Development of hydrogen projects in Scotland

Lessons learnt from three Local Energy Challenge Fund projects

LOCAL ENERGY SCOTLAND

Executive summary

This report investigates the lessons learnt from three Local Energy Challenge Fund projects. The report is structured as an introduction to the three individual projects and an analysis of lessons learned as outlined by interview respondents from the projects.

The three projects considered are:

1. **Levenmouth.** A full smart microgrid incorporating solar and wind to produce hydrogen for a fleet of vehicles and power for businesses on the business park.
2. **Surf 'n' Turf.** Establishing a supply chain for hydrogen that also helped to address renewable electricity curtailment.
3. **Outer Hebrides Local Energy Hub (OHLEH)**. A circular economy project developing a demand for hydrogen for heat, power, and transport in the Outer Hebrides.

The projects were supported by the Scottish Government Local Energy Challenge Fund. The projects were intended to be truly innovative and therefore carried a higher risk (technical, commercial and financial) than other CARES funded community projects.

The projects had three common themes:

- Demonstrating the use of curtailed renewable energy to produce hydrogen.
- Using green hydrogen (hydrogen generated from renewable energy) for transport applications.
- Establishing a market for hydrogen as part of the project.

Major learning themes that came out of this analysis work were:

There is a need to build a hydrogen market for projects of this type. A range of different use cases were explored by the projects. Examples included energy storage for later generation, hydrogen for transport and oxygen for aeration purposes. Unlike conventional energy generation projects funded by CARES at that time which looked solely at the supply side, there was a requirement to consider the use of the hydrogen, so looking at the demand side as well as the supply side.

There is a risk that new technology will function unreliably. All three projects have suffered from problems with the electrolysers. Although electrolyser technology is not new, at this scale and for this application the designs were new. The technology is becoming more reliable but in an innovation project, the project delivery team should consider the impact of unreliable technology in the project planning phase and be aware of the track record of equipment suppliers.

Long timescales of two years or more are likely to be required to establish operational hydrogen projects. This is due to the time it takes to establish contracts between partners and technology suppliers, long lead times on equipment particularly electrolysers, time to complete project design, receive planning permission and meet market regulations. Time delays add to the expense of the project and this should be considered in the timeline and budget allocation of the project.

Project management is key. The project manager is key to making the project successful and it can be difficult to get the ideal project manager. Selecting project managers from within the existing project team may mean that they do not have the necessary expertise to deliver the project and external project managers may leave; as happened on the Levenmouth project who had three different project managers. Skills that were outlined for the project management role were excellent project management skills in managing complex projects. This could be further enhanced by general engineering skills and, ideally, a hydrogen or gas handling background.

Site design for operation and maintenance needs to be considered in detail.

The technology developers and the site need to understand the practicalities of site design as this can save re-engineering later. Examples include turning circles on vehicles, access for operation and maintenance and interfaces between equipment (whether this is communication protocols or pipe sizing). Design for maintenance can also reduce downtime of the installation, this may raise initial design costs but operating costs for the projects' lifetime may be reduced. Involving local partners who can bring their specific local area knowledge can help ensure success.

Funding challenges. The project partners were initially required to complete the project in a one-year time frame. This created time pressure and the projects completed on a two-year time scale. Additionally, there was no allowance for contingency which meant that the projects had to request further funding.

Awareness and knowledge of hydrogen projects. At the time of these projects not many green hydrogen projects (hydrogen generated from renewable energy) had been undertaken. The industry is still assimilating collective learning. Education, dissemination of results from projects and training will be required to develop the industry further.

The projects met and overcame many different challenges:

- The Levenmouth project team had many issues arranging contracts within a reasonable time frame and suggested development of standardised contracts would be beneficial. They also had issues continuing the project after installation due to higher than expected costs in the operation phase and have suggested that the market for the hydrogen needs to be secured.

- The Surf 'n' Turf project also had issues with establishing a hydrogen market as they had originally intended to fuel the ferries. There is potential for hydrogen injection as part of HyDime but the Surf 'n' Turf project was resolved by cold ironing (providing electricity from hydrogen for the fuel cell to run auxiliary services from the quay at Kirkwall for ferries) and also moving forward new regulations in respect of the transportation of hydrogen with the Maritime and Coastguard Agency (MCA).

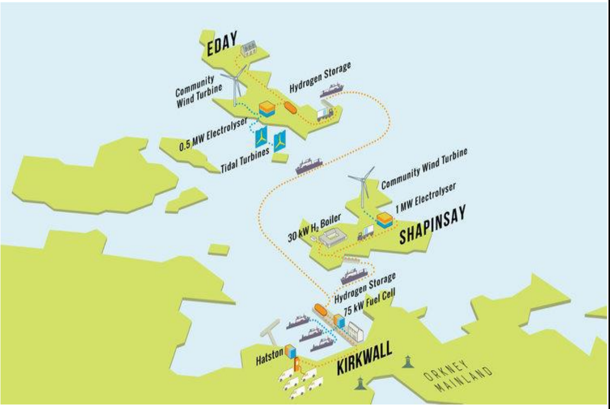
- The Outer Hebrides Local Energy Hub project ran relatively smoothly. The main challenge was the breakdown of the electrolyser, for which replacement funding is currently being sought, and the breakdown of the digestion process due to the introduction of fish waste into the anaerobic digester.

The future of hydrogen appears to be bright, as one part of the overall future energy solution with a number of countries (including Australia, Germany and the Netherlands) and the EU making bold statements on a hydrogen future and backing this with significant funding. For instance, Germany have committed to a £9 billion package for hydrogen projects and major companies have taken shares in fuel cell and electrolyser companies. This could lead to significant cost reductions in equipment as there is a move from bespoke manufacture to mass manufacture and an increase in efficiency. This would be expected to shift the economics of hydrogen generation. There is likely to be competition over the next few years between renewable energy generated hydrogen (green hydrogen) and hydrogen generation from fossil fuels with carbon capture and storage.

Contents

1. Project overview

This report highlights lessons learnt from three hydrogen projects developed under the Scottish Government Local Energy Challenge Fund in 2015.



Surf ‘n’ Turf

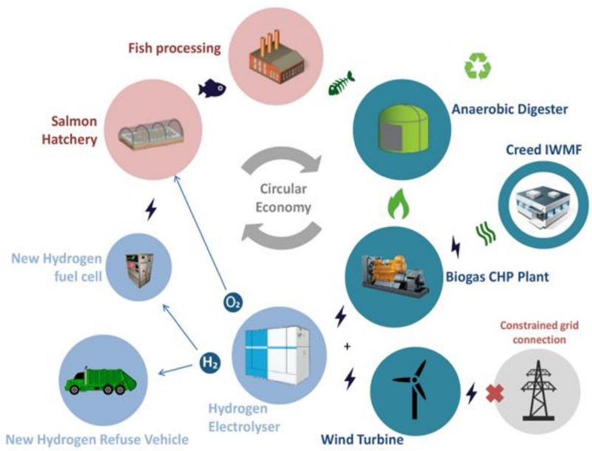
The Surf ‘n’ Turf project uses otherwise curtailed electricity from the Eday wind turbine (900kW) and tidal turbines being tested at the European Marine Energy Centre to generate electricity for a 500kW electrolyser. The electrolyser produces hydrogen which is transported by tube trailers and ferry to Kirkwall where it is used in a fuel cell for electricity for ferries in dock (cold ironing). The project demonstrates hydrogen generation from renewables, transportation of hydrogen and use of hydrogen in fuel cells to generate electricity for cold ironing.

Figure 1: Surf and Turf project on Eday and Big Hit development at Shapinsay (Source: Surf ‘n’ Turf case study, 2018)

Levenmouth

The Levenmouth project uses electricity produced from a wind turbine plus two photovoltaic systems to produce hydrogen for an business park. The hydrogen is used for electricity generation and as a transport fuel for 5 converted Ford transit vans (running on a duel fuel of hydrogen and diesel), 10 Kangoo vans and 2 converted duel fuel refuse collection vehicles.

Figure 2: Levenmouth site showing buildings and wind turbine (Source: Logan Energy website, 2020)



Outer Hebrides Local Energy Hub (OHLEH)

The OHLEH project is set up as a circular economy project. The project added three new components, a hydrogen electrolyser, a hydrogen refuse collection vehicle and a new hydrogen fuel cell. Waste from a fish processing plant is used in the digester as feedstock to produce biogas which is then fed into a CHP plant. Some of the electricity from the plant is used at Creed Park (a waste materials facility) near Stornoway. The two power inputs (electricity from biogas and otherwise constrained electricity from a wind turbine) are used in the hydrogen electrolyser. The circular economy concept is novel in that it uses the hydrogen for the refuse collection vehicle and for a fuel cell to generate electricity for the salmon hatchery. Additionally, the oxygen from the electrolyser process is collected and used for aeration of water at the salmon hatchery

Figure 3: Circular economy project for OHLEH (OHLEH report 2019)

The project cost, team and summary of achievements are summarised in the following table.

Project cost	Main Partners	Achievements
Surf 'n' Turf **Value:** £1.79 million **Location:** Orkney Islands	Community Energy Scotland (Lead) Eday Renewables EMEC Orkney College	- World first demonstration of the production of green hydrogen from tidal energy. - One of the earliest demonstrations of the use of green hydrogen from otherwise curtailed electricity. - Led to a clutch of hydrogen projects (including HyDime, HySEAS I/II/III, Big Hit, HyFlyer, Reflex) that enabled EMEC to take on a further twelve staff. - Led to new regulations and training courses being developed for hydrogen handling, shipping and storage. - World first demonstration of cold ironing for ferries using a hydrogen fuel cell.
Levenmouth **Value**: £6.4 million **Location**: Methil, Fife	Bright Green Hydrogen (Lead org) Toshiba Fife Council	- One of the first demonstrations of an integrated energy system on a smart microgrid for decarbonising the business park including the provision of duel fuel diesel/hydrogen vehicles. - Integration of electrolysers, fuel cells, microgrid system, solar and wind within the microgrid.
Outer Hebrides Local Energy Hub **Value**: £1.15 million **Location**: Stornoway, Isle of Lewis	Comhairle nan Eilean Siar Pure Energy Centre The Scottish Salmon Company Community Energy Scotland	- Successful integration of hydrogen into existing infrastructure, transport and technologies. - Use of electrolysis process to produce commercial commodities for island communities. - Successful organisation of a multiple industry partnership to deliver a hydrogen project. - Won VIBES award for best partnership project in Scotland.

2. Funding sources and risks

The primary funding source was the Local Energy Challenge Fund (LECF) supplemented by funding from the projects themselves.

Surf 'n' Turf. The original project budget was £1.68 million (including a LECF £1.175,200 grant and £288,000 loan). This was increased to a total cost of £1.79 million (which included an increased contribution from LECF of £1,356,700 grant and £300,300 loan). The cost over-run for the project was due mainly to changes to the electrical system, increase in costs for the trailers and increase in costs for the installation of the fuel cell.

Levenmouth. The original budget for the Levenmouth project was £5.9 million including a LECF grant of £4.24 million and match funding contributions from parties involved in the project. The Levenmouth project had cost over-runs and a further £293,000 was funded from LECF. The expenditure eventually came to £6.6 million with the addition of contribution from the derelict land funding, Fife Council and other organisations. In addition, the project team applied for further funding to run the project for a five-year period. This was not granted as state aid rules restrict the funding of operational costs.

OHLEH. The project cost £1.15 million with £600,000 funding from the LECF. Further funding came from Comhairle nan Eilean Siar (CnES) and the Western Isles Council. CnES contributed funding up to £545,000, primarily for the capital works elements of the project. For the partners, CES and Pure covered 20% of their staff costs. CnES and SSC covered 35% of staff costs.

The interview respondents highlighted a number of risks around funding as identified through the interview was as listed below:

Funding Risk	Learning	Potential solution
Lack of contingency led to projects needing to make further requests for funding.	As the funding did not provide any contingency then this meant that any overspend immediately required further funding. On projects of this type contingency should be considered. Levels of contingency for innovation projects were suggested by the project interviewees of up to 40%. Analysis of the overspend on these projects could be used to determine an appropriate level, which should balance against the mitigation of the risks highlighted.	**Project partners should consider the level of contingency they need. This is also dependent on the technology readiness level, the level of innovation in the project and the experience of the project partners.**
Time pressures were created by the one-year funding window	The funding from the Local Energy Challenge fund needed to be spent in one year. Typically, projects were 45% to 50% grant or loan funded with the remainder being supplied by funds from the project teams or from other grant sources. The one-year time schedule put extreme time pressure on the projects particularly after early contract delays. For projects of this type at least two-year timescale would be more suitable.	**Project teams should carefully consider the impact of the timescale of the funding for the project.**
Eligibility of potential partners for funding	In respect of the Levenmouth project the hydrogen system integration market meant the project had to	**Consideration of potential partners needs to take into account the funding and regulatory requirements to ensure that project partners**

	publicly procure an otherwise potential project partners.	**are defined as being eligible with the grant funding**
Time taken for preparing funding applications and risk of refusal	It was noted that preparing applications for funding is time consuming. It was suggested that some help and advice from the funding bodies and bid assessors should be given as to how to complete applications and strengthen their case.	**Project teams should be aware of the time and effort required to apply for funding, and should seek help and advice where available. Project teams should also check to see whether funding is being provided for initial feasibility studies. LECF provide £20k funds for working out ideas.**
Public policy changes may damage economics of projects	The only case where this was highlighted was with a more severe degression change in the solar FiTS than had originally been envisaged. This led to difficulties in completing the solar PV installation for the Levenmouth project.	**Public policy changes can happen. Project teams should understand risks in this respect and aim to complete the elements of the project such that they can claim the most advantageous subsidies.**

3. Project delivery risks

This section reviews the risks encountered at the various stages of the implementation stage and operations and maintenance stage of the projects

3.1 Risks at Consenting Stage

The consenting stage requires the applicant to get planning consent (for refuellers and new switchgear) and abstraction licences.

Funding Risk	Learning	Potential solution
Lack of early stakeholder engagement can hamper projects going forward	All projects highlighted the importance of engaging with stakeholders (e.g. local people and local organisations) early on. For instance, with the Surf 'n' Turf project it was necessary for the local community to be convinced that hydrogen is safe before the project could go ahead.	**Early engagement with stakeholders (particularly the local community) is usually essential, for example, through school activities, parish council meetings and exhibitions.**
Permitting requirements need to be secured for planning consent and water abstraction.	Requirements for permitting should include planning consent and water abstraction licences. These should be applied for as early as possible. Most of the projects had begun this process before applying for funding. The Surf 'n' Turf project interviewee highlighted there can be challenges in getting a water abstraction licence from SEPA.	**Permitting applications should be submitted early in the project – doing so before submitting the funding application is a good way of demonstrating that the applicant is committed to the project.**
Insufficient size of electrical connection to run the new equipment	A sufficient electrical connection was highlighted as an issue. For the Surf 'n' Turf project new switchgear to supply electricity from the turbine to the hydrogen electrolyser was required.	**Assessment of the project electricity demand and arrangement of the electrical equipment to supply the project should be undertaken as early as possible.**

3.2 Risks at Detailed Design Stage

Detailed design stage is very important and ideally the design team should look at all aspects of the project. In particular, it would also be valuable to consult with the operations and maintenance staff who will be responsible for managing the equipment.

Funding Risk	Learning	Potential solution
Design not considering all the interfaces correctly (pipework/communications) between equipment.	There are a number of pieces of equipment with interfaces between them in hydrogen projects. Logan Energy who managed the Levenmouth project outlined that their biggest challenge was getting the equipment interfaces right. Ensuring that pipes are dimensioned correctly to interface between equipment was a challenge and equipment protocols between controllers on the equipment were highlighted as a particular challenge.	**Early consideration of how the different elements should be integrated is important to avoid expensive reworking. This could be achieved with the aid of consultancy from industry experts to review design plans and applications.**
Design not considering operation and maintenance (O&M) requirements leading to expensive reworking	Operations and maintenance on some of the projects (particularly Surf 'n' Turf) were hampered by a lack of consideration at the design stage. Practical examples of this was insufficient working space and hiding pipework behind cowlings making maintenance of the equipment difficult and time consuming.	**Operation and maintenance considerations should be built into the design by including O&M staff at the design stage.**
Selection of correctly specified equipment for the environment the project is operating in	Corrosion was a factor on the Surf 'n' Turf project. The equipment material was not properly specified for the maritime conditions in which it was being operated in the Orkney islands.	**Design needs to consider the environment that the project is going into.**
Lack of knowledge of hydrogen project characteristics leading to lengthy discussions on design	It was highlighted that there was insufficient knowledge of hydrogen projects across designers, planners and installers. There is still limited knowledge of green hydrogen, its use and potential and a need for further information dissemination. Knowledge could be built through time with trial and error but learning from past projects should be sought and collated.	**Project leads and designers should consult with companies who have carried out projects to understand the challenges involved.**
Insufficient specialist knowledge of new features being introduced to the project	OHLEH project partners highlighted that more specialist knowledge should have been sought before introducing new feedstock into the anaerobic digestion process. The unknown effect of the introduction of fish waste led to the digester breaking down and needing to be restarted.	**Focused use of specialist knowledge should be encouraged as trial and error can be costly.**

3.3 Risks at Construction, Installation and Commissioning Stage

This is the final development phase of the project.

Construction, installation and commissioning risk	Learning	Potential solution
Itemised contingency not always possible	The nature of some funding mechanisms for innovation projects do not allow for the profiling of contingency. Being able to profile a contingency against tasks and level of risk should contribute to project success.	**Profiled contingency budgets should be encouraged.**
Ground reinstatement not fully considered	Reinstatement of the ground after ground works can be costly. This was not properly budgeted on two of the projects and led to extra costs that were not budgeted.	**The design and the budget should fully consider the costs and difficulties associated with ground re-instatement.**
Principal contractor role not assigned at early stage	The principal contractor role is an important part of the site supervision process and is responsible for safe practices on site. It is mandatory for projects of a certain size or complexity under CDM regulations. It was highlighted on one project that they needed to employ an external company to take the principal role, which was not budgeted and so an added expense.	**Ideally the principal contractor duties should be allotted to the main contractor otherwise extra costs will be incurred to employ a third-party contractor to carry out the principal contractor role.**
Co-ordination of contractors at commissioning stage	Co-ordination of contractors for the commissioning phase of the projects was difficult. On the Levenmouth project there were a number of different contractors needing to be on site at the same time to commission the systems including from far afield (e.g. Toshiba engineers from Japan). Due to this reason commissioning was delayed by six months.	**The process of co-ordinating the contractors needs to be well managed to ensure that an efficient commissioning can be carried out without delay.**
Project management skills are inadequate	A skilled project manager is required at all stages. Although technical skills are not required they would be very helpful when understanding the projects.	**Project teams should employ excellent project managers ideally with a gas or hydrogen background to manage the projects.**
Network harmonics issues due to new equipment	It was recorded that there were issues with network harmonics on the distribution system for the Levenmouth project when the electrolyser and fuel cells were connected. Rectification equipment was required to be installed.	**Network harmonics should be assessed before new equipment is introduced. Network regulations should be followed.**

3.4 Risks at Operations and Maintenance Stage

Construction, installation and commissioning risk	Learning	Potential solution
Incomplete handover documentation leads to operation and maintenance being more time consuming	It was noted that obtaining a full set of handover documentation was difficult. Handover documentation should include as-built drawings, installation and operation manuals for all pieces of equipment. Contractors often move on to the next project before providing this. Inadequate documentation will lead to delays in maintaining the plant.	**A condition should be made for all the documents to be provided before final payment and a project team member assigned to check through the documents.**
Standby loads being underestimated leading to unforeseen costs	Electrolysers and fuel cells have standby electrical loads. The equipment can degrade if standby electricity is not supplied.	**The impact of standby electricity use needs to be factored into the financial calculations.**
Insufficient working space for carrying out maintenance making maintenance time consuming	Some equipment was not sufficiently well designed to allow easy access for operations and maintenance. This was cited on Surf 'n' Turf with regard to access around the electrolyser and access to the pipework on the hydrogen trailers.	**Involvement of O&M team at design stage or detailed consideration of O&M requirements should be made.**
Insufficient training for local staff leading to a reliance on expensive external contractors	Some training of onsite staff was not always well completed. The projects cited that this became an issue as there were delays in making repairs while waiting for contractors to arrive. This was further complicated in remote locations such as the Orkney Islands where access is governed by the weather conditions.	**The equipment suppliers contract should ensure a suitable level of training is provided to qualified people so that most issues can be resolved locally. This should be conditional to final payment and sign off.**
New equipment being unreliable leading to unexpected downtime	Equipment reliability was found to be poor particularly for the electrolysers and fuel cells. The supply chain is improving but is still underdeveloped with equipment suppliers still identifying opportunities for improvement in reliability.	**It is necessary to consider the assurances provided by equipment suppliers regarding the time for repairs and replacement of the equipment. This should be factored into contract terms.**
Warranties and guarantees are short leading to insufficient protection against equipment breaking	Warranties and guarantees on electrolysers and fuel cells vary between suppliers. Warranties for fuel cells are provided on the number of hours run (8,000 hours total run time is typical). Electrolysers are typically provided with a two-year warranty. In comparison in the solar industry the major components have five-year to ten-year equipment warranties.	**Project leads should ensure that the warranty for the equipment is appropriate. Advice should be sought from other projects. There may be a balance between extra cost to extend warranty or accepting normal short term conditions.**
Need to establish a hydrogen market to guarantee revenue	This is key to any hydrogen project, where a use case for the hydrogen created must be secured. This could be electricity generation, transportation or heating. The more uses for the hydrogen the less risk there is in being reliant on a single demand/customer. Whilst there maybe a	**For all the projects a hydrogen market needed to be established. This is a fundamental requirement for a successful project and needs to be**

	green premium on price the long-term market must support the technology.	**considered at an early stage.**

Monitoring and evaluation	There was a final project report that was produced that gave the results of the project and this was mainly written up by the project lead. Most projects did not provide in-depth monitoring although the equipment was set up to do this. This was mainly due to the time-consuming nature of this analysis work. Some of the project teams worked well with academic institutes to get reasonable performance data but typically short term of around 2 months of useable data.	**Further funding should be earmarked for this. Project teams could engage with a local University to carry out this part of the work.**
Ongoing maintenance and level of training	It was highlighted that some of the systems (electrolyser and fuel cells) required specialist knowledge and this needed to be sourced from further afield. The Levenmouth project team mainly relied on the local hydrogen company who were based in Edinburgh to ensure good service was maintained. The more remote Surf ‘n’ Turf team had greater technical skills and took on more of the overall maintenance requirement. This also helped with skills development.	**Project teams need to assess how maintenance is carried out after the commissioning stage has been completed. Considerations will be how close the original equipment supplier is, the location of third party maintenance providers and how difficult the maintenance is likely to be.**

4. Contractual challenges

Complex projects are likely to come across many contractual challenges. The project lead had to negotiate contracts with all the sub-contractors and amongst the project partners. Negotiating and signing of contracts often took longer than expected.

Contractual challenges	Learning	Potential solution
Time delays in negotiating grant and subcontractor contracts	The experience across all the projects highlighted that contracts took longer than expected to negotiate between the project team, Scottish Government and the individual contractors. This was particularly critical for a project with a twelve-month window	**Enough time for projects to negotiate contracts should be included in the timeline of the project. The suggested time frame for this would be at least three to six months.**
Initial tender document specification being too exact and thereby not allowing optimisation	Tendering for equipment and subcontractors was required for some of the projects. The brief for the tendering specification needed to be carefully considered. If it is too prescriptive there is no room for the subcontractors who have the specialist knowledge to be able to improve the specification.	**The tender specification needs to be considered carefully. Performance specifications rather than detailed design specification would allow for more flexibility.**
Time taken for specifying and tendering bespoke contracts	Contracts for the individual elements of the project were typically bespoke and agreed by the individual projects with the sub-contractors. As the industry is developing standard contracts for equipment were not available at the time. As the industry has moved on, standard contracts may be available from trade organisations or from equipment suppliers.	**Project teams should either adapt standard M&E/construction contracts (where available) or seek new ones that have been developed by industry bodies (.**
Enough project management time to ensure smooth delivery	Project management can be challenging for such complex projects. For two of the projects, the project lead acted as the project manager, and in one an external project manager was employed. Employing a project manager is an additional expense to the projects but worth considering as project management is time consuming; this should be budgeted into the projects overall costs.	**Project teams should consider whether to employ a project manager or to resource this internally and budget appropriately.**
Project delays are costly and consideration of penalty clauses in contacts should be considered	Delays were encountered on all the projects. This was either through long lead times on equipment or lack of personnel at some stages. It may be worthwhile looking to introduce penalty clauses in the contracts. However, this may be difficult to impose as there are multiple contractors on each of the projects and blame passing between project is likely.	**Project leads should consider whether tenders should include penalty clauses to encourage sub-contractors to perform to time. Projects should actively monitor progress and utilise risk management to mitigate against project slippage.**
Long lead times on bespoke equipment leading to longer timescales	There are long lead times on the equipment currently particularly refuellers, fuel cells and electrolysers as they are made to order currently due to the small order volumes.	**Long lead times (up to nine months currently) for the equipment should be factored into the timeline of the project.**

5. Safety Risks

Health and safety are paramount across any project. Some, but not all hydrogen projects, will need to go through the full CDM process as well as considering the safety risks of the whole system; this will depend on the complexity of the project and types of activities being carried out. Safety reviews were typically engaged in at the start of the process and are likely to have led to rework being carried out as each risk was identified and mitigated.

Construction Design and Management (CDM) process. The CDM process was applied on the Levenmouth project because of its size and complexity. CDM regulations require a principal contractor and a design team to comply with significant health and safety procedures. Costs for this process need to be built in.

Hazard Identification (HAZID) and Hazard and operability study (HAZOP) assessments. HAZID and HAZOP statements were required for all the projects and this is also likely to be the case for any future hydrogen projects. Both the Surf and Turf project and Levenmouth projects employed professional risk assessment consultants to carry out HAZID and HAZOP studies. The studies and safety register were updated at regular intervals throughout the project and it was stated that involvement of risk consultants should occur at the very start of the process to help the project run more smoothly, identify problems and enable early understanding of potential risks.

> **Levenmouth.** BGH managed the HAZID/HAZOP statements for Levenmouth and employed Abbott Risk Consulting to carry out the assessments. The assessments were at an early stage in the process and helped to guide the health and safety plans.
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> **Surf 'n' Turf.** On the Surf 'n' Turf project, ITM Power did a three-level safety assessment for the hydrogen electrolyser and fuel cell. Level 1 was review of relevant legislation, Level 2 was a HSEQ site report, an operational risk assessment and CE check for the equipment and a level 3 point of work risk assessment and training competency.
>
> **OHLEH.** The electrolyser used was ten years old and had full risk assessment and HAZID/HAZOP studies at the time of installation. The equipment supplier handled the HAZOP/HAZID for the fuel cells. The risk assessment was completed by the project team and covered standard risks. This was maintained throughout the project.

Some health and safety risks were specific to particular projects. The transportation of the hydrogen for the Surf and Turf project required the use of a chartered ferry. This is due to current regulations precluding the transport of more than 25 people at any one time while carrying a hydrogen load. This was not considered during the project design and was an unexpected additional cost. The regulations around the use of hydrogen are changing. Currently, EMEC are building a case for amending these regulations and are waiting for approval for transportation of hydrogen loads on the public ferry system. However, changing standard practices will take time. The Maritime and Coastguard Agency (MCA) have been fully engaged in this process and have been helpful with the investigation of new regulations.

Whilst the safety lifecycle is the same for all projects, any safety programme will need to be appropriately scaled and tailored, and projects should get advice on the level of safety assurance they need to undertake. Any safety assurance process should also consider the 'whole system' not just the individual items of equipment being deployed. This means it should cover all the items of equipment, interactions between that equipment (and the deployment context), the procedures/processes used to operate and manage the system, and training requirements. A minimum would be a standard risk assessment using a 'whole system' checklist based on best practice industry knowledge to ensure complete coverage. However, it is more likely that complex projects will require a full safety programme including the establishment of a Safety Management System (SMS), development of a Safety Plan (covering the complete system), a series of HAZID and Hazard Analysis (HAZAN) activities (such as HAZOP studies), tracking of hazards and hazards controls in a Risk Register and consolidation of the safety assurance information in a summary document to support through life safety assurance. These are the outline activities that are becoming expected by funding bodies including the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU). The project team would need to consider whether to engage an external consultant to carry out the safety assurance activities, including HAZID and HAZOP studies. These studies have typically been an intensive two day session where the project team meet with the consultants and undertake detailed analysis of the process and likely hazards, the cost of which should be built into the project budget. There may also need to be multiple studies through the life of the project.

6. Project outcomes (including community/employment opportunities)

The technical outcomes that have been demonstrated (by the projects in the study) so far are:

- Demonstration of the use of otherwise curtailed energy to produce green hydrogen.
- The use of hydrogen to produce electricity in a fuel cell.
- The use of hydrogen for vehicle transport. All the projects had at least one vehicle that was powered by green hydrogen.
- The use of Oxygen as a by-product for aerating a salmon farm. The OHLEH project demonstrated that a market for Oxygen could be established.

In addition to the specific project outcomes there have been wider benefits that have come out of the project.

Job creation and knowledge building

The project partners and suppliers have built up knowledge and skills in hydrogen through participation in these projects and this has meant that their businesses have been able to grow. Logan Energy, the main contractor for the hydrogen system on the Levenmouth project and based in Edinburgh benefitted significantly from the lessons learnt on the project. The company has grown from nine people since finishing the project in 2017 to 20 people currently and attribute much of their growth to being able to leverage the skills and knowledge learnt from the Levenmouth project. EMEC have benefitted from the Surf and Turf project as they have leveraged their experience to get further funding for hydrogen projects leading to 12 people currently being employed mainly on these projects.

Education and dissemination

There have been various educational initiatives that have led from the projects. The Surf 'n' Turf project has resulted in training materials and courses being established by Orkney Technical College to re-skill oil and gas workers to work in hydrogen.

Bright Green Hydrogen (Levenmouth) are conducting tours for schools and businesses around the Levenmouth site showcasing the electrolysers, fuel cells and renewable energy components. Logan Energy (Levenmouth) and EMEC (Surf 'n' Turf) regularly present the projects at international conferences.

Community Energy Scotland along with EMEC have also developed a dissemination project called Powering Isolated Territories with Hydrogen Energy (PITCHES). This is an Innovate project to use the knowledge gained on Surf 'n' Turf to help isolated territories (including Scottish Islands and Malawi) in setting up hydrogen projects.

OHLEH have also done a lot of dissemination and skill sharing. This has included hosting visits, presenting at events and the system has been used for student research.

International reputation building and further funding

EMEC have benefitted from being able to establish an international reputation around hydrogen projects and are heavily involved in a large number of both UK and EU funded projects trying to address various aspects of the hydrogen economy. Projects have included:

- **BigHIT**. Funded by Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) under the EU Horizon 2020 programme. A £10.4 million project to extend surf and turf project to Shapinsay;
- **Hyspirits**. £148,600 project funded by Department of Business, Energy, and Industrial Strategy (BEIS) to investigate decarbonising the whisky industry using hydrogen to replace fossil fuels as the combustion fuel in the distilling process.
- **Hyflyer**. The project aims to demonstrate the use of hydrogen for aircraft. This could be a significant development for decarbonising aviation.

- **Hydime**. An Innovate UK funded project (£430,332) was focussed on the use of hydrogen as a fuel in marine transport and will see the design and integration of a hydrogen/diesel dual fuel conversion system on a commercial ferry operating between Kirkwall and Shapinsay.
- **Integrating Tidal Energy into the European Grid (ITEG)**. EU funding – €6.46 m/ Total budget – €11.79 m. The hydrogen element is to understand whether tidal energy should be fed into an electrolyser or directly to the grid.
- **H100**. LCEP led SGN to consider Levenmouth as the location for their H100 project – a plan for a world-first green hydrogen heating network planned to become operational from 2022/2023 and heat 300 homes in Fife.

A number of the project participants have showcased projects at international conferences, demonstrating Scotland's experience in this field, including last year at Hannover Messe, Europe's largest energy exhibition and conference.

Effecting regulation changes

EMEC are working closely with the Maritime and Coastguard Agency (MCA) to further regulation changes around the use of hydrogen for marine applications. This has included getting permission for shoreside fuel cells to charge ancillary services and are in discussions over transporting hydrogen on ferries with more than 25 passengers and mixing hydrogen with diesel in marine engines.

There are a lot of benefits above and beyond the original project that can achieved. Project teams should look to see what benefits they can cultivate for example, using hydrogen as a steppingstone to other low carbon technologies or innovative renewable projects. As a result of the Surf,n,Turf project Orkney has a portfolio of an estimated £65 million through its umbrella projects BIG HIT, HyDime, HySeas 3, ReFlex. A first planning application has also been submitted of a multi-million pound privately invested off grid wind to ammonia project.

7. Commercialisation opportunities

Taking the lessons from these projects, we conclude with the suggestions made by the project delivery team on the opportunities and barriers for replication.

None of the projects are currently working in the way that was originally envisaged at the start of the project. A new electrolyser is being received for the Surf and Turf project, and the OHLEH partners are seeking funding to replace their electrolyser to make their project operational again. This would also enable them to scale up by adding further vehicle charge points. The projects resulted in important learning about commercialisation and replicability.

Establishing a market for hydrogen
One of the key challenges for developing a hydrogen project is ensuring that there is a sustainable market for the hydrogen that is produced. Projects tended to approach this by identifying a need in the local area.

The markets developed in the project were:

- The OHLEH project team produced the hydrogen from fish waste for use in a dual-fuel refuse collection vehicle (amongst the first examples of this application) and for supplying oxygen and electricity to a nearby salmon fishery hatchery,
- The Surf and Turf project team used the hydrogen for ancillary services on a ferry that was docked at Kirkwall as well as for vehicles
- Levenmouth generated hydrogen from the solar systems and the wind turbine for energy storage with subsequent re-use in a fuel cell to generate electricity and was also used to run a fleet of vehicles.

At this early stage of development of the hydrogen sector there is not a large market for green hydrogen and there will therefore still be a need to establish the market as part of the project.

Commercialisation opportunities
Technically, the projects all show good potential for replication and have looked to do this through dissemination and through development and support of further projects. Commercially the challenge is the lack of a market demand for hydrogen. The commercialisation opportunities for each of these projects is given below:

Surf 'n' Turf. There has been considerable interest in the technology deployed on Surf 'n' Turf and BigHIT (developed from the learning on Surf 'n' Turf). A number of representatives from Scandinavian countries have been on site tours and are investigating potential applications for ports and for using hydrogen as a fuel on ferries and large commercial ships. The Orkney model of generation of hydrogen using renewable energy has been disseminated through the Powering Isolated Territories with Hydrogen Energy Systems (PITCHES) project. The intention is to demonstrate the Surf 'n' Turf and BigHIT projects in other regions. These would still be demonstrators, so a pathway to commercialisation; hydrogen as a fuel is still an expensive option compared to fossil fuels, and commercial models of these projects need to be validated.

OHLEH. The generation of hydrogen and oxygen from anaerobic digestion processes and otherwise curtailed renewable electricity has some technically interesting advantages. The advantage of having a range of diverse renewable energy sources means that the electrolyser can operate more consistently, and potentially constantly, which would not be possible using a single, intermittent renewable energy source. OHLEH have highlighted that the same ideas could be deployed on agriculture and waste plants, whisky and gin distilleries and aquaculture sites.

Levenmouth. The development of microgrids on industrial estates and business parks means it may be possible to satisfy the majority of the electricity needs locally, of those on the industrial estate. This could have widespread application on industrial estates throughout the country. Logan Energy have used the elements from the Levenmouth project in other projects.

8. Barriers to replication of hydrogen projects, solutions and prospects for the future

There are a number of barriers to the production and use of green hydrogen. These include:
The high cost of green hydrogen. The cost of green hydrogen is currently expensive. Typically, the cost is of of the order of £7/kg to £10/kg for green hydrogen compared to £2/kg to £4/kg produced from fossil fuels by steam methane reforming. The cost is due to three factors, the cost and use of the equipment (electrolyser and fuel cell/refuelling station), the cost of the energy input and the efficiency of conversion (typically 50% to 60% for a round trip for energy storage).
Project teams will benefit from:

- The use of curtailed energy where the additional cost compared to fossil fuels can be partially compensated for if it is coming from renewable electricity that would otherwise have to be curtailed and is therefore losing revenue from Feed in Tariff or Renewable Obligation Certificates.
- Doing projects that have vehicles as their main objective can claim from the Renewable Transport Fuel Obligation (RTFO). This is similar to the renewable heat incentive as there is an income for using zero carbon fuels.
- The recent net zero drive by many organisations will change the economics of hydrogen projects. In particular, economic incentives like the carbon tax and companies being forced to go for net-zero will have a large impact.
- Green hydrogen costs are linked to the amount of use of the electrolyser. For utilisation rates per year of less than 2,000 hours the cost of hydrogen goes up significantly. Therefore, there will be a need to use renewable energy from cheap (e.g. curtailed sources) and also high capacity factor systems (such as offshore wind and wind turbines in high wind speed areas) to ensure that sufficient run hours are achieved.

The need to establish a market for green hydrogen. The maturity of the hydrogen market is still low although the market is exhibiting significant and rapid growth and some predictions are showing cost competitive applications within a five-year but more likely ten-year timeframe. The markets for green hydrogen are only just developing which means that, typically, there is not a ready market for the hydrogen to be consumed. They are likely to be different to industrial markets where the hydrogen is typically generated by steam methane reforming and are currently a lot cheaper but require the hydrogen demand to be located close to the reformer.
Project teams will benefit from:

- Identifying and establishing a hydrogen need and incorporating this into the project.
- Conceiving and designing the project with the end user in mind.

Technology readiness levels of equipment. The technology and commercial readiness of some components, such as electrolysers and fuel cells of the scale (500kW) used in these projects, has not yet reached a high enough level to provide reliable, affordable equipment. This is to be expected as the technologies are still maturing. The hydrogen market is currently seeing large growth with a number of big players buying fuel cell and electrolyser manufacturers in the coming years this will lead to a much higher level of quality and reliability.
Project teams will benefit from:

- Assessing the market and looking for reliable and well proven technology suppliers.
- Assessing the terms and conditions that they are being offered particularly around equipment supply and protection (e.g. warranties).

Efficiency of the process for specific applications. Efficiency of conversion of renewable energy into hydrogen and then using it for electricity generation (around 50% to 60%) is not economic compared to battery storage (80% to 90% efficiencies) and therefore it is unlikely to become an attractive choice for storage applications at the small scale when compared to batteries. Hydrogen has a role to play in applications where the weight of batteries and size of batteries will preclude battery use, in particular, on ferries, aeroplanes and larger vehicles.

Project teams will benefit from:

- Tracking the technology as more efficient methods for generating hydrogen are slowly being developed.
- Concentrating their efforts on high value worth areas or areas that have some Government support, such as the transport sector, as the efficiency of the process will have less of an impact.

International developments. There are significant international developments that will help the hydrogen market particularly the announcement of that Germany is investing £9 billion into hydrogen is a significant development. Other countries including the Netherlands and Australia have announced considerable interest in the development hydrogen. Additionally, the EU have recently launched their hydrogen roadmap for the development of hydrogen in Europe. Currently there is competition between the generation of hydrogen from fossil fuels with carbon capture and storage and green hydrogen which is purely from non-carbon sources, usually electrolytic sources. Large amounts of investment will have a significant impact on the cost of electrolysers, fuel cells and refuelling stations. Additionally, higher carbon taxes or restrictions on the use of fossil fuels as there is a drive towards net zero are likely to change the economics of green hydrogen projects significantly.

It is clear from these projects, that there are technical opportunities for replication and specific markets where hydrogen may have a role to play. There are a number of risks and barriers that need to be addressed before projects such as these could be commercially viable. A number of the project participants are still active in the market working on further pilot demonstration projects and technology innovations. There is a current debate over how quickly hydrogen will become economically viable from a few years to never. The high level of international interest in hydrogen market would suggest that there will be a significant market for hydrogen projects in the coming years.