WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

Hydrogen Heat and Fleet

CLOSEDOWN REPORT

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Prepared by:	Faithful Chanda	20.02.2019
Reviewed by:	Roger Hey	28.02.2019
Approved by:	Roger Hey	28.02.2019

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Contents

Glossary

Term	Definition
ANM	Active Network Management
BEIS	Department for Business Energy and Industrial Strategy
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
DfT	Department for Transport
DG	Distributed Generation
DMU	Diesel Multiplier Units
DNO	Distribution Network Operator
FCHJU	Fuel Cells and Hydrogen Joint undertaking
GB	Great Britain
GWh	Gigawatt-Hour
HSE	Health and Safety Executive
HV	High Voltage
HVAC	Heating, Ventilation, and Air Conditioning
IPR	Intellectual Property Register
kWe	Kilowatt - Equivalent
kWh	Kilowatt-Hour
MW	Megawatt
NGN	Northern Gas Networks
NIA	Network Innovation Allowance
OEM	Original Equipment Manufacturer
Ofgem	Office for Gas and Electricity Markets
PEA	Project Eligibility Assessment
PEM	Polymer Electrolyte Membrane
WPD	Western Power Distribution

Executive Summary

Western Power Distribution (WPD) developed an outline proposal for a hydrogen Heat and Fleet project to explore the use of electrolysers to generate hydrogen from excess local renewable electricity. This concept could result in less curtailment of renewable resources, and provide a highly controllable demand allowing energy storage in the form of hydrogen gas.

WPD contracted Delta-ee to conduct a research to ascertain the viability of the project, and to help inform a detailed project proposal and plan. WPD's specific questions for the research were:

- Is the project feasible? What does the project look like and is the concept sound from a technical and economic perspective?
- How mature is the hydrogen market? What is the overarching state of the hydrogen market and how is this likely to change? What existing research trials are taking place which may be relevant and can inform Heat and Fleet?
- Can the market deliver? Who are the likely partners in terms of project delivery and equipment? What are the collaboration opportunities for this project with other UK network operators, and what could their role be?

The approach to meet the project objectives were structured around three main tasks:
Task 1: Market study

- Review current hydrogen market activity
- Understanding the scope of existing trials / case studies
- Identify the main market players

Task 2: Technical and economic feasibility

- Develop high level project specification
- Produce a simple technical model which will assess energy flows
- Provide a high level financial analysis of the project

Task 3: Refinement of project scope and identification of potential partners

- The feasibility of the project –sweet spots in terms of project size and configuration
- The level of innovation in the project
- The learnings from existing projects
- The ability of the market to deliver –are suitable technologies and skills available?

By looking at other trials, the project may be able to identify gaps in existing trials, or areas where further work could be conducted which is relevant to WPD and the wider energy industry; challenges and barriers identified by other trials. For example, are there any recurring technical problems, or common implementation challenges? Where existing trials have been successful, what has driven this? Are there common technology providers, specialist consultants, partnerships with associations or funders, or favourable policy levers?

1. Project Background

An increase in intermittent renewable generation has pushed networks within the WPD license areas to capacity and no further renewable generation can be connected without reinforcement. Consequently solutions that can effectively smooth renewable generation intermittency on the distribution grid level and as a result allow further connection of generation are being explored.

The UK Government has placed huge emphasis on decarbonising the electricity system through a number of initiatives such as heat pumps and the displacement of conventional fossil-fuelled generation such as coal by cleaner sources like solar and wind. Adding to that list is the potential for hydrogen to be used as another source of clean energy. There have even been assertions that entire cities can feasibly be converted to hydrogen mains gas.

As part of the UK H2Mobility programme, hydrogen vehicle refuelers are being installed across the UK, a large proportion of which has local electrolyser-based hydrogen production. Sixty-five such stations are expected before 2020 with the numbers increasing exponentially thereafter.

When a new electricity generation connection is requested at a constrained site, current practice is to either reinforce the network or offer the generator alternative network connection arrangements. Novel techniques for reducing constraint issues have been explored by WPD, including the use of batteries to shift load and the use of active network management technologies. However, to date, these practices have not extended to electrolysers and fuel cells.

2. Scope and Objectives

The primary aim of this project was to research the use of hydrogen electrolysers as a controllable load that could help with increasing renewable electricity output. In areas with large penetrations of renewable generation, a controllable load will increase the capacity for further generation connections and further allow for renewable output that is currently curtailed to be put to use.

This research was intended to be a high level scoping study that aims to answer the following:

- Is the project feasible? What does the project look like and is the concept sound from a technical and economic perspective?
- How mature is the hydrogen market? What is the overarching state of the hydrogen market and how is this, likely to change. What existing research trails are taking place which may be relevant and can inform Heat & Fleet?
- Can the market deliver? Who are the likely partners in terms of project delivery and equipment? What are the collaboration opportunities for this project with other UK network operators, and what could their role be?

This project would provide insight into both cross-vector and cross-sector opportunities covering the electricity and gas networks, heat, and transportation and as suggested by the project name, there are two potential end uses for hydrogen:

- Heating: Use in a fuel cell for heating a building, combined with electricity output.
- Transport: Use in hydrogen vehicles (either internal combustion or fuel cell).

Objective	Our approach	Status
Is the project feasible? What does the project look like and is the concept sound from a technical and economic perspective?	Task 1: Market study: • Review current hydrogen market activity • Understanding the scope of existing trials / case studies • Identify the main market players	✓
How mature is the hydrogen market? What is the overarching state of the hydrogen market and how is this likely to change? What existing research trials are taking place which may be relevant and can inform Heat and Fleet?	Task 2: Technical and economic feasibility: • Develop high level project specification • Produce a simple technical model which will assess energy flows • Provide a high level financial analysis of the project	✓
Can the market deliver? Who are the likely partners in terms of project delivery and equipment? What are the collaboration opportunities for this project with other UK network operators, and what could their role be?	Task 3: Refinement of project scope and identification of potential partners: • The feasibility of the project – sweet spots in terms of project size and configuration • The level of innovation in the project • The learnings from existing projects • The ability of the market to deliver –are suitable technologies and skills available?	✓

Table 1: Objectives and Achievement Status

3. Success Criteria

There were targets set throughout the project and the team delivered against each of them. The Success criteria covered a broad range of subjects and are summarised below.

1. Review of the technology:

A comprehensive review of hydrogen technology has been presented. The project has given an overview of the production of hydrogen from electrolysis including the types of electrolysers available on the market. Further, the research has given a view on how Hydrogen has been distributed and utilised in a range of applications.

2. A case study of how the technology can bring benefits to WPD's networks is demonstrated:

A site within WPD for the project was identified - the WPD Church Village Depot. There are approximately 100 WPD utility vehicles based at the site along with an office building that is occupied by approximately 100 employees at any given time during working hours. The Heat and Fleet concept could result in a number of benefits, which are also all possible project drivers:

- Less curtailment of renewable resources – maximising use and increasing efficiency of the overall network
- Reduce constraint payments for the system operator
- Provide a highly controllable demand to help with network management
- Possibly provide additional revenue to renewable generators in a post subsidy environment
- Allow for energy storage in the form of hydrogen
- Production of a low carbon fuel for transport
- Production of a low carbon fuel for heating and electricity production
- Provide an interface between the gas and electricity networks

3. A viable pathway leading to a trial project is recommended where full details of capital and operating costs is documented:

Given the heat and power demand of the Church Village site, a ~0.2 MW electrolyser is likely to be most suitable to avoid exporting large amounts of electricity to the grid.

The results indicate that an electrolyser smaller than 1 MW is required to meet the depot's heat and power requirements. A larger electrolyser would result in a larger CHP unit being required with much of its output going straight back into the grid. A larger CHP unit coupled with more storage is also an option. From analysis of the Church Village electricity consumption data, the baseload electricity consumption of the site is ~20 kW-e. The peak power consumption in the winter is ~ 90 kWe. The annual non heating electricity consumption is ~100,000 kWh, and the electricity used for heating is ~200,000 kWh. Therefore if the electrolyser were larger than 0.2 MW (25% load factor), there would be significant export of electricity to the grid at times, along with a lot of waste heat.

Success Criteria	Status
Present a comprehensive review of the technology	✓
Produce a case study of how the technology can bring benefits to WPD's networks is demonstrated.	✓
Identify if the solution can bring benefits to WPD's networks	✓
A viable pathway leading to a trial project is recommended where full details of capital and operating costs is documented.	✓

Table 2: Success Criteria

4. Details of Work Carried Out

4.1 Project Proposal

WPD developed an outline proposal for a Hydrogen Heat and Fleet research project which would explore the use of electrolysers to generate hydrogen from excess local renewable electricity. The Hydrogen Heat and Fleet project was a 6 month feasibility study with the aim to improve knowledge of the technology's benefits, challenges and costs to determine whether a demonstration project was appropriate. The project aimed to investigate the feasibility of the use of hydrogen for vehicles and as a fuel for combined heat and power.
WPD and Delta-ee held an initial project meeting to discuss the overarching project aims and objectives, and defined a set of clear outcomes. It was important to clearly identify how the research would address some of the network challenges and provide genuine new innovative insight for WPD and other network companies. The meeting will also be used to explore the project concept, and start to define key metrics such as the approximate size of plant (fuel cells, electrolyser, number of vehicles, etc.) and potential trial programme. A set of initial boundary conditions were defined to help focus the research.

As a research, the project could provide insight into cross-sector opportunities covering both electricity and gas networks. The theme for the scoping study was structured around three components:

- Feasibility of the project: What does the project look like and is the concept sound from a technical and economic perspective?
- Maturity of the hydrogen market: What is the overarching state of the hydrogen market and how is this likely to change? What existing research trials are taking place which may be relevant and can inform Heat and Fleet?
- Markets and deliverability: Who are the likely partners in terms of project delivery and equipment? What are the collaboration opportunities for this project with other UK network operators, and what could their role be?

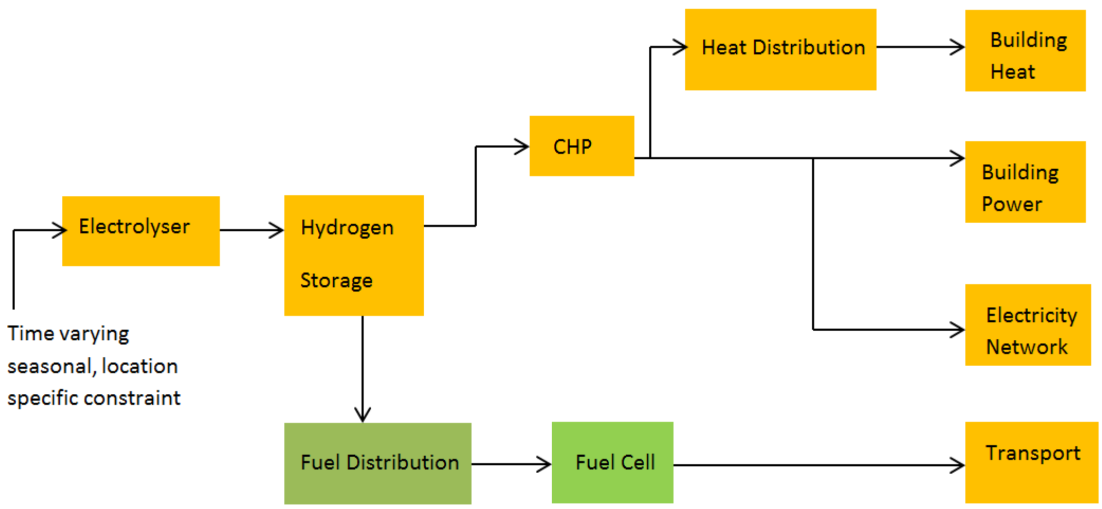


Figure 1: Project Proposal – System Overview

4.2 Methodology

Approach:

The approach to meet the project objectives was structured around three main tasks:

Task 1: Market study

- Review current hydrogen market activity;
- Understanding the scope of existing trials / case studies;
- Identify the main market players

This task will assess the level of maturity of the hydrogen market and the likely future market for larger scale role out / getting to business as usual. This task will review the current hydrogen market activity drawing on existing academic research and studies. This will provide an overarching position of the hydrogen economy and state of the market in the UK, and a viewpoint on the likely progression for further roll out. This research will include interviews with industry stakeholders and associations involved in developing the technologies / demonstration projects to understand their experiences and learnings to date. This task will identify a range of current market players ranging from technology providers (electrolysers, stationary fuel cells / CHP, transport solutions), to integrators and delivery partners. This task will also focus on organisations and associations active in the delivery of hydrogen projects in the UK and Europe. For example:

- Low Carbon Vehicle Partnership
- Scottish Hydrogen and Fuel Cell Association
- Hydrogen Mobility Europe programme
- UK Hydrogen and Fuel Cell Association
- Hydrogen London
- Fuel Cell and Hydrogen Joint Undertaking
- UK network companies (e.g. Hydrogen work by SGN, NGN and Cadent)
- UK Government research
- And others

Task 2: Technical and economic feasibility

Key components of this task are:

- Develop high level project specification. Identify the key technical components and boundary conditions to the project including site identification for the project (Church Village Depot. The site will help in setting some of the boundary conditions in terms of energy loads, vehicle capacity, etc.
- Produce a simple technical model which will assess energy flows (renewable electricity supply, building energy demands, and transport demands) and provide a high-level estimate of equipment sizes (for the electrolyser, and fuel cell), hydrogen storage volumes, and vehicle capacity.
- High level financial analysis of the project / trial taking into account capital and operational costs. This will help identify indicative project investment costs, lifetime cost benefits, and provide comparison with any alternative network reinforcement costs.

Task 3: Refinement of project scope and identification of potential partners.

Key components of this task are:

- The feasibility of the project –sweet spots in terms of project size and configuration
- The level of innovation in the project - is it new, what questions is it trying to answer, and where can it add new insight over existing trials.
- The learnings from existing projects - how should this trial build on existing projects and add value to network companies
- The ability of the market to deliver –are suitable technologies and skills available?

4.3 Understanding the Hydrogen Market

Hydrogen has been produced, distributed and utilised in a range of applications for more than a century.

Global hydrogen production:

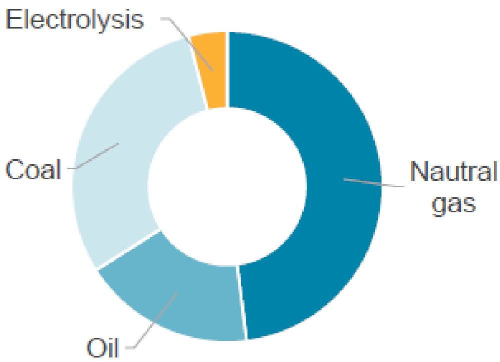


Figure 2: Global Hydrogen Production

1. Hydrogen types

Hydrogen can be produced in many different ways. The following terms are commonly used to identify the manner in which the hydrogen was produced.

- Grey / Brown Hydrogen: Produced by chemical process which removes carbon from (fossil) methane. The process releases CO2 into the atmosphere.
  - Not renewable
  - Not sustainable
  - Not low carbon

- Blue Hydrogen: Same process as above, but with the additional step of capturing and sequestering (possibly even utilising) the carbon component.
  - Not renewable
  - Low Carbon

- Green Hydrogen: Production of hydrogen using renewable electricity. In Europe there is potential to include hydrogen production from farm bio-waste. However, this but will require close certification to ensure sustainability.
  - Renewable
  - Sustainable

- Zero Carbon

Hydrogen generated via nuclear processes currently does not have any associated 'colour'.

Most hydrogen that can be bought and sold on the open market is referred to as 'merchant hydrogen' and is in most cases is Grey Hydrogen. 'Captive hydrogen' is hydrogen produced and used onsite in an industrial process. By-product hydrogen is hydrogen produced in an industrial process that is no longer required and is therefore valueless to the industrial facility as a feedstock

2. Ways to produce hydrogen

Steam methane reformation and oil oxidation are currently the main ways hydrogen is produced. Both these processes use unabated fossil fuel technology and are therefore fairly carbon intensive. There are many ways to produce low carbon hydrogen. The following are the main ones, most of which rely on the use of carbon capture and storage, which is still yet to be proven large scale:

- Steam methane reforming + CCS
- Advanced gas reforming + CCS
- Electrolysis using low carbon electricity
- Coal gasification + CCS
- Biomass gasification + CCS
- Other novel tech such as solar to fuel, microbial conversions, microwave technology and pyrolysis

3. Types of electrolysers

- PEM electrolyser**:** Characterised by rapid start up (low seconds) and ability to ramp up and down to match fluctuating load. They are more expensive than alkaline technologies but their costs are declining and will likely reach parity with alkaline electrolysers in the next 5-10 years. The efficiency of electrolysers degrade over time. 2.5% /years is standard degradation for normal operation of a PEM electrolyser. This can be higher depending on how strenuous the operating regime is. A PEM fuel cell has a system lifetime of ~20 years. However the fuel cell stack might require replacement anywhere from every 4-11 years depending on the acceptable efficiency degradation limits set. Start-up time: <10 seconds

- Alkaline electrolyser–a mature technology considered the 'traditional' electrolyser type. Alkaline electrolysers can be produced in very large scale, but they have the reputation of not being as suitable for fluctuating load (longer start-up times). This is changing somewhat with changes in design, but they are still best suited to stable load and a load <15% of max output.
  Start-up time: <1 minute

- Solid Oxide Electrolyser –under development, likely to be commercially available ~2025. Value add to the marketplace, or business model, are also still under development. Solid oxide fuel cells can in theory achieve high efficiencies, in excess of 80%. However, they

will likely run more like large power stations and would require long start up and cooldown periods.
Start-up time: minutes

4.4 The European Market and Market Structure

4.4.1 European Hydrogen Market Basics

- European hydrogen consumption is in the order of 68 million tons per annum.
- Of this merchant hydrogen represents 10%, captive hydrogen 68% and by-product hydrogen 22%.
- Only merchant and by-product hydrogen are potentially available for sale into the market place
- Consumers of the market are split by: 63% chemical industries, 30% refineries, 6% metal processors, 1% others (including hydrogen in transport).
- Of these 68 million tons, production of green hydrogen (hydrogen from renewable energy via electrolysis) currently represents less than 1% market share.
- The current hydrogen market operates as an oligopoly with new entrants, threatening the long term status quo.

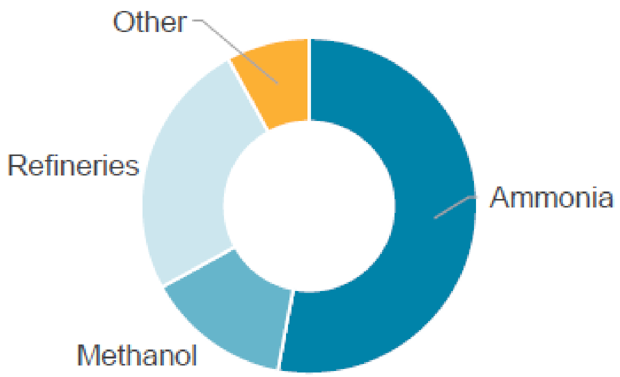


Figure 3: Global Hydrogen Consumption

4.4.2 The Structure of the Global Hydrogen Market

Currently the hydrogen production market is shared by a small number of producers/sellers. There is no traded market for hydrogen. No spot price, no futures market and no open pricing structure. Unlike other products such as steel, oil, gas etc. it is not a traded commodity. Hydrogen is currently sold by volume by industrial gas companies who can command prices depending on a number of factors. These factors are not openly published.
Just two companies, Air Liquide and Air Products, control over 90% of the merchant hydrogen market. The electrolyser market is considered a threat to the merchant hydrogen producers is already causing some surface level structural change. The “narrative” from the large gas companies is that for bulk hydrogen it is more economical to use their services, but for bespoke, or boutique production, electrolysers could have a role play. In other words, Air Liquide and Air Products keep the large orders, and electrolysers fill smaller more bespoke needs on the fringe.
With the development of >5MW PEM electrolysers on the near term horizon, developed for the renewable energy market, and the push for green hydrogen (certification scheme coming online

in the next 2 –3 years) the "fringe" market for electrolytic hydrogen will grow rapidly but realistically highly unlikely to dominate the 6.8 million ton merchant hydrogen market for the long term. It is more likely that electrolytic hydrogen will open up new markets in the short to medium term, say linking production to the deployment of local fleets of service vehicles, rather than deployment enmasse into refineries and the ammonia sector. However, interest from the ammonia industry in production of "green ammonia" is on the rise.

4.4.3 The UK Hydrogen Market - An Overview

The UK market for hydrogen is currently focused almost exclusively on industrial use of hydrogen produced from fossil fuels. Whilst there is significant focus around the UK on future potential for green and blue hydrogen, the reality is that at present this represent <1% of market demand.

The UK government is supportive of future uses of hydrogen and fuel cells, and have so far released a number of (relatively) small scale pots of funding to support deployment of hydrogen refuelling stations. Most funding for projects in the UK has so far come from the European Union through a dedicated instrument known as the Fuel Cell and Hydrogen Joint Undertaking (FCH JU). At present hydrogen refuelling stations deployed under UK government funding have no stricture imposed that requires they all use green hydrogen.

4.4.3.1 Stakeholders –Private Sector

The UK market is a mixed bag of traditional companies and new entrants. Of the traditional firms Johnson Matthey, who supply components into the supply chain, the natural gas companies and the industrial gas companies are the largest and due to their position, and ability to fund marketing, dominate in terms of market discussions. There is one indigenous electrolyser firm –ITM power, but the deployment market is open to importing.

4.4.3.2 Stakeholders –Public Sector

The Department for Business Energy and Industrial Strategy (BEIS) has given £25M of innovation funding to "develop and trial hydrogen appliances for homes and commercial properties", and to define a hydrogen 'quality standard'. This is quite significant as it is the first such project we are aware of in Europe specifically considering hydrogen-fired heating. BEIS have more recently made a £20M funding boost aiming to reduce the high cost of producing large volumes of low carbon hydrogen.

The UK Government's 'Clean Growth Strategy' published in October 2017–indicates possible future governmental support for hydrogen's contributing to fully decarbonised domestic heating by 2050. The 'Hydrogen Pathway' examines the steps that should be taken to develop hydrogen infrastructure –research is key. The Scottish Government's 'Scottish Energy Strategy' published in late 2017 also recognises the potential contribution of hydrogen to decarbonising the energy system across heat, power and transport. Politically the Scottish Parliament is leading in terms of focusing on opportunity and currently has a scenario of 100% hydrogen for transport in their energy plan.

Due to the level of funding available for research the university sector is highly active in the area of hydrogen. The latest being the opening of the brand new Manchester Fuel Cell Innovation Centre (which includes a suite of electrolysis research kit).

4.4.3.3 Stakeholders – The Big Picture

The positive story across the stakeholder environment is the level of community action. Hydrogen, and especially electrolytic hydrogen, is a potential power decentralising agent, with communities now able to produce not only electricity but also fuel. Orkney (Scotland) is one such community and has created three very high profile renewable-to-hydrogen projects, with EU funding. The next logical steps are self-sufficiency in terms of power, and removal of energy poverty, then hydrogen export, either to other communities or into other markets, such as marine fuel.

Overall, and perhaps understandably, the key messages from stakeholders are not focused primarily on the environmental benefits of hydrogen, especially when most of the hydrogen is produced from fossil fuels, but on the economic value add.

The potential to create high value direct jobs across the hydrogen industry is one of the main topics being discussed at the moment. Position papers from the sector highlight the potential for tens of thousands of new jobs to be created with the right level of support. This is from a mix of growing current companies, encouraging overseas companies to co-locate in the UK and developing the home market for the product.

The reality is that this is a long game and any significant jobs gain in one area is usually offset by losses in another. The number of new jobs created under various deployment scenarios is not something that has been calculated for the UK.

4.5 Transport Market Overview

Hydrogen use in fuel cells in transport, stationary and portable applications, as well as energy storage makes up only a fraction of the global hydrogen market. However, of late, there is hardly a week that goes by without a new hydrogen related transport development being announced.

The highest value market for hydrogen in the “other” market is currently in the transport sector. Given the prevailing economics surrounding the production and use of hydrogen this is unlikely to change in the short term. Within the transport sector, heavy duty vehicles are currently been seen as having volume potential in the short to medium term. Driving the business case further is the fact that for longer range heavy haulage vehicles current batteries do not meet customer needs. According to the 2018 KPMG survey of Automotive Executives, longer term the light duty vehicle market is still seen by the majority in the automotive industry as being the best route forward for cars.

Between now and 2030 the UK market will develop as a mixed bag of light and medium duty transport vehicles. This will include cars, scooters, taxis, buses, vans and potentially towards the end of the forecast period, trucks. Replacing light duty rail with hydrogen trains is currently a hot area for policy makers. The Transport Secretary, Chris Grayling, verbalised a desire to see all current DMUs (diesel locomotives) replaced by hydrogen trains by 2040. Whilst this is aspirational it provides a route marker to the speed of change once government is on-board. In terms of volumes, the overall numbers of vehicles will remain much lower than forecast by the piece produced as part of the UKH2Mobility report.

4.5.1 Vans

Scale of demand will be harder to achieve in this sector, in the UK, due to the lack of predominance of large fleets of vans, and the dominance of driver owned vans. However, this market is now starting to see companies re-evaluate and focus on company fleets, e.g. water companies, gas companies etc. Commercial OEM products in this category are not currently available, though there are some retrofit products on the market. Once, or if, the market switches to fleets of vans this sector has potential.

4.5.2 Trucks

A number of companies are now looking at deploying a hydrogen fuelled, fuel cell truck. Predominately these are Class 7 / 8 (heavy duty) or their European equivalent.

Figure 4: Hydrogen for Transport Applications

4.5.3 Buses

Whilst buses have made many headlines over the last few years the reality is that this is a market dominated by China. At present a fuel cell bus, fuelled by hydrogen, is not a standard product offering in catalogues. China is leading the way due to the strong policy pull, backup by subsidy at national and local level. This has created orders for thousands of fuel cells buses per location.

European deployments are very much project led, with finance from the FCH JU, and are not fully commercial deals. With finance packages potentially available from 2020 this could change. This is likely to apply in the medium term. In Europe order size is usually limited to 5 –10 busses. This is not to downplay the European market, which has been critical to drive cost down. Currently product offering is centred on the single decker 11 metre length bus, with initial deployments of double decker buses starting. Half-length midi buses are not available as a standardised option, and need to be developed to order.

4.5.4 Trains

The majority of interest, at present, is moving to replace diesel multiplier units (DMUs) with hydrogen engines. This obviates any need for overhead electrification and allows rapid turnover of the DMU fleet. Current interest in the UK includes in Scotland, Teesside and the new Oxford to Cambridge lines.

Perhaps most notably, as of November 2018 SNCF (France's national state-owned railway company) have announced their intentions to replace 20% of their overall fleet with hydrogen trains by 2035. This most likely means the end of diesel trains on their network. In the UK Arriva Northern Rail have announced their first hydrogen train will be up and running during the early 2020’s.

Trams and commuter rail are the focus of interest at the minute though there are initiatives underway in Canada and Australia to develop high speed hydrogen options.

4.5.5 Ships

The biggest challenges to shipping to convert to using hydrogen are:

- Regulations –regulations do not move fast in this area. It is likely that it will not be until 2032 until the necessary codes and standards have been developed. This means that till then each ship has to have bespoke certification, which pushes up cost.
- Hydrogen –the quantities of hydrogen required by shipping would be a step change in levels. For example, if the 30 ships currently in construction across Norway are to be fuelled by green hydrogen this will require in the region of 223 MWs of electrolysers. To put this in context this is nearly a quarter of total global manufacturing capacity of electrolysers.

The three main types of ships that will see traction in this market between now and 2032 are: ferries, platform supply vessels and cruise ships. It is also likely that inland waterway vessels will rapidly rise up the agenda in the coming handful of years.

4.6 Utilities and Hydrogen

Electric utilities' interest in the production of hydrogen using electrolysis comes down to two main reasons -long term energy storage and the provision of ancillary services (including short term energy storage, demand side response, frequency response or other types of network constraints).

The provision of long term energy storage is currently not a function provided by UK DNOs. Current market conditions and state of the UK electricity grid mean that dealing with the variable output of renewable energy generators is the form of ancillary service most suited to the use of electrolysers. To date product development linked to renewable energy has focused on two areas, full time feed of renewables to produce hydrogen and curtailed renewables to produce hydrogen. The production of hydrogen results in the formation of a short term energy storage vector.

The reasons why electrolysers are not suited purely for the provision of ancillary services such as frequency response, and that an element of short term energy storage is required are twofold:

- Electrolyser are not suited to sub-second start time and
- Electrolysers are not suited to rapid cycling.

Rapid and repeated cycling reduces the overall operational lifetime of the electrolyser stack.

In Europe at least, renewable energy to hydrogen projects are still very much in the demonstration phase. This means that most, if not all, are partially underwritten by some form of innovation grants or funding.

4.7 Multi –Vector Case Studies

4.7.1 Big Hit Project, Orkney

The Big Hit demonstration project is the first of its kind and aims to utilise hydrogen produced by community wind power on the island of Eday and Shapinsay to be stored and used locally to power a ferry and a number of facilities on Mainland (name of the main island in the Orkney group of islands).

Project status: Operational
Project lead: Orkney Islands Council
Project funding: FCH 2 JU providing €5 million. Total project cost = €10.9 million
Source of electricity: Curtailed output from wind and tidal turbines
Energy delivery vectors: fuel, heat & power (CHP)
Electrolysers: 1 x 1MW PEM + 1 x 0.5MW PEM (provided by ITM power)
Vehicles: 5 x Symbio Renault Kangoo

The Orkney Islands have over 50 MW of installed wind, wave and tidal capacity. Together these sources generate over 46 GWh per year of renewable power. This large output has resulted in the Orkney Islands being net exporters of electricity since 2013. The excess renewable electricity is often curtailed due to limited grid capacity. This curtailment results in up to 30% of the renewable energy generated per year being lost.

Overall the two PEM electrolysers will produce about 50 tonnes of hydrogen each year from constrained renewables. This will then be used to heat local buildings, and will also be transported by sea ferry to Kirkwall in 5 hydrogen tube-trailers.

In Kirkwall a 75 kW hydrogen fuel cell will supply heat and power for several harbour buildings, a marina and 3 ferries (when docked) in Kirkwall. And finally, a hydrogen refuelling station in Kirkwall will fuel the 5 Symbio hydrogen fuel cell road vehicles.

This project has gained a lot of worldwide attention for its level of innovation, community involvement and starting to tackle local energy poverty. Note that as a demonstration project it is not economically optimised, but set up to test the potential.

Figure 5: Big Hit Project, Orkney

4.7.2 HyDeploy

HyDeploy a 3 year project (2017-2020) led by Cadent (gas network operator) and Northern Gas Networks to test hydrogen injection up to 20% in a live gas network. As part of the three year project, there will be a year-long live trial of blended gas on part of the University of Keele gas network to determine the level of hydrogen which could be used by gas consumers safely and with no changes to their behaviour or existing domestic appliances

Project status: final approval received. Project to go live summer 2019

Project lead: Cadent and Northern Gas Networks. The HyDeploy live trial is being hosted on the Keele University campus

Project funding: £6.8 million project, funded by Ofgem's Network Innovation Competition

Source of electricity: Grid electricity

Energy delivery vectors: standard gas appliances using up to 20% hydrogen blend

Electrolysers: 0.5 MW PEM (provided by ITM power)

Customers will continue to use gas as they do today, without any changes needed to gas appliances or pipework. The trial will take place on part of Keele University's private gas network, serving 17 faculty buildings and 100 domestic properties. The HSE granted HyDeploy exemption to the current limit of 0.1% hydrogen in the UK gas network after the project gathered extensive evidence to demonstrate the hydrogen blend would be 'as safe as natural gas'. The exemption is similar to that granted to allow the first bio-methane producers to inject biogas into the natural gas network.

4.7.3 Aberdeen Hydrogen Bus Project

The Aberdeen Hydrogen Bus Project is made up of two separate European funded projects, High VloCity, which funds 4 buses and HyTransit which funds 6 buses, both of which are supported by the Fuel Cells and Hydrogen Joint Undertaking (FCHJU).
Project status: Operational
Project lead: Aberdeen city council
Project funding: £20 million project, funded mainly by FCH JU, Innovate UK and the local Council
Source of electricity: Grid electricity
Energy delivery vectors: hydrogen as a fuel
Electrolysers: 3 x 310kW = 1MW total Alkaline (provided by Hydrogenics)
Vehicles: 10 hydrogen fuel cell busses (produced by Van Hool), with talks of adding a further 10 buses underway
The buses had travelled more than 730,000 kilometres and carried an average of 36,700 passengers per month, operating six days a week at 90 percent availability. More than 1,600 refuelling events had taken place at the hydrogen station, each taking just five to seven minutes per refuelling.

Figure 6: Aberdeen Hydrogen Bus Project

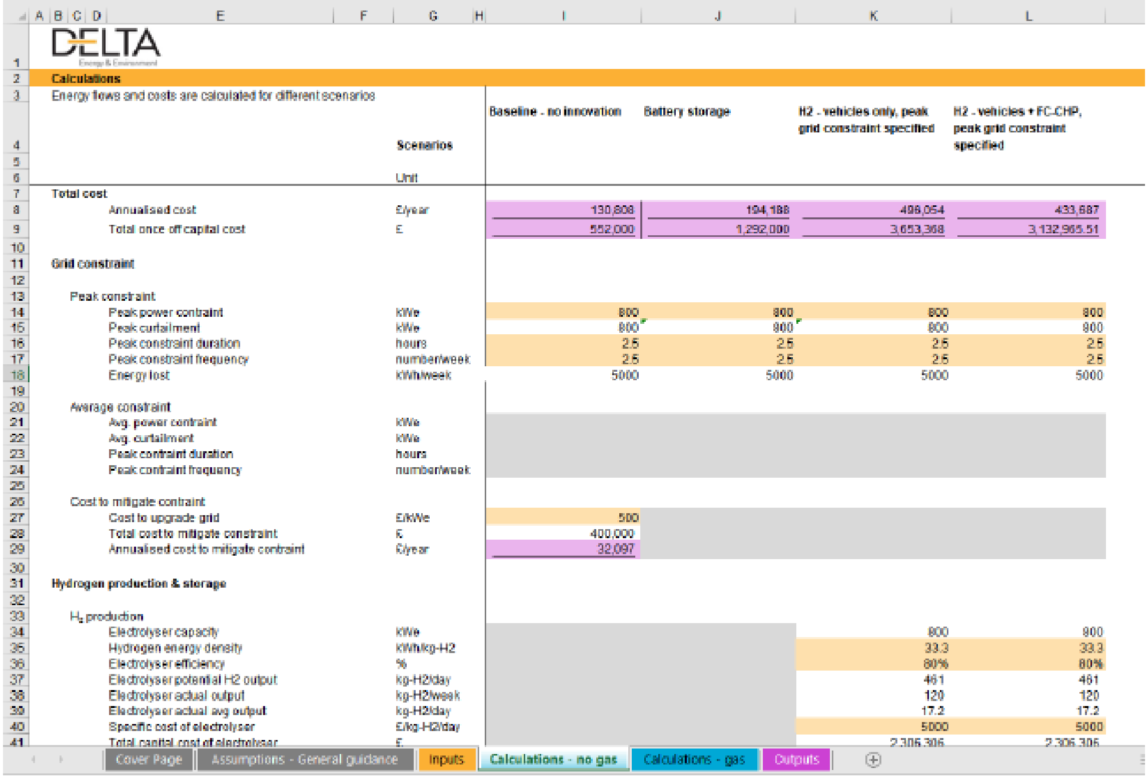
4.8 Modelling the Heat & Fleet Concept

4.8.1 Developing the Model

An Excel based model was developed to provide some shape to the project -allowing for a basic technological and economic analysis of the proposed project.

The techno-economic analysis conducted helps identify the key technical components and boundary conditions to the project based on discussions with WPD and Delta-ee. A potential site for the project was identified (Church Village Depot) and this provided some of the boundary conditions in terms of energy loads, vehicle numbers, etc.
Using the boundary conditions a simple technical model was developed. The model assesses energy flows (renewable electricity supply, building energy demands, and transport demands) and provides a high-level estimate of equipment sizes (for the electrolyser and fuel cell), hydrogen storage volumes, and vehicle capacities.
The model developed also allows for a high level financial analysis of the project / trial taking into account capital and operational costs. This helps identify indicative project investment

costs, lifetime cost benefits, and provide comparisons with the alternative of network reinforcement costs.



DELTA Energy & Environment

		Unit	Baseline - no innovation	Battery storage	H2 - vehicles only, peak grid constraint specified	H2 - vehicles + FC-CHP, peak grid constraint specified
2	**Calculations**					
3	Energy flows and costs are calculated for different scenarios					
4		Scenarios				
6		Unit				
7	**Total cost**					
8	Annualised cost	£/year	130,808	194,188	498,054	433,687
9	Total once off capital cost	£	552,000	1,292,000	3,653,368	3,132,965.51
11	**Grid constraint**					
13	Peak constraint					
14	Peak power contraint	kWe	800	800	800	800
15	Peak curtailment	kWe	800	800	800	800
16	Peak constraint duration	hours	2.5	2.5	2.5	2.5
17	Peak constraint frequency	number/week	2.5	2.5	2.5	2.5
18	Energy lost	kWh/week	5000	5000	5000	5000
20	Average constraint					
21	Avg. power contraint	kWe				
22	Avg. curtailment	kWe				
23	Peak contraint duration	hours				
24	Peak contraint frequency	number/week				
26	Cost to mitigate contraint					
27	Cost to upgrade grid	£/kWe	500			
28	Total cost to mitigate constraint	£	400,000			
29	Annualised cost to mitigate contraint	£/year	32,097			
31	**Hydrogen production & storage**					
33	H_2 production					
34	Electrolyser capacity	kWe			800	800
35	Hydrogen energy density	kWh/kg-H2			33.3	33.3
36	Electrolyser efficiency	%			80%	80%
37	Electrolyser potential H2 output	kg-H2/day			461	461
38	Electrolyser actual output	kg-H2/week			120	120
39	Electrolyser actual avg output	kg-H2/day			17.2	17.2
40	Specific cost of electrolyser	£/kg-H2/day			5000	5000
41	Total capital cost of electrolyser	£			2,306,306	2,306,306

Figure 7: Excel Model – Modelling Concept

4.8.2 Defining the Project Boundaries – Church Village Depot

Parameters for the project were defined in consultation with personnel at Church Village. The main points arising out of this consultation were:

- The site is not connected to the gas grid
- A new all electric HVAC system is used for heating
- There are approximately 100 utility vehicles based at the site
- Each vehicles travel on average approx. 60 miles per day
- The majority of the people based at the depot operate on a typical weekday 09:00 – 17:00 schedule
- The electrical baseload of the site is approx. 20kW

Figure 8: The Church Village Depot, South Wales

4.8.3 Configurations for Hydrogen as a Fuel

The diagrams below show the different configurations modelled related to the use of hydrogen as a transport fuel.

4.8.3.1 The Base Case – Paying for a Network Upgrade

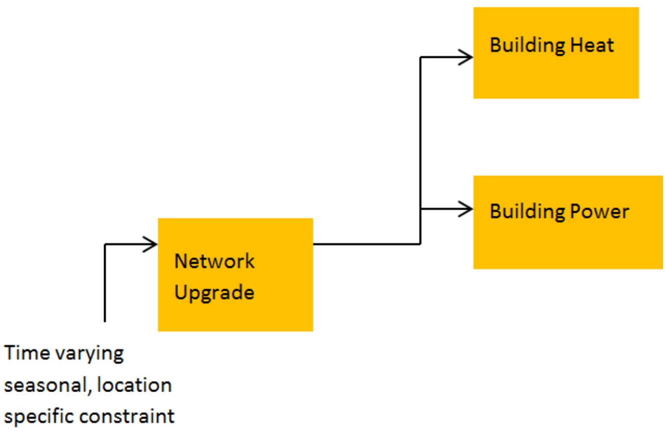


Figure 9: The Base Case – Paying for a Network Upgrade

4.8.3.2 Using Dual Fuel Combustion Vehicles

In this case, all the hydrogen is used in a duel-fuel combustion vehicle burning a combination of hydrogen and diesel fuel. These vehicles are modelled around the Ulemco-modified vehicles that are fitted with hydrogen tanks.

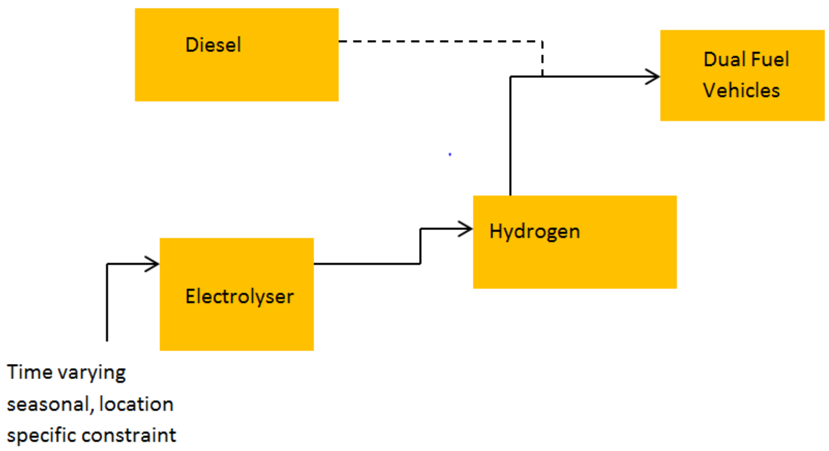


Figure 10: Using Dual Fuel Combustion Vehicles

4.8.3.3 Using Hybrid Hydrogen-Electric Vehicles

In this case, the vehicles are modified plug in electric vehicles that use a hydrogen range extender. They are assumed to not require any charging from the grid. This is modelled around the Renault Symbio-hydrogen range extended vehicle.

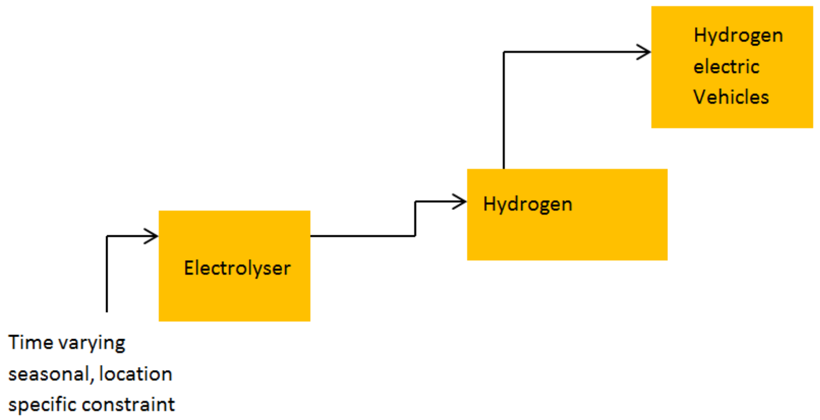


Figure 11: Using Hybrid Hydrogen-Electric Vehicles

4.8.3.4 Using the Hydrogen in a Fuel Cell to Provide Heat and Power

In this case, all the hydrogen produced is used in a PEM fuel cell unit to provide heat and power.

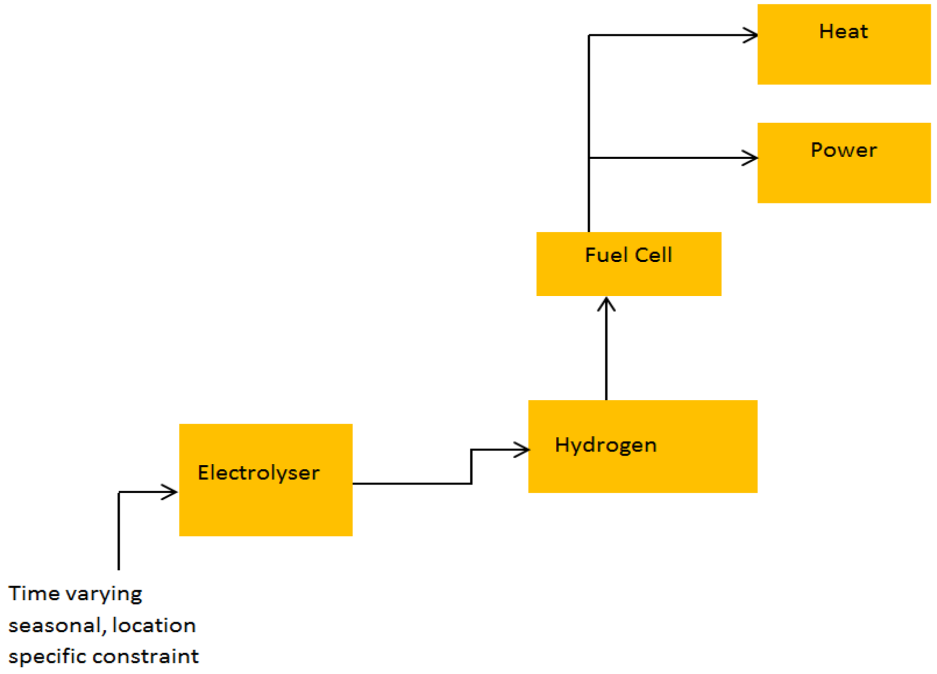


Figure 12: Using Hybrid Hydrogen in a Fuel Cell to Provide Heat and Power

4.8.3.5 An Alternative Non-Hydrogen Case – Using a Battery to Gain Further Perspective

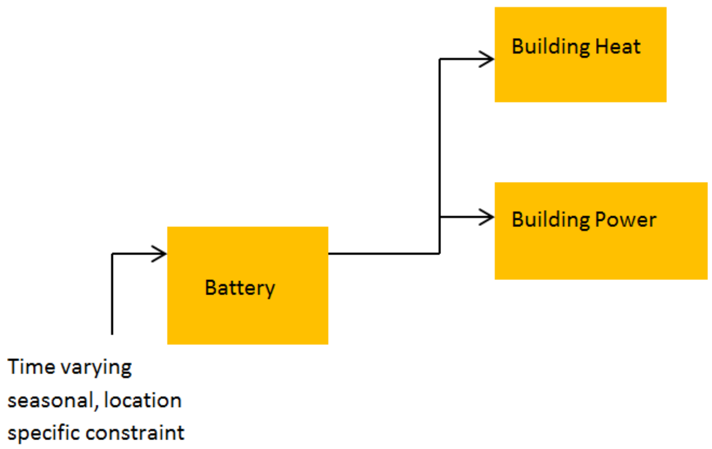


Figure 13: Using Non-Hydrogen based Solution

4.9 Outline Project Plan

Milestone	Description	Due Date
Milestone	Project initiation	14/08/2018
Document	1a. High level specification	10/09/2018
Document	1b. Technical analysis	17/09/2018
Document	1c. Cost analysis	24/09/2018
Report	Initial financial modelling outputs	28/09/2018
Milestone	Interim meeting	28/09/2018
Document	2a. Current market activity	12/10/2018
Document	2b. Existing trials / case studies	26/10/2018
Document	2c. Current market players	26/10/2018
Report	Draft market report	02/11/2018
Document	3a. Refinement of scope	09/11/2018
Document	3b. Identification of partners	22/11/2018
Report	Draft final report and recommendations	07/12/2018
Milestone	Final meeting / presentation	07/12/2018
Report	Final report and recommendations	17/12/2018

Table 3: Project Milestones

Task number	Task name	Start week	End week
1	Project kick-off	1	1
2	1a. High level specification	1	5
3	1b. Technical analysis	4	12
4	1c. Cost analysis	10	15
5	2a. Current market activity	9	15
6	2b. Existing trials / case studie	9	15
7	2c. Current market players	10	14
8	3a. Refinement of scope	11	17
9	3b. Proposing a way forward	14	17
10	Reporting writing	13	18
11	Final project meeting	18	18

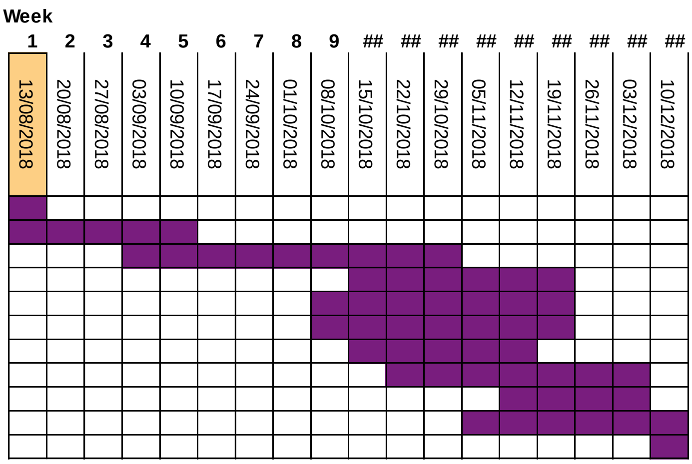


Figure 14: Project Milestones

4.10 Project Resource

Western Power Distribution (WPD) and Delta-ee formed a team to deliver the Hydrogen Heat and Fleet Project under the NIA funding mechanism.

Project Partner	Resource	Detail
Western Power Distribution	Faithful Chanda	Project Manager, WPD
Delta - EE	Andrew Turton	Principal Analyst
	Matthew Myers/Jennifer Arran	Senior Analyst

Table 4: Project Resource

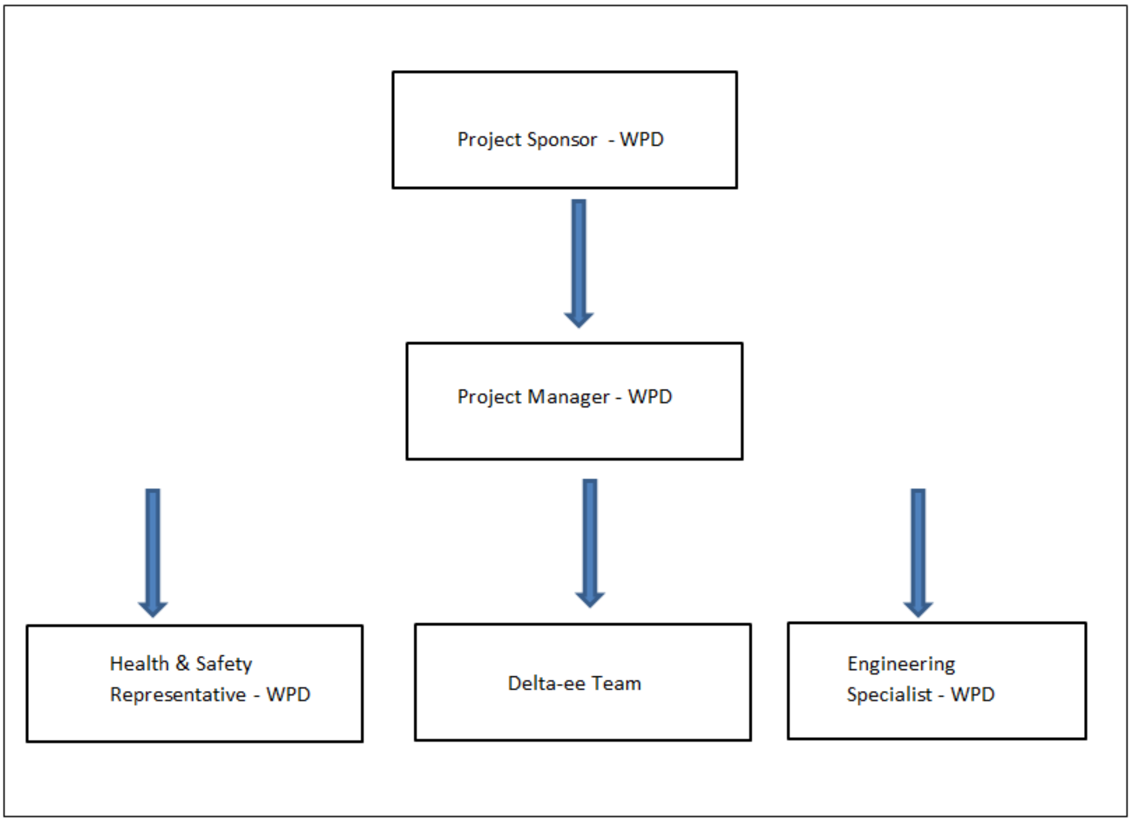


Figure 15: Project Structure

4.11 Project Partners and Roles

- Delta EE: Delta Energy & Environment (Delta-ee) is a leading research and consulting company in low carbon heat and distributed energy. Delta-ee brings a wealth of insight into the heating markets from a number of consulting assignments and via its research services. Most of Delta-ee's research involves close dialogue with the industry, including technology manufacturers, policy makers, network companies, energy companies and many more in the UK and internationally. Delta-ee brings a wealth of insight into the heating markets from a number of consulting assignments and via its research services. All of Delta-ee's research involves close dialogue with the industry, including technology manufacturers, policy makers, network companies, energy companies and many more in the UK and internationally.

- Innovation Project Manager: WPD's overall responsibility, leadership and authority for the project. Major tasks included:
  - Owning the vision for the project.
  - To run the project and realise the benefits.
  - Managing the interfaces and communication with the project's stakeholders.
  - Ensuring that the aims of the project continue to be aligned with evolving project needs.
  - Compiling Progress Reports that formally assess the achievements of the project and the benefits realised from the NIA investment.
  - Overall control of the project implementation, with personal responsibility for the project's achievement.

4.12 Project Risks

The project was managed using proven project management methodology previously used in other projects. The associated risk management processes ensured that risks were recorded, clearly defined, responsibility assigned and mitigating actions identified. The risk register was reviewed at regular project meetings and significant risks were escalated to relevant members of the team. The Project Managers had responsibility for managing the risks on a day to day basis.

4.13 Reporting and Communications Cycle

The successful delivery of the Hydrogen Heat and Fleet Project was ensured through the implementation of best practice project management, governance and effective controls. Central to this was:

- A detailed baseline project schedule (down to the level of daily activities) used to track progress.
- Live Risk Register and Issues Log that were updated and reviewed monthly.

- Clear roles and responsibilities, including ownership of activities, risks and deliverables.
- An agreed meeting schedule that included monthly progress reviews with WPD/Delta-ee.

4.14 Reporting Cycle

The project team met on a monthly basis and this was to ensure progress, risks and issues to be reported and identified in a timely and accurate manner. This meeting will also review the Risk Register and Issues Log and cover any resourcing issues. Two days in advance of this meeting Delta-ee will circulate a concise report that sets out the following in a standard format:

- Overall progress – Red, Amber, Green (RAG) status
- Key activities in last reporting period
- By Task – progress vs project plan
- Deliverables
- Top five Risks and Issues
- Key dependencies
- Costs / budget / invoicing
- Change control
- Decisions required
- Key activities planned for next period.

4.15 Data Analysis

Obtaining good quality data was a key factor of success for the Hydrogen Heat and Fleet project.

An Excel based model was developed to provide some shape to the project -allowing for a basic technological and economic analysis of the proposed project. The techno-economic analysis conducted helps identify the key technical components and boundary conditions to the project based on discussions with WPD and our internal expertise. Using Church village depot as the site to create and develop the Excel model, with some specific site considerations, such as energy loads, vehicle numbers, etc.

The model developed also allows for a high level financial analysis of the project / trial taking into account capital and operational costs. This helps identify indicative project investment costs, lifetime cost benefits, and provide comparisons with the alternative of network reinforcement costs.

The analysis of the data has been another challenge because of the volume of data and the amount of analysis required in order to test the hypothesis. However, this has been completed and the full results are detailed within the Final Report.

The market study research was based on secondary desktop research as well as in depth primary research calls with associations, vehicle manufactures, electrolyser manufactures, the government and gas distribution networks. In total 15 research calls were carried out through the course of the project. Research calls lasted between 15 and 45 minutes each. After each call the call notes were checked and the main themes identified. After all the interviews had been completed the call notes were divided into the different stakeholder groups. The themes arising from each stakeholder group were then aggregated.

5. Performance Compared to Original Aims, Objectives and Success Criteria

The project has addressed all aspects of its aims and objectives, with specific focus on the potential to be transformational in delivering solutions that will shape future energy market dynamics.

The project has considered a comprehensive range of use cases. The primary aim of this project was to research the use of hydrogen electrolysers as a controllable load that could help with increasing renewable electricity output. In areas with large penetrations of renewable generation, a controllable load will increase the capacity for further generation connections and further allow for renewable output that is currently curtailed to be put to use.

6. Required Modifications to the Planned Approach during the Course of the Project

The project did not require any changes to its approach. It did however require defining a set of targets during its lifecycle to review the milestones at agreed times. No change in Methodology (it remained a waterfall delivery) was required throughout the project

7. Project Costs

Activity	Budget (£)	Actual (£)	Variance
WPD Project Management	25,000	8,518	66%
DELTA EE Contract	35,000	35,000	0%
Total	60,000	43,518	27%

Table 4: Project Costs

The total project was successfully delivered approximately 27% under the project budget. WPD project management costs were lower than initially budgeted because we didn’t need to spend as much time on the project as originally planned.

8. Lessons Learnt for Future Projects

- Consumer base: The transition to a hydrogen – based vehicle fleet requires taking a closer look at the current fleet of vans available in the UK. Hydrogen vans are the main option for WPD considering its needs / fleet requirements. At the moment there are only two available van options available for purchase on the open market. A number of other vehicle types are becoming available, including trucks, but there is little development in the utility vehicle space. The only market ready solution for direct combustion hydrogen vehicles are converted vans by ULEMCo. These vans burn a mix of hydrogen and diesel in the van's conventional engine. The other is the Electric vehicle with fuel cell range extender. The only zero emission hydrogen using van currently on the market is the Symbio Renault Kangoo. It is a plug in battery electric vehicle that has been fitted with a fuel cell range extender. In order to develop an innovative hydrogen project going forward the best economic sink for the hydrogen generated is a vehicle fleet. A pure hydrogen fuel cell vehicle fleet offers the best economic case. However there are no pure hydrogen fuel cell vans currently on the market. Huge efforts would need to be invested to work with a supplier to develop such a vehicle.

- Economics: There are viable electrolyser solutions on the market today and a number of electrolyser companies in the market place all with proven electrolyser solutions. The main UK players are Hydrogenics (Canadian) and ITM Power (UK based).Electrolysers range in size from a few kW to many MW. The largest electrolysers being considered today have capacities in excess of 100MW. These are however comprised of a number of subunits that are a few MWs each. In order to achieve decent economies of scale and production outputs worth the upfront investment, electrolysers in the 1MW and bigger range are currently the dominant size of projects. Most electrolysers of this scale come containerised.

- Relocating Electrolysers: While the degree of renewable curtailment is likely to grow significantly over coming years, currently the limited overall renewable curtailment duration would result in an electrolyser load factor that would result in a high levelised cost of hydrogen. Given the spatially and temporally diverse nature of constrained renewables, further investigations could be made into portable electrolyser units that would be able to address constraints that appear on different parts of the network. By relocating the electrolyser to the parts of the network that are most constrained the cumulative load factor of the electrolyser could be boosted to produce a viable business case.

- Distribution electricity networks become constrained when they operate close to, or above, their designed operational limits as defined by their specific thermal capacity (most common), voltage bandwidth and fault level. In order to best help with renewables curtailment on parts of WPD's network the following options, from most to least economically viable, are available:

  1. Non-hydrogen related solutions

  - Best economic case might be to pay for network upgrades

- Battery (Li-Ion) options may also be cost competitive

2. Hydrogen related solutions – using the hydrogen generated by an electrolyser to:

- Run a pure fuel cell vehicle fleet
- For heat and power (fuel cell CHP)
- Run a dual fuel (hydrogen + diesel fuel) vehicle fleet.

- It would be advantageous to develop a High Innovation Scenario: This would entail:
    - Working with industry to create a mobile fast response electrolyser (first of its kind in the world)
    - Order a (small) fleet of hydrogen vans, creating a market for the product and being seen as a first mover
    - Creation of the software to work with the electrolysers and renewable assets in real time, creating the most economically advantageous settings for both
    - Develop a bounded "islanded" system to create a first of its kind integrated project.

8.1 Dissemination Events

Learning has been a fundamental part of the success of the Hydrogen Heat and Fleet project. It has been a very informative exercise for WPD and Delta-ee and helped shape how knowledge on innovation projects should be managed in the future.

Listed below are some of the dissemination events on the project.

Event	Date	Attended by/ To be attended by	Location
Hydrogen Networks	24/09/18	Wessex Energy and Environmental Management Group	Dorset
Electricity Innovation Forum	26/02/19	SME's in Network Innovation	Glasgow

Table 5: Dissemination Events

9. The Outcomes of the Project

9.1 Key Learnings from the Project

- The challenge: The use of green hydrogen for energy storage and mobility is both timely and technologically achievable. The global markets are huge and the UK has world-leading technology. The UK's challenge is being first-to-market products that can be manufactured at industrial scale whilst meeting demanding market price points. Cost reduction through large scale deployment is paramount. Achieving widespread use of hydrogen as a fuel for vehicles will massively decarbonise the transport sector and enable smart new ways of integrating ultra-low carbon energy sources into the energy system as key components of the energy transition. However, until now the technology has yet to reach the point of being able to offer an unsubsidised ownership proposition which is appealing enough to allow mass market take up. As a result, the hydrogen sector has not developed as fast as expected.

- Opportunity for productivity growth: It will make it cheaper and more effective to address the challenges of decarbonising transport, reducing city air pollution, improving energy security, improving the UK's balance of payments and creating high value employment growth in several sectors. Achieving a commercial breakthrough for green hydrogen would stimulate a range of sectors in the UK:
  - Renewable energy developers – hydrogen production will provide new and valuable revenue for developers of renewable energy projects in the UK (electricity and biomass based).
  - Gas network operators – who benefit from the introduction of a cheap green fuel to help decarbonise and future proof their gas systems.
  - Energy companies – such as Shell and ENGIE, who are looking to invest in future technologies which enable diversification from existing fossil fuel portfolios.
  - Vehicle manufacturers – UK vehicle manufacturers can be leaders in heavy duty and niche fuel cell vehicle manufacture (examples include Wrightbus, Alstom UK, Alexander Dennis, RiverSimple, HV systems, Arcola Energy and Revolve).
  - International manufacturing partners (such as Toyota, Hyundai and Honda) are invested heavily in developing fuel cell vehicles and see the UK as a launch market in Europe.
  - UK supply chain for component manufacturers that support hydrogen technology, for both automotive and non-automotive applications.
  - The existing hydrogen sector – companies such as ITM Power, Luxfer, Anglo American, Haydale Composites and Johnson Matthey stand to benefit from the expansion of the hydrogen sector.
  - Vehicle users – companies under pressure to meet strict emissions legislation such as taxi companies and bus operators to enable continued operation in polluted cities.

- Market opportunity: Realising a commercially viable and sustainable green hydrogen production system for energy storage and mobility based on UK manufactured products will massively strengthen the UK's ability to export technologies into developed and

emerging global markets. The opportunity is to replace a significant fraction of our existing transportation system using a zero carbon and zero emission fuel.
The market is ready to deliver a hydrogen solution today; however, questions regarding feasibility are economic, not technical.

- There is lots currently going on in the hydrogen space today –space is growing
- There are a range of public and private stakeholders investing
- Transport is key
- There are a growing range of transport applications of hydrogen
- The main electrolyser types are PEM and alkaline
- There are a range of current and past hydrogen demonstration projects that have taken place to date
- Producing hydrogen is capital intensive when run hours are low.

- Supply chain and logistics: The most economic use case for hydrogen is large vehicle fleets. There are limited off -the -shelf hydrogen utility vans. There are direct combustion conversion vans available that combust a mix of diesel and hydrogen. These vehicles, while flexible and offering lower overall carbon emissions are not a 100% green option. There are smaller plug-in electric utility vans that are fuel cell range extended. While these are considered '100% green', they are smaller than traditional vans and still need to be plugged in to charge. Part of the issue is the lack of orders for such vans.

- Utilities and Hydrogen: The best business case is to use the full output from a renewable site to generate hydrogen. Current focus of interest is green electrolytic hydrogen – electrolysers have been used with renewable electricity as an input extensively before. Hydrogen has the potential to store vast quantities of energy and charge and discharge it as other forms of energy at a high power output. Hydrogen production via electrolysis is a market ready solution to reduce renewable curtailment.

- Big Hit –Orkney Islands study: Electrolysers have successfully been deployed in the UK, to produce hydrogen for multi-vector output use cases, using curtailed renewables. The Big Hit project in Orkney is an example of a project that makes use of electrolysers to help with issues of renewable curtailment due to a grid constraint. An increasing number of new electrolyser projects are now being commercially driven, rather than being purely research or demonstration projects requiring total government funding to get them off the ground.

- Technical and economic feasibility: In order to best help with renewables curtailment on parts of WPD's network the following options, listed from most to least economically viable, are available:

1. Non-hydrogen related solutions:

- Best economic case might be to pay for network upgrades. This is however a 'no-innovation' scenario.
- Battery (Li-Ion) options are also competitive. Battery solutions would be able to provide grid ancillary services but not any cross vector applications. This is a 'low-innovation' scenario.

2. Hydrogen related solutions –using the hydrogen generated by an electrolyser to:

- Run a pure fuel cell vehicle fleet
- For heat and power (fuel cell CHP)
- A combination of running a vehicle fleet and a fuel cell CHP
- Run a dual fuel (hydrogen + diesel) vehicle fleet

- UK strengths and competitive advantage: The UK has become one of the leading players in hydrogen technology, with UK companies supporting deployment. In a number of sectors, we have leading players willing to develop green hydrogen at scale. These include:
  - Bus manufacturers Wrightbus and ADL have hydrogen buses which when produced at scale (hundreds of buses/year) offer the lowest cost of ownership of all zero emission buses, competing in markets where regulators require zero emission vehicles (TfL, Birmingham and Oxford CC).
  - Bus operators are ready to use the technology at scale e.g. National Express, Tower Transit, Metroline and First Group.
  - Train manufacturers such as Alstom UK are developing designs for UK specific hydrogen trains. Electrification requires new zero emission solutions; many operators are engaged and DfT is supportive.
  - Smaller vehicles – numerous innovators in small vehicles are based in the UK (RiverSimple, Arcola, Revolve, and HV Systems).
  - International manufacturers (Toyota, Honda, Hyundai), see the UK as a European launch market for their FCEVs offering vehicles to willing fleet operators e.g. Met Police, Commercial Group, Greentomatocars and Yorkshire Ambulance service (and many more).
  - Hydrogen production – we have leading players in the field of electrolysis (ITM Power), gasification (e.g. Advanced Plasma Solutions, Progressive Energy) and gas handling from our oil and gas heritage (e.g. BOC).

- Network operators: The Heat & Fleet concept is not of great interest to the gas network operators due to a lack of direct interaction with the gas grid. As part of the Heat and Fleet research, calls were held with both Wales & West Utilities (WWU) and Cadent. The takeaway message form the conversations were that there is little that a project such as Heat and Fleet could offer them in the short term. The main focus at the moment is on large projects such as HyDeploy (blending of up to 20% hydrogen into a private gas network at Keele University), Hynet (hydrogen production by methane reformation + CCS), H21 Leeds City Gate Project (looking at developing a 100% hydrogen gas network) and H21 North of England (a solution for converting 3.7 million UK homes and businesses from natural gas to hydrogen). One of the major barriers to injection of hydrogen into the gas grid is the Gas Safety (Management) Regulations 1996 which places a statutory upper limit on the hydrogen content of natural gas to 0.1% (molar). This limit is likely to only be revised after the conclusion of the HyDeploy project in 2021. Although it is likely that even if the HyDeploy project concludes successfully in 2021 that there will be a move to an special permission / exemptions based system, such as the one employed for biomethane injection, rather than a full revision of the statutory limits.– Hydrogen solutions are valuable to developers and operators of green energy (e.g. SSE, ENGIE) and regulations e.g. the revised RTFO mean that all energy players (e.g. Shell) can make a commercial case for introducing hydrogen fuelling.

- Sizing the electrolyser: We learnt from Church Village depot that a modest size electrolyser could be required given the requirements of the site; an electrolyser of 0.1 - 0.5MW is perfect for the site. The electrolyser size and levelised cost of hydrogen it produces is heavily dependent on the annual operational hours of the electrolyser. It is very difficult to foresee any viable economic case if the electrolyser is run less than 2500 hours per year.

- Operational hours: The best use case for electrolysers is load levelling. The biggest obstacle to this at the moment is the limited number of hours per year that the cumulative output of renewables breaches the network capacity on the different parts of WPD's network. The economic case is unlikely to be highly profitable and hinges on things like the availability of low cost electricity. The cost of the electricity used by the electrolyser is a major driver of cost. The cost of the input electricity is a very significant driver of cost. Only in cases when the cost of hydrogen falls below the cost of diesel will it be possible to make an economic case for hydrogen.

- Heat and Fleet solutions – We can avoid network upgrades by generating green hydrogen. The alternative to constraining the output of local renewable energy generators or paying to reinforce the network is to generate hydrogen using an electrolyser. By locating an electrolyser on the part of then network upstream of the constraint, the excess renewable output can be used to generate green hydrogen rather than being curtailed and lost. This option also avoids the need for costly network reinforcements. Active network management can help –some reduction in lost renewable output. In reality the network is actively managed and the degree to which renewable energy generators output is constrained varies depending on the requirements of the network at any given time. The alternative, upgrading the network, when the firm capacity of the local network is exceeded, in order to accommodate more output one option is to pay for network upgrades. A further issue to consider is that upgrading the network to cope with sporadic peaks results in lower overall network utilisation which may be considered an inefficient investment.

9.2 Next Steps

In order to go to demonstration, WPD would work with an electrolyser manufacturer, such as ITM Power or Hydrogenics, to develop a better business case for an electrolyser running at a lower load factor. The best economic sink for the hydrogen generated is a vehicle fleet. A pure hydrogen fuel cell vehicle fleet offers the best economic case. However there are no pure hydrogen fuel cell vans currently on the market. WPD could work with a supplier to develop such a vehicle.

10. Data Access Details

The scale and timeframe of the project has remained consistent with the registration document, a copy of which can be found here:

file:///C:/Users/Internet/Downloads/032-Hydrogen-Heat-Fleet-New-PEA%20(2).PDF

The full report and other documents can be found on the following links: https://www.westernpower.co.uk/innovation/projects/hydrogen-heat-fleet-viability-assessment

Aurora Energy (2018) –Delivering "net zero", Will the wholesale market cease to function in a high renewables world?, 2018

BEIS (2017)–Digest of United Kingdom Energy Statistics (DUKES), Chapter 5, 2017
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11. Foreground IPR

A complete list of all background IPR from Delta-ee has been compiled. Delta-ee and WPD will continue to disseminate the knowledge created through energy market forums and events with the aim of achieving broad market adoption of the technology.
A number of modelling scenarios have been produced by Delta-ee.

12. Planned Implementation

There are no plans at the moment to implement any of the proposals from the project, as it was purely a research and intended to inform the business.

13. Contact

Further details on replicating the project can be made available from the following points of contact:

Future Networks Team
Western Power Distribution,
Pegasus Business Park,
Herald Way,
Castle Donington,
Derbyshire
DE74 2TU
Email: wpdinnovation@westernpower.co.uk