020, 30% of the UK's electricity supply needs to come from renewable sources. As the UK moves towards an increasing proportion of electricity being produced by renewable energy, the requirement for services that can either smooth or balance intermittent electricity generation will also increase.

The UK Government recognises this: "storage has significant potential to grow (particularly with the electrification of heat and transport) as it can capture energy generated by inflexible low-carbon generation and reproduce this in times of scarcity. It also offers significant technical flexibility which can assist the fine tuning of the network which is carried out by the System Operator (SO), National Grid[2]."

Recent research by Imperial College London[3] shows that the value of energy storage increases significantly with increasing penetration of renewable generation. In a high renewables scenario (DECC Pathways, Grassroots scenario), energy storage technologies could generate whole systems savings of £10 billion/year by 2050. However the study notes that the time scales and rate at which the value of storage increases poses a strategic challenge. The long-term value will not be very tangible to market participants in 2020, yet a failure to deploy storage in a timely manner may lead to higher system costs in 2030 and beyond.

2 The Current Network Configuration

Bridge of Don is a suburb located to the north of Aberdeen. It is primarily a residential area the majority of which is heated by gas; therefore there are only a limited number of electrically heated homes. However, the area does have a significant commercial and industrial customer base primarily involved in the oil and gas sector and also includes the Aberdeen Exhibition and Conference Centre. located to the east. The area is served by two primary substations, Bridge of Don to the east and Whitestripes at the north west as shown below.

1 DECC's Carbon Plan, December 2011
2 Planning our electric future: A White Paper for secure, affordable and low carbon electricity generation. DECC, July 2011.
3 Strategic assessment of the role and value of energy storage systems in the UK low carbon energy future, a report for the Carbon Trust by the Energy Futures Lab at Imperial College London, June 2012

Figure 1 Location of the Bridge of Don Primary Substation

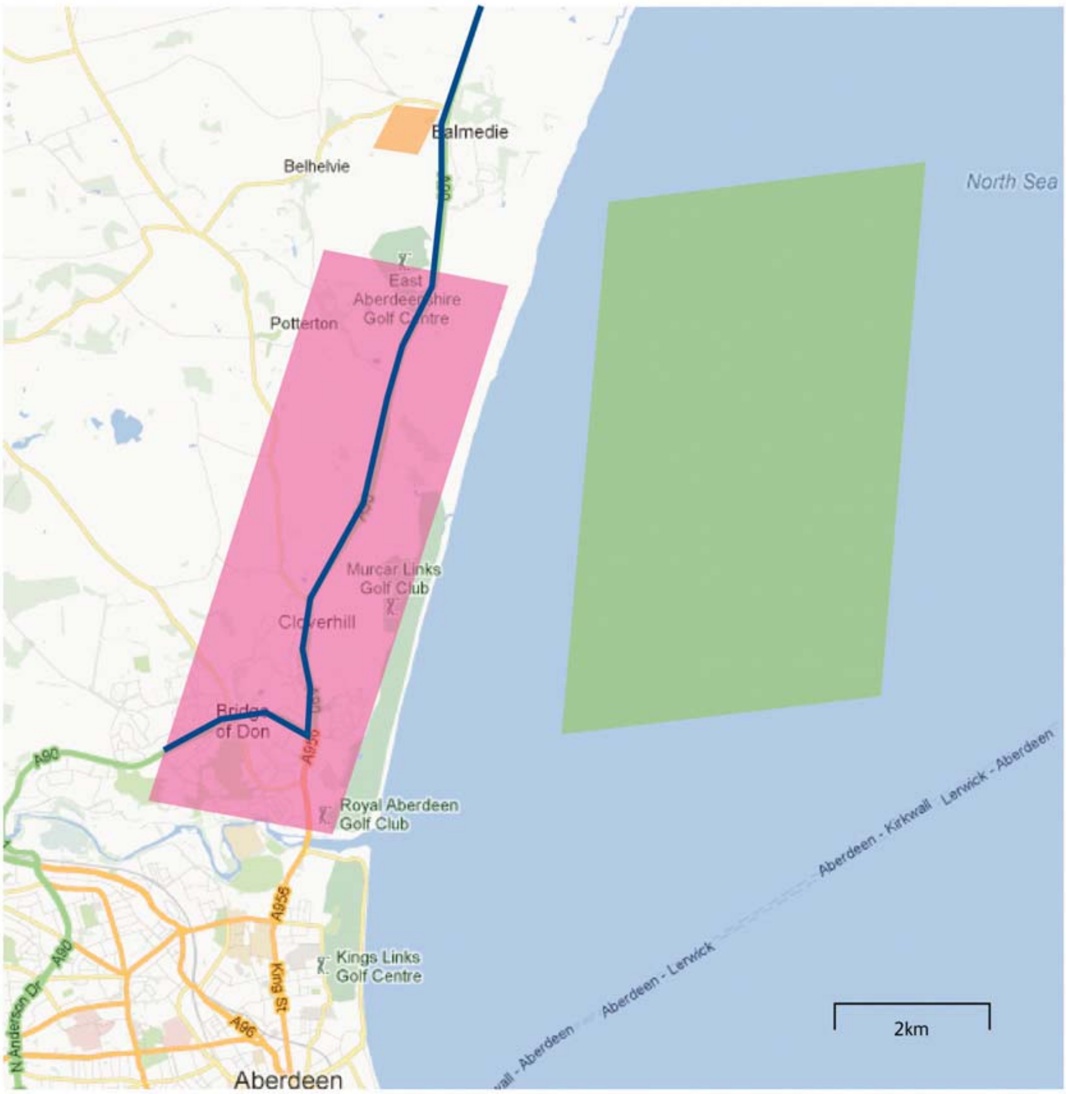
Bridge of Don Primary is rated at 12/24 MVA and is supplied from Persley Grid via two x 33kV circuits rated at 24.9/27.4MVA each (summer/winter). Current demands are:-

Winter peak – 19MVA
Summer Min – 6MVA

Whitestripes Primary is rated at 7.5/15 MVA and is supplied from Persley Grid via two x 33kV circuits rated at 20.6/22.7MVA each. Current demands are:-

Winter peak – 9MVA
Summer Min – 3MVA

The physical locations for phase one and two of the project are shown in figure 3.



Pink zone	Green zone	Blue line	Orange zone
Potential zone of locations for the electrolyser	Windfarm location	Main spine of the gas network in the zone of electrolyser locations	Phase 1 – Quarry Location

Figure 3 Map of the main PATHS project areas

Active Network Management Scheme – ANM

The ANM scheme lies at the heart of the PATHS project and relates to the use of intelligent operation, automation and control to manage grid constraints associated with the integration of distributed generation along with the new controllable demand created by the electrolyser.

SHEPD have already successfully operated an ANM scheme on Orkney to manage thermal and voltage constraints. A further scheme for Shetland is approaching implementation to manage frequency and stability constraints. The proposed scheme for PATHS will need to address similar thermal and voltage constraints but will for the first time also need to consider the requirements of the heat and transport sector in the development of its control algorithms. This will be the first time that an ANM scheme can be used to integrate previously unconnected energy systems. This will require a detailed analysis and modelling of the various technical and commercial requirements of each of the stakeholders. In order to facilitate this it is our intention to develop a series of detailed Use Case models in order to properly capture the requirements of each of the stakeholders.

The electrolyser and hydrogen production system

Adding a 3MW load to the network can help to utilise the peak output from the wind farm. This allows the DNO to offer a non-firm connection to the wind farm via the distribution network, rather than offering an underutilised connection to the transmission network, with a longer lead time. The 3MW load in the form of an electrolyser produces hydrogen. The hydrogen is used to fuel hydrogen fuel cell buses in Aberdeen, and also injected into the natural gas grid to decarbonise the gas. Hydrogen can also be sold for industrial usage – demand in Scotland for industrial hydrogen is around 110 tonnes per year.

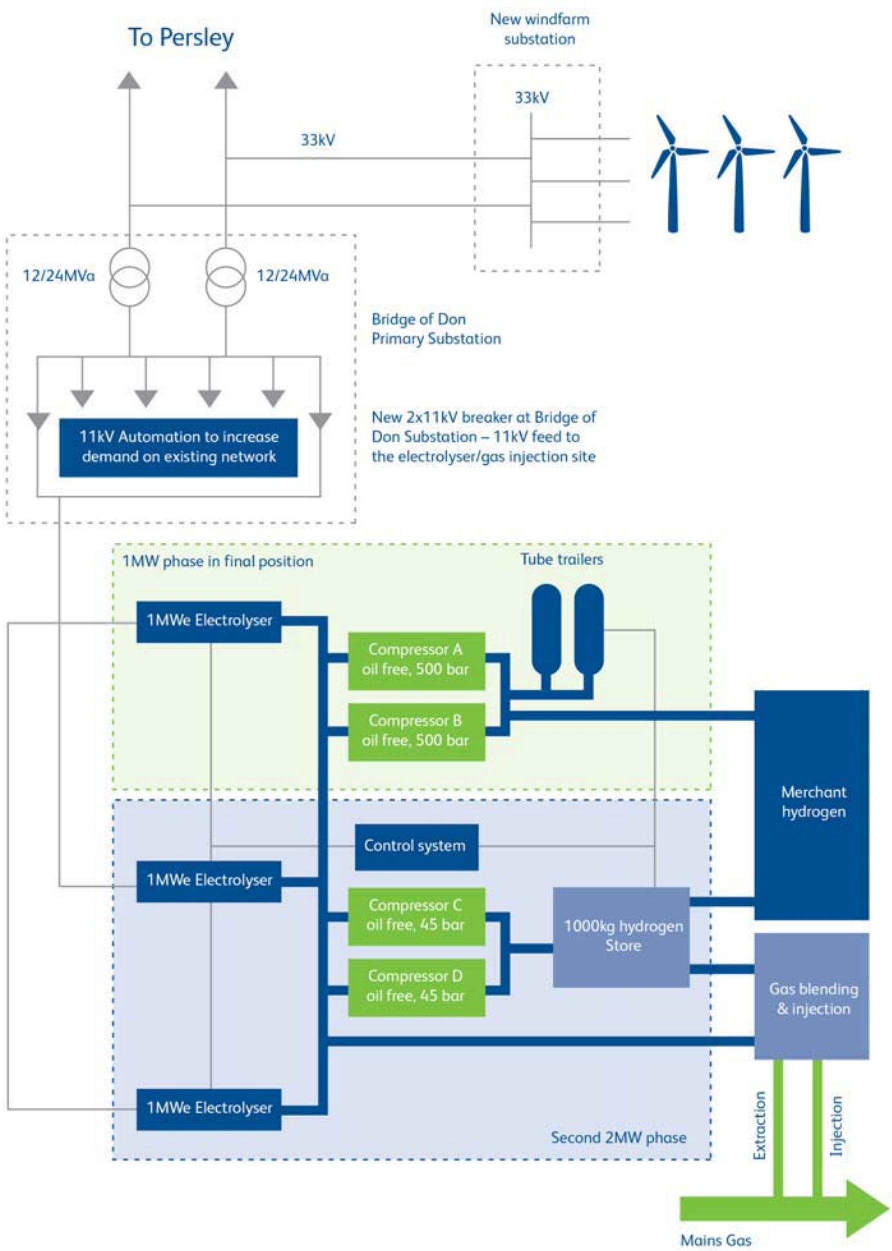


Figure 4 PATHS system diagram

The electrolyser
One of the key advantages of water electrolysis is the ability for the technology to fulfil several different needs. Electrolysers have the capacity of near-instantaneously matching a variable power supply, meaning they can be used to peak-lop renewable output. They can also be used as a very responsive load to offer some grid balancing services.

Hydrogen production from electrolysis of water is the decomposition of water (H_2O) into oxygen (O_2) and hydrogen gas (H_2) by using an electric current. The electrolyser works by decomposing water (H_2O) at the cathode to produce H_2 and HO^-. The HO^- migrates through the electrolyte and a separating diaphragm, and discharges at the anode, releasing O_2.

Electrolyser operation under variable load
PATHS electrolysers may operate at high load factors, maximising utilisation of the capital plant while still peak lopping renewable output from wind. This operational mode is similar to how electrolysers are used at present. Alternatively, the electrolyser may be only activated when wind output is above a threshold acceptable to the network. In this latter case, the load factor is lower, while variability in output is much greater. While the performance of all electrochemical systems degrades with variable output, the lower load factor for variable operation mitigates against this, over the electrolyser lifetime.

Technoeconomic optimisation
A techno-economic optimisation has shown that 3MW of electrolysis provides sufficient additional load at peak times to boost the windfarm loadfactor. A larger system could absorb more wind energy, but for marginal gains.

Working in partnership with SSEPD and SGN, BOC will be responsible for the design of the electrolyser and associated balance of plant. BOC have existing global electrolyser supply agreements in place with well-proven suppliers (>20,000 hours operation, 98% availability etc.) but also recognise the potential for one or more UK manufacturers to become a global player at this scale.

A new smart control system developed will be adapted to work with the electrolyser system, requiring novel interface designs e.g. on the control algorithm side. The system needs to understand the transient state of the electrolyser and the various hydrogen stores, whilst ensuring a response consistent with grid issues such as frequency or a price signal.

Hydrogen as fuel for the bus fleet:
The need for compression and storage depends on the end use of the hydrogen. Vehicle refuelling is part of the complete PATHS system but the refuelling components have already been funded and no further contribution to these is requested.

The system requires two compressors to produce the pressures required for vehicle refuelling (500 bar). BOC will provide diaphragm compressors, which will be oil free to ensure that the hydrogen remains uncontaminated and meets the high purity requirements of fuel cell stacks. Two compressors are required to allow for maintenance and downtime, ensuring that fuel for the buses can always be produced.

BOC will also provide three compressed gas trailers, and a novel trailer filling system, designed for a) simplicity and b) unmanned use for collection of remote renewable hydrogen. The electrolyser output will pass first into a buffer tank, via the compressors and into the waiting tube trailers. The system is designed so that there will always be two tube trailers at the electrolyser site offering over 600kg of storage (3 days of bus demand). H2 will be transported by BOC drivers from the point of generation to the fuelling station.

Hydrogen injection into the gas grid:
Hydrogen for the gas grid does not require compression as pressures in the grid are <2 bar. However there will be times in the day and in the year when hydrogen production from electrolysis will exceed allowable percentage of hydrogen that can be injected into the gas grid, and therefore some storage will be required. Two compressors will be required to allow for maintenance and downtime, ensuring that compression does not become a limiting factor which prevents the electrolyser from producing hydrogen in response to a signal from the grid. When storing hydrogen for the purposes of injecting into the gas grid, storage at pressures of 45 bar is the most cost-effective solution. The project proposes that storage for 1000kg of hydrogen at these pressures is the optimum level – this represents just under one day's production at full capacity. This stored hydrogen could be injected into the gas grid (after passing through regulators to reduce the pressure), or it could pass back through the higher pressure compressors to meet the transport demand, or it could be sold as merchant hydrogen to industrial users. For these reasons the 45 bar compressors must also be oil-free.

SGN have commissioned a feasibility study of injecting hydrogen into the natural gas grid, which will report in October and inform a detailed bid for funding for the gas infrastructure. For the purposes of estimating the hydrogen flows to the gas grid and therefore sizing the electrolyser we have made conservative estimates on the likely gas flows in the network close to the electrolyser location, and a conservative estimate of 5% by volume of hydrogen that can be mixed with natural gas before being injected into the grid via a network entry plant.

Dispatching the electrolyser:
There will be 3 main requirements that the electrolyser will need to respond to:

- A request from the network operator to switch on when required, in order to consume electricity from the peak output of the wind farm.
- Ensuring a regular supply of hydrogen is available in order to fuel the buses (~70,000kg per year, or 190 kg/day).
- Maintaining a supply of hydrogen to the gas injection point (into the natural gas network).

In addition to these requirements there are the following factors the electrolyser operator will need to take account of:

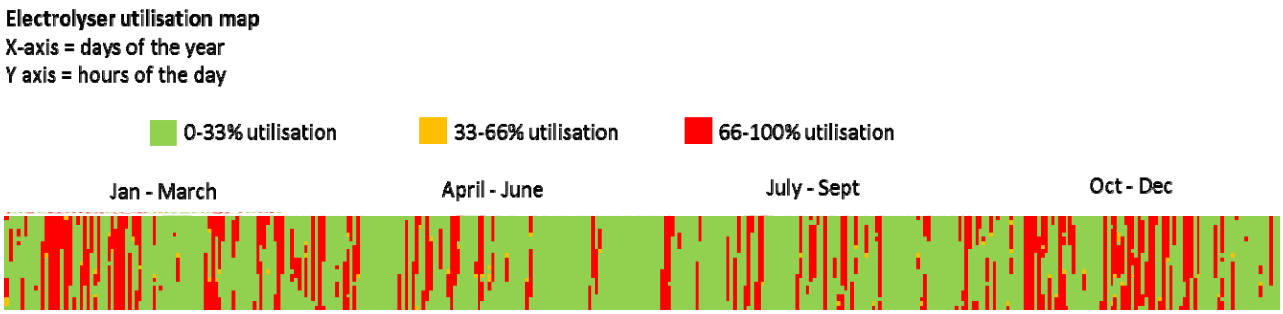
- This load could provide applicable balancing services to the grid (i.e. short term operating reserve, frequency control demand management).
- Taking advantage of time periods with lower electricity prices to generate fuel for the bus fleet or for merchant hydrogen.
- Whether the hydrogen storage has reached full capacity.

The detailed algorithms for the electrolyser dispatching will be developed as part of the project.

A simulation of the system with a year of modelled wind data shows the following results:

- The electrolyser will receive a request from the network operator to be turned on approximately 270 times per year, with the average length of a wind event requiring the electrolyser to be switched on of 9.5 hours.
- With a 3MW system, this results in an electrolyser load factor of 28%.
- We estimate that the demand for hydrogen will be c. 70 tonnes per year for the fleet on 10 buses, c. 20 tonnes per year for the gas grid at relatively low injection percentages.

The maps below show some of the results of the simulation. They show that the peak of hydrogen production is during the winter when anticyclones lead to increased wind speeds. There is therefore a correlation between times of the year when hydrogen production is high, and times of the year when for gas from the natural gas grid is higher.



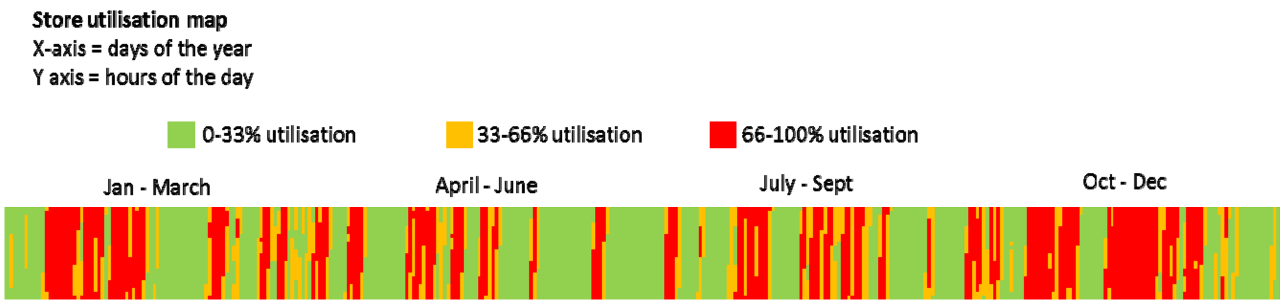


Figure 5 utilisation maps for a 3MW electrolyser and a 1000kg hydrogen store through a year's worth of modelled data. The x-axis shows the days of the year, so the data starts on the left end of the map in January and ends on the right end of the map in December

Case studies, selected wind hydrogen electrolyser projects:

Enertrag project, Prenzlau, Germany[4]
The Enertrag hybrid power plant in Germany is trialling similar technologies, with a project consortium including Vattenfall Europe Innovation GmbH, Total Deutschland GmbH, and The Linde Group. The power plant produces hydrogen from wind energy, and the hydrogen is then used as fuel for a number of different sources. The hydrogen can be combined with locally produced biogas to power a CHP plant, thereby regenerating electricity when there is demand from the grid. The hydrogen fuel will also be used to supply industrial and transport uses.

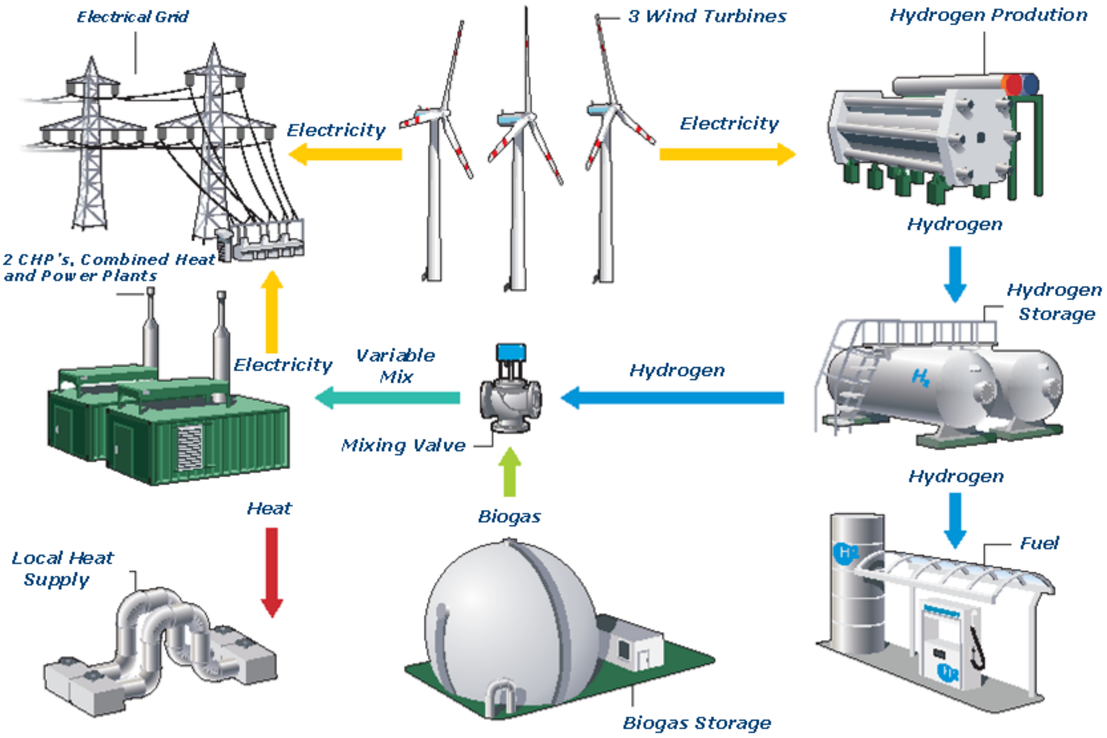


Figure 6 schematic of the Enertrag hybrid power plant

E.On pilot plant, Falkenhagen, Germany[5]
E.On are developing a pilot scheme to investigate the injection of renewable hydrogen into the natural gas grid. The Plant is expected to be operational from the third quarter of 2013. Wind electricity will be used to create hydrogen using water electrolysis.

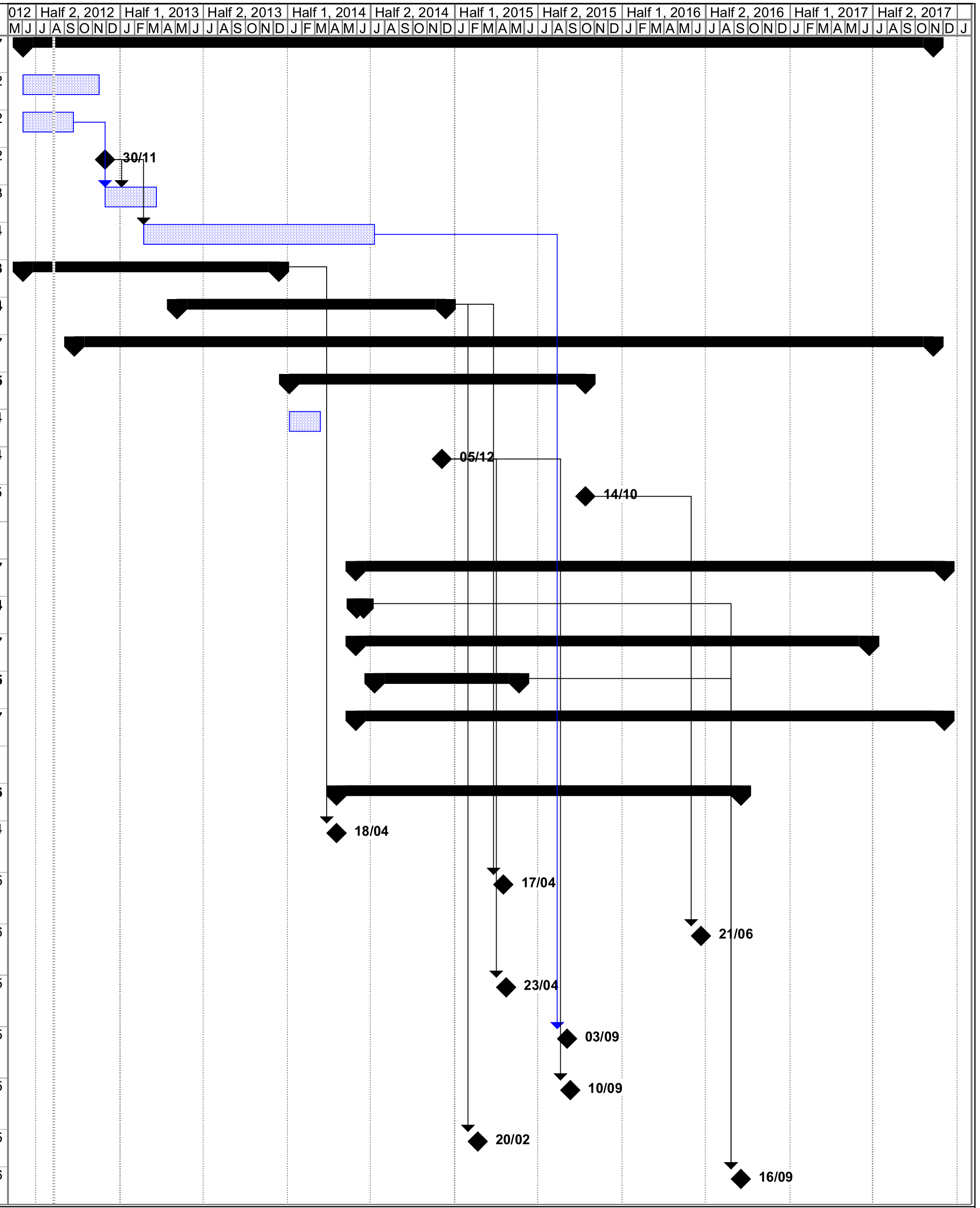
HafenCity H2 station
As part of the Clean Energy Partnership project, Linde Group -in partnership with Vattenfall and Hydrogenics- has installed and is now operating a hydrogen station in Hamburg in 2011. The fueling station is expected to supply H2 for both cars and buses using two HySTAT-60 electrolyzers that, combined, produce about 260 kilograms of fuel daily. BOC will install the electrolyser and supplement this capacity with delivered H2 as needed.

[4] https://www.enertrag.com/en/project-development/hybrid-power-plant.html
[5] http://www.eon.com/en/media/news/press-releases/2011/11/11/e-dot-on-examines-options-for-storing-wind-power-in-the-german-gas-grid.html

BOC has been at the forefront of developing refuelling solutions that are of a commercial scale, capable of filling several vehicles an hour at both 350 and 700 bar pressures. To date, the group has installed over 50 refuelling stations in the USA, Germany and also in the UK. In the UK, BOC has been operating a state of the art hydrogen refuelling station in Swindon since August 2011. The project is a public/private partnership between BOC, Honda UK and Forward Swindon, the economic development arm of Swindon Borough Council. The station provides refuelling capability at both 350 & 700 bar.

Appendix C(i): Summary project plan

ID	Task Name	Duration	Start	Finish
1	**Project delivery**	**1420 days**	**Mon 04/06/12**	**Fri 10/11/17**
2	Mobilisation	6 mons	Mon 04/06/12	Fri 16/11/12
3	Planning	4 mons	Mon 04/06/12	Fri 21/09/12
4	LCNF Tier 2 funding decision	0 days	Fri 30/11/12	Fri 30/11/12
5	Recruitment and resourcing	4 mons	Fri 30/11/12	Thu 21/03/13
6	RGU modelling	18 mons	Fri 22/02/13	Thu 10/07/14
7	**Phase 1 System - 1MWe**	**400 days**	**Mon 04/06/12**	**Fri 13/12/13**
13	**Phase 2 System - 2MWe (additional)**	**420 days**	**Mon 06/05/13**	**Fri 12/12/14**
18	**ANM and communications**	**1340 days**	**Mon 24/09/12**	**Fri 10/11/17**
27	**Partner Works**	**462 days**	**Mon 06/01/14**	**Wed 14/10/15**
28	ACC - Hydrogen busses deployed	10 wks	Mon 06/01/14	Fri 14/03/14
29	SGN - Gas blending and injection point available	0 days	Fri 05/12/14	Fri 05/12/14
30	Vattenfall - Windfarm connection	0 days	Wed 14/10/15	Wed 14/10/15
31				
32	**Learning Outcomes**	**916 days?**	**Fri 30/05/14**	**Tue 05/12/17**
33	**1: What are the network benefits of actively managed loads?**	**11 days?**	**Mon 02/06/14**	**Mon 16/06/14**
36	**2: What services can dispatching electrolyser systems provide to electricity networ**	**800 days**	**Fri 30/05/14**	**Fri 23/06/17**
39	**3: What is the potential for energy transfer to supply transport, heat and agricultura**	**225 days**	**Thu 10/07/14**	**Thu 21/05/15**
43	**4: How can the integration of multiple energy networks be replicated in locations ac**	**916 days**	**Fri 30/05/14**	**Tue 05/12/17**
47				
48	**Success Criteria**	**630 days**	**Fri 18/04/14**	**Fri 16/09/16**
49	1.Publish key learning from Phase 1: delivery and integration of a 1MWe electrolyser	0 days	Fri 18/04/14	Fri 18/04/14
50	2. Publish key learning from Phase 2: integration of 3MWe electrolyser to remove network constraint	0 days	Fri 17/04/15	Fri 17/04/15
51	3. Publish key learning on technical performance of electrolysers as dispatchable load	0 days	Tue 21/06/16	Tue 21/06/16
52	4. Report on the market possibilities which will arise from integrating agriculture, heat and transport with the distribution network.	0 days	Thu 23/04/15	Thu 23/04/15
53	5. Develop the methods and tools to establish the physical replication potential for this method across the rest of the UK distribution network	0 days	Thu 03/09/15	Thu 03/09/15
54	6. Report on commercial arrangements and models which would support the deployment of the PATHS solution across the rest of the GB distribution network	0 days	Thu 10/09/15	Thu 10/09/15
55	7. Physically complete the infrastructure works to accommodate the full system	0 days	Fri 20/02/15	Fri 20/02/15
56	8. PATHS solution toolkit	0 days	Fri 16/09/16	Fri 16/09/16



Project: MSProj11
Date: Wed 08/08/12

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

Appendix C(ii): Risk register

Risk Number	Risk Name	Risk Description	Inherent Risk			Risk Control Actions	Residual Risk			Date Raised	Last Update	Status	Date Closed
			Impact	Likelihood	Score		Impact	Likelihood	Score				
1	Hydrogen safety	Project involves the production and storage of hydrogen at high pressures. Risk of fire or explosion.	5	2	10	1. Hydrogen work to be carried out by experts in this area (BOC) 2. Wood Group have been appointed to the project to provide an independent safety overview 3. Allow for exclusions zones in the site design	3	2	6	10/05/2012	06-Jul-12	Open	
2	Project resources	The project could be delayed if resources are not available. This has been raised as an issue on a number of other LCNF projects.	4	5	20	1. Project resourcing plan has been developed utilising experience from other LCNF projects and includes for recruitment time 2. Contractor resource can be used to fill gaps 3. Project partners have agreed to the programme and have committed resources	3	4	12	10/05/2012	18-Jul-12	Open	
3	Lack of generation	The offshore wind farm develoment is not available to the project.	4	3	12	1. Identify other generators which could give us the same net energy position.	3	3	9	10/05/2012	25-Jul-12	Open	
5	Constraint level	If the electrolyser equipment does not perform as required, the generator will see an increased (and commercially unsustainable) level of constraint.	4	3	12	1. Equipment to be diversified (i.e. no single point of failure) 2. Programme allows for 12 months of electrolyser operation before windfarm connection	3	3	9	10/05/2012	09-Jul-12	Open	
8	Tier 2 Funding	The PATHS project is not awarded Tier 2 funding in 2012	5	3	15	1. The first phase of the project will be delivered using Tier 1 LCNF 2. Funding timescales have been included in the project plan 3. Contracts and agreements will be based on final confirmation only being received after the funding decision.	4	3	12	10/05/2012	03-Aug-12	Open	
10	Electrolyser site	We can not find a suitable site for the hydrogen production and storage. This will need to be close to the gas network, but away from properties etc.	5	3	15	1. Early engagement with the council to identify suitable sites 2. Vattenfall can provide an area of land at the landing site for us to use if required. 3. Wayleave discussions will begin as a priority	3	2	6	10/05/2012	25-Jul-12	Open	
15	Gas injection volume	Gas injection is not feasible at the required scale, either due to maximum hydrogen percentage or due to the flow rates at the connection point.	4	3	12	1. Working figures have been agreed with SGN 2. We will work with conservative assumptions for the injection levels in our commercial estimations 3. Gas connection point will be optimised for maximum flow rates, based on all commercial and way leave factors.	3	2	6	10/05/2012	09-Jul-12	Open	
20	capturing project learning	We are unable to effectively capture the project learning, this has been highlighted as an issue on other LCNF projects.	5	4	20	1. Knowledge and learning delivery will be managed by a dedicated project management resource 2. Work with other LCNF projects to establish best practice 3. Create and agree a PATHS knowledge and learning strategy	3	3	9	30/05/2012	20-Jul-12	Open	
23	Gas funding	SGN are unable to secure the required funding for the gas blending and injection works	5	3	15	1. Early engagement regarding the innovation funds available to SGN and the level of funding required (accurate costing) 2. Identification of alternative funding mechanisms (TSB, FCH JU) 3. Alternative hydrogen markets to be explored	4	2	8	22/06/2012	08-Aug-12	Open	
29	Funding streams	Failure to comply with the governance around the various funding streams, partnership arrangements and revenue allocations	4	3	12	1) Dedicated project management office resource to be allocated to the project 2) Requirements to be drawn out by project analysts 3) Finance department engagement in all funding streams	3	2	6	13/07/2012	20-Jul-12	Open	

Risk assessment categorisation:

		Likelihood					
		Almost never	**Hardly ever**	**Unlikely**	**Possible**	**Likely**	**Almost certain**
		Never heard of in industry / work type	Heard of in industry / work type	Occurred within SSE	Occurs several times within SSE	Occurs on site	Occurs several times on site
Impact		**1**	**2**	**3**	**4**	**5**	**6**
Catastrophic	**6**						
Severe	**5**						
Major	**4**						
Serious	**3**						
Minor	**2**						
Incidental	**1**						
		10^{-6} - 10^{-5} /yr	10^{-5} - 10^{-4} /yr	10^{-4} - 10^{-3} /yr	10^{-3} - 10^{-2} /yr	10^{-2} - 10^{-1} /yr	>10^{-1} /yr

Impact assessment:

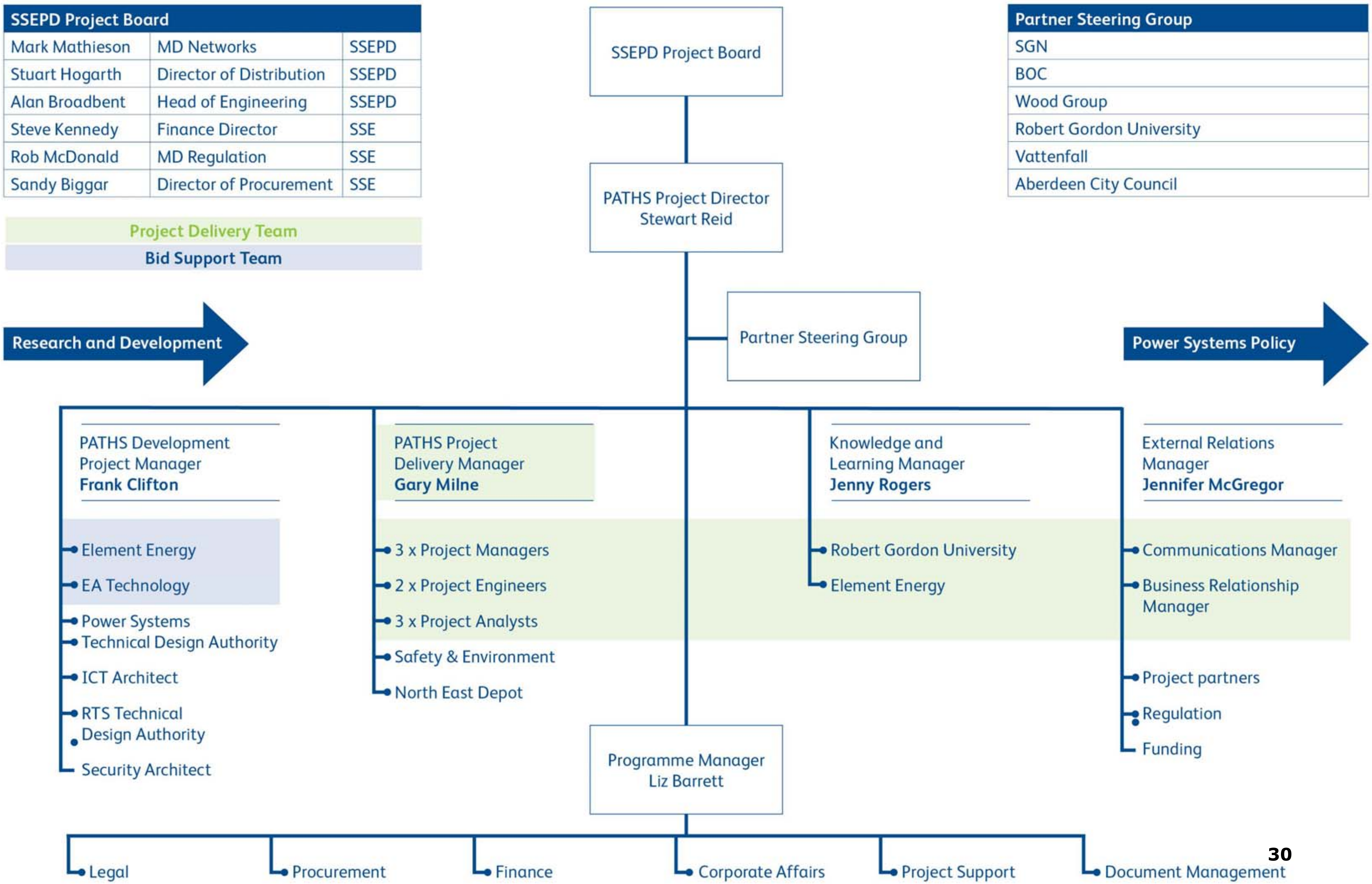
No.	Descriptor	People	Environment	Asset	Reputation
6	Catastrophic	> 10 ♦ Fatalities ♦ Serious Disability ♦ Life Threatening Health Effect	• Impact on / Release to Sensitive Receptor • Damage outside SSE boundary • Permanent Loss of Sensitive Receptor	♦ Destruction of Entire Asset	♦ International Media Coverage ♦ International Political Reaction
5	Severe	4-9 ♦ Fatalities ♦ Serious Disability ♦ Life Threatening Health Effect	• Impact on / Release to Sensitive Receptor • Damage outside SSE boundary • Extensive Remediation resulting in Visible Change	♦ Destruction to > 25% Entire Asset ♦ Disruption to Asset (< 3 years)	♦ National Media Coverage ♦ National Political Reaction ♦ Investor Reaction
4	Major	1-3 ♦ Fatalities ♦ Serious Disability ♦ Life Threatening Health Effect	• Impact on / Release to Sensitive Receptor • Damage outside SSE boundary • Extensive Remediation • Multiple Breach of Legislation or Permit	♦ Damage to Key Operational Component ♦ Disruption to Operation (< 1 year)	♦ Regional Media Coverage ♦ Regional Political Reaction ♦ Organised Protest
3	Serious	♦ Serious Injury (reportable) ♦ Lost Time Injury (>3 days) ♦ Irreversible Health Effect	• Impact on / Release to Sensitive Receptor • Slight localised damage outside SSE boundary • Recoverable • Single Breach of Legislation or Permit	♦ Damage to Major Item ♦ Disruption to Operation (< 1 month)	♦ Prolonged Local Media Coverage ♦ Local Political Reaction ♦ Local Protest ♦ Reputation damage with regulator
2	Minor	♦ Minor Injury (medical treatment <3 days lost time)) ♦ Reversible Health Effect ♦ Restriction to Work Activity	• Release to non sensitive receptor • Minor localised damage within SSE boundary • Easily Recoverable	♦ Damage to Large Stock Item ♦ Disruption to Operation (< 1 week)	♦ Local Media Coverage
1	Incidental	♦ Slight Injury (first aid) ♦ Slight Health Effect	• Release to non sensitive receptor • Slight localised damage within SSE boundary • Easily Recoverable	♦ Damage to Small Stock Item ♦ No Disruption to Operation	♦ Complaints From Neighbours

Appendix C(iii): Contingency plan

A contingency plan has been written for the significant risks on the Risk Register (Appendix C(iii)). All risks will be continually monitored and the most significant referred on a monthly basis to the project board. Below are details of the contingency arrangements for the most significant risks at the point of bid submission:

Risk Number 2: Lack of resources to effectively deliver the project
This is an issue which has been raised on a number of other LCNF projects and is therefore a key risk. The project plan has been developed in conjunction with a resource plan and this includes realistic timescales for recruitment and mobilisation. We are in the process of converting the resource plan to a resourcing strategy and this will be complete by November 2012. This will detail our arrangements for meeting each resource requirement, whether we will recruit or use contract resource. There is sufficient flexibility in our future networks team to assist with shortfalls in the project resources.
Risk Number 3: The offshore windfarm development is not available to the project
There are alternative generator developments in the area which we could utilise if required. It is unlikely that in the required timescales an alternative single large site would be developed, however through aggregation we could achieve the same net energy position. This would reduce our ability to work with a single constraint, but through increased levels of simulation and analysis we could achieve the same learning outcomes.
Risk Number 5: The generator is constrained to levels which are uneconomical
The proposed system is technically robust with multiple end use markets which will reduce this risk. However should the system be generally unavailable, the generator would be constrained to uneconomical levels. Should this be the case, we will maximise the extent of local demand to utilise the energy. This may include temporary reconfiguration of the network.
Risk Number 8: The PATHS project is not awarded LCNF Tier 2 funding
The PATHS project has been designed for delivery in two phases. If LCNF tier 2 funding is not secured this year, it is unlikely that the second phase would be viable in the future, due to the offshore windfarm having to secure their connection and SGN a site for the gas injection. The first phase of the project can be secured through the use of LCNF tier 1 funding if required. Should the project be unsuccessful in this years funding it would require substantial review and rework to understand if it was viable in future years.
Risk Number 20: We can not effectively capture the project learning
The learning outcomes have been a central part of the project development. We are able to use best practice from our other LCNF projects and from the wider industry. We believe that we have included sufficient resource and robust mechanisms to effectively capture and disseminate the project learning. The learning process will be regularly reviewed and additional resources allocated to this area if required.
Risk Number 23: SGN do not secure the required funding for the works to inject blended gas
The primary means of funding this part of the project is through the gas network innovation fund. At the time of bid submission this funding mechanism is not established and therefore is an identified risk. We have identified other funding mechanisms which expect to open during the life of the project (specifically a TSB funding call and the Fuel Cells and Hydrogen Joint Understanding Fund (FCHJU)) and would look to secure some or all of the funding from these sources. Work is ongoing to understand other markets for the hydrogen which could take some of the capacity if the gas blending and injection works can not be funded.

Appendix C(iV): Organogram



Appendix D: Project partners

Organisation	**Aberdeen City Council**
Relationship to	None
Type of Organisation	Local Government responsible for all public services in Aberdeen.
Role in Project	Aberdeen Council will provide local project management for the bus aspects of the project, Aberdeen Council are managing the budgets to procure and operate the 10 hydrogen buses which form the demand for the UK Renewable Hydrogen Hub project. This involves interaction with Europe over the HyTrasit and High V.lo City project (over €10 million of EC funding)
Prior experience brought to Project	• In 2002 the Council established Aberdeen Heat and Power which now provides district heating to approx. 1500 homes in Aberdeen. The council have also been involved in several other EU funded initiatives : • Care North–looking at Carbon Responsible Transport Strategies along with European partners to reduce carbon emissions. • STRATMOS - promote and facilitate the shift of cargo from road to sea. • North Sea Sustainable Energy Planning - Developing Models for Renewable Energy and Energy Efficiency.
Funding	In Kind
Contractual relationship	Being developed in parallel with specific requirements of the project.
External Collaborator benefits from the Project	Aberdeen City responsible for all environmental compliance in city – this project particularly transport element is key meeting air quality objectives. In addition, the council is committed to further reducing the cities carbon emissions.

Organisation	**Aberdeen Offshore Wind Farm Ltd.**
Relationship to	Potential for wind farm to connect to distribution network
Type of Organisation	Joint venture, offshore wind farm, with emphasis on deployment of new to market, pre-commercial wind turbines. Aberdeen Offshore Wind Farm Limited (AOWFL) is an established legal entity owned by Vattenfall Wind Power Ltd (75 %) and Aberdeen Renewable Energy Group (25 %).
Role in Project	Potential supplier of offshore wind power to the DNO for use in the electrolyser and demand side management.
Prior experience brought to Project	Through Vattenfall, experience as one of Europe's largest owner and operator of offshore wind, including Thanet, Kentish Flats, Ormonde and East Anglia Round 3. AREG represent the interests over 170 members organisations that span the entire supply chain active in Aberdeen City and Shire.
Funding	Benefit-in-kind contribution via man-hours spent on the project.
Contractual relationship	NA – will depend on final network configuration
External Collaborator benefits from the Project	To explore the potential to dynamically control the power production and consumption that would allow for smart integration of renewable energy into the distribution grid via demand side management.

Organisation Name	**Aberdeen Renewable Energy Group (AREG)**
Relationship to DNO	Partner in the Aberdeen Hydrogen Project
Type of Organisation	Aberdeen Renewable Energy Group (AREG) is an innovative public-private membership organisation at the cutting edge of Scottish and UK efforts to build a sustainable renewable energy industry in a fast moving, globally competitive market.
Role in Project	A) Promotion of the project - dissemination activities for supply chain and academia, both nationally and internationally B) Co-developer of the European Offshore Wind Deployment Centre (EOWDC).
Prior experience brought to Project	AREG has been the driving force behind the EOWDC since 2004 and currently fulfils the role of project communicator for this £230 million project. This also included the identification of European funding for the project which translated into a grant of €40 million. AREG has also been instrumental in creating the Aberdeen Hydrogen Project which has also benefited from European investment of €10 million.
Funding	
Contractual relationship	AREG is a partner in this TSB project, which is led by SSE.
External Collaborator benefits from the Project	This project is crucial to: A) AREG's aspirations to make Aberdeen as famous for renewables and it is for oil and gas. B) Aberdeen City Council's wish to become a world Hydrogen City AREG will use their extensive network for dissemination to local stakeholders and the UK renewable energy sector.

Organisation N	**Aberdeenshire Council**
Relationship to DNO	None
Type of Organisation	Local authority responsible for delivery of public services in Aberdeenshire
Role in Project	In the first instance, the Council intends providing the project with access to the output from a wind turbine, a suitable site for an electrolyser with associated space for hydrogen storage and a grid connection.
Prior experience brought to Project	The Council is aligned to the objectives of PATHS and has been working on identifying commercially viable end use and production equipment for renewable hydrogen for over 5 years in partnership with other parties including SHFCA and Scottish Enterprise. The Council wishes to introduce hydrogen infrastructure and commercially sustainable end users of renewable hydrogen to the Energetica project, most of which is based in Aberdeenshire

Funding	
Contractual relationship	The Council and SSE will sign a Memorandum of Understanding identifying the expectations and outcomes expected from each party
External Collaborator benefits from the Project	We anticipate benefits to farmers through the ability to use stranded wind to generate an income other than from sale of electricity into the grid, a contribution to decarbonising food production, the use of hydrogen to displace fossil fuels in applications where emissions or noise are an issue and powering fishing vessels and North sea Oil Support vessels.

Organisation	**BOC Linde**
Relationship to DNO	No direct relationship
Type of Organisation	BOC is the largest provider of industrial, medical and special gases in the UK and Ireland**.** BOC offers refuelling concepts for compressed gaseous hydrogen as well as for liquid hydrogen. Internationally BOC is a member of The Linde Group, a world leading gases and engineering company with almost 50,000 employees working in around 100 countries worldwide.
Role in Project	BOC will be responsible for the provision of hydrogen equipment and expertise to the project. They will design, install, own and operate the refuelling station for the buses at Kingswell. They will also supply the hydrogen generation and tube trailer filling equipment to SHEPD, as well as operating the tube trailers moving hydrogen between sites.
Prior experience brought to Project	As an experienced gas specialist BOC expertise covers the entire value chain, from generation and liquefaction through transportation and storage solutions to fuelling of hydrogen-powered vehicles. BOC as a member of the Linde group has participated and shared its know-how in several EU funded programmes (EIHP, HyWays, HyLights, HyApproval, ZeroRegio, NaturalHy) and is partner in CHIC.
Funding	
Contractual relationship	Letter of Intent in place. Ongoing contractual negotiations in line with TSB and EU funding requirements
External Collaborator benefits from the Project	BOC will further develop there portfolio of hydrogen based projects.

Organisation	**First Aberdeen Ltd**
Relationship to DNO	No direct relationship other than also being a partner in the High V.Lo City Project
Type of Organisation	Bus Operator
Role in Project	Intended Operator of Hydrogen Vehicles

Prior experience brought to Project	First Aberdeen has been operating buses in Aberdeen for over 15 years and carries on average 50,000 customers a day. First serves almost all areas of the city through a network of cross city centre routes. First Aberdeen is a Part of FirstGroup plc which is a leading transport operator in the UK and North America
Funding	
Contractual relationship	N/A
External Collaborator benefits from the Project	Knowledge and experience of operating and maintaining Hydrogen Fuel Cell vehicles. Understanding of the facility requirement in terms of safety as well as potential environmental benefits from operating zero carbon emission vehicles.

Organisation	**Robert Gordon University**
Relationship to DNO	None
Type of Organisation	University (Academic/Research)
Role in Project	To provide research and knowledge transfer in testing the feasibility of using hydrogen as an energy transfer methodology for managing variable renewables supply into electricity distribution networks.
Prior experience brought to Project	Numerical modelling of systems, power generation from all forms of renewables (onshore and offshore), electrical power management, hydrogen generation and usage, knowledge transfer, GIS and software capabilities, publication and dissemination of results
Funding	
Contractual relationship	Collaborative partner
External Collaborator benefits from the Project	Increased knowledge of sustainable energy and energy transfer systems, interaction with UK distribution network organisations, access to data sets for teaching and possible publications, development of staff and support for PhD student(s), increased visibility and stature in the field.

Organisation Name	**Scottish Enterprise / Scottish Government**
Relationship to DNO	No direct relationship - Strategic level partner.
Type of Organisation	National economic development agency.
Role in Project	Providing matched funding for Aberdeen City led EU funding projects.
Prior experience brought to Project	Involvement in multiple energy-based economic development projects over 20 years.
Funding	Up to £3.3m for Phase 1

Contractual relationship	Contract details to be agreed but SE's role will be that of minority funder.
External Collaborator benefits from the Project	Will help inform further economic development in the renewables and smart grid sectors.

Organisation Name	**Scotland Gas Networks**
Relationship to DNO	SGN is a wholly owned subsidiary of Scotia Gas Networks Limited and SSE plc owns 50% of Scotia Gas Networks Limited. SSE is SHEPD's ultimate holding company.
Type of Organisation	Scotia Gas Networks Ltd is the holding company owning Scotland Gas Networks and Southern Gas Networks and therefore covers the gas networks across Scotland and the South and South East of England. It is the UK's second largest gas distribution network company and provides natural gas to 5.8 million customers through 74,000km of gas mains and services.
Role in Project	SGN will be a minority funder of the electrolyser plant proposed for Phase 1 and will provide their network management expertise from the gas sector. SGN's main interest in the project is to learn lessons around renewable gas generation , subsequent storage, leading to Phase 2, when the injection of hydrogen to the gas grid will be explored.
Prior experience brought to Project	Aside from the day to day gas grid and gas handling expertise, SGN are also a leading adopter of biogas injection technologies, which is particularly relevant here, for example they participated in the first biogas to gas grid project at Didcot in 2010.
Funding	
Contractual relationship	Being developed in line with other project partners
External Collaborator benefits from the Project	Further develop SGN innovation portfolio and build upon the previous experience in biogas injection.

Organisation	**Stagecoach Bus Holdings Limited**
Relationship to DNO	No direct relationship other than also being a partner in the High V.Lo City Project and HyTransit projects.
Type of Organisation	Provider of bus and coach services through subsidiary companies within the UK.
Role in Project	End user of Hydrogen buses on interurban routes to/from the City of Aberdeen.
Prior experience brought to Project	Extensive experience of bus operation over the last 30 years. UK leader in operational use of alternative propulsion buses, with experience of biogas/methane and lpg powered vehicles as well as the largest fleet of diesel electric hybrid buses in the UK.
Funding	

Contractual relationship	Prime contractual relationship with Aberdeen City for the lease of the hydrogen buses complete with contracts covering maintenance, availability and refuelling.
External Collaborator benefits from the Project	Significant upskilling of staff in the procedures required for the maintenance and operation of hydrogen powered vehicles. Currently only 8 hydrogen powered buses in the UK, all with London Transport. Knowledge and experience of operating and maintaining Hydrogen Fuel Cell vehicles. Understanding of the facility requirement in terms of safety as well as potential environmental benefits from operating zero carbon emission vehicles.

Organisation Name	**Wood Group/Wood Group Kenny**
Relationship to DNO	None. Wood Group/Wood Group Kenny (WGK) is an independent provider to the DNO.
Type of Organisation	Wood Group is an international energy services company with $6 billion sales, employing more than 41,000 personnel worldwide and operating in over 50 countries. Wood Group Kenny, which is part of Wood Group, specialises in the development and delivery of major infrastructure projects. For over 30 years, WGK has undertaken numerous energy development projects for the majority of leading international Oil & Gas and Renewable Operators and Developers.
Role in Project	WGK would undertake the role of Project Integrator and Process Safety Expert for the proposed Aberdeen Hydrogen project. As a leading integrator of major infrastructure projects, WGK is uniquely placed to provide management and safety expertise during all stages of the proposed development to the DNO.
Prior experience brought to Project	WGK are experienced in the project and interface management of the supply chain through involvement in the engineering, manufacture, transportation, installation, operation and decommissioning of major infrastructure projects worldwide. WGK have successfully managed the delivery of major energy projects using its established integrated management processes and procedures developed over the past 30 years. In addition, this experience also includes the management of health safety and risk during all stages of the project development.
Funding	
Contractual relationship	SHEPD and WGK have yet to define and agree the contract terms and condition. SHEPD and WGK would be partners to the proposed Aberdeen Hydrogen project.
External Collaborator benefits from the Project	WGK will further develop its experience and capability in delivering renewable infrastructure projects as part of its ongoing commitment to support alternative energy projects. This will enable WGK to become a leader in the management and delivery of hydrogen infrastructure projects throughout the United Kingdom

Appendix G: Integrating energy systems

Introduction

The PATHS project will integrate wind energy into electricity, transport and gas energy infrastructures to reduce renewable connection costs, demonstrate a path to systemic decarbonisation of energy systems, and utilise the significant latent energy storage available in gas networks.

The PATHS system has been developed in response to a number of SHEPD customers needing cost effective grid connections for renewables, and to deliver low carbon transport fuel for buses. PATHS proposes to utilise a MW scale electrolyser as a dispatchable load, increasing the effective capacity on the existing distribution system and allowing a cost effective connection for a windfarm with a commercially viable load factor and minimal constrained generation. The primary market for the produced hydrogen is public transport buses. As shown below, this application not only increases the value of the electricity (transport fuels have a higher value per kWh) but also delivers significant carbon benefits by offsetting emissions from a relative inefficient system (internal combustion engines, see below). Excess hydrogen is used to decarbonise the gas grid. Note that PATHS does not propose to regenerate grid electricity from hydrogen, due to the unfavourable systemic energy losses which arise with current technology[1].

The component technologies of PATHS – electrolysis; H2 transport; H2/methane mixtures – are relatively mature technologies. The primary innovation of PATHS is in combining these to form an integrated and comprehensive decarbonised energy system. In PATHS, hydrogen has been chosen as the energy vector used for the integration of energy infrastructures. However, hydrogen is not central to the widespread deployment of PATHS. Alternative vectors (such as the creation of renewably derived natural gas via the Sabatier process) are also feasible. Aside from technology, key PATHS outcomes are centred on exploring markets for deep energy integration, the technical, environmental and economic benefits arising, and the commercial models required to deliver these. The primary components of PATHS are described below.

Decarbonising transport

While there is significant scope for improving the efficiency and environmental performance of internal combustion vehicles, the reductions in CO2 emissions which are required to meet UK targets will require low carbon fuels and electric drivetrains. The options are limited to battery electric drivetrains; biofuels, and hydrogen fuel cell drivetrains as clearly identified in the Carbon plan 2011[2]. Battery Electric vehicles (BEVs) have started to reach the passenger car market, and are being supported by a number of government initiatives including the Plugged-In Car Grant and the OLEV PIV charging projects. Despite this support, take-up of BEVs has been disappointing, and evidence (on consumer behaviour and on the high costs of batteries[3],[4],[5]) has begun to emerge which

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[1] Although some technologies such as high temperature reversible fuel cell/electrolysers have the promise to deliver good system efficiencies.
[2] "as deeper cuts are required, vehicles will run on ultra-low emission technologies such as battery electric vehicles, hydrogen fuel cell, and hybrid electric technologies."
[3] "Influences on the market for low carbon cars 2020-2030", Element Energy report for the Low Carbon Vehicle Partnership, 2011.

suggests that BEVs will remain a niche technology and not deliver the decarbonisation levels required in the transport sector. The grid impact of BEVs may be minimal.

An alternative electric vehicle prime mover is a hydrogen fuel cell. Like batteries, H2FC technologies have been in development for an extended period of time and have struggled to achieve acceptable economics. However, the concerns over sustained high battery costs, and the continued downward pressure on emissions (primarily though EC legislation) means that automotive OEMs (original equipment manufacturers) are actively pursuing H2FC drivetrains as an alternative low carbon option. A number of cross industry studies (including battery and fuel cell developers[6]) have concluded that fuel cells are on a significantly steeper volume/cost reduction curve than batteries.

Four of the leading OEM's have announced that they will begin serious commercial production of FC vehicles in or before 2015 (GM, Toyota, Daimler, Hyundai) with plans for tens of thousands of vehicles sold per annum by 2020. The California Fuel Cell Partnership predicts the first commercial wave of approximately 20,000 fuel cell vehicles in 2015. (www.cafcp.org/RoadMap). Much of these projections are based on significant cost reductions of fuel cell vehicles through volume production.The UK has recently demonstrated its commitment to facilitating this market through the UKH2Mobility process, which aims define the roll-out of hydrogen in the UK from 2015. UKH2Mobility[7] is a joint industry / government / energy utility study tasked with determining the potential role of hydrogen in the UK transport system. Stakeholders include three government departments (BIZ, DECC, DfT); eight automotive OEMs; and a range of technology providers, fuel suppliers, and vehicle end users. SSE is a member of UKH2Mobility. The project developing similar uptake projections which cannot be shared for confidentiality reasons. Both BOC and SSE are partners in this project and are using these results to justify business decision in this area.

These plans will require coordinate action by industry and governments. If the UK is to become one of a limited number of H2 vehicle early adopters, it might take 10% of the global market, suggesting 50,000 vehicles on the road by 2020. Using realistic growth rates, the stock could increase to 1M by 2030. National Strategic studies point to 50% of future H2 transport demands to come from electrolysis linked to low carbon energy sources, to justify the introduction of H2 vehicles on environmental grounds.

Given the long term challenges associated with high battery costs and the renewed interest in H2-fuel cell drivetrains, it is appropriate that PATHS explores the technical and commercial viability of these systems now, to ensure that the technology and commercial arrangements are seen as viable in the period 2015-2020. The transport applications (transit buses) in the PATHS project are already funded and so are outside this LCNF funding request. This significantly de-risks the PATHS project.

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[4] The Energy Technologies Institute commissioned Element Energy to develop a quantitative survey and model of consumer response to low carbon cars. This work showed that only a very small consumer group was positive about electric vehicles, and that unprecedented levels of incentives would be required to bring the BEV and PHEV share beyond 5-10% of the passenger car fleet, even in the long term past 2030.

[5] "Cost and Performance of EV Batteries" 2011. A report for the Committee on Climate Change, by Element Energy Limited. This report was commissioned by the CCC in response to concerns about the viability of the EV uptake figures published by the CCC. The report showed that, while both battery cost and performance metrics will improve significantly, limited range and high capital cost will remain a challenge for EVs in the medium to long term.

[6] "A portfolio of powertrains for Europe" a report by McKinsey and company, 2011

[7] www.ukh2mobility.com

Decarbonisation of gas

As stated in the Carbon Plan, UK government is committed to reducing the carbon intensity of heating via measures such as the Renewable Heat Incentive (RHI). Recognising the strategic importance of heating sector decarbonisation, Government is acting now even though it admits that mass market take-up will not occur at least until after 2020[8]. Instead of "backing winners", the Carbon Plan sets out a portfolio approach to decarbonisation of heating. PATHS is strategically aligned with this aim, providing a decarbonisation option which has very widespread replication potential.

In contrast to electricity networks, the energy storage potential of gas networks is vast. Some of this is used on a diurnal and seasonal basis to accommodate varying demand; even so the utilisation of storage capacity is low[9]. Furthermore, in developing PATHS we have ascertained a high degree of correlation between wind generation and natural gas consumption. Wind generation is higher in winter months, and not only is heating higher in this season, but also there is a good correlation between high wind events and gas consumption for heating. Instead of extensive electricity grid upgrades, the gas grid can be used as a short term store of renewable derived fuel.

PATHS proposes that the fuel vector between electricity and gas networks is hydrogen. However PATHS principles are not limited to hydrogen, which could for example be used to generate renewable methane via a Sabatier process.

The use of hydrogen within gas networks is not novel, nor (at low concentrations) is it technically challenging[10]. A number of networks around the word transport and deliver to customers gas mixtures with a significant concentration of hydrogen (Hong Kong, 49% hydrogen, Hawaii, 11% hydrogen) through a mixture of older metal and newer polyethylene pipes. In countries with widespread availability of natural gas, standards and regulations have changed to ensure that the fuel delivered is methane at a very high level of purity. Indeed, one of the biggest obstacles to the use of hydrogen in gas networks is the regulatory environment and PATHS will provide useful learning on this

From reviews of existing hydrogen-methane mixtures, and research projects on the subject[11] it is generally accepted that hydrogen can be accommodated in gas pipelines up to a concentration of 20%. Beyond this level, there may be issues with hydrogen embrittlement of metal pipes; promoting crack propagation. Also, plastic pipes are more permeable to H2 than natural gas and at high H2 concentrations this could be a concern. A low H2 concentration also avoids any issues with consumer products using the mixture.

In this project we have taken a more conservative assumption of 5% H2 concentration by volume. This is based on Scotia Gas data on (conservative) gas consumption figures at the proposed site. By taking a conservative approach, we are increasing the replication potential of the system.

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[8] "The UK Carbon Plan" 2011

[9] Energy stored in gas linepack in the UK is 96GWh (National Transmission) and 290GWh (Distribution) – Grant Wilson University of Strathclyde.

[10] "Hydrogen Enriched Natural Gas" A White Paper by National Grid and Atlantic Hydrogen

[11] http://www.naturalhy.net/.

Agriculture and industry

Agriculture accounts for approximately 45 $MtCO_2e$ of annual greenhouse gas emissions in the UK (about 8% of net national emissions)[12]. Greenhouse gas emissions from the industrial production of ammonia – required for use in agricultural synthetic fertilisers – contributes an additional 1 $MtCO_2e$ per year to national greenhouse gas emissions and mobile machinery on farms accounts for a further 3.6 $MtCO_2e$ annually.

The Committee on Climate Change recognises the opportunities for reducing emissions from mobile machinery in agriculture (such as diesel use in tractors, harvesters, mowers, sprayers and balers) through the use of alternative vehicle fuels like hydrogen[13]. In recent years, considerable development work in the area of hydrogen fuel cell drive trains for tractors has been carried out with several commercial demonstration units now available[14]. In the context of this project, the demonstration of effective renewable hydrogen production and integration into the transport sector will provide a proof of capability for the low-carbon domestic supply chain required to fuel such a transition within agricultural mobile machinery. An analysis of energy transfer issues specific to the supply requirements and commercial considerations of mobile agricultural applications for hydrogen will also be undertaken.

The production of ammonia, primarily for use in fertilisers, is largely based on variations of the Haber-Bosch process in which hydrogen and nitrogen are combined in a volume ratio of 3:1 at elevated temperatures and pressures in the presence of an iron catalyst[15]. The emissions factor for the production of ammonia is between 1.2 to 2.2 $kgCO_2e$ per kg of product[16]. The unique combination of renewable power and hydrogen made available by the PATHS project provides an opportunity to address ammonia production emissions via the implementation of a renewable Haber-Bosch process. While this action plan would not be included within the scope of this project, it is technically feasible that available wind power could be used to produce nitrogen feedstock (via the liquefaction and fractional distillation of air) and combine it with renewable hydrogen from the electrolyser to renewably produce ammonia. In fact, the integration of ammonia plants with other manufacturing processes which produce excess hydrogen (such as methanol and acetic acid production) is a common practice to increase efficiency and improve production economics.

With such opportunities for decarbonisation within agriculture and related industries available, PATHS seeks to prove the fundamental renewable supply chain feasibility of these options. In this context, the aim of PATHS is to demonstrate a supply chain "readiness" to address abatement in these sectors which, as identified in the Carbon Plan, possess limited decarbonisation options. The analysis will include an assessment of hydrogen production and renewable power supply dynamics and their implications for hydrogen fuel supply for agriculture and integration with industrial processes such as the production of ammonia.

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[12] "UK Greenhouse Gas Inventory", DECC 2011
[13] "The Fourth Carbon Budget: Reducing emissions through the 2020s", Committee on Climate Change, 2010
[14] "New Holland NH_2™ Hydrogen Powered Tractor", New Holland Agriculture, 2011
[15] Engelstad, O. 1985, "Fertilizer Technology and Use", 3rd Ed., Wisconsin: Soil Science Society of America, Inc.
[16] "A Review of Greenhouse Gas Emission Factors for Fertiliser Production" A report for IEA Bioenergy, 2004

Appendix H: Differentiators from other LCNF Projects

Project Differentiators

PATHS differs to all other projects submitted to the LCNF Tier 2 fund in three fundamental ways

- its approach to integrating energy networks which tackles areas identified as 'hard to treat' in the Carbon Plan;

- the range of funding which can be accessed due to this approach; and

- the way in which the project has been developed in response to approaches from stakeholders wishing to understand how hydrogen can help meet their economic and environmental ambitions.

GB-first integration of energy networks

PATHS is the first Low Carbon Networks Fund project to investigate how integrating multiple energy networks can deliver benefits for the electricity distribution system and its customers.

PATHS establishes links with other innovative energy network projects to extend beyond the traditional boundaries of electricity distribution to understand how a 'whole system' approach can help manage the impact of increasing levels of renewable energy on the distribution network.

Unique integration with the gas network

SHEPD's collaboration with Scotland Gas Networks allows PATHS to explore the opportunities that exist for energy transfer from electricity to gas networks. SGN are currently undertaking parallel works to investigate the potential from hydrogen blended gas injection and this work will report in late 2012. This will position SGN perfectly to undertake a trial project in the time frame required for the PATHS project. The nature of gas demand is the same as that for electricity and therefore, the electricity and gas networks are in close proximity throughout GB. Establishing a viable method of transferring constrained energy, could offer a significant benefit to all distribution network customers.

Ground-breaking integration with transport

PATHS is stakeholder driven, meeting the immediate need of organisations in the SHEPD network area. It facilitates a solution to a specific energy related problem – that of pollution caused by carbon particulate emissions from diesel-fuelled buses. Linking PATHS to the low carbon transport project being developed by the local authority allows the LCNF project to benefit from European funding secured by the local authority.

Future transport scenarios include a proportion of hydrogen fuelled vehicles and fuelling the connection of these may pose significant challenges to the distribution network. In this project we will establish the potential scale of this market and develop the tools for all DNO's to establish if it will cause future network issues.

Paving the way for integration with agriculture

The research commissioned as part of the PATHS project will provide an invaluable first step to understanding how agricultural energy networks can be effectively integrated with sustainable electricity, heat and transport, to provide a whole system solution to regional energy needs.

Establishing the mechanisms for contracted network services

The PATHS project will develop the work undertaken on the Orkney storage park project (SSET1009) to establish the framework for contracted network services. This would see electricity distribution networks benefiting by removing network issues through contracted services or incentivised activites, rather than traditional re-enforcement methods.

Complementing other stakeholder-driven energy projects

The use of hydrogen as the vector which facilitates the integration of energy networks in PATHS reflects the ambitions of the north east of Scotland to champion new energy technologies. This ambition is present in other areas of the UK, including the Isle of Wight, where the Eco Island project is introducing a number of hydrogen-fuelled vehicles, powered by a small-scale electrolyser (250kW). Southern Electric Power Distribution is working with the Eco Island partnership to test, at small scale, the effect of electrolysers on the distribution network. PATHS will use findings from the small scale Eco Island trial to inform its large scale project.

Appendix I: Letter of support from ITM Power

ITM POWER
Energy Storage | Clean Fuel

ITM Power Plc

22 Atlas Way
Sheffield
S4 7QQ

phone
+44 (0) 114 244 5111
fax
+44 (0) 114 244 5117
email
gc@itm-power.com
website
www.itm-power.com

08 August 2012

Brian Shewan
Future Networks and Policy
SSE
55 Vastern Road
Reading
Berkshire
RG10 8BU

Dear Brian

ITM Power recognise that SEPD's PATHS project is innovative as it embodies leading edge solutions that will deliver customer value and facilitate the expedient adoption of hydrogen technology and other low carbon technologies. The project will serve to reduce the carbon content of not only the electrical network but also the heat and transport sectors.

ITM Power is already working with SEPD and recognises that the solutions identified in PATHS of using hydrogen as an energy vector to manage electrical network constraints has the potential to be replicated in a number of UK locations.

This work and the expected learning will compliment ITM Power's ongoing projects in the UK including The EcoIsland project on Isle of Whyte and the Gas Injection study both funded by the TSB and the proposed DECC Methanation study.

Therefore, ITM Power is delighted to write this letter of support and look forward to continuing our work with SEPD in the future.

Signed for and on behalf of ITM Power

Dr Graham Cooley

CEO

Registered office as above
Company No 3973827

Appendix J: Aberdeen hydrogen project press release

Green light for Scottish hydrogen hub
FM confirms up to £3.3 million funding for EU-backed green transport in Aberdeen

Alex Salmond today gave the green light for a pioneering clean energy hub in Scotland, including Europe's largest hydrogen bus fleet, as he announced funding of up to £3.3 million for the EU-backed project.

The Scottish Government and Scottish Enterprise funding will enable Aberdeen City Council, supported by Aberdeen Renewable Energy Group, to start the project's first phase with an order for 10 hydrogen fuel-cell buses – which produce water vapour instead of carbon monoxide and other harmful emissions.

They will be operated on First and Stagecoach bus routes in the city by early 2014 and refuelled at Scotland's first large hydrogen refuelling station, which will also be able to refuel hydrogen-powered passenger cars, as they become available. Scottish & Southern Energy Power Distribution (SSEPD), working with BOC, will develop an integrated 'whole hydrogen' system which can harness wind energy to produce and store hydrogen that is then used as fuel for the bus fleet, and for generating electricity at times of peak demand.

The First Minister said: "Through our Green Bus Fund, the Scottish Government is already supporting the roll-out of 74 low carbon buses, such as diesel-electric hybrids, to cut harmful vehicle emissions. Hydrogen buses will eliminate these local emissions. Aberdeen is already Europe's offshore energy capital and this exciting new project can help position it as a leading city for low carbon technology and green transport. With a strong group of project partners, this initiative will boost Scotland's profile as a key hydrogen technology hub and a world-leading investment location for pioneering low carbon energy and transport systems."

The Scottish Government and Scottish Enterprise have each committed up to £1.65 million to support the project, which has also received funding from the European Commission, and the UK Technology Strategy Board. In addition to the City Council, SSE and the two bus operators, other project partners include Aberdeen Renewable Energy Group, Ballard Power Systems, BOC, Element Energy, Scotia Gas Networks and Van Hool.

Aberdeen City Council leader Barney Crockett commented: "This funding is a vital contribution to Aberdeen City Council and its partners' work to introduce a fleet of hydrogen buses to the area. I believe this initiative will stimulate further innovative hydrogen technology projects and attract even more high-level investment to this city. It is a crucial step towards Aberdeen becoming a world-leading, smart hydrogen city."

Giles Fearnley, Managing Director of First UK Bus said: "This is an exciting, ground-breaking project which we are delighted to be a part of, particularly in our home city, Aberdeen. Throughout the UK, First is committed to reducing its carbon footprint, particularly emissions from our buses. We already operate 68 hybrid vehicles, including 10 in Scotland, with a further 41 on order across the UK and have made tremendous advances in engineering which has reduced our fuel consumption. This project therefore is a natural fit, and one we hope that will be very successful. We're looking forward to operating the hydrogen buses."
Andrew Jarvis, Managing Director, Stagecoach Bluebird, added: "Bus travel can deliver huge environmental advantages over taking the car. Powering vehicles from renewable sources such as hydrogen can make the bus an even greener and smarter option. We already source energy for one of our bus depots in Aberdeenshire using geothermal heat extracted from the ground, as well as harvesting rainwater to clean our buses. Locally-generated hydrogen fuel is an exciting prospect and will complement the range of measures we are taking across Stagecoach Group to grow our business sustainably and help our customers cut their carbon footprint."

SSEPD's Director of Distribution Stuart Hogarth commented: "This is an ambitious project which allows us to explore new ways of managing energy flows on our network and should help keep the costs of energy down in the future. We're pleased to be working with a group of partners who are experts in their field and to be helping introduce a new form of sustainable transport for Aberdeen."

Scottish Enterprise Director of Energy & Low Carbon Technologies Adrian Gillespie said: "In supporting this project we can help to realise the long-term benefits of investing in hydrogen infrastructure. By providing a means of managing or storing surplus electricity from wind-farms, this project could play a vital role in enabling the management and storage of Scotland's vast renewables resources. The recently-published Smart Grid Sector Strategy estimates that the UK market for energy management products and services will be worth over £1.2 billion by 2020. As well as creating opportunities for companies already involved in hydrogen-related technologies, this project could also create opportunities for companies in other sectors to diversify their activities into the hydrogen production and storage market."

Background:

The First Minister announced the funding in Aberdeen where he also viewed a hybrid-electric bus – powered by a sophisticated battery system and supported by a traditional diesel engine – which was recently introduced with support from the £5.9 million Green Bus Fund. Local emissions from the hybrid buses are around a third less than conventional buses. The hydrogen fuel-cell buses, to be introduced following today's announcement, will produce zero local emissions.