Services to Energy Networks – pre-read in advance of workshop on 11th April

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This project aims to drive sustainable economic growth in the UK hydrogen and fuel cell industry in the period to 2025 and beyond

- **Public-private project** steered by Innovate UK, the Department of Energy and Climate Change (DECC), Transport Scotland, Scottish Government, Scottish Enterprise, Scottish Hydrogen and Fuel Cell Association (SHFCA), UK Hydrogen and Fuel Cell Association (UKHFCA), and the Knowledge Transfer Network (KTN)
- **Delivered by E4tech and Element Energy**, in consultation with the Steering Board and wider stakeholders
- Launched in January, due to be completed in early June
- Consists of **11 mini roadmaps**, on different sectors of hydrogen and fuel cell use, which will be brought together with an overall national case

WP 1 – kick-off workshop

Aligning on scope, timescale, governance

↓

WP 2 –Analysis of individual roadmaps

↓

WP 3 – Consultation

Workshops + bilateral discussions

↓

WP 4 – Revision of individual roadmaps

- Based on feedback and evidence received from consultation, revise individual roadmaps and benefits assessments

↓

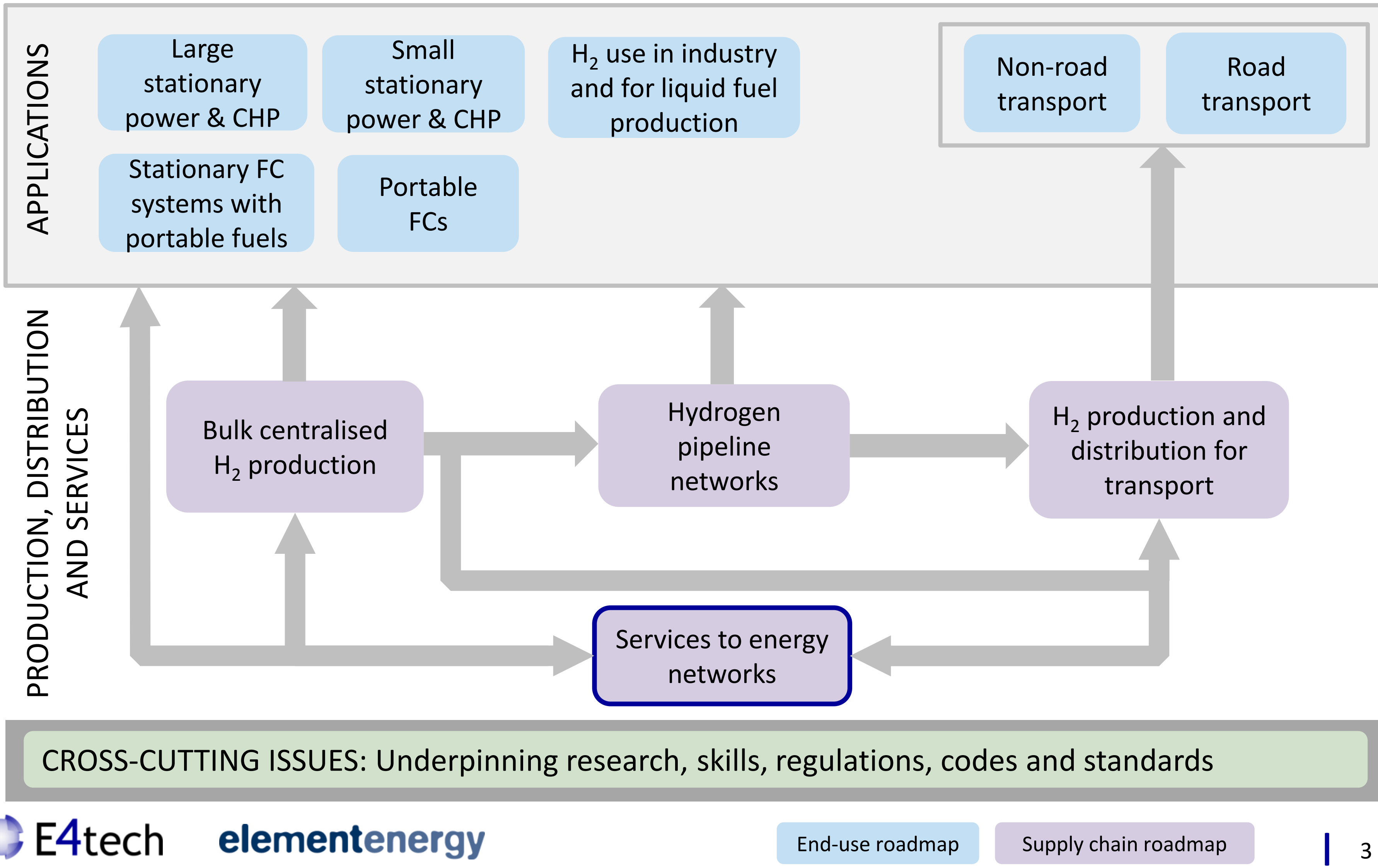
WP 5 – Understanding the overall national case

- Understand interdependencies between roadmaps and critical decisions on each roadmap
- Agree on a prioritisation
- Assess required support
- Calculate national benefits

↓

WP 6 - Draft and final reports

The 11 mini roadmaps cover uses of hydrogen and fuel cells, and production and distribution of hydrogen



This workshop is to get your feedback on the draft mini-roadmap on potential HFC services to energy networks

- This draft mini-roadmap has been issued as a straw man document to provide a basis for discussion. All aspects are up for discussion and we welcome all input
- The roadmap shows **aims** for each application for 2025, **barriers** to achieving those aims, **actions** that need to be taken to overcome the barriers, and **benefits** of doing so
- During the workshop on 11th April, we will discuss **your views on**:
  - Accuracy (45 mins) - Have the main issues and barriers been captured in the draft roadmaps?
  - Ambition (45 mins) - Are the aims for 2025 appropriate? What level of ambition is reasonable?
  - Action (60 mins) - Will the actions proposed be enough to overcome the barriers? If not, what else is needed? How reasonable is it to expect these actions? What might they cost, how long will they take and who might pay?

- Note that we are focusing on **actions to 2025**, not the long term vision for the hydrogen and fuel cell sector. The longer term vision will be articulated in the overall national roadmap
- Also note that in the first workshop, we will be focussing mainly on the provision of services to network as opposed to the aspects of long term storage in salt caverns
- We also want your views on cross cutting issues that could affect more than one mini-roadmap

We welcome your views on cross cutting issues that could affect all mini-roadmaps

Underpinning research
e.g. What breakthroughs could change the outlook for several roadmaps?

Safety
e.g. What further work is needed?

Skills
e.g. Is education and training needed that spans several of these areas?

Financing
e.g. are there financing mechanisms that could help in several sectors?

Regional activities
e.g. Can pioneer regions be valuable in deploying several HFC technologies together?

Manufacturing and supply chain
e.g. joint design, production or procurement of certain components

Regulations, codes and standards
e.g. What further work is needed?

Marketing
e.g. how can one sector help another?

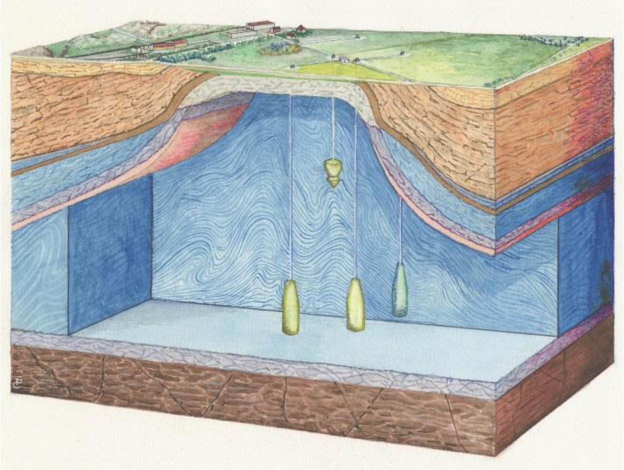
Market structure
e.g. ways to monetise value to grid of CHP could also apply to electrolysis

Joint initiatives between sectors
e.g. would these be useful?

Services to Energy Networks – draft roadmap

Hydrogen and fuel cell technologies can support the UK energy system by providing a variety of energy management services

- Renewable Energy Systems (RES) are contributing to an increasing proportion of electricity generation in many European markets thanks to a combination of Europe-wide policies, national incentives, as well as a progressive reduction in technology costs
- The existing electricity grids (based on conventional energy system architectures inherited from decades of centralised planning) are facing new challenges in terms of providing reliable, safe and high quality power supply to customers while accommodating an increasing share of intermittent renewable generation and a range of new end uses.
- Hydrogen and fuel cell technologies are well placed to support the penetration of renewable energy into the European energy system. They can provide a variety of energy system services (e.g. grid balancing and energy storage) as well as support for small communities in managing large RES capacities in grid-constrained areas (e.g. areas with very limited electricity transmission capacity)
- Gaseous hydrogen storage in salt caverns can support utility or city-scale energy decarbonisation efforts by providing a large-volume storage buffer for pre-combustion CCS plants and gas networks converted to hydrogen



This roadmap focuses on grid balancing services, hydrogen for energy storage in remote areas and hydrogen storage in caverns

A prioritisation exercise at the start of the project agreed that this roadmap would focus on three main areas:

1. **Provision of grid balancing services -** Both electrolysers and fuel cells have the potential to respond to control signals sufficiently rapidly that they can be an important dynamic load (or source of generation) to support the management of the electricity grid. The UK has a well-developed market for these services, which can be exploited to improve the economics of both fuel cells for heat and power production and generation of hydrogen for transport. This market is also a competitive advantage for the UK, as other countries do not yet rewarded distributed response services in the same way as the UK, allowing UK actors to experiment early.
   - To date, the principle of accessing these markets for hydrogen have been often discussed and some experiments have been carried out (e.g. the Aberdeen hydrogen bus electrolyser station), but the real world contractual arrangements for accessing these services still need to be demonstrated for hydrogen applications.
   - Longer term, hydrogen and fuel cell applications could provide other services to the grid, for example supporting efforts to damp diurnal (or intermittent) fluctuations in electricity price (transmission level), or supporting the management of local grids (distribution level) by avoiding the need for grid reinforcement.
2. **Salt caverns -** The UK has over 30 caverns that can be converted to store hydrogen at the utility scale. They could support the conversion of gas networks to hydrogen, or other large scale energy storage from 2025
3. **Islanded communities -** The UK has a number of companies and islanded communities that are currently testing hydrogen storage solutions in remote areas. Though this market is a niche, it is a potentially valuable early adopter and the UK (particularly Scotland) could become a leader in this area given the companies already active on both the hydrogen and island grid management side.

- This roadmap does not focus on electricity to electricity storage using hydrogen. This could be used for both short and longer time energy services. However, conversion efficiencies and high costs related to multi-step approaches mean that this market is far less attractive than using hydrogen technologies in demand side mode only, whilst using the hydrogen to satisfy another energy end use.

Applications in focus

- **Grid balancing and energy storage services**
- Hydrogen storage in caverns
- Energy storage applications in remote communities
- Link to the other roadmaps

Short and long-term energy services can offer additional revenues to improve the economics of HFC applications

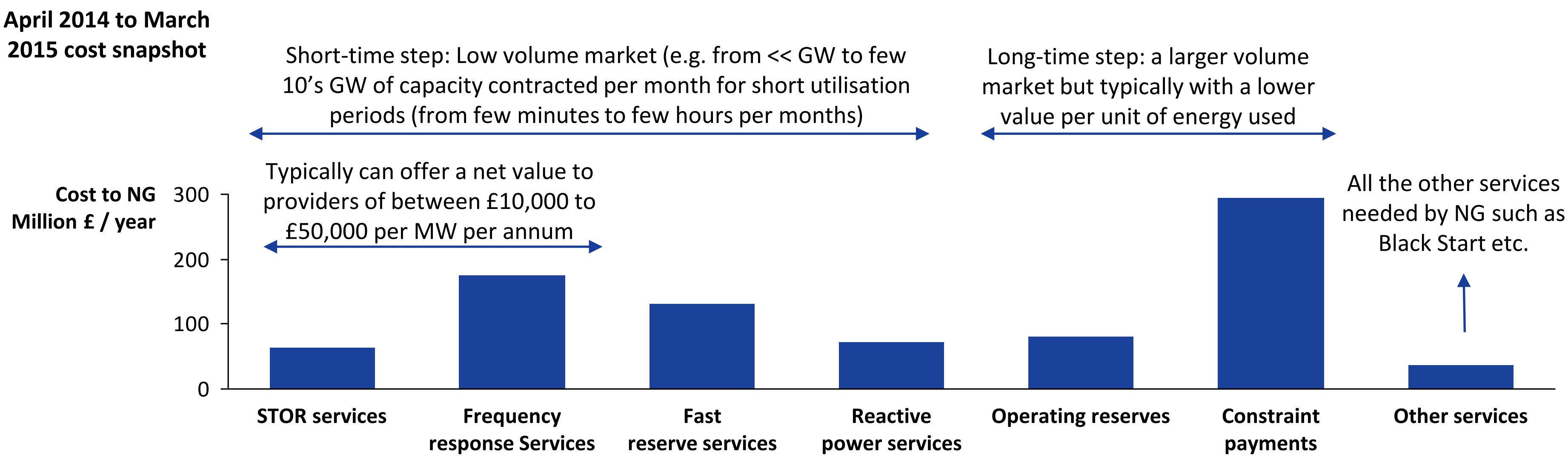
- **The UK has one of the most developed market frameworks for the provision of electricity system services in Europe**. This is a remunerative market which can be accessed by power generating or consuming technologies able to meet service-specific technical requirements. National Grid expenditures for balancing the UK transmission grid system have risen from £642 million p.a. in 2005/06 to ~ £1,000 million p.a. in 2013/14 and £850 million p.a. in 2014/15. Costs are projected to increase over time as more renewable assets are installed across the UK
- **HFC technologies as well as large-scale hydrogen storage applications can offer a variety of services within this framework from today** and can become one of the leading technology candidates for supporting the integration of more renewable electricity generators in the UK national mix over the coming years
- **Work is required to prove the technical suitability for HFC technology to participate in distinct services** and their economic competitiveness against other technologies (such as conventional power generators, batteries, smart aggregation of conventional residential and commercial loads, etc.)
- This is a competitive market but the most valuable services today are limited by the 'depth' of the markets (i.e. GW / GW demand for services - see next slides). This implies that **this market cannot be the only focus for HFC applications. It can be used as an opportunity to improve their economic performance** by accessing additional revenue streams. In turn, this can unlock the following benefits:
  - **Additional revenues can reduce the levelised cost of the main product to customers** (e.g. £ per kg of hydrogen). In turn, this can **accelerate the pace of HFC technology rollout** in the UK market by reducing costs for early deployments
  - **UK companies can optimise their HFC technology to maximise revenue potential from energy services** (e.g. by optimising efficiencies and other operational performance aspects at variable loads, etc.) **Advanced HFC solutions can be marketed to other countries** having developed grid balancing markets
  - The UK's deregulated markets make this an ideal testing ground so that other **UK companies can develop HFC-specific software and hardware solutions** (e.g. aggregation algorithms, etc.) for the optimal operations of HFC technologies in these applications

National Grid contracts several services to balance the UK electricity system at a transmission level

Scope	Services (main services only)
Second by second stabilisation of the system frequency (i.e. ±1% of nominal system frequency 50.00Hz) by contracting power in real time (sub-second to 30 seconds services) (either generation or demand reduction)	• **Frequency response** (non-tendered) and tendered): instantaneous (seconds or less) capability to operate when instructed via dynamic response or automatic relay. Tendered services include: Firm Frequency Response (FFR), Frequency Control by Demand Management, FFR Bridging Contract, Enhanced Frequency Response (aimed at storage assets)
Provision of reserve power (either generation or demand reduction) to deal with unforeseen demand increase and/or generation unavailability (from < 5 minutes to 20 minutes or more service)	• **Fast reserve** (tendered and non-tendered): rapid active power delivered within 2 minutes of the despatch instruction at a delivery rate in excess of 25MW/minute, and sustainable for a minimum of 15 minute
	• **Short Term Operating Reserve** (STOR)(tendered): provision of full capacity within 240 minutes or less from receiving instructions and sustain it for at least 2 hours when instructed • **STOR Runway** (tendered): demand side load providers are contracted to deliver additional STOR volume
	• **Operating reserve**: access to sources of extra power in the form of either generation or demand reduction (longer support)
Local stabilisation of the transmission system voltage in real time	• **Reactive power services**: National Grid contract a sufficient number of reactive power reserves across the network (mainly generators)
Management of energy flow across areas of limited network capacity to avoid damage to equipment of shutdowns	• **Constraint payments**: compensation to generators for reducing their output due to local network limitations and/or payment to generators located elsewhere to produce more to keep the overall system balanced

HFC technologies could in principle target most of the balancing services tendered by National Grid but volumes can be modest

Note: volume and value of all services is projected to increase with higher RES penetrations



	STOR services	Frequency response Services	Fast reserve services	Reactive power services	Operating reserves	Constraint payments	Other services
Unit	GWh/month	MW/month	GWh/month	TVAh/month	GWh/month	Large fluctuations: e.g. up to ~ TWh/month of absolute constrained volume	GWh/month
Average service used or holding volume (tendered):	~ 20	~500	~150	NA	NA		NA
Average service used or holding volume (non-tendered / other arrangements):		~ 1,000	~300	~ 2.3	NA		NA

Market which can be accessed today by most HFC technologies (power consuming or producing)

Market which can be accessed mainly by large-scale power producing HFC technologies

Constraints payments are by far the biggest costs to National Grid. This is a large market potential for large-scale HFC applications consuming power (to manage network / generation constraints)

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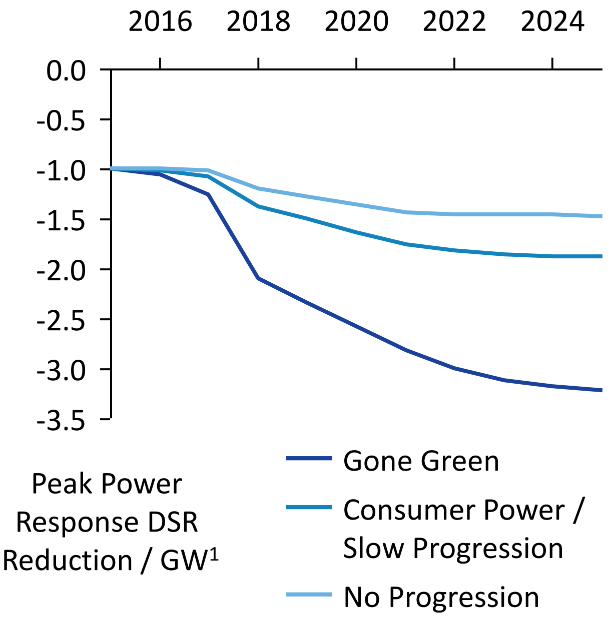
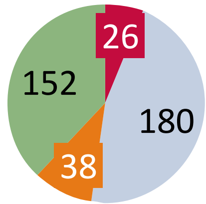
Source: National grid, Monthly Balancing Services Summary, March 2014/15

A number of factors within the gas and electric networks have the capacity to boost or limit the opportunities for balancing in 2025

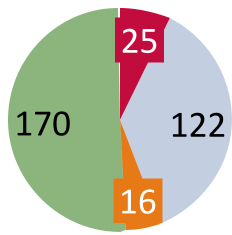
- The other roadmaps suggest that by 2025 ~100MW's of electrolysis is expected to be deployed ad perhaps 100's of MW of responsive fuel cell CHP. Based on projections from national Grid, the market appears large enough for the early years of HFC roll-out:
- **It is expected that by 2025 DSR services will be able to unlock up to 2 GW of peak power capacity by shifting loads.**
- For microgeneration with longer lead in times it is expected that STOR may be the most appropriate technology: **National Grid STOR requirements are expected to increase from 3.5GW (2014) to 8GW by 2025[2]**
- UK electricity demand is currently met by renewable generation (with zero/low levels of mechanical inertia, and conventional generation (with high levels of mechanical inertia). Higher inertia provides significant frequency response capacity, so as the renewable share increases, system inertia will decrease and more frequency response services will be required. Analysis suggests that **by 2025, the mean primary frequency response requirement could increase from ~1.1GW (2015) to between 1.3 and 1.45GW[3].** The needs for other short time step services are expected to increase for the same reason
- Key factors influencing the size and value of these markets include:
  - Renewable energy penetration see for example the "Gone Green" scenario from National Grid.
  - Increased electrification of heat could cause further congestion on the grid and thereby lead to an increased requirement for demand response
  - Other options for demand response, particularly if existing electricity users can be adapted to provide demand response (e.g. electric water heaters), could reduce the size of the market. *Note that HFC should be able to out-compete existing electricity to electricity options in these markets as they will not be relying on the revenues from the provision of balancing services.*



Peak Power Response DSR Reduction / GW[1]



2025 "No Progression" Power Mix (TWh / year)



2025 "Gone Green" Power Mix (TWh / year)

Gas CHP
Nuclear
Renewables
Fossil Fuels

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1: National Grid Future Energy Scenarios 2015
2: RWE npower: *Demanding times for energy in the UK*
3: Element Energy (for National Grid): *Frequency Sensitive Electric Vehicle and Heat Power Consumption* (based on FES 2015)

A number of Hydrogen and Fuel Cell technologies have potential for use in grid balancing services

Fuel Cells for standalone power and Combined Heat and Power (CHP)

Stationary fuel cells – stand-alone power and CHP systems offer two main services to grids:

- Many systems (particularly lower temperature PEM fuel cells) have the ability to modulate their output rapidly and hence can provide the range of balancing services discussed above
- Because fuel cell CHP systems can be installed close to the point of use, they have the potential to be installed/controlled to ease local network constraints for urban centres.

These principles have not been demonstrated in the UK for fuel cells, but the balancing markets are standard for large (MW+) scale generators. For smaller systems, work will be required to understand how to aggregate sufficient generators to bid for balancing services. For all fuel cell types more work is needed to develop an offer to distribution network system operators.

Electrolysers: Production for Transport/ Industry

Electrolysers have flexible outputs, which can be controlled over very short timescales (sub-second). As a result, **provided there is a demand for hydrogen** they can offer relatively low cost balancing services to transmission system operators. They can also be used to alleviate network constraints, particularly constraints associated with excess generation (e.g. windy regions)

Actions

Support field demonstrations of the principle of acquiring balancing services form fuel cell and electrolyser operation.

Review of regulations related to provision of balancing services on distribution networks

Electrolysers: Power to gas

When no demand for hydrogen exists, it could also be created. An apparently attractive option is the injection of hydrogen generated from electrolysers providing these balancing services into the natural gas grid (power to gas).

There are concerns over economics of these systems, as the calorific cost of electricity is considerably higher than natural gas (and will remain so while gas provides the baseload generation for most electricity in the UK). This limits the economic attractiveness of these systems to locations with extremely low electricity prices (e.g. highly constrained networks with abundant renewables) or situations where regulators are prepared to subsidise the production of green gases.

Putting these economic concerns to one side, there are currently challenging regulations in place which limit the potential for gas injection – via GSMR (Gas Safety management Regs) and Flow Weighted average CV, which prevent concentration over 0.1% hydrogen in the gas grid. A no regrets move would be to look at low cost options to loosen these restrictions.

Work to remove regulatory barriers to hydrogen injection into gas grids – identify low cost measures to overcomes GSMR and CV issues

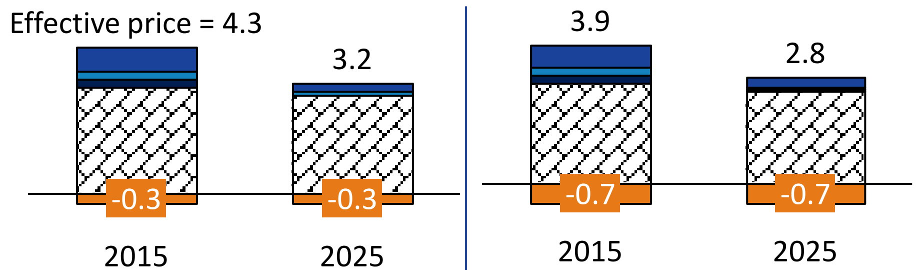
1: Ecuity: *The role of micro CHP in a smart energy world*

Volume and value of balancing services can substantially increase by 2025/2030

- The value of response services to the grid will depend on the timestep, controllability, the volume of the market for balancing services and the penetration of competitors.
- The graph shows the effect of a balancing revenue of £50,000 per MW per year on the price of hydrogen generation from an electrolyser. £50k per MW per year is the value which can be obtained from National Grid for balancing services today.
- The graph shows a reduction in hydrogen price of £0.3/kg or between 5 and 10%. This illustrates the potential for demand response – it cannot on its own make the business case for hydrogen production, but it can reduce the effective price of electricity by £10-£20 per MWh helping improve the margin available for hydrogen producer (which can then be used to reduce hydrogen price or improve profitability). A similar argument would apply for fuel cells providing responsive generation, where the balancing revenues would raise revenues by 5-10%.
- In future, it is expected that very fast response for frequency control could attract higher revenues. The calculation illustrates that at £100k per MW per year (the level currently being bid into National Grid's advanced response competitions, the saving rises to 15-25% for the end user.

Example: impact on H2 production costs from PEM electrolysis

£/kg - Excluding margin on hydrogen,
All assumptions as discussed in the 'H2 production and distribution for road transport' roadmap



Additional revenues of **£50k per MW per annum** from balancing services
This is **conservative estimate** of values available today (based on National Grid contracts)

Additional revenues of **£100k per MW per annum** from balancing services
Contract size expected for advanced demand response services (based on current auctions for advanced frequency response)

- A fleet of 100 HRS equipped with 1 MW electrolysers can access > £5 million pound per annum within the UK balancing market at today's best revenue levels for frequency response services (e.g. around £ 50k /MW/p.a.)

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Source: National Grid

There are several areas of potential intervention within the UK market framework to support HFC technologies in energy service applications (1/2)

<table>
<tr><th>Aspect</th><th>Discussion</th><th>Action to support UK companies</th></tr>
<tr><td>Lack of HFC awareness amongst existing market players (<u>transmission system</u> market)</td><td>• Some of the most remunerative services tendered by National Grid today are aimed at demand-side providers who aggregate loads to deliver the service
• Although some of these services are relatively new, aggregators / service providers have mainly focussed their attention on aggregating conventional loads or using battery technologies to date due to lack of knowledge / awareness about the potential offered by HFC technologies</td><td rowspan="2">• Large-scale trials (e.g. > MW of aggregated power at a transmission and distribution level) are needed to prove the technical suitability for HFC technology to participate in distinct services:
○ Ability to meet the specific technical / performance criteria required by the TSO / DNOs; identify any technology gap
○ Reliability of technology in real-world balancing applications and under sustained utilisation
○ Actual economic and GHG reduction performance potential versus alternative technologies
○ Control strategies which optimise decisions on providing balancing vs meeting hydrogen demands
• Trials are also needed to resolve non-technical aspects, such as contractual and operational practices suitable for/specific to HFC technologies and locational aspects of services requirements
• The ultimate objective of the trials is to create HFC expertise across the UK electricity system stakeholders and cement confidence around the technology potential (current trends in this sector is to require more accurate and rapid response services – this is a good fit for reactive PEM technologies, for example)</td></tr>
<tr><td>Potential new services for <u>distribution network</u> operators</td><td>• Distribution network operators (DNOs) are considering novel technologies to reduce the costs associated with local stabilisation of voltage, harmonics, thermal loading and reversible energy flows across low-voltage networks. This will lead to increased management of supply and demand on the distribution network
• Trials to date focussed on smart demand management technologies and batteries due to lack of commercial maturity of HFC technologies</td></tr>
</table>

There are several areas of potential intervention within the UK market framework to support HFC technologies in energy service applications (2/2)

Aspect	Discussion	Action to support UK companies
Framework for supporting constrained generators at a local level	• DNOs are legally obliged to provide connection to both local power producers and power consumers across their networks. However, obligations towards local power producers are in practice limited by network upgrade cost consideration. This has created a situation where distributed renewable developers may not be able to connect their assets or are systematically curtailed • Trials to date aimed at resolving this problem mainly focussed on testing Active Network Management (ANM) solutions (where generators are ranked or managed in real time to avoid energy flow constraints) or other demand side technologies (e.g. battery) • Demand side options (e.g. electrolysis) could resolve these issues by offering to link demand to generation on the distributed network (encouraging a "distribution system operator" (DSO) approach. The regulatory regime wlil need to evolve to allow this type of approach.	**Large-scale trials** (as suggested in the previous slide) can be used to demonstrate the **benefit of clustering HFC technologies around local constrained renewable assets or network segments.** This could also include stand-alone RES-H2 systems **The trials should involve the relevant industry stakeholders** (TSO, DNOs, regulators, utilities, HFC developers, load aggregators, etc.) **and produce evidence for understanding:** • Optimal integration strategies with power generating / transmission assets (from a technical and operational point of view) • **Potential for deferring network reinforcement needs** • Regulatory issues (e.g. whether any major regulatory changes if needed) • Economics of these systems Findings can be used to inform a technology-neutral discussion on whether to modify Use of System charges for network-supportive technologies
Use of system charges	• Electricity prices to customers include system charges and levies meant to spread the costs of managing the distribution and transmission system as well as support the integration of renewable energy systems (RES) • If HFC technologies are helping balance the grid, these changes could be deferred (a discussion on this is taking place in Germany but not in the UK yet)	

There are several active and latent UK players that could benefit from targeted national interventions

UK Companies active in the sector

- **ITM Power** is planning to aggregate electrolytic hydrogen refuelling stations to provide grid balancing services (as a part of a number of European demonstration projects such as HyFive and H2ME)
- Several feasibility studies were commissioned to understand the business opportunity for using hydrogen to support constrained renewable assets. One demonstration project is currently on-going in the Orkney Islands (**Orkney Surf 'n' Turf**: renewable marine hydrogen – Orkney Islands Council, Eday Renewable Energy Ltd (ERE), European Marine Energy Centre Ltd (EMEC), ITM Power (Research) Ltd)

UK Latent potential

- A number of UK SMEs and Start-Ups (like **Kiwi Power**, **Open Energy, UPSIDE, Origami** and others) are testing novel software / hardware solutions for aggregating loads in smart balancing services and have already expressed an interest in using HFC loads
- **DNOs & TSO** are always looking for new technological solutions / services for managing their networks. For example, Northern Power Grids, Western Power Distribution, UK Power Networks, Scottish Power, SSEPD and other players have experimented with smart grid technologies and batteries for managing high and low voltage networks.

UK Research potential

- Several UK universities (**ICL, UoM, University of Strathclyde** etc.) are actively involved in understanding and modelling solutions for balancing transmission and distribution networks
- There also is ongoing software research associated to aggregating passive/active loads for smart grid balancing applications

Overview of the deployment timeline, technology progress and possible actions for supporting this application

	2016-2020	2020-2025	2025 onwards
Global activities and deployment	Increasing penetration of renewable energy assets, electric cars and smart appliances will likely increase the need for gird balancing and energy storage services across most developed countries		
UK market development	Depth and value of the UK balancing and energy storage markets to increase in line with global trends (see above)		
	NG and DNOs to test new technologies for managing high and low voltage networks		
	Selected electrolyser-HRS will test provision of services as a part of EU and UK projects	Follow-up projects to test new regulatory/contractual arrangements identified in the first trials	
Technology progress	Aggregators, utilities etc. to develop business models and products for aggregating load and generators in 'smart services'		
UK actions	Build on existing / planned efforts to prove the technical suitability for HFC technology to participate in distinct energy storage and balancing services across the UK		HFC technology accepted as a valid technology solution to provide balancing and energy storage services (transmission and distribution level). Protocols and requirements for HFC in these application agreed
	Collaboration between HFC developers, load aggregators, NG, OFGEM, UK DNOs to 1) understand future service needs 2) ensure supporting regulations and 3) understand local supply / demand needs		

Focus applications

- Grid balancing and energy storage services
- **Hydrogen storage in caverns**
- Energy storage applications in remote communities
- Link to the other roadmaps

Hydrogen storage in salt caverns can support a nation-wide transition to low carbon energy

- **Salt caverns are artificial reservoirs made for storing very large volumes of gas.** The UK has around 30 commercial caverns (spread across the country) which are mainly used to store natural gas (e.g. for managing diurnal / seasonal demand fluctuations) and support industrial-scale chemical applications (such as refineries, etc.). Further caverns could be created fairly easily
- There are **no major technical barriers** for storing hydrogen in salt caverns. The UK already has had one cavern used for gaseous hydrogen storage in Teesside (~200,000 m^3 storage capacity / 25 GWh LHV H_2)
- **Dedicated engineering studies** will nevertheless be required to understand specific technical, contractual and regulatory needs to convert existing caverns to hydrogen applications
- Salt caverns **could be needed from 2025** to support a nation-wide energy transition:
  - Support and improve the flexibility of pre-combustion CCS plants. In these applications methane, coal or biomass is converted into syngas (a mixture of H_2, CO_2 and CO plus traces of other molecules) to facilitate CO_2 capture and storage. The hydrogen produced can be stored in salt caverns and then converted into electricity on demand via the use of dedicated turbines or other technologies (e.g. fuel cells).
  - Support the conversion UK gas network segments into hydrogen (see separate roadmap). Salt caverns can be used as large-capacity storage assets for managing daily and seasonal demand fluctuations (as similarly done today with natural gas).
  - Provide on-demand utility-scale power reserve and energy storage services. A recent ETI report[1] estimates that just six caverns could store ~ 0.5 TWh of hydrogen, e.g. sufficient to deliver ~150 GWh-e on a seasonal and ~30 GWh-e on a daily basis. The ETI estimates this to be comparable to the cumulative UK pumped hydro storage capacity.

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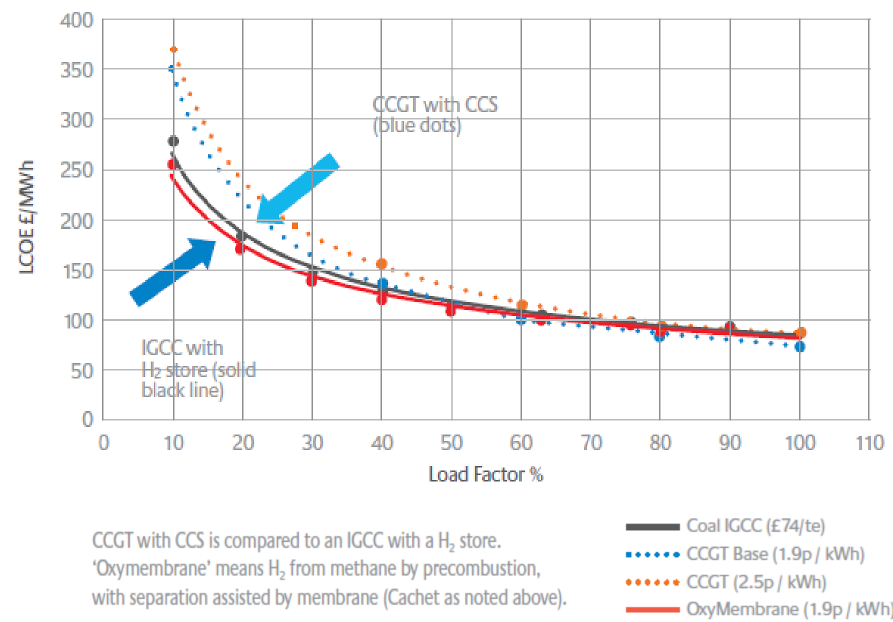
1 – ETI, Hydrogen: The role of hydrogen storage in a clean responsive power system

The case for H_2 storage in salt caverns is conditional on the introduction of pre-combustion CCS applications OR conversions of cities to hydrogen pipelines

- The business case for hydrogen storage in salt caverns is conditional to commercial demand for very large hydrogen storage volumes
- This demand could materialise in two ways:
  - Large H_2 storage may be required to improve the economics of pre-combustion CCS power plants. Recent ETI analysis (*see right hand side*) concluded that pre-combustion CCS with hydrogen conversion to power can be more competitive than post combustion CCS when coupled with hydrogen storage capacity
  - Large H_2 reservoirs may be required to manage gas demand fluctuation in cities converted to hydrogen (*covered in a different roadmap*)
- Both options are unlikely to materialise before 2025 - therefore it is unlikely that any salt cavern conversion to hydrogen will be needed before that date
- There are a number of needs which need to be resolved to prepare the ground for this application before 2025 (discussed in the next slide)

Example application – IGCC with pre-combustion CCS



Source: ETI, Hydrogen: The role of hydrogen storage in a clean responsive power system

Potential intervention for supporting this application

Aspect	Action to support UK companies
Definition of a shared strategy	**Support a multilateral study** to: • Define of a strategy for using salt caverns in hydrogen storage applications to support CCS industry or city conversion to hydrogen applications • Identify target salt cavern sites • Produce a plan to move forward
Engineering / preparatory studies	**Support preparatory engineering studies** (this is a common practice before implementing any large scale infrastructure project). The studies should take place before 2025 – i.e. in advance of any pre-combustion CCS deployments or city conversion to hydrogen – to: ○ Identify any specific requirement associated to each target salt cavern site and develop a strategy to resolve any identified barrier ○ Identify any non-technical or economic barrier (e.g. contractual, land preparation, etc.) which could prevent the use of HFC technologies for this application and develop a plan to resolve any identified issue ○ Prepare relevant documentation for e.g. planning applications and other activities needed for making the sites conversion-ready before 2025

There are several latent UK players which could take an active role in developing hydrogen storage in salt caverns

UK Companies active in the sector

- **Sabic Petrochemicals** stores hydrogen for chemical application in Teesside (salt cavern with 3 × 70,000 m^3 storage capacity)
- The **ETI** (in collaboration with **Amec Foster Wheeler**) has recently produced a study assessing the role of hydrogen in salt caverns to support pre-combustion CCS technologies in the UK

UK Latent potential

- **All major gas and oil companies, industrial gas companies and utilities** in UK could take an active role in commissioning or operating salt caverns for hydrogen storage applications
- This is a tailor-made market (low volume, site-specific) so local UK companies are best placed to take advantage should some caverns be converted to hydrogen (e.g. development of specialty equipment for hydrogen storage and handling)

UK Research potential

- Engineering activities will require the UK's research base in geology, hydrogen safety and the engineering of cavern structures.

ETI will be consulted as a part of the consultation process

Overview of the deployment timeline, technology progress and possible actions for supporting this application

	2016-2020	2020-2025	2025 onwards
Global activities and deployment / UK market development	Demonstration of first pre-combustion CCS plants;		Deployment of pre-combustion CCS technologies; conversion of selected gas networks to hydrogen
	Demonstration / planning of city gas networks conversion to hydrogen		
Technology progress			First pre-combustion CCS plants deployed in the UK One or two UK cities converted to H2
UK actions	• Define a strategy for using salt caverns to support CCS and cities conversions to H_2 • Identification of target salt cavern sites	• Engineering studies to prepare for the conversions of the target salt caverns to hydrogen storage	Beginning of works to convert one or more salt caverns to hydrogen storage (*conditional to CCS happening in the UK and conversion of cities to H_2*)

Focus applications

- Grid balancing and energy storage services
- Hydrogen storage in caverns
- **Energy storage applications in remote communities**
- Link to the other roadmaps

HFC initiatives in remote communities can offer a platform for testing and developing scalable HFC energy storage applications and business models

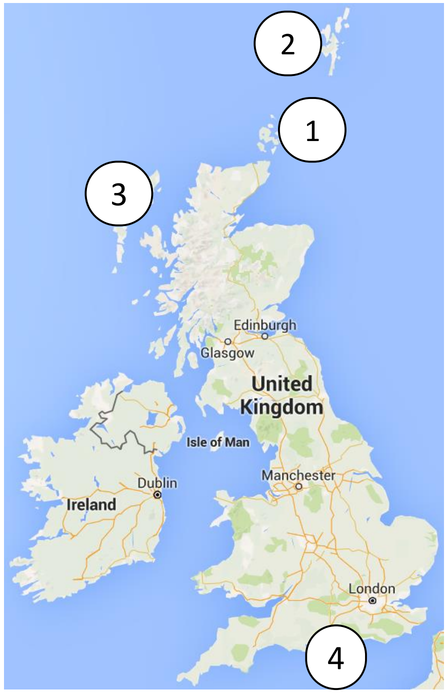
- The UK has a number of companies and island communities who have / are testing HFC technologies for renewable energy storage and fossil fuel displacement in remote communities (*see right hand side*)
- Although this is a relatively small long term market which can deliver modest national GHG benefits, it can offer a platform for testing novel technology solutions and business models for converting local energy systems to hydrogen (at a reduced scale and thus cost)
- HFC technologies in remote applications may reach a competitive market position earlier than elsewhere as: 1) incumbent fossil fuels may be more expensive (e.g. due to low-volume imports to remote areas) and 2) the prices per unit of energy produced by local renewable assets can be far lower than the UK average (e.g. due to severe curtailments / underutilisation regimes)

Recommendation

Where the right conditions exist, such projects can:

- Become technology incubators
- Offer an early market opportunity for specialty products (e.g. marine HFC applications)
- Become UK centres of excellence for alternative HFC applications

Recent H2 projects in remote communities



1. Orkney Surf 'n' Turf
2. PURE (Promoting Use Renewable Energy)
3. H2 SEED
4. EcoIsland Hydrogen Refuelling

E4tech elementenergy

Case study – Orkney's Surf 'n' Turf hydrogen project

Project synopsis

- Renewable generators across the Orkney islands are subject to large curtailment levels which threaten their financial viability (up to 60% p.a. in outer areas in spite of being managed under an Active Network Management scheme)
- Orkney's Surf 'n' Turf is an initiative taking place in the in the outlying island of Eday to explore the role of hydrogen in improving the utilisation of the local renewable generators and replacing fossil fuel demand for land/marine transport applications
- The project will integrate curtailed electricity supplies from EMEC's tidal stream and ERE's onshore wind generators to power an electrolyser and store curtailed electricity as gaseous hydrogen
- The H_2 produced will be transported (over land and sea) from Eday to Kirkwall to power a fuel cell system to 1) generate power for buildings and berthed ferries and 2) provide a training environment to lay the foundations for use of hydrogen on board for auxiliary power and main propulsion in marine applications (by operating on land with the same standards as if the FC system was installed in a vessel)

Partners

- Orkney Islands Council
- Eday Renewable Energy Ltd (ERE)
- European Marine Energy Centre Ltd (EMEC)
- ITM Power (Research) Ltd

Project objectives and legacies

- Optimum strategies for integrating curtailed tide & wind generation for electrolytic H_2 production
- Develop new gaseous hydrogen transport solutions for land and sea transport (and fit for use on Pier)
- Undertake training and develop full UK certification and approval plan for on-board marine applications
- Create a platform for increased local H_2 use and further investment in alternative technologies
- A Marine and Coastguard Agency (MCA) / Merchant Navy Training Board (MNTB) backed UK facility for maritime H_2 training

Economics – case study: on-site electrolytic H_2 production for road transport applications

- Electrolyser Capex
- Electrolyser Fixed Opex
- Stack replacements
- Electricity cost
- HRS costs
- Diesel equivalent - excluding VAT and duty
- Diesel equivalent - fuel duty

Cost considerations:

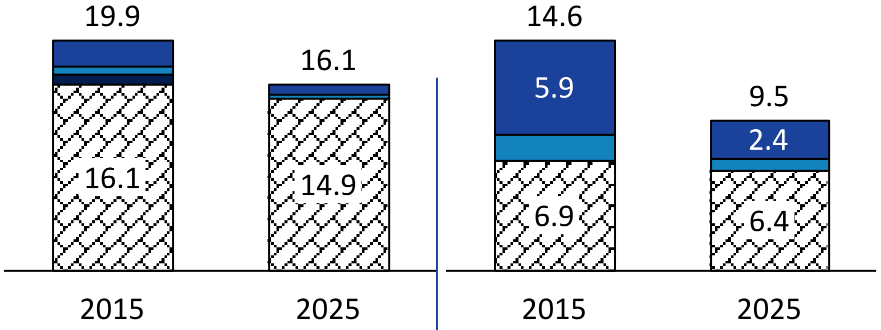
- Electrolysers powered by constrained wind assets in remote locations can benefits from very low electricity prices (e.g. as low as 4p/kWh)
- Hydrogen production costs can substantially be lower than in mainland areas, where electrolysers would be subject to market-average electricity prices (unless better deals are secured with generators)
- Hydrogen fuel production powered from dedicated wind assets can be competitive with Diesel and Petrol fuel (see right hand side)

Deployment considerations:

- English and Scottish islands account for ~1% of UK population (ONS, 2011)
- Approximately ~ 300 x 1M electrolysers would be needed across the English and Scottish islands to fully convert their passenger car fuel demand to hydrogen (e.g. cater for a fleet of ~200,000 fuel cell vehicles)

Example: impact on H2 production costs from PEM electrolysis

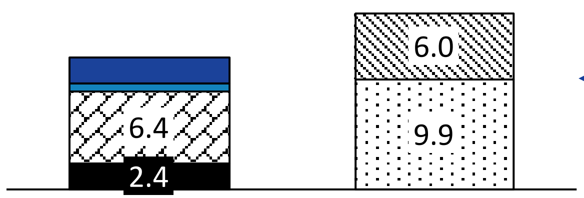
***p/kWh** - Excluding margin on hydrogen, All assumptions as discussed in the 'H2 production and distribution for road transport' roadmap*



Average UK 2015 price for non-domestic consumers (~ £10p/kWh)

'Behind-the-meter' levelled electricity price from wind @ £4p/kWh (35% load factor for wind and electrolyser assets)

Comparison versus Diesel in 2025



PEM on-site electrolysis + HRS costs

Hydrogen price for cost parity with Diesel

Focus applications

- Grid balancing and energy storage services
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- **Link to the other roadmaps**

Links to other roadmaps

Dependencies

- The business case for hydrogen storage in salt caverns is conditional to commercial demand for very large hydrogen storage volumes (*see roadmap on hydrogen pipelines*)

Beneficial effects

- An accessible market for energy storage and grid balancing services can generate additional revenues and thus reduce costs for most HFC applications
- HFC initiatives in remote communities can offer a platform for testing novel HFC applications and a niche market for early low-volume deployments