Feasibility study - Green Hydrogen Production at the Science Museum Group’s Science and Innovation Park'

This project was funded by the South West Energy Hub

SOUTH WEST ENERGY HUB

Trust
Quality
Progress

31190 / South West Energy Hub

Feasibility study - Green Hydrogen Production at the Science Museum Group's Science and Innovation Park'

Report number: 31190

Prepared for: South West Energy Hub

Date: 04 March 2022

Status: Final version

Prepared by:

Sam Cottrill	Senior Energy Consultant	Kiwa Gastec
Mark Lewitt	Senior Technical Reviewer	Kiwa Gastec
Nikhil Hardy	Senior Energy Consultant	Kiwa Gastec
Nick Pannell	Managing Partner	Pannell Hayes
Belinda Perriman	Senior Partner	Pannell Hayes
John Buxton	Senior Partner	Pannell Hayes

Approved by:

Paul McLaughlin Head of Consultancy

Commercial in confidence

The maps within this report use data from:
OpenStreetMap © OpenStreetMap contributors
Licensed under Open Database Licence (map data) and CC BY-SA 2.0 (map tiles)
Office for National Statistics licensed under Open Government Licence v3.0
Contains OS data © Crown copyright and database right 2022

© Kiwa Ltd 2022

© Kiwa Ltd 2022

© Kiwa Ltd 2022

1 Executive summary

The feasibility study into renewable hydrogen production at the Science Museum Group's Science and Innovation Park (S+IP) has shown that it is feasible to produce competitively priced hydrogen at scale for use in the surrounding area which can make a significant contribution to the delivery of the region's net zero carbon ambitions. Hydrogen supplying transport demands was found to be the optimal use of the hydrogen from the site, with depot refuelling of heavy vehicles the key market for the hydrogen produced.

The concept of integrating local renewable energy supplies to produce green hydrogen for transport in the area around Swindon was central to the study. Choosing demands which are challenging to decarbonise by other routes such as HGVs and some buses enables the hydrogen market to be defined, and this real deliverable project to be outlined. This would continue the region's strong link with hydrogen transport infrastructure. The study also focussed on producing hydrogen at scale allowing several different end users to be supplied with hydrogen reducing the risk and maximising the benefit from the hydrogen produced. End users at the S+IP have also been included in the demand study, as the site has the potential to host several SMEs utilising hydrogen alongside the potential for refuelling existing and developing transport demands at the site.

The work in this study also looked at a diverse range of demands for the hydrogen. This included assessments of hydrogen for heat, power and for use in buildings at the S+IP. The study has found that hydrogen produced at the site is best used for transport application due to the premium price that these demands provide. The low cost and lower comparable purity requirements of other demands such as for heat ensured that hydrogen produced from renewables at the S+IP was not as attractive or viable for this demand as it was for transport. The scale and seasonality of heat demands was also a challenge. The integration of consistent and predictable transport demands has been shown to be vital to allow for large scale production of hydrogen, particularly where sites do not have large scale geological storage required to meet variable demands. Large vehicles which currently have limited technology options for decarbonisation have been found to be the best options for supply. In addition HGVs and Buses are typically refuelled frequently and have back to base refuelling which is an advantage for hydrogen supply.

The concept developed in this study is potentially replicable across other renewable energy production sites in the region where large transport energy demands sit close to large renewable energy production sites. For example: renewable energy production close to transport infrastructure which can be used by buses and HGVs could be supplied with locally produced green hydrogen rather than relying on national scale. This means hydrogen production within proximity to refuelling locations for large vehicles using major road infrastructure, or cities with public transport infrastructure or HGV distribution centres. A large number of vehicles is not a requirement but rather a consistent stable demand from which to build a hydrogen supply system, which could be provided by a small number of vehicles requiring frequent refuelling. Single large users could provide potential options for hydrogen demand however this presents its own risks and will limit viable locations. A diverse number of large demand locations in the area is therefore the preferred option.

This study has shown that meeting these large transport demands would also enable additional hydrogen production for additional demands to be met e.g., smaller vehicles or stationary demands. S+IP is the ideal first, or early location for such a system in the UK because of its strategic location close to major transport infrastructure and demands in the UK. This would allow

 © Kiwa Ltd 2022

S+IP to make innovative and substantial carbon reductions via hydrogen, whilst supporting the Science Museum Group's existing ambition to develop its S+IP site.

1.1 The location for the study

Owned by the Science Museum Group (SMG), the S+IP comprises of large hangars and buildings supporting the collection of the SMG, and is used for technology and engineering research, automotive testing, and renewable energy generation alongside collections storage. The renewable energy generation is significant with on-site renewable energy generation of 50MW of solar installed. The collection contains many of the firsts of hydrogen production and use as part of the historic artefacts housed at the site and SMG strong commitment to sustainability has led to the use of hydrogen fuel cell vehicles at the site since 2017, along with other zero-emission electric vehicles.

The 545-acre site (Figure 1) is 5-miles south of Swindon and junction 16 of the M4, accessed by the A4361. This is the only main road that passes close to the site. This road connects to the M4 at junction 16 but requires vehicles to pass through the village of Wroughton. This means that although hydrogen produced at the site is well located for supply into Swindon and surrounding area, it is not well located for onsite vehicle refueling serving motorway users. Figure 1 shows the location for the solar arrays which take up the southern part of the site. Development plans to expand the buildings housing the collection are underway including a new 26,000 m^2 collections management facility - Building ONE - at the centre of the site can be seen. This collection will be open to visitors from the spring of 2024. There is currently no hydrogen production at the site.

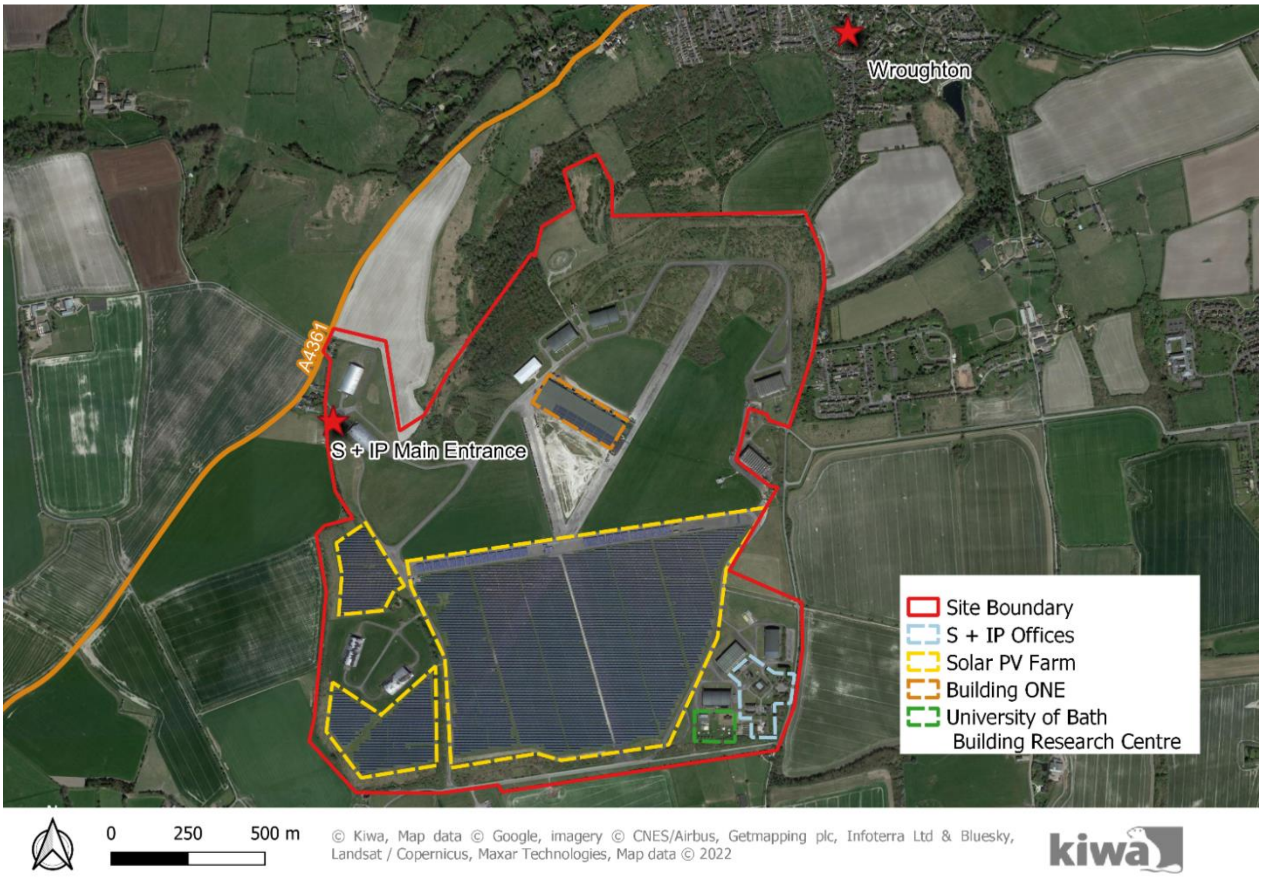


Figure 1: S+IP site showing current activities and layout

 © Kiwa Ltd 2022

1.2 The Strategic Case

The strategic case was approached in two parts: a strategic review of existing published information at the national, regional, and local levels; and a hydrogen workshop was held at the S+IP with key stakeholders. This ensured that the best options for what could be achieved at the site were considered, enabling the best project outcome to be selected. The outcome from working with hydrogen stakeholders was to define the project concept used in the system design.

1.2.1 Strategic Review of Existing Published Information

National Level

As the focus of the study has been on transport demands it is noted that the Department for Business Energy & Industrial Strategy (BEIS) places transport as one of the largest components of the hydrogen economy in the future and expects hydrogen vehicles, particularly depot-based transport including buses, to constitute the bulk of 2020s hydrogen demand. This is important as the study has focussed on what can be achieved in the near future. In August 2021, BEIS published its UK Hydrogen Strategy [1] which sets out for the UK some detail what needs to happen to enable the production, distribution, storage, and use of hydrogen and to secure economic opportunities. The Government has also announced The Net Zero Hydrogen Fund (NZHF) which will support at-scale deployment of low carbon hydrogen production during the 2020s.

In addition to these hydrogen strategies, transport strategies are also aligned with the development of hydrogen infrastructure at S+IP. Government aims to deliver the National Bus Strategy [2] (NBS) which has a vision of a green bus revolution. Although Swindon has bid for electric buses as part of the Zero Emission Bus Regional Areas (ZEBRA) scheme, there are several routes in the area which cannot be electrified. These may present an opportunity for hydrogen deployment.

Opportunities for Funding

BEIS announced in 2021 its high-level Hydrogen Strategy, in which it presented significant commitments to building the hydrogen economy. Two main routes for funding have been identified:

- Emerging BEIS funding pathways
- Renewable Transport Fuel Obligation (RTFOs)

BEIS has also not only increased the overall budget for the UK hydrogen economy to £1bn but set out new and clearer funding pathways and criteria. In this context, potential grants, and other funding opportunities for the development of green hydrogen production at S+IP are more accessible, should they be called upon by a developer.

The project is also well suited to apply for RTFO certificates, specifically under the 2021 criteria for Renewable fuels non biological origin (RFNBOs)[3]. There is the potential to support a developer of hydrogen production at the S+IP through this scheme resulting in a payment of £1.374 / kg of hydrogen (assuming current price of RTFC of 30p) up to £2.29 /kg of hydrogen

---

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf
[2] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/980227/DfT-Bus-Back-Better-national-bus-strategy-for-England.pdf
[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1042787/renewable-transport-fuel-obligation-compliance-guidance.pdf

© Kiwa Ltd 2022

1.2.2 Regional level

It is within the overall national policy context that the regional and local authorities must work to deliver their contribution to the overall objectives. Of particular interest is the Western Gateway, England Economic Heartland and the Swindon and Wiltshire Local Enterprise Partnership.

Western Gateway

The Western Gateway is a cross border economic partnership between City Regions, Local Authorities, Local Economic Partnerships (LEPs) and the Welsh and UK Governments. It covers the core cities of Bristol and Cardiff stretching across south Wales and western England, from Swindon to Swansea, Wiltshire, and Weston-Super-Mare to Tewkesbury. The focus is inclusive and clean economic growth[4] through better collaboration between regional partners.. There is an opportunity through the Western Gateway as regions develop their hydrogen infrastructure to strategically connect hydrogen infrastructure to provide a fuller refuelling network.

Subnational Transport Bodies

The Western Gateway – the Western gateways Strategic Transport Plan 2020-2025 states: There are many benefits to the business community from switching to alternative fuels (such as biodiesel, electricity, and hydrogen).

England Economic Heartland - EEH covers an area which overlaps completely or partially six LEPs. It's a subnational transport body, with its sole focus is transport and as such a key focus is on transport issues with various publications and reports having been produced[5]. In the regional transport strategy[6] under Decarbonizing our Transport System, it is noted that the EEH support the opportunity to deploy at scale new technology such as Hydrogen Electric Vehicles.

Swindon and Wiltshire – Local Enterprise Partnership (SWLEP)

The Swindon and Wiltshire LEP (SWLEP) has been working in collaboration with four LEPs along the M4 corridor to progress its New Energy Vehicle Fuelling Infrastructure strategic priority, presented in its Local Industrial Strategy (LIS). The Swindon and Wiltshire Local Industrial Strategy[7], aims to mobilise hydrogen related priorities previously identified in its Energy Strategy (2018) including: tackling capacity constraints and the lack of affordable access to electricity and exploring further uses for hydrogen.

In addition, the LIS identified the development of research and innovation opportunities at the Science Museum Group site at Wroughton as one of its 12 strategic priorities, this is now known as the Science and Innovation Park (S+IP) site. SWLEP has been working with the Science Museum Group to help progress its research and innovation aspirations.

1.2.3 Local Level

Swindon Borough Council

At the local level the Swindon Borough Council (SBC) Local Plan and Local Transport Plan stress Swindon's heritage as a transport town. By pioneering transport solutions, hosting major energy

---

[4] https://western-gateway.co.uk/
[5] https://www.englandseconomicheartland.com/publications-and-responses/
6 https://eeh-prod-media.s3.amazonaws.com/documents/Connecting_People_Transforming_Journeys_av.pdf
7 https://static.swlep.co.uk/swlep/docs/default-source/strategy/industrial-strategy/emerging-lis-v0-1-master-31032020.pdf?sfvrsn=4fe0ce5e_14

© Kiwa Ltd 2022

and automotive firms added to the previous rapid uptake of Hydrogen fuel domestic vehicles in the Borough highlights that Swindon as a town should continue to innovate in energy, transport, and mobility. To this extent, producing green hydrogen at S+IP for local and regional use is coherent strategic planning for the town.

Swindon Borough Council's (SBC's) planning framework commits to "contributing to carbon reduction targets by achieving a shift towards a more sustainable transport network". Swindon is the center from which bus transportation is provided in the town and further afield.

1.3 Stakeholder Engagement

Initially, a provisional review of potential green hydrogen use was carried out and combined with the first stages of a market and demand assessment. This early analysis was used to identify potential green hydrogen uses, users and local/regional stakeholders critical to project success. To maximise impact and accelerate the formulation of feasible concepts, a two-day workshop at S+IP was scheduled, and key stakeholders invited (a full list of participants is included in Appendix B).

The outcomes of the workshop were a series of recommendations to be taken forward into the feasibility study. Three outcomes taken through to the design phase of the feasibility study, see below:

- Production of Green Hydrogen at S+IP
- Supply of hydrogen fuel to Transport Sectors
- Supply of hydrogen fuel for use at the S+IP

Electricity production from hydrogen and hydrogen for heat have not been taken forward into the design stage of the study. These opportunities have been discounted from the projects scope but may be exploited by a developer if it is commercially viable. There are however challenges around how this could be implemented at the S+IP. For electricity generation it is not clear if the additional storage and generation equipment could be viable at the site due to the capital cost of equipment, efficiencies, and complexities with how this might be operated. Hydrogen for heat has been discounted due to the price associated heat energy. Even with recent increases in gas prices hydrogen is unlikely to be competitive with other heat technologies at the scale of production possible at the S+IP. Due to this, these options have not been included in the design work.

1.4 The Economic Case

For the economic case the study looked at the hydrogen market and demands for hydrogen in the region. This has shown that there is a strong potential for growth in the adoption of hydrogen technologies year on year over the next 5 years. Current demand in the region is small and supplied to small vehicles which refuel infrequently. However, early predictions show that 1300kg per day could be the potential demand within a year in the region with buses and HGVs making the largest proportion of this demand. This is scheduled to grow to up to 8000kg in the region in the next 5 years. The planned closure of other hydrogen production infrastructure on the region also provides an opportunity for the site to develop 'at pace' and to provide hydrogen to the existing hydrogen users in the region. Figure 2 shows a summary of the demand forecast for hydrogen for the next 5 years. A detailed version of the demand model is attached in Appendix C.

© Kiwa Ltd 2022

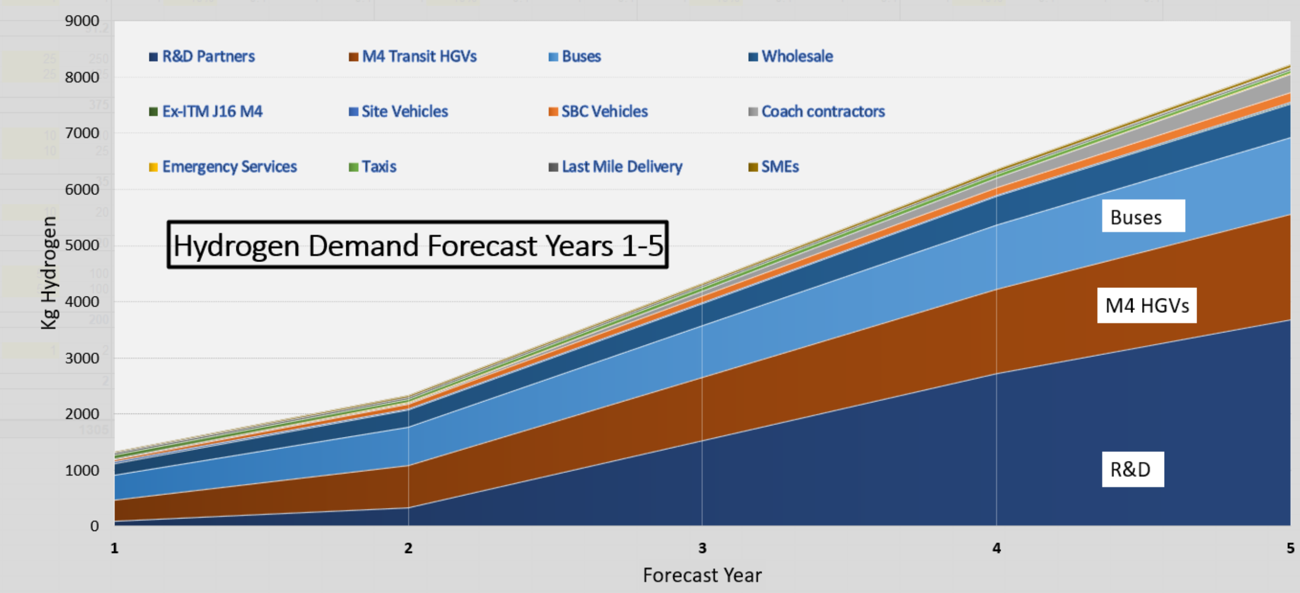


Figure 2: Hydrogen demand forecast for the next 5 years

The demand modelling looked at many diverse demands including demands other than transport. These assessments have shown that there are additional opportunities to developing hydrogen on the site which should be exploited. Early adoption of hydrogen has been identified in heavy vehicles particularly buses and HGVs which make up most of the demand in years one to two. A critical success factor is to get these demands established early in the project life. Also particularly important in the demand modelling were opportunities for SBCs fleet vehicles which, while these themselves will not drive the substantial five-year growth modelled in the demand forecast, Swindon Borough Council's leverage and influence as the contracting party for some of these service providers offers potential to convert vehicles to hydrogen as early as years 1 and 2 of operation and have been assumed in the demand profile. These early demands will be needed to ensure the project is viable.

Given that this multi-segment demand a) spreads any contracted supply risk and b) offers the potential for early adoption by a small number of vehicles in much larger fleets, another success factor in building the demand-side case is gaining agreement from Swindon Borough Council's officers to engage its contracted parties in hydrogen operation for a proportion of their vehicles as well. By including a larger number of transport demands reduces risk to the project.

1.5 System Design

To design the system at the S+IP a review of the site resources was used to understand what limitations there may be to the development. In addition to the 50MW of installed solar panels installed onsite, there is an electrical connection and water resources are available at the site. This meant that electrolysis of hydrogen is possible on the site. The availability of land for development was also a key consideration however because of the historical use of the site the availability of land for development was not found to be a restriction.

© Kiwa Ltd 2022

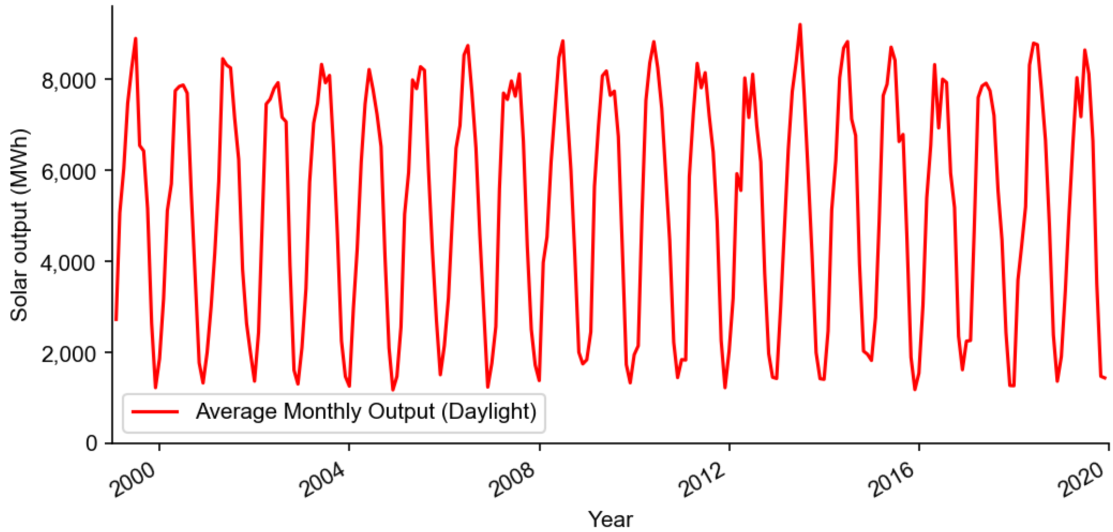


Figure 3: Simulated average monthly l output of a 50 a MW PV array at S+IP for last 20 years

Electrolyser sizing was a key consideration for the system design. This was constrained by the solar energy availability which has large seasonal variation (Figure 3). It was found that an electrolyser system of around 5MW is the optimum size for production of hydrogen at S+IP using the 50MW solar farm.

Storage of hydrogen at the site would need to be in above ground storage tanks called bullets. There is no available geological storage in the area which would provide the large-scale storage which can be used to provide inter-seasonal storage smoothing variations in production. Hydrogen storage bullets would be required to provide an intraday buffer and a few days supply to allow maintenance and shutdowns of production equipment. Figure 4 shows the output of the modelling work for 5 refills (1000kg/day) of hydrogen. The whole year (2004) is shown in Figure 4 with the graph showing the daily average for the values. Historic data has been used for the past 20 years to model the electrolyser system to see if it could manage historic periods of bad weather. 2004 is a median year for solar output so not particularly challenging for the electrolyser system. The storage level does not vary too much over the year as it goes from 75% to 90% which are its upper and lower limits of operation.

The daily average efficiency also does not vary much as the pattern of operation of the electrolyser is stable across the year. One parameter that does change is the import of electricity from the grid which is very low in the summer but rises steadily on either side of the summer period towards a peak the middle of the winter period where the import from the grid is at its highest. The models have shown that due to periods of low solar output in the winter and due to parasitic loads, there are challenges around providing the required renewable energy to the electrolysers from solar alone. Using only solar energy on average around 20% of electrical energy for electrolysis would be imported from the grid.

The limit for grid import into production is limited to 5% of total annual electricity used as this allows green hydrogen limits to be met. The amount of renewable energy available in the winter periods therefore needs to be increased to enable green hydrogen to be produced all year round without relying on the Grid. During the lowest periods of solar output around 2.5MW of additional

© Kiwa Ltd 2022

renewable energy is needed. This new renewable energy resource needs to be diversified away from solar as increased solar would not provide the additional electricity required. Wind energy is an example of a diversified source of energy which would allow for a greater share of renewable energy to be used whilst also allowing increased utilisation as hydrogen could also be produced outside daylight hours. Designing and costing the additional renewable energy capacity required to provide this energy is outside the scope of this report. However, rough calculations using wind power load factors of 40% which peak during winter and daylight hours[8] (when the energy is needed) would require 6 MW of wind power to be installed. Whilst not a preferred option If increased renewables cannot meet the 5% limit on grid imports, then the option of purchasing green electricity from the grid may be an acceptable fallback.

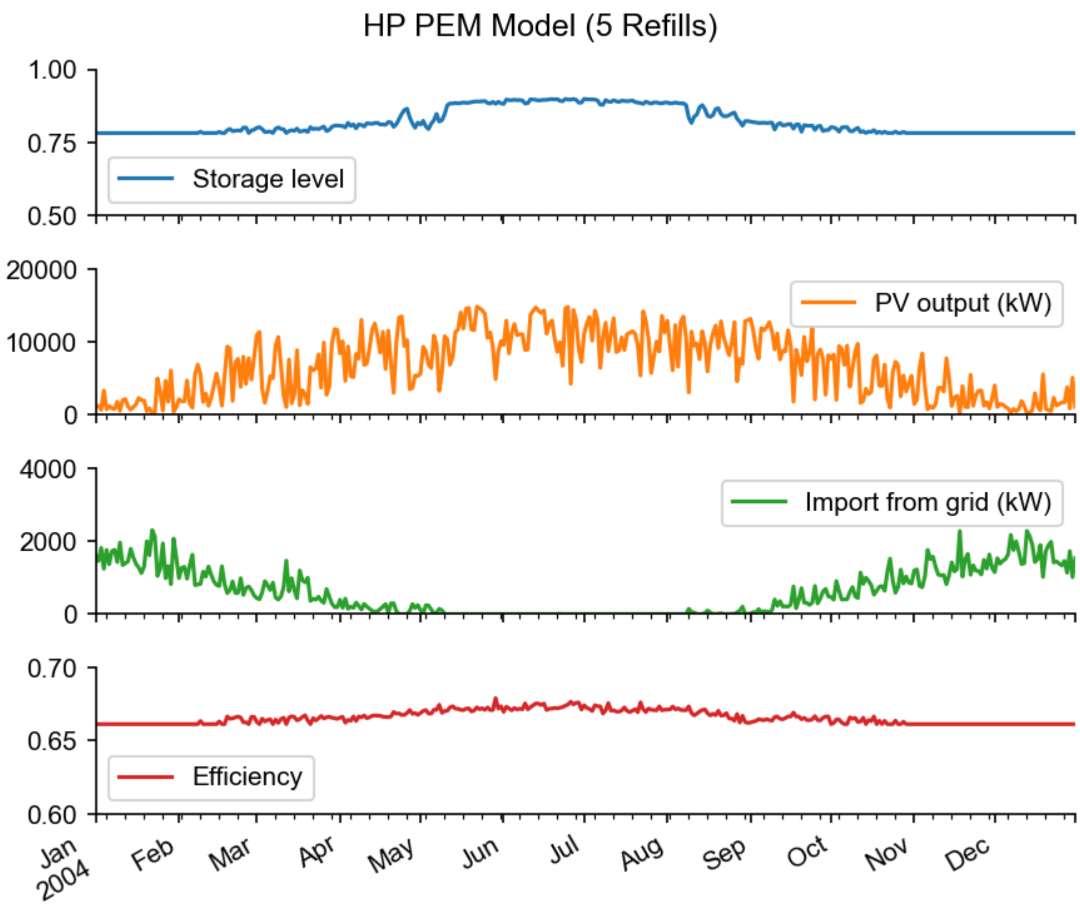


Figure 4: Model output for 5MW electrolyser with 5 refills

Even with new resources of renewable energy available, because of the intermittent nature of generation from renewables there will always be periods where no renewable electricity generation is available. Grid import will therefore also play an important part of the project to enable the system to operate during these periods of low output.

Figure 5 is a diagrammatic representation of the basic components of the proposed system. The electrolyser is supplied with green electricity from the PV array was much as possible, with electricity being supplied from the grid when solar electricity is unavailable. Hydrogen is produced

[8] https://www.eci.ox.ac.uk/publications/downloads/sinden06-windresource.pdf

© Kiwa Ltd 2022

and then must be compressed prior to refuelling the road tankers. Outside periods of demand and to maintain backup supply, hydrogen is produced and sent to storage. Any hydrogen removed from storage must also be compressed prior to refuelling.

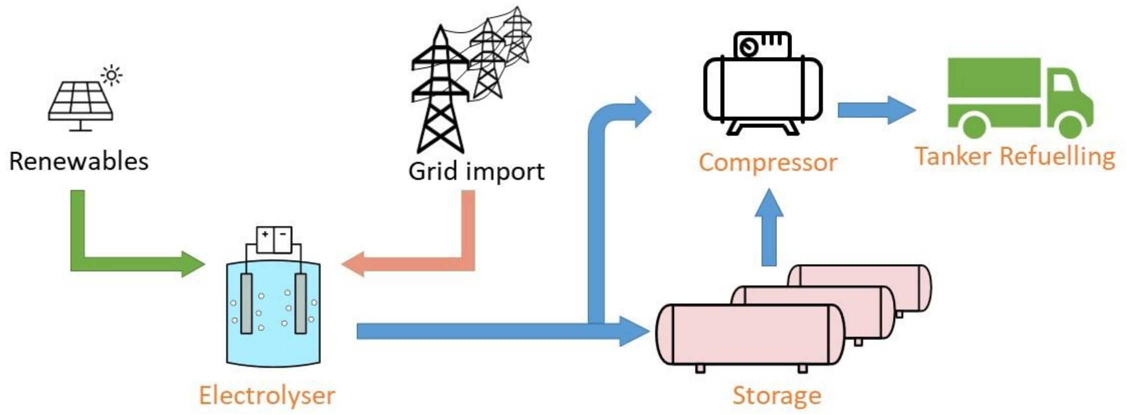


Figure 5: Block diagram of proposed system

The total area that is required for the site is 3,486m^2. The space requirements and layout have been sized for expansion if the system in future. This is the total area and includes all equipment excluding the access road required by the filling tankers.

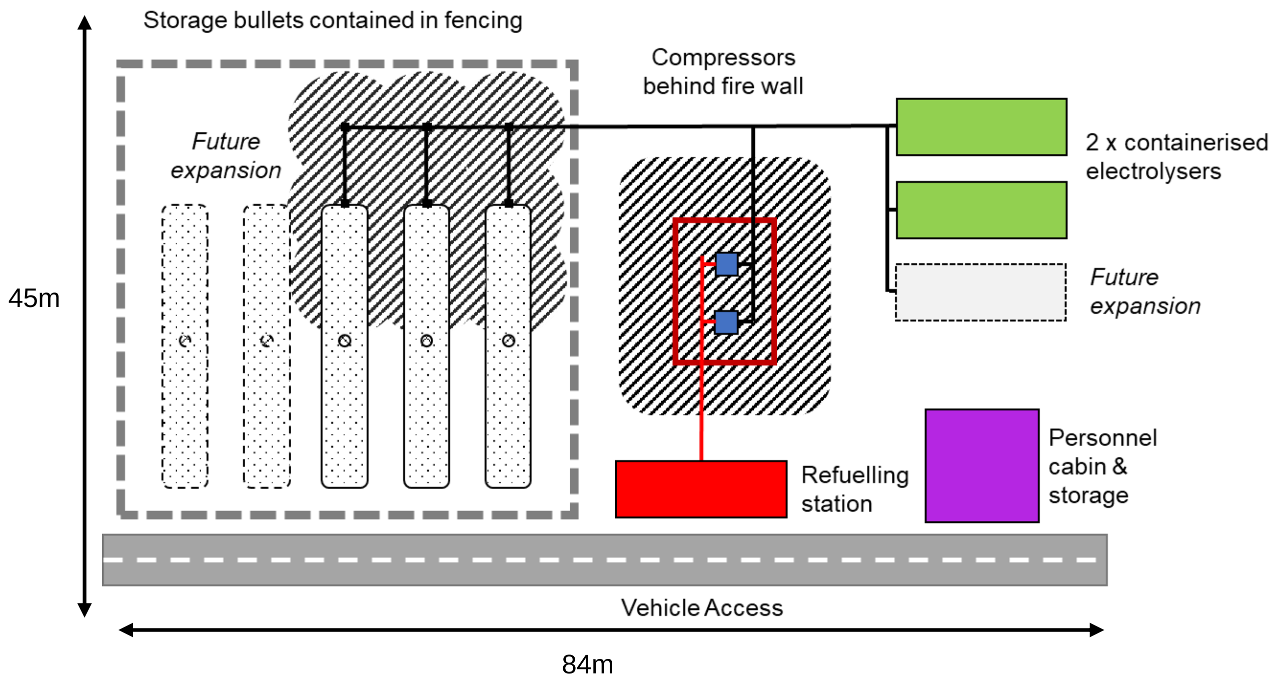


Figure 6: Hydrogen production plant layout

© Kiwa Ltd 2022

Figure 6 is a suggested plant layout, showing the relative sizes of each component and the necessary spacing between each component to maintain safe distance. The drawing is to scale to show how the site would look with the required separation distances.

1.6 The Commercial and Financial Case

Using stable consistent transport demands provides an opportunity to quickly achieve a scale of production not possible for smaller production sites, providing a route to cost effective production of hydrogen, driving down costs and creating greater flexibility and resilience. Cost is one of the major barriers to hydrogen as an energy vector, as the low cost of fossil fuel energy used for transport and other demands make commercialisation of hydrogen supply a significant challenge. The CAPEX (Table 1) and OPEX (Table 2) of the demand have been calculated to enable the minimum hydrogen price to be assessed.

Table 1: Total CAPEX including installation costs

CAPEX	Development
	PEM Electrolyser System (5 MW)
Equipment Cost (£)	£6,010,000
Installed Cost (£)	£1,773,000
Total Capex (£)	£7,633,000

Table 2: Utility cost per unit, variable, and total fixed costs

Utility	Cost	Annual Operating Cost
		Electrolyser (5 MW)
Electricity	5p (p/kWh)	£1,124,000
Demineralized water	188 (p/m^3)	£ 14,000
Instrument Air	0.4 (p/m^3)	£ 2,000
Misc.	N/A	£ 18,000
Total Variable Cost		£1,158,000
Total Fixed Cost		£ 239,000
Total OPEX		£1,397,000

The hydrogen price has been calculated using the Green Book requirements and setting a hurdle price of 10%. The price of hydrogen in the study was shown to be a minimum of **17.0p/kWh** or **£6.66/kg** without government support. Figure 7 shows the hydrogen price for different internal rates of return.

© Kiwa Ltd 2022

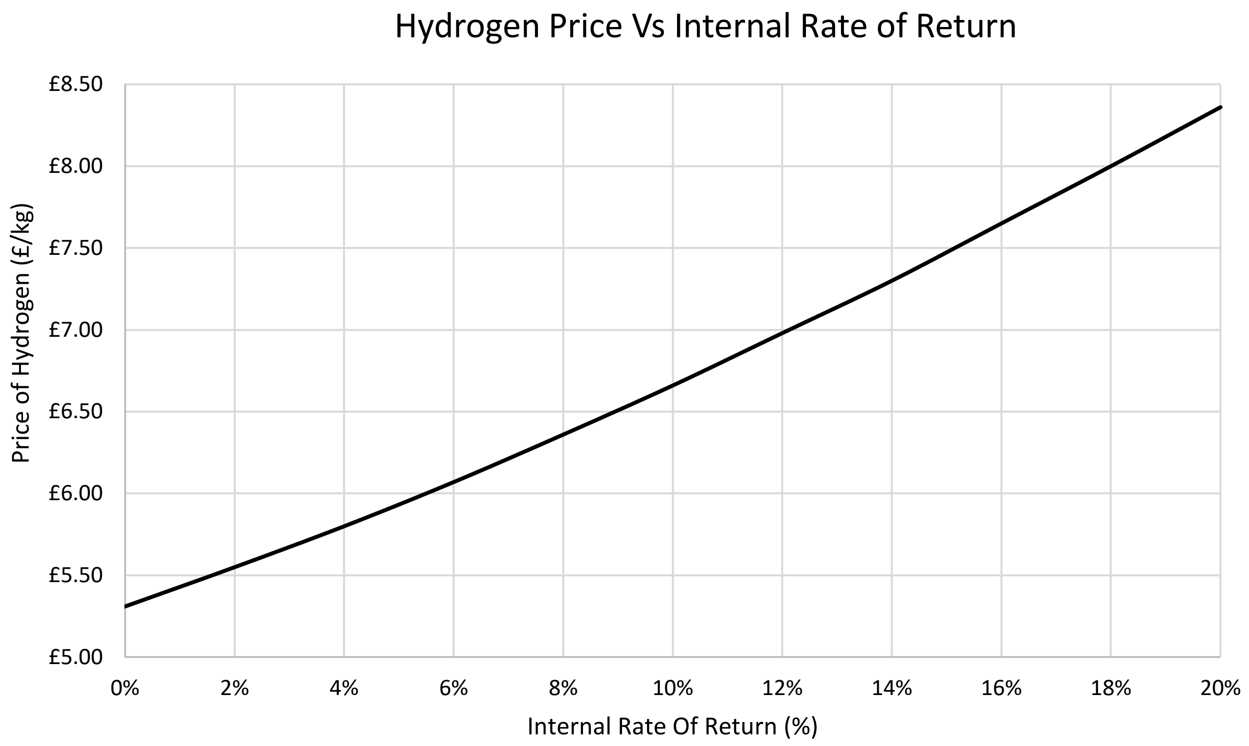


Figure 7: Hydrogen price vs internal rate of return

The focus of the cost modelling has been undertaken to show that hydrogen production can be supported without government funding, and this is the basis of the prices shown above. However, there are government support mechanisms for hydrogen production. By also including a 50% grant CAPEX and RTFCs under the RTFO scheme providing £1.374/ kg of hydrogen. This would further reduce the hydrogen price required by the developer making the hydrogen more competitive for the end users. This minimum hydrogen price using these support mechanisms was shown to be **9.8p/kWh** or **£3.86/kg**.

The reason hydrogen price is important is that it will determine whether the project is acceptable to the end users. It is therefore an important way to assess the commercial and financial case by comparing the cost of hydrogen with other fuels (Table 3).

Table 3: levelized price of usable energy for different transport fuels.

Energy Type	Energy Price (p/kWh)	Efficiency of Energy Conversion	Levelized Price (p/kWh usable)
Electricity	15.0	0.80	18.8
Hydrogen (No gov support)	17.0 (£6.66/kg)	0.44	38.9
Hydrogen (With gov support*)	9.8 (£3.86/kg)	0.44	22.3
Diesel**	14.9	0.32	46.6

*50% of the CAPEX (matched funding) current RTFC prices of £1.374/ kg
**diesel price of £1.50 per litre

These costs do not consider the differences in infrastructure and operating costs of the different technologies so have limited use as a direct comparison of the technologies themselves. It is

© Kiwa Ltd 2022

useful to understand some of the differences in the operating costs between the technologies and current energy costs compare to hydrogen.

1.7 The Management Case

Whilst the Feasibility Study seeks to define a 'main' business case of sufficient interest for a Developer to take the project forward, it is vital that there is sufficient attractiveness perceived in the project from the other two principal participants: the owners of the site, the Science Museum Group (SMG) and the Government - represented locally by the SW Energy Hub and supported by the SWLEP. Attractiveness to these overlapping and well aligned three main interested parties are summarised in the following diagram (Figure 8), before going into more detail on each.

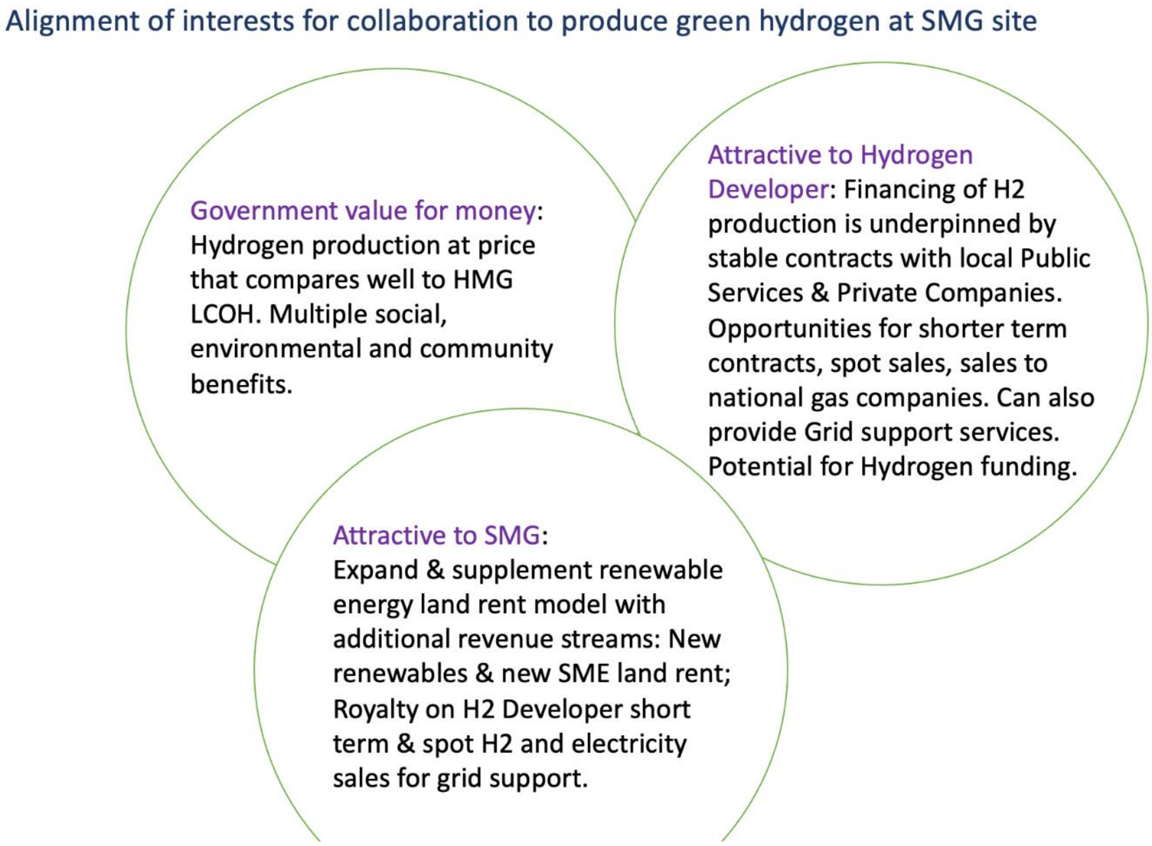


Figure 8: Alignment of interests for collaboration to produce green hydrogen at SMG site

1.7.1 Business Case/Attractiveness for the Developer

A particularly attractive structure for a Developer of the hydrogen production facilities would be to enter into a Partnership Agreement with a Developer of new renewable energy. With such a strategic partnership alignment, the Hydrogen Developer would not then in practice be beholden to the market electricity price- a key input assumption of the Green Book Methodology for green hydrogen production. Instead, the Partnership could optimise their 'private-wire' electricity price arrangements to maximise their combined profitability from the hydrogen sales.

A further optimisation in structure and commerciality could come from the new renewable energy Partner being committed not to a single technology, but to multiple and innovative clean energy generation technologies. Examples would be technologies involving harnessing kinetic energy from

© Kiwa Ltd 2022

wind[9]. The Partnership would then be incentivised to incorporate innovative technologies that will improve their commerciality; this in turn will encourage wider 'roll-out' from the S+IP of the new technology by other projects and regions.

The project is expected to be underpinned by relatively long-term contracts with local transport companies utilising the majority (but not all) of the hydrogen generated. It is not optimal for either the Developer or the buyers to be locked into 100% of the output from electrolysers that are mainly powered by renewable energy. Examples of 'merchant' (shorter term and on the day, 'spot') contracts include SMEs onsite at S+IP who use hydrogen for testing or for use all the way up to national carriers of hydrogen by road who have short term demands to meet. In addition to initial contracts with HGV logistics companies, hydrogen could be made available for testing by additional logistics bases in the Swindon area. Both being on the 'right side' of being able to supply hydrogen to meet long term contracts and some potential for economic upside increases the interest for a Developer, as well as helping a Developer to attract at least part private financing- an important Feasibility Study Workshop group output.

Whilst the ideal would be for a Developer to secure funding and to be able to press on with the development of the project without being dependent on securing government funding, there are the aforementioned Govt schemes for which the project is eligible that also make this project attractive to a private developer.

1.7.2 Business Attractiveness for the Science Museum Group

Incremental revenue streams can be generated for SMG through development of S+IP as a green hydrogen Science and Innovation Park. At the same time, the proposed S+IP builds significantly upon SMG's profile as a leader in science engagement.

Additional income from use of space at S+IP

The overall S+IP site extends over an area of some 220 ha. To build an expandable green hydrogen production and storage facility to the specifications included in this report, a relatively small area of c.0.35 hectares (0.07%) will be used, and rent will be received for this land use from the Developer of the hydrogen production facilities.

Income from tarmac testing track at S+IP

The site's use as a centre for research, piloting and testing of commercial hydrogen vehicle operation and the availability of land to develop a fit-for-purpose test track (supplementing the existing runways etc) boosts the suitability of the site as an effective centre for hydrogen transport research and development activities. It is highly likely to increase its attractiveness to commercial logistics operators interested in testing and piloting hydrogen-fuelled vehicles before scaling up hydrogen operations. Income to SMG would be generated from these track activities.

Exploitation and potential upgrade

Exploitation and potential upgrade and/or extension of existing solar farm at S+IP. The incremental development of green hydrogen production and storage capability using renewable energy is a) entirely consistent with SMG's purpose and b) further supports the sustainable energy commitments made by Swindon Borough Council in its Local Plan and Local Transport Plan (LTP3).

---

[9] . https://vortexbladeless.com

© Kiwa Ltd 2022

Attracting new zero-carbon business

In the context of the workshop's recommendations for the use of the site as a centre for commercial hydrogen transport research, piloting, and testing – space and facilities can be provided at S+IP for both public and private sector organisations to establish research and development bases.

New companies could come in and pay land rent, following the existing model, and make their own investments for buildings/facilities. Alternatively, and potentially more efficiently, SMG could invest to make one or more of the currently empty hangars ready for commercial occupation and use, it should be noted that:

- Rental income from SMEs using such facilities would go to SMG; this would be additional to the rental income that would go to SMG as part of the hydrogen Developer costs.
- Planning permission for re-purposing would be expected to be uncomplicated given broad SBC support for the project (see section 4.5).

1.7.3 Attractiveness for public sector investment

The project is fully aligned regarding the UK Hydrogen Strategy. The project would both be eligible, and in terms of timing, 'dovetails' well with the timing for national hydrogen grant funding. As well as calculating full project costs, we have followed the Green Book supplement provided by HMG in calculating a Levelised Cost of Hydrogen (LCOH) that has enabled the favourable comparison of the estimated costs of this project with those in the document [10].

The project makes a significant contribution to local and regional growth and to carbon reduction targets, detailed in the following section on the Environmental and Community Benefits. Specifically, the project fits the vision for a SW Net Zero Economy, playing a leading (catalysing) role in building the regional hydrogen economy for transport. Furthermore, the project could provide a multi-sector regional hydrogen cooperation hub. The project also fits into Western Gateway strategy and planning.

Because of the very high alignment between the three main participants, this makes the project more attractive. This is because, due to the limited time and resources of local government and public sector bodies, projects need to be realistic in their requirements and risks at the outset, but also scalable – in this case as the demand for green hydrogen grows. The possibility of funding the project with both commercial and government part-funded routes again adds to its attractiveness.

1.7.4 Top 3 identified Risks & Opportunities

PPA Contracts - There is a key risk that a deal cannot be agreed with the current owners of the solar park, to make use of existing solar capacity to produce hydrogen. Making use of existing capacity is a good first step and would appear to be easier than building new renewables. Building new renewables, however, may offer far greater opportunities for strategic alignment between the new renewables Developer and the hydrogen Developer.

Uptake of Hydrogen Vehicles - There is a risk that if the upfront CAPEX cost of hydrogen buses remains higher than that of alternatives, then the range, space and fast charging advantages of hydrogen buses may not outweigh the additional costs in the eyes of bus companies and HGV fleet operators. The 'whole life' sustainability of hydrogen fuel cells, compared

[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011506/Hydrogen_Production_Costs_2021.pdf

© Kiwa Ltd 2022

to batteries, was identified as an important element to highlight in the project. This risk is being mitigated as further specifics on government funding for the bus companies are announced, in order that they may be leaders in the growth of the hydrogen economy. Thus, the bus companies may wait for specifics on their own funding before signing up to long term hydrogen contacts. Currently, strong evidence that such contracts will be signed is required for the Developer themselves to also apply for funding. Whilst signed long term contracts will likely be required before investor funds are fully released, the approach taken in the Feasibility study was to aim for a project that is likely to attract development funding i.e., the project is of sufficient attractiveness to a Developer, that it does not have an absolute need for full clarity on government funding for the Developer at each stage of the development.

National Hydrogen Developments - Whilst interest in purchasing hydrogen has been expressed by locally based international companies, there could be a risk that the supply opportunity to a refuelling site supplied from S+IP will be confined to fleets operating in a local/regional radius (<100kms). This is because commercial road transport in the UK is a national business – with most goods being moved between the UK's industrial hubs. While the mid M4 corridor is a commercial road transport refuelling node, unless a UK-wide network of hydrogen supply points on similar transport "golden routes" is built in parallel, supply opportunity to a refuelling site supplied from S+IP will be confined to fleets operating in a local/regional radius (<100kms). Whilst viable with focus on local areas with local opportunities, the project could in turn eventually generate the national market/changes required for national developments to prevent FCEV assets becoming stranded in the region and limiting further development of the site.

1.7.5 Environmental and Community benefits

The system could prevent 5,000 tonnes CO_2 being emitted to atmosphere per year if replacing diesel from transport demands. Based on ONS estimates of carbon emissions, this equates to 0.5% of the Borough of Swindon's total emissions from 2019 or 2% of transport emissions. This is a significant reduction in CO_2 and would also lead to reductions in other pollutants, particularly NO_x and particulates associated with combustion of diesel. Future developments of hydrogen production supplying the area would result in further reductions in carbon emissions, which could help the city meet its overall CO_2 reduction ambitions.

1.7.6 Planning / Regulation

Much of the land surrounding Swindon, including the S+IP, sits within the North Wessex Downs AONB: the fact that the S+IP can comfortably accommodate the incremental build of additional renewable energy generation and the green hydrogen production facility within the existing site counts significantly towards the relative feasibility of the site when compared to other locations in the area and region. Policy RA2 in SBC local plan maximise opportunities associated with the Science Museum to benefit Wroughton and the Borough through realising tourism benefits associated with the Science Museum; and allowing expansion of museum related activities and enabling development providing the benefits of the development are delivered sustainably and do not conflict with other policies in the Local Plan.

1.8 Next steps

A base case hydrogen production system at S+IP providing transport demands in the area has been proven to be technically and financially feasible. There are now steps required to optimise and take this project to the stage where a full front end engineering design (FEED) study can be carried out. As a full FEED study will require local and national support before it can be funded, it is

© Kiwa Ltd 2022

proposed that a preliminary front end engineering design (PreFEED) project is required to bring together a project consortium, provide the final technical evidence, strengthen the business case, and manage project stakeholders. This PreFEED will allow the selection of the optimum design option and the project consortium to be taken forward into the full FEED study.

To be successful the PreFEED would require the following steps:

1. Identification and engagement with potential developers and operators for the hydrogen production at the S+IP site. To take the project into the next stage the project will require a developer identified to operate the hydrogen production facility. The PreFEED should therefore identify, approach, and select the best candidates to operate the system.
2. Direct engagement with the end users identified in this study to identify and outline the demand and locations for supply of hydrogen from the S+IP. This includes council fleets, bus operators and HGV fleet operators. This stage is required for the business case to be strengthened enough to allow a developer to have the confidence to get involved.
3. Provide the final technical evidence required for technical aspects of the study. Some areas identified in this study are outside of the scope of work to be considered at this stage. This includes additional diversified renewable energy production and the commercial contracts for energy supply to the electrolyser systems. This will allow the optimum design choice to be made regarding the hydrogen production system.
4. Bring together a project consortium to support the project into the next stage. The stakeholder analysis has identified a number of key stakeholders which will be required to support the project into a FEED project. The support of these stakeholders will be key to enable the project to be developed further. The work completed so far should be continued to ensure ongoing support for the project.

 © Kiwa Ltd 2022

2 Introduction and Background

This report presents the stakeholder engagement work, technical design and business case assessment completed under the Hydrogen Feasibility at the Science + Innovation Park (S+IP). near Wroughton, Swindon. The project was to produce a feasibility study for a proposed green hydrogen production and vehicle refuelling network to be based at the S+IP. The overall aim of the study was to investigate how a green hydrogen network could be established, in a commercially viable way, at S+IP.

The feasibility study was commissioned by the South West Energy Hub on behalf of the Swindon and Wiltshire Local Enterprise Partnership (SWLEP). The project was designed to inform the future strategic plans for the area as hydrogen technologies have been identified by the SWLEP as a strategic priority within the Swindon and Wiltshire Local Industrial Strategy (LIS). The SWLEP have identified barriers to hydrogen adoption in the area:

- A lack of existing zero-carbon hydrogen availability
- The capital investment required to install hydrogen generation equipment
- The capital cost of hydrogen refuelling equipment
- The capital cost of equipment able to use hydrogen as a fuel
- A lack of end-users

These barriers occur not only in the Swindon and Wiltshire area but across the UK where the challenges of adopting hydrogen technologies are met by the limited supply and availability of green hydrogen. This ‘catch 22’ situation can only be broken with the implementation of increased hydrogen production alongside increased demand and investment in hydrogen technologies. This feasibility study has been tasked with addressing the challenge of green hydrogen supply by looking at both the production of hydrogen from the S+IP and identifying potential customers. By structuring and delivering the feasibility study in this way, opportunities can be identified to help overcome these barriers to the adoption of hydrogen.

 © Kiwa Ltd 2022

3 Project Partners

There are five project partners who have been working together to deliver the feasibility study: Kiwa Gastec, Pannel Hayes, South West Energy Hub, SWLEP and the S+IP. Kiwa Gastec and Pannell Hayes are lead contractors, with support from the other three project partners. The Southwest Energy Hub are funding the project on behalf of the SWLEP and have been working closely together to support and guide the project. The S+IP have also been directly involved with the development of the study, as the concept is based on developing hydrogen production on their site. The following introduces each organisation:

Kiwa Gastec undertakes energy consultancy activities for many parts of the energy sector including feasibility studies. Kiwa Gastec's hydrogen expertise has been developed over the past 10 years during which Kiwa has been involved with a significant number of the major UK projects working to progress hydrogen.

Pannel Hayes Consulting based in Swindon, is a specialist operational consultancy, helping businesses and local authorities to decarbonise transport operations and to work towards achieving Net Zero transport well before the legal deadline of 2050.

South West Energy Hub helps public sector and not-for-profit organisations get green energy projects up and running; its aim is to increase the number, scale, and quality of low carbon energy projects across the South West, reducing the region's carbon footprint. The energy hub is one of five that have been established across England, funded by the Department for Business, Energy & Industrial Strategy. For the wider South West, the West of England Combined Authority is the lead partner in the project and hosts the energy hub team. They support their host LEP and the following LEP areas: Cornwall & Isles of Scilly; Heart of the South West; Solent; Swindon Wiltshire; GFIrst and Dorset. Their objectives are to:

- Increase the number, quality and scale of local energy projects being delivered
- Raise awareness of the opportunity for, and benefits of, local energy investment
- Enable local organisations and community groups to attract private and/or public finance for energy projects
- Support and deliver national and local Government schemes
- Collaboration, co-ordination and sharing of best practice

SWLEP is the Local Enterprise Partnership for Swindon and Wiltshire; it is a private sector-led partnership between local businesses, Swindon Borough Council, Wiltshire Council, the military, and education. It is a company limited by guarantee whose object is to bring about the sustainable economic growth of the area.

Science Museum Group's (SMG) Science and Innovation Park (S+IP) The focus of the feasibility study is production of green hydrogen at the SMG's S+IP's site. The site was previously based a maintenance unit for RAF aircraft. Today it includes clusters of aircraft hangers and new storage facilities which house the Science Museum Group's (SMG) national collection. The site also includes offices and facilities for the S+IP operations and a 50MW solar farm which has been developed on the site. The SMG are developing the site (as a science and innovation park, with a core focus on low carbon and sustainable technologies that mirror the mission of the SMG. Interest in the site comes from its potential for development as the site has 545 acres of developable land which has huge potential. The development of research and innovation activity on the site is one of the SWLEPs strategic priorities and it supports this site's development and expansion plans in these areas, Developments at site already include: a vehicle test track, a film

© Kiwa Ltd 2022

studio, a Bath University research centre, a cultural hub, and an exhibition centre in the new 26,000 m^2 collections management facility, Building ONE. From 2024 the site will welcome 15,000 visitors to the Building ONE.

The S+IP has its on-site energy demand (from vehicle including fleet and buildings) and its significant on-site renewable energy generation (50MW solar PV array) which could be used for hydrogen production. Furthermore, the expansion plans of the site present opportunities to engage site visitors with a hydrogen future, linking to the historical hydrogen items contained within the National Collection. The development of renewable energy at the site fits exactly with the Science Museum Group's mission statement "To make sense of the science which shapes our lives, help create a scientifically literate society and inspire the next generation".

3.1 Project Aims

This report presents the assessment of potential hydrogen demands and the technologies for hydrogen production for feasibility at the S+IP.

This study had four aims:

- Assess the technologies relevant for hydrogen production at the S+IP and select the best options based on their key performance factors.
- Quantify the key hydrogen demands in the local area and present the demand profiles to enable design of a hydrogen supply system.
- Demonstrate the cost of hydrogen, its carbon savings, and evaluate its commercial potential, barriers, and risks.
- Identify potential customers and pioneer partners and assess planning permission considerations

3.2 Report approach

The report approach to understand whether the project is feasible by following key parts of five case model using the government Green Book methodology:

- The Strategic Case – a review of strategy and stakeholders
- The Economic Case – a review of hydrogen markets
- The Financial Case – a review of capital and operation costs
- The Commercial Case – hydrogen pricing and internal rate of return
- The Management Case – review of project risks

In addition to the five-case model the study also had to show whether the system is technically feasible. The technical aspects in the study feasibility report for hydrogen production at the S+IP was split into three distinct areas: Hydrogen Stakeholders, System Design and Business Case. These three areas when reported together are designed to show the overall feasibility of the green hydrogen production project at the S+IP whilst allowing each area to be individually assessed. Each of the three areas used in this approach are all important components to the overall feasibility of a project at the S+IP (Figure 9.

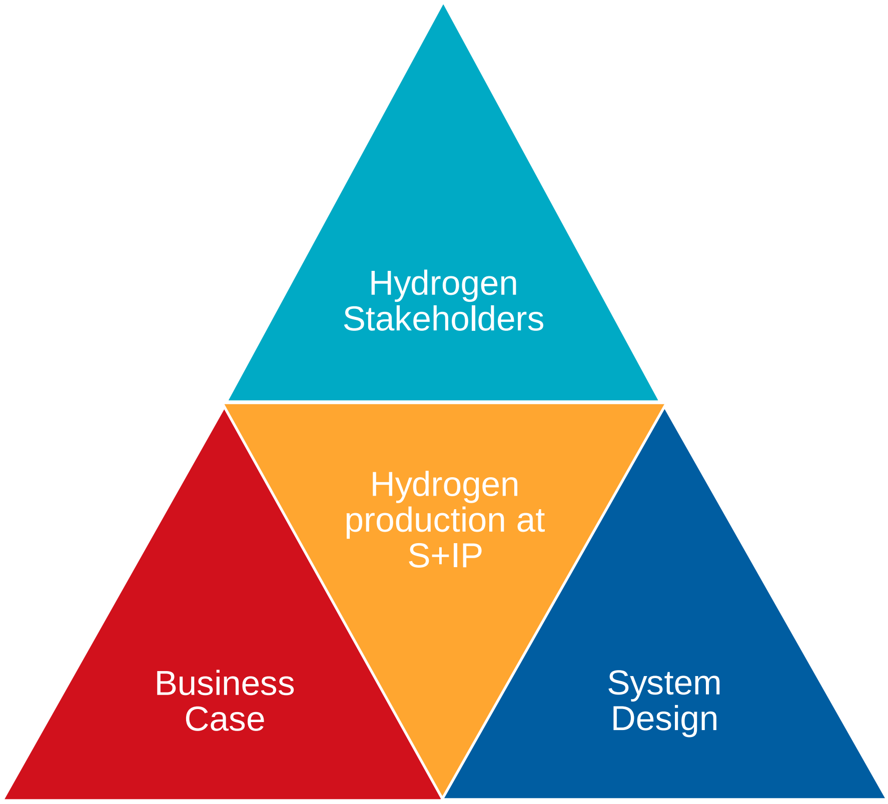


Figure 9: Three areas of importance for the feasibility study.

 © Kiwa Ltd 2022

3.2.1 Hydrogen stakeholders

This section covers the strategic and economic review of the system. The hydrogen stakeholders included in this study cover a diverse group of entities from national, regional, local governmental organisations and local businesses. This diverse group is required because of the opportunities for different energy demands to be met, opportunities for project developers, and opportunities for technology suppliers. This is also driven by an increased interest and investment into hydrogen currently underway in the UK especially around transport applications. The stakeholder review was key for ensuring that the project delivers for the correct stakeholders, an example of this is that the project should deliver on the strategy of the local area.

The stakeholder review also identified hydrogen demands in the region and assessed their requirement and overall feasibility for supply from the S+IP. The study assessed all the supply options for Heat, Transport, Electricity Generation and Grid Injection.

3.2.2 System Design

This section also investigates the commercial and financial case for the system by investigating the OPEX and CAPEX as well as the IRR required by the project to set the minimum hydrogen price. This section has a large focus of the technical feasibility of the project on the practicalities of production and supply. This area of work is focussed on system design within the S+IP and the production of hydrogen and its interaction with renewable energy supply. The hydrogen production equipment, storage requirements, supply systems are all important for the feasibility study as these are needed for the project to be feasible. By specifying all the requirements for production, it is possible to calculate the OPEX and CAPEX number required to outline the commercial and financial case.

The detailed modelling of an appropriately sized system is key for optimising the production but also for creating opportunities and forms a key aspect of the feasibility study. The sizing of the production of hydrogen has been completed to maximise the options around use of existing renewable energy production and building new renewable energy production. This also enables flexibility in supply contracts. It also creates options around potential customer contracts and on demand supply of hydrogen.

3.2.3 Management Business Case

The final section of the report sets out the management requirements and discusses the perspectives of all three principal stakeholder participants in the project before evaluating the base case for the Developer. This presents the management business case for the Developer of the Hydrogen Production facilities as well as income generation and businesses opportunities for the Science Museum Group (SMG). This section also looks at the social and environmental benefits of the production of hydrogen and sets out the carbon intensity and savings as well as the planning and regulation and requirements.

This section also set out the considerations around financing of the project, as well as the risks and opportunities associated with the option chosen.

 © Kiwa Ltd 2022

4 Strategic Case

The strategic case was approached in two parts:

- A strategic review of existing published information at the national, regional, and local levels to ascertain the most appropriate concepts which may fit with these strategies and plans. The review also aimed to identify any developments - hydrogen based or otherwise that would have an impact on the viability of hydrogen production at the S+IP site.
- Second a hydrogen workshop was held at the S+IP with Key stakeholders to explore the options that could be considered for the site. The workshop was designed to provide discussion of the options for the site and output the best options that would enable the study to deliver a successful project. The expertise of the stakeholders invited to the workshop was also used to provide further context around how the project would succeed.

The identification and engagement with Hydrogen Stakeholders was undertaken to provide the context and ultimately the requirements of a hydrogen project at the S+IP. This ultimately helped define the economic case for the system modelling and design work to ensure that the system had a focussed concept to work with. This ensured that the best options for what could be achieved at the site were chosen and the best outcome selected. It was therefore vital that this engagement with the stakeholders was undertaken before the modelling and design work. This was done to ensure that the feasibility study had the best chance of success.

The outcome from working with hydrogen stakeholders was the project concept that was subsequently used in the work on System Design and Business Case.

4.1 Strategic Review - Project Context

The proposed hydrogen production facility on the S+IP site is aligned with national, regional, and local priorities. These are presented in this section.

4.1.1 National level – UK Government

UK Government has set fixed and binding targets for greenhouse gas emissions reduction[11]. This was subsequently tightened[12] to net-zero emissions by 2050. The emissions reduction policies set out in the UK government's Clean Growth Strategy[13] (laid before Parliament in October 2017) had two guiding objectives:

- To meet our domestic commitments at the lowest possible net cost to UK taxpayers, consumers, and businesses; and,
- To maximise the social and economic benefits for the UK from this transition.

The Department for Business Energy & Industrial Strategy (BEIS) places transport as one of the largest components of the hydrogen economy in the future and expects hydrogen vehicles, particularly depot-based transport including buses, to constitute the bulk of 2020s hydrogen demand. By 2030, BEIS envisage hydrogen to be in use across a range of transport modes including HGVs, buses, and rail along with early stage uses in commercial shipping and aviation.

11 Climate Change Act 2008
12 The Climate Change Act 2008 (2050Target Amendment) Order 2019
13 The Clean Growth Strategy Leading the way to a low carbon future (April 2018) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

 © Kiwa Ltd 2022

In August 2021, BEIS published its UK Hydrogen Strategy [14] which sets out for the UK **"what needs to happen to enable the production, distribution, storage and use of hydrogen and to secure economic opportunities"**.

The Government has also announced The Net Zero Hydrogen Fund (NZHF) which will support at-scale deployment of low carbon hydrogen production during the 2020s. This fund is being finalised due for completion in 2022 alongside the Hydrogen Business Model and the Low Carbon Hydrogen Standard.

Bus transport

An area of interest for this study is bus transport. To understand national strategy to decarbonising this sector the Government aims to deliver the National Bus Strategy [15] (NBS) which has a vision of a green bus revolution. The delivery for this strategy initiatives have already commenced:

- All-Electric Bus Town or City competition[16] (19 applications were received)
- Zero Emission Bus Regional Areas (ZEBRA) scheme for Local Transport Authorities (LTAs) in England, outside London. (50% Greenhouse gas savings vs Euro VI diesel bus with no combustion engine on board) ZEBRA will provide up to £120 million in 2021/22 to LTAs to deliver 500 zero-emission buses either hydrogen or battery electric, and the infrastructure needed to support them. This represents the start of delivery of the commitment to deploy 4,000 new zero emission buses.
    - Phase 1 of ZEBRA has now closed – 35 EOIs received. The LTAs selected to progress to Phase 2 have been announced and these must now create a business case for investment.
    - A full list of the LTA's who have progressed and information about Phase 2 can be found here [17].

Swindon LTA has been selected from ZEBRA Phase 1 for the standard track[18] and will prepare a Phase 2 business case [19]. As Swindon has already been selected for ZEBRA for electric buses there has been some discussion on whether hydrogen buses are required. Hydrogen fuelling does have the potential to provide greater ranges for buses that are needed for some rural and inter-conurbation routes that can't be covered by electric buses.

These routes can currently be met with buses from the **Ultra Low Emission Bus** (**ULEB)** Scheme (2019-present) which requires 30% better GHG emissions than Euro VI and has Euro VI engine or better. **ULEB certification** [20] **is provided by the Zemo Partnership.** However, this is not the zero emission transport required in the region. **Zero Emission Bus (ZEB)** requires 50% Greenhouse gas savings vs Euro VI diesel bus with no combustion engine on board**.** Accreditation [21] is provided

14https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf
15 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/980227/DfT-Bus-Back-Better-national-bus-strategy-for-England.pdf
16 https://www.gov.uk/government/news/coventry-and-oxford-set-to-be-uks-first-all-electric-bus-cities
17 https://www.gov.uk/government/publications/apply-for-zero-emission-bus-funding
18https://www.gov.uk/government/publications/apply-for-zero-emission-bus-funding
19 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/998855/zebra-scheme-phase-2-business-case-development-guidance.pdf.pdf
20 https://www.zemo.org.uk/work-with-us/buses-coaches/low-emission-buses/ultra-low-emission-bus-scheme.htm
21 https://www.zemo.org.uk/work-with-us/buses-coaches/projects/zero-emission-bus-definition-accreditation-process.htm

 © Kiwa Ltd 2022

by the Zemo Partnership which is working on providing ZEB certification for Electric and for Hydrogen buses. This may provide a demand for hydrogen for buses in the region.

Still to come is setting of a statutory end date for the sale of new diesel buses. A key challenge is the range achievable with an all-electric bus compared to that achievable with a diesel bus.

Heavy Goods Vehicles

Large long-haul HGVs are the most challenging segment of the road sector for developing zero emission options due to their long journey distances. Limitations on the range achievable with battery electric powered vehicles mean that there is a gap for long haul freight decarbonisation. The Government is investing up to £20 million[22] in trials for electric road system and hydrogen fuel cell HGVs and battery electric to establish the feasibility, deliverability, costs, and benefits of these technologies in the UK. With regards to the setting of an end date for the sale of new non-zero emission goods vehicles a consultation has been run[23.] A phased approach was proposed due to the limitations on current non-zero emission technologies.

UK Developments in Heavy Vehicle Refuelling

With regards other aspects of bulk, long distance freight transport decarbonisation there are multi modal Hydrogen transport hubs being planned in the UK such as is planned in The Tees Valley area[24] and in Aberdeen's Hydrogen Hub. As the concept, multimodal transport hubs require refuelling of a diverse range of vehicles at one site, location is therefore key for this model as the production needs to be located close to significant numbers of heavy vehicles for refuelling.

Other models are being developed for delivering hydrogen to heavy goods vehicles in the UK, however long-distance transport of hydrogen from large scale production is often the most widely used route. The low-cost large-scale production of hydrogen often being the main driver for this route and is used for sites not linked to multimodal hubs or dedicated onsite generation. These models are currently limited by the distance the hydrogen needs to be transported which ends up equating to a significant proportion of the hydrogens overall cost.

Hydrogen For Heat

Heat is a particular challenge to decarbonise as its the UKs largest energy demand which is predominantly supplied through the UKs Natural Gas Network. To tackle these emissions since 2012 there have been significant projects underway in the UK investigating repurposing of the gas network for use with Hydrogen Gas. Recent projects such as the Hy4Heat programme in the UK has shown it is technically possible, safe, and convenient to replace natural gas with hydrogen in residential and commercial buildings and gas appliances[25]. The H100 Fife project[26] will be the first project in the UK to demonstrate 100% hydrogen networks used for heating people's homes in a live trial (due to start in 2023). Hydrogen blending is also of interest in the UK as the HyDeploy[27] project has shown that it is feasible to blend up to 20% into gas networks without impact on the

[22] https://www.gov.uk/government/news/road-freight-goes-green-with-20-million-funding-boost
[23] https://www.gov.uk/government/consultations/heavy-goods-vehicles-ending-the-sale-of-new-non-zero-emission-models
[24] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/969468/tees-valley-multi-modal-hydrogen-transport-hub-masterplan.pdf
[25] https://www.hy4heat.info/about-us
[26] https://www.sgn.co.uk/H100Fife
[27] https://hydeploy.co.uk/winlaton/

© Kiwa Ltd 2022

end user. It is likely that these projects will accelerate in the UK with plans for hydrogen village by 2025 and the first hydrogen towns by 2030[28].

4.1.2 Opportunities for Government Funding

BEIS announced in 2021 its high-level Hydrogen Strategy, in which it presented significant commitments to building the hydrogen economy. The timing of the S+IP H2 proposal is opportune.

Emerging BEIS funding pathways

BEIS has also not only increased the overall budget for the UK hydrogen economy to £1bn, but set out new and clearer funding pathways and criteria. In this context, potential grants, and other funding opportunities for the development of green hydrogen production at S+IP are more accessible, should they be called upon by a developer.

For example, the project is well suited (if required) to submit in response to the Request for proposals under Breakthrough Energy Request for Proposals [29]:

Transport Opportunities - Renewable Transport Fuel Obligation (RTFOs)

The project is also well suited (if required) to apply for Certificates, specifically under the 2021 criteria for Renewable fuels non biological origin (RFNBOs)[30]. The Renewable Transport Fuel Obligation (RTFO) is a cornerstone of the UK's environmental policies to combat climate change. The RTFO obligates suppliers of road transport fuels (such as refiners and importers) in excess of 450,000 litres annually to use a certain percentage of sustainable fuels. On the other hand, suppliers of sustainable fuels of any size can get certificates (RTFCs) issued which they can either use to meet their own obligation, or sell on the market. Three options are available to obligated companies for compliance:

- Companies can supply the necessary number of applicable biofuels themselves to the UK market
- Buy-out-option: suppliers can choose not to comply and instead pay a fixed fee per litre for an amount equal to their obligation.
- Suppliers can purchase RTFCs

RTFCs are certificates that can be traded between suppliers of fossil transport fuels, eligible transport fuels and traders. Their price is set by principles of demand and supply, with the buyout price providing an upper limit. Hydrogen is worth 4.58 RTFCs per kg of fuel. The current RTFO buy-out price is 50p/litre of fossil fuel. The most recent update on the price of RTFCs was around 30p which was the maximum previously allowed under the scheme. As of September 2021, the maximum price of these certificates has been raised to 50p to increase support for renewable fuel producers[31]. There is therefore the potential to support a developer of hydrogen production at the S+IP through this scheme resulting in a payment of £1.374 / kg of hydrogen (assuming price of RTFC of 30p) to £2.29 /kg of hydrogen (assuming the maximum certificate price of 50p).

[28] https://www.gov.uk/government/news/uk-government-launches-plan-for-a-world-leading-hydrogen-economy
[29] https://www.breakthroughenergy.org/catalyst-uk-rfp/
[30] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1042787/renewable-transport-fuel-obligation-compliance-guidance.pdf
[31] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1015513/notification-to-parliament-of-a-draft-si-the-rtfo-amendment-order-2021.pdf

 © Kiwa Ltd 2022

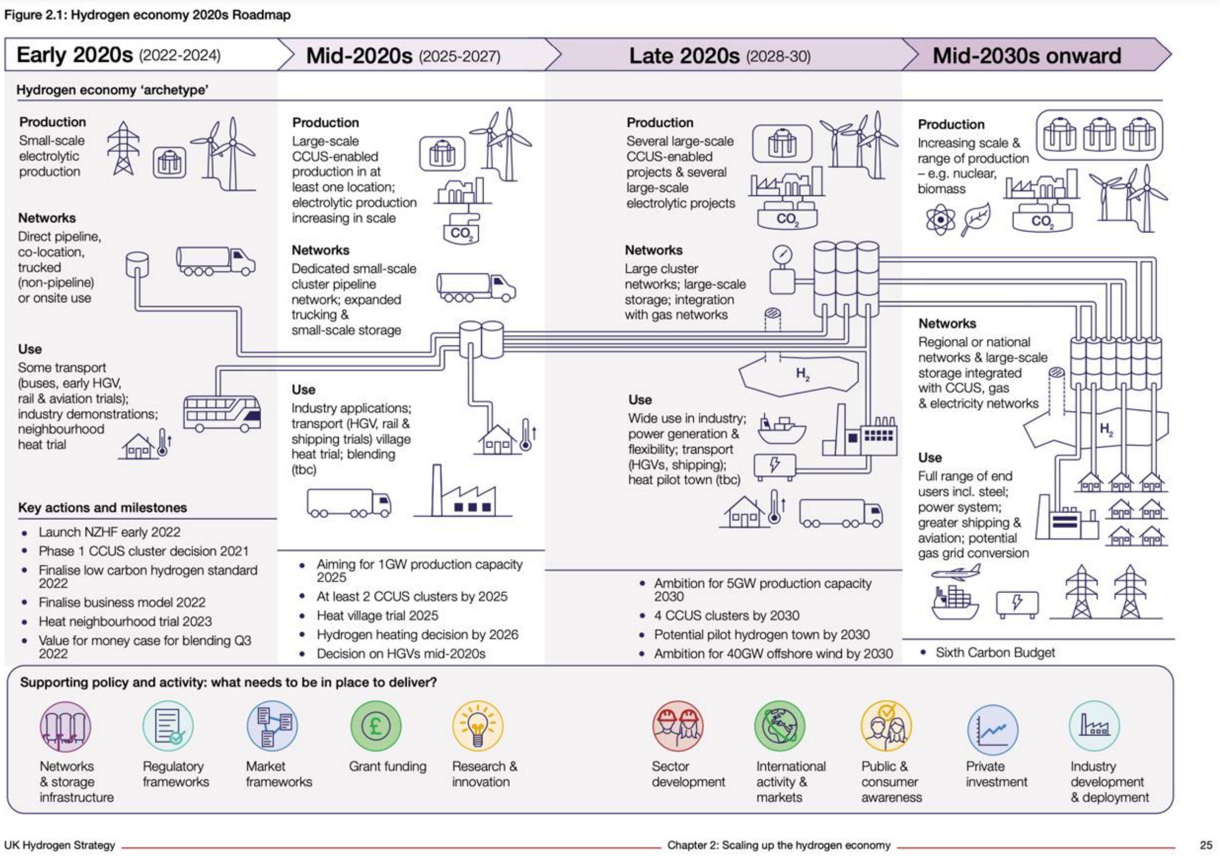


Figure 10: Flow diagram of emerging BEIS funding pathways

4.1.3 Regional level

It is within the overall national policy context that the regional and local authorities must work to deliver their contribution to the overall objectives. This does provide limitations on what can be achieved at regional and local levels as policies set at national level can tend to be 'siloed' so transport policy may focus on only particular aspects. Of particular interest is the Western Gateway, England Economic Heartland, and the Local Industrial Strategy.

Western Gateway

The Western Gateway is a cross border economic partnership between City Regions, Local Authorities, Local Economic Partnerships (LEPs) and the Welsh and UK Governments. It covers the core cities of Bristol and Cardiff stretching across south Wales and western England, from Swindon to Swansea, Wiltshire, and Weston-Super-Mare to Tewkesbury. The focus is inclusive and clean economic growth[32] through better collaboration between regional partners.. There is an opportunity through the Western Gateway as regions develop their hydrogen infrastructure to strategically connect hydrogen infrastructure to provide a fuller refuelling network.

A report produced in March 2021 by Deloite LLP identified that the region lags behind the UK average in terms of economic output and investigated the strengths of the region and its opportunities to improve economic growth.

[32] https://western-gateway.co.uk/

Green energy was identified as a unique strength for the region with access (via existing port infrastructure) to marine and tidal energy as well as emerging hydrogen assets. Coupled with Advanced Manufacturing and Engineering and research strengths (particularly at Swansea and Bristol) the region is said to be in a good position to lead the energy transition and help realise the Net Zero ambitions of both the UK and Welsh Governments.

Net Zero was identified by project partners as one of 3 key priorities for immediate action and they agreed to create a Net Zero Working Group (mid 2021), develop the panel by late 2021 and commission a strategy in 2022.

Swindon lies to the very East of the region and was identified as home to significant cyber cluster as well as research expertise in green energy, specifically hydrogen.

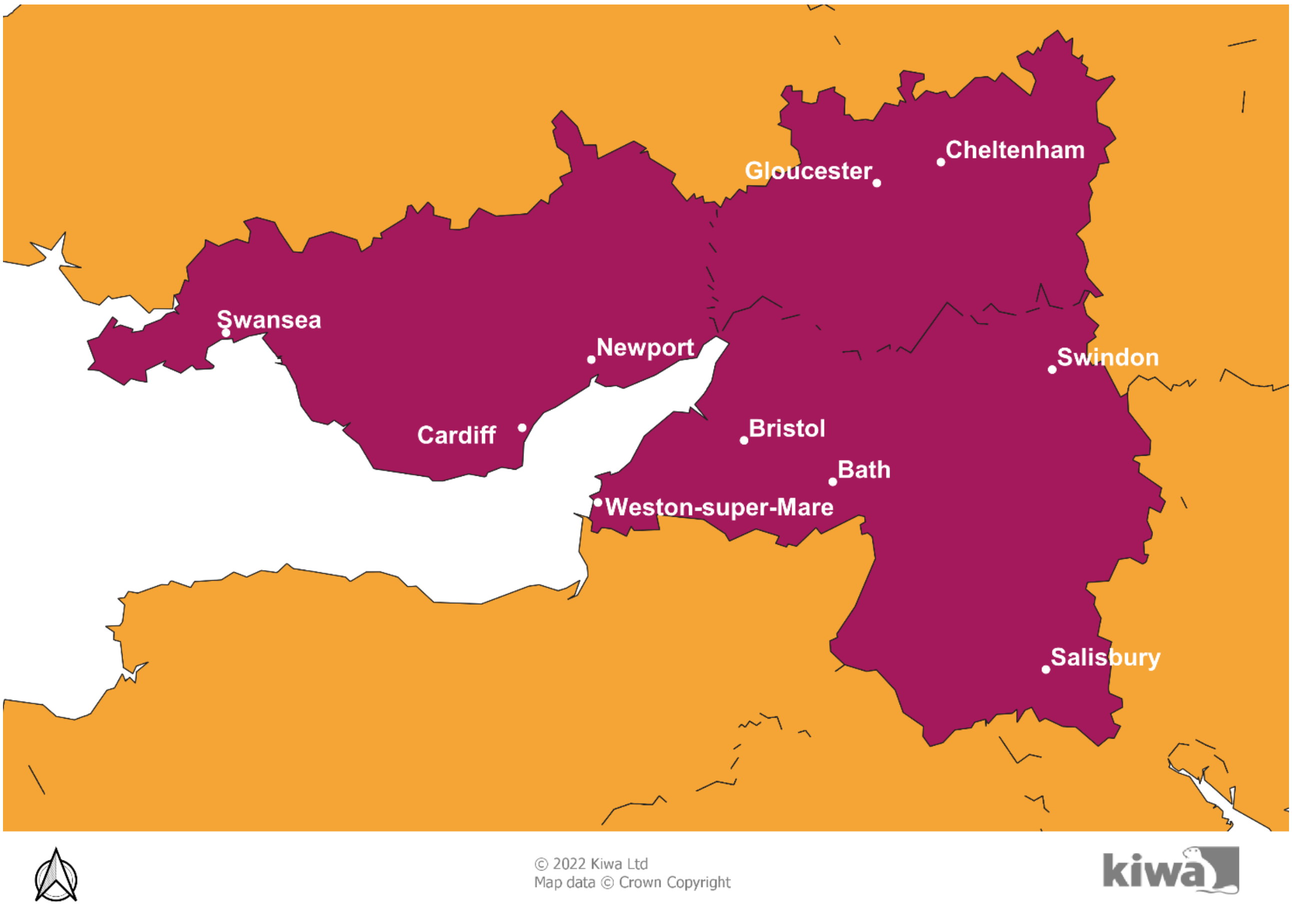


Figure 11: Western Gateway area highlighted purple

Subnational Transport Bodies

The Western Gateway – the Western gateways Strategic Transport Plan 2020-2025 states: There are many benefits to the business community from switching to alternative fuels (such as biodiesel, electricity, and hydrogen). In particular, the increasing cost of diesel, and the volatility of oil prices, means that alternatives are becoming increasingly attractive financially. Additionally, as clean air policies such as vehicle bans continue to increase on the political and public agenda, fleet operators may be forced into adopting less polluting vehicles to enable them to access markets, particularly in city centres.

England Economic Heartland - Swindon is the westernmost tip of England Economic Heartland (EEH) which extends northeast to Cambridgeshire (Figure 12). EEH covers an area which overlaps completely or partially six LEPs. It's a subnational transport body, with its sole focus is transport and as such a key focus is on transport issues with various publications and reports having been produced[33]. In the regional transport strategy[34] under Decarbonizing our Transport System, it is noted that the EEH support the opportunity to deploy at scale new technology such as Vehicle to Grid and Hydrogen Electric Vehicles.

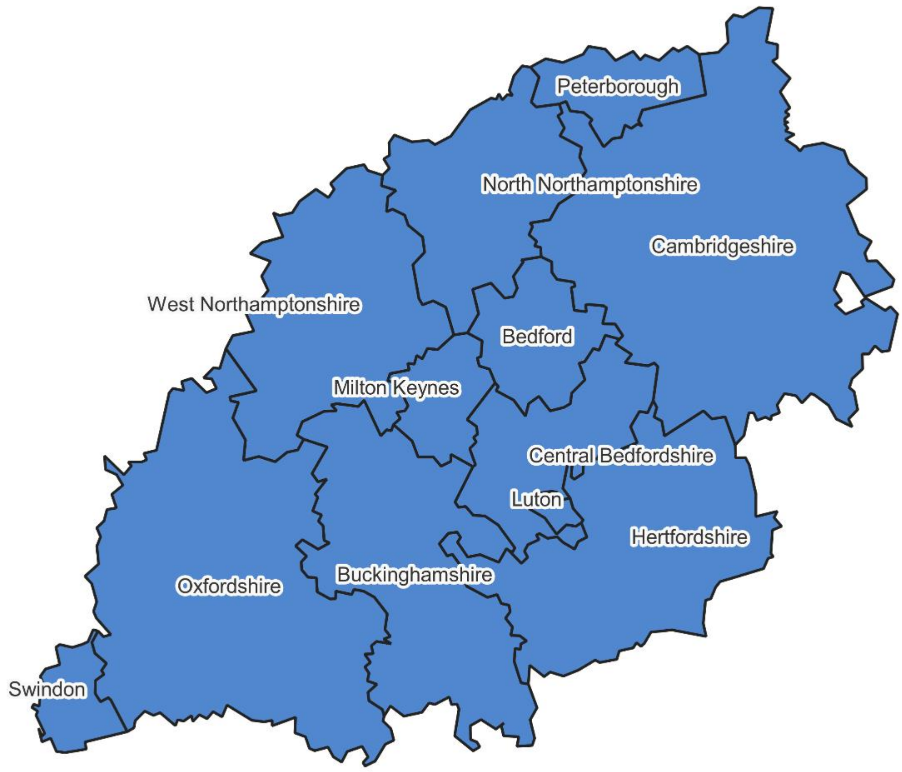


Figure 12 Swindon and England's Economic Heartland

In the regional transport strategy[35] under Decarbonising our Transport System, it is noted:

"Electrification offers a significant opportunity to decarbonise our transport system. We will continue to support the deployment of renewable energy generation in our region and beyond, as well as the opportunity to deploy at scale new technology such as Vehicle to Grid and Hydrogen Electric Vehicles. Delivering the utility infrastructure required to support such initiatives will require partnership to ensure it is achieved at pace and at a scale that achieves economies of scale."

Swindon and Wiltshire Local Enterprise Partnership (SWLEP)

SWLEP has been working in collaboration with four LEPs along the M4 corridor (Thames Valley Berkshire, Oxfordshire, G-First and West of England LEPs) to progress its New Energy Vehicle

---

33 https://www.englandseconomicheartland.com/publications-and-responses/
34 https://eeh-prod-media.s3.amazonaws.com/documents/Connecting_People_Transforming_Journeys_av.pdf
35 https://eeh-prod-media.s3.amazonaws.com/documents/Connecting_People_Transforming_Journeys_av.pdf

 © Kiwa Ltd 2022

Fuelling Infrastructure strategic priority presented in its Local Industrial Strategy (LIS). In 2019, SWLEP commissioned the production of four strategic outline business cases to progress the development and installation of new-energy vehicle fuelling infrastructure along the M4 corridor. In doing so the Swindon and Wiltshire Local Industrial Strategy[36], aims to mobilises hydrogen related priorities previously identified in its Energy Strategy (2018) including: tackling capacity constraints and the lack of affordable access to electricity and exploring further uses for hydrogen, through engagement with Distribution Network Operators, energy companies and the Hydrogen Hub.

Strategic priority 4 in the LIS: Research and innovation opportunities at the Science and Innovation Park

"...the site is being developed into a location where innovation, energy, technology and creative sectors can thrive, collaborate and engage with a wide range of audiences.

The Science Museum Group is currently looking for commercial and institutional partners from a range of sectors including cultural and heritage storage, **renewable energy generation**, **energy storage**, automotive testing, data storage and technology R&D"

Strategic Priority 6 in the LIS: New energy vehicle fueling infrastructure:

"… Extensive business engagement suggests that greater usage of new energy vehicles can also be improved by supporting and incentivising businesses to become early adopters of industrial applications, such as hydrogen-powered forklift trucks, which would help us achieve our critical mass faster."

"… In particular we are investigating a range of potential demonstrator projects to ***stimulate development of the fuelling infrastructure*** so that new energy vehicles are a viable option in both urban and rural areas."

Strategic Priority 10: Rural communities: levelling up opportunities:

"… Furthermore, we will aim to improve road and rail connectivity, as well as encourage greater take-up of new energy vehicles, electric and hydrogen, in an effort to reduce carbon emissions and support our clean growth agenda."

The Strategic Economic Plan published by SWLEP in 2014 identified 3 "Growth Zones" where there are currently clusters of economic activity and capacity for economic growth in the future (Figure 13). The S+IP site falls just within the Swindon M4 zone. The M4 Growth zone has been identified as having the potential to extend growth into the area that has developed out of London through to Reading and Swindon, as well as the potential to draw in investment from the west out of Bristol and Bath. Linking hydrogen infrastructure with these regions may help to extend these investment opportunities. Transport is highlighted as a key area for investment in all three growth zones to improve accessibility in the zones but also to accelerate economic growth through transport investment unlocking employment and housing sites. The SWLEP has stated that it will target investment in the Growth Zones to exploit these advantages.

[36] https://static.swlep.co.uk/swlep/docs/default-source/strategy/industrial-strategy/emerging-lis-v0-1-master-31032020.pdf?sfvrsn=4fe0ce5e_14

 © Kiwa Ltd 2022

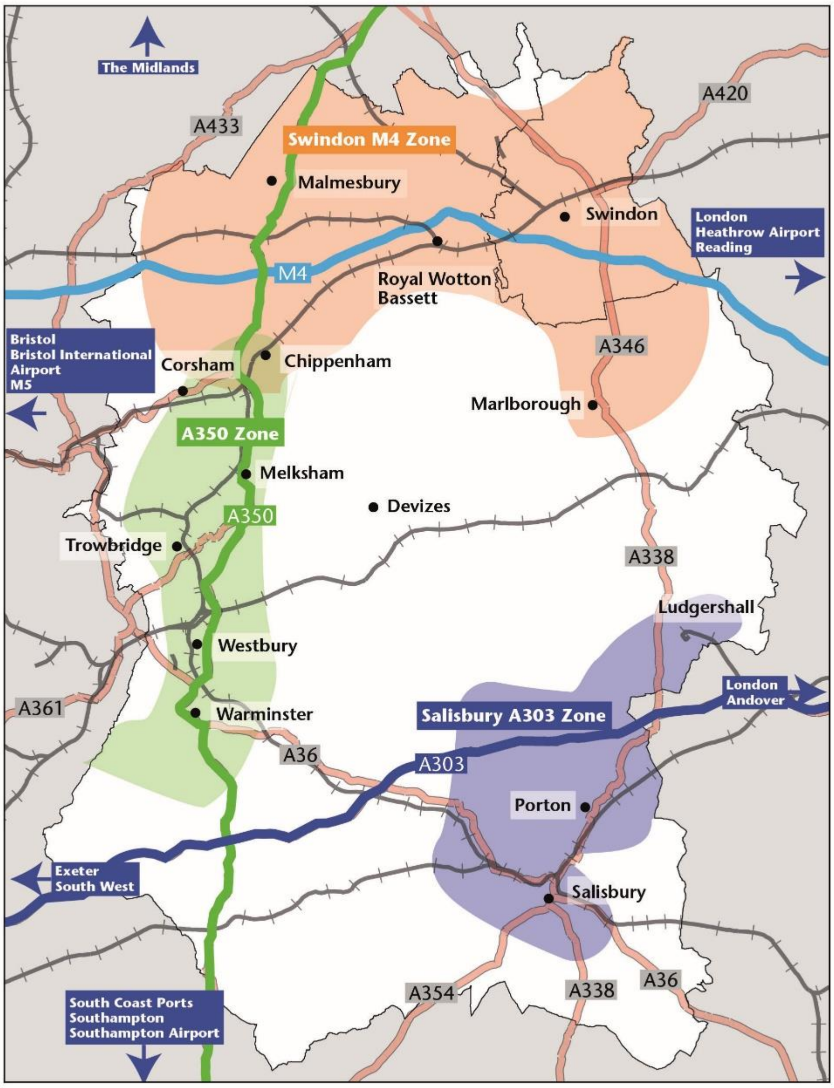


Figure 13 SWLEP and growth zones

4.1.4 Local Level

At the local level the Swindon Borough Council (SBC) plays a big part in strategic planning. SBC's Local Plan and Local Transport Plan stress Swindon's heritage as a transport town. Pioneering transport solutions, hosting major energy and automotive firms – Swindon is a town which should continue to innovate in energy, transport, and mobility. To this extent, producing green hydrogen at S+IP for local and regional use is coherent strategic planning for the Borough.

Swindon Borough Council

The Swindon and Wiltshire area has seen extensive development of PV with numerous arrays installed. The renewables map[37] enables focus on the area and several large, 50 plus MW, solar farms are indicated close to Swindon. One of which is that on the S+IP (50 MW) with others at MOD Lyneham (70 MW) and Corner Copse Solar Farm (50 MW).

37 https://weca.maps.arcgis.com/apps/instant/interactivelegend/index.html?appid=5213f17df5124166a208f377f400f105

Swindon Borough Council (SBC) has used the Low Carbon Local Development Order (LC LDO) route to facilitate developments. Currently there are 27 sites covered by LC LDO3 for solar arrays[38]. LC LDO2 grants planning permission for hydrogen fuel cell and electric car refueling points at all existing petrol filling stations in Swindon Borough. The LDO also grants planning permission for electric car refueling points at identified supermarket car parks in the Borough.

In 2020[39] SBC published their Carbon Reduction Strategy which set outs the ambition of the council to achieve Net zero in its Scope 1 and Scope 2 emissions by 2030. This is significantly earlier than the national target of 2050 however it is in line with what other councils have pledged across the UK. To deliver this ambition 11,823 tCO2e will need to be reduced to zero by the council. These emissions cover gas, electricity, petrol, diesel, gas oil and heating oil. Around 1/4 of the emissions come from fleet operations 1/4 on street lighting with the remaining 1/2 split equally between heating and lighting council property. There is not much detail on how the council will make these carbon savings however SBC notes that note the following key initiatives that have already been delivered:

- Swindon was home to the UK's first commercial hydrogen filling station, delivered in partnership with Honda and BOC.
- S+IP with a capacity of 50 MW is one of the largest ground mount solar parks in the UK.
- Chapel Farm Solar Park was the first solar farm funded by a Council backed community solar bond, winning 2017 APSE award for Best Renewable Energy Initiative.
- Common Farm Solar Park was the first solar farm funded by an ISA-eligible renewable energy bond.

To help it deliver on its carbon reduction targets SBC also notes their engagement with / membership of a range of other organisations in this context:

- SWLEP
- Gas and Electric DNOs
- England's Economic Heartland (see below)
- Association for Public Service Excellence (APSE)
- REGEN
- Inter Authority Climate Emergency Partnership

Swindon Borough Council's (SBC's) planning framework commits to "contributing to carbon reduction targets by achieving a shift towards a more sustainable transport network". Swindon is the center from which bus transportation is provided in the town and further afield. The town's bus station is now located in a former car park in Cheltenham Street. The Swindon Depot is in the Cheyney Manor Industrial Estate (north-west Swindon, SN2 2PN). The two companies operating from Swindon are Stagecoach[40] and Swindonbus[41] part of Go South Coast[42].

Swindon Borough Council's most recent Local Transport Plan (LTP) which was published in 2011 and runs to 2026. As LTPs are statutory documents they show how plans will contribute to meeting

---

38 https://www.swindon.gov.uk/info/20113/local_plan_and_planning_policy/648/local_development_orders/2
39 https://www.swindon.gov.uk/download/downloads/id/7017/swindon_borough_council_carbon_reduction_strategy_2020.pdf
40 https://www.stagecoachbus.com/about/west
41 https://www.swindonbus.co.uk/about
42 https://gosouthcoast.co.uk/our-companies

 © Kiwa Ltd 2022

the Department for Transport's five national goals for transport set out in "Delivering a Sustainable Transport System" (DaSTS) (2008):

- To support national economic competitiveness and growth, by delivering a reliable and efficient transport network.
- To reduce transport's emissions of carbon dioxide and other greenhouse gases, with the desired outcome of tackling climate change.
- To contribute to better safety, security and health and longer life expectancy by reducing the risk of death, injury or illness arising from transport, and by promoting travel modes that are beneficial to health.
- To promote greater equality of opportunity for all citizens, with the desired outcome of achieving a fairer society.
- To improve quality of life for transport users and non-users, and to promote a healthy natural environment.

SBC has a wholly owned subsidiary, Public Power Solutions, which describes itself as offering "innovative solutions for public sector organisations in the areas of Power and Waste". They are based on the site of the local Waste to Energy Facility (Waterside Park, Darby Close, Swindon SN2 2PN[43],.They have had successful projects including:

- A recent announcement relating to injection of biogas into the grid with a small (1%) concentration of hydrogen being permitted by HSL. The biogas plant is at South Marston[44] and is operated by Advanced Biofuel Solutions Limited (ABSL)[45]. It is expected to produce 22GWh or 2.2 million cubic metres of biomethane for grid injection and 6,000 tonnes of carbon dioxide to be liquified for use in industry.
- A battery energy storage system (BESS) the Mannington project storing 35MW/70MWh (2 hours duration) utility-scale, subsidy-free BESS asset in Swindon. The Mannington project site houses fifty 40-ft containers which integrate lithium batteries and will provide up to 75GWh of annual import and export capacity to the National Grid.

43 https://www.publicpowersolutions.co.uk/
44 South Marston Industrial Estate, Stirling Road, Swindon SN3 4DE
45 https://absl.tech/swindon-plant

© Kiwa Ltd 2022

Local Swindon Hydrogen Economy

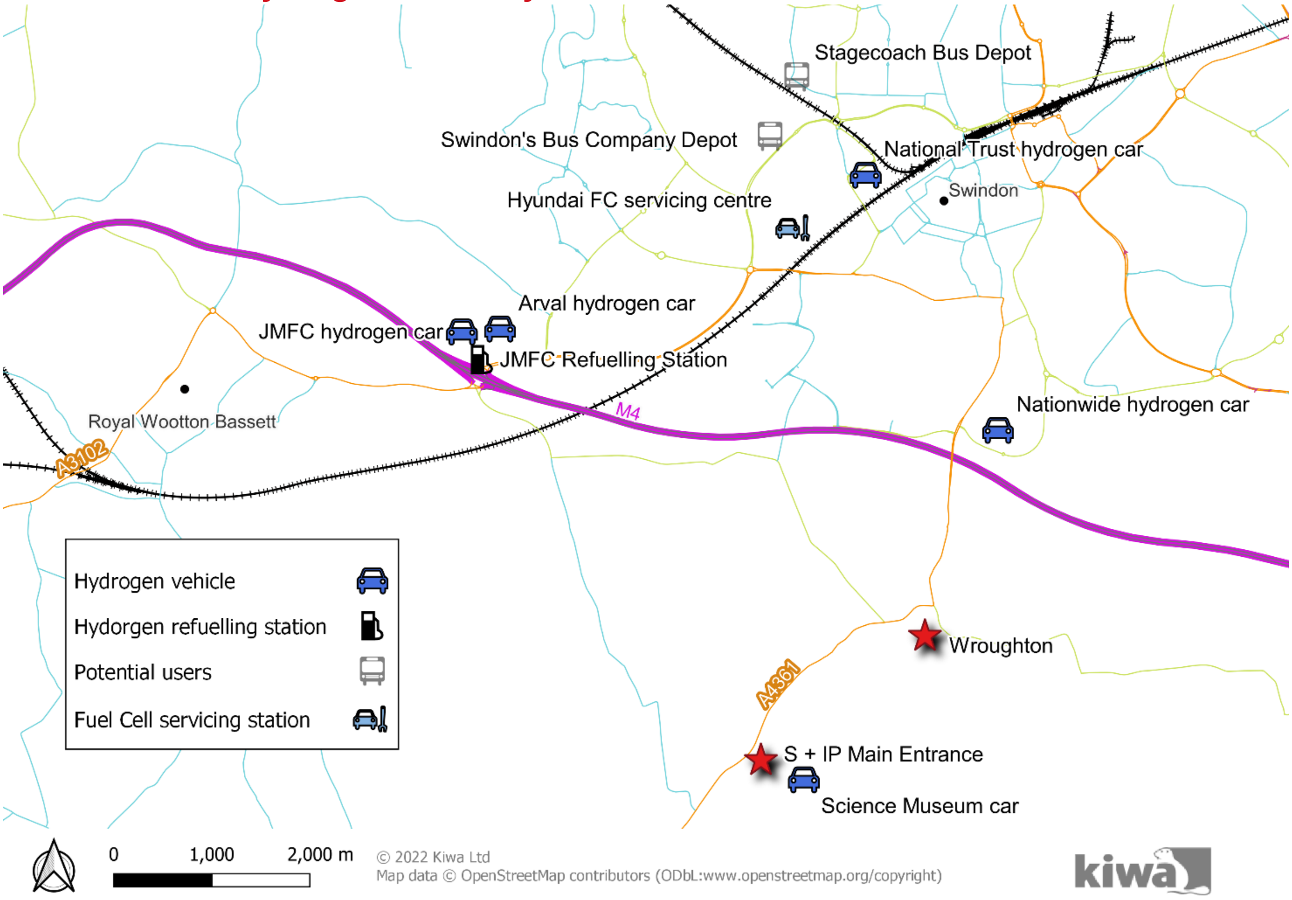


Figure 14: Location of S+IP site in relation to transport infrastructure in Swindon area

Figure 14 shows the location of some of the bus depots in the Swindon area and any other hydrogen infrastructure relevant to this study. Several hydrogen transport operations have developed in and around Swindon most notably some of the hydrogen fleets currently in operation. The map shows the ITM power hydrogen refuelling station at Johnson Matthey in Swindon. Until recently there have been two hydrogen refuelling stations operating in the area. The facility at the Honda manufacturing plant and the ITM power site.

There has been rapid growth in the presence of major warehousing, logistics, supply, and distribution companies on the outskirts of Swindon, and next to the main A419 artery which links the M4 (Swindon) with the M5 (Cheltenham/Gloucester). These companies include Panattoni (which has taken over the former Honda manufacturing plant at South Marston); B&Q and FedEx (which both have regional super-hubs at G-Park), and Amazon (which has recently opened a very large distribution hub South of the White Hart A419/A420 interchange). These developments have been located alongside the HGV routes in the region (Figure 15).

 © Kiwa Ltd 2022

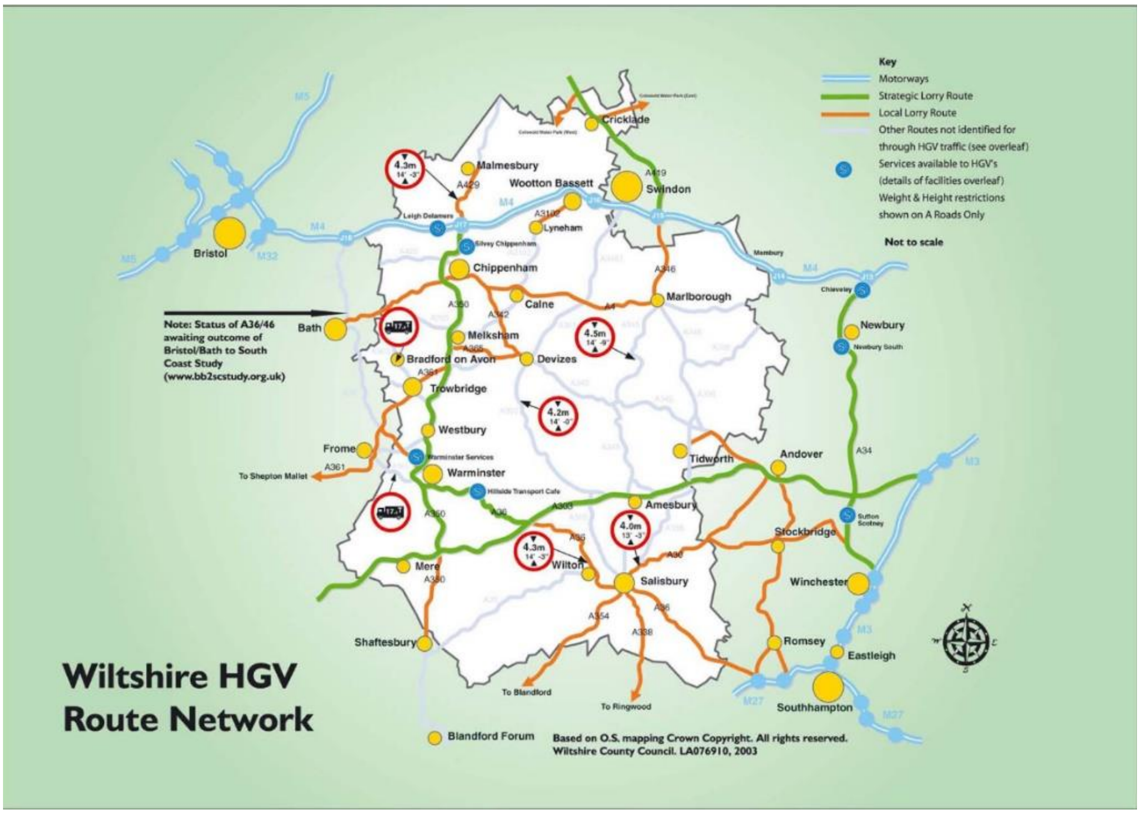


Figure 15 Wiltshire HGV Route network advised routes

Science Museum Group's Science and Innovation Park, Wroughton

Owned by the Science Museum Group (SMG), the S+IP comprises of large hangars and buildings supporting the collection of the SMG, and is used for technology and engineering research, automotive testing, and renewable energy generation alongside collections storage. The renewable energy generation is significant with on-site renewable energy generation of 50MW of solar. The collection contains many of the firsts of hydrogen production and use as part of the historic artefacts housed at the site and SMG strong commitment to sustainability has led to the use of hydrogen fuel cell vehicles at the site since 2017, along with other zero-emission electric vehicles.

The 545-acre site (Figure 1) is 5-miles south of Swindon and junction 16 of the M4, accessed by the A4361. This is the only main road that passes close to the site. This road connects to the M4 at junction 16 but requires vehicles to pass through the village of Wroughton. This means that although hydrogen produced at the site is well located for supply into Swindon and surrounding area, it is not well located for onsite vehicle refueling serving motorway users. Figure 1 shows the location for the solar arrays which take up the southern part if the site. Development plans to expand the buildings housing the collection are underway including a new 26,000 m^2 collections management facility - Building ONE - at the centre of the site can be seen. This collection will be open to visitors from the spring of 2024.

There is currently no hydrogen production at the site.

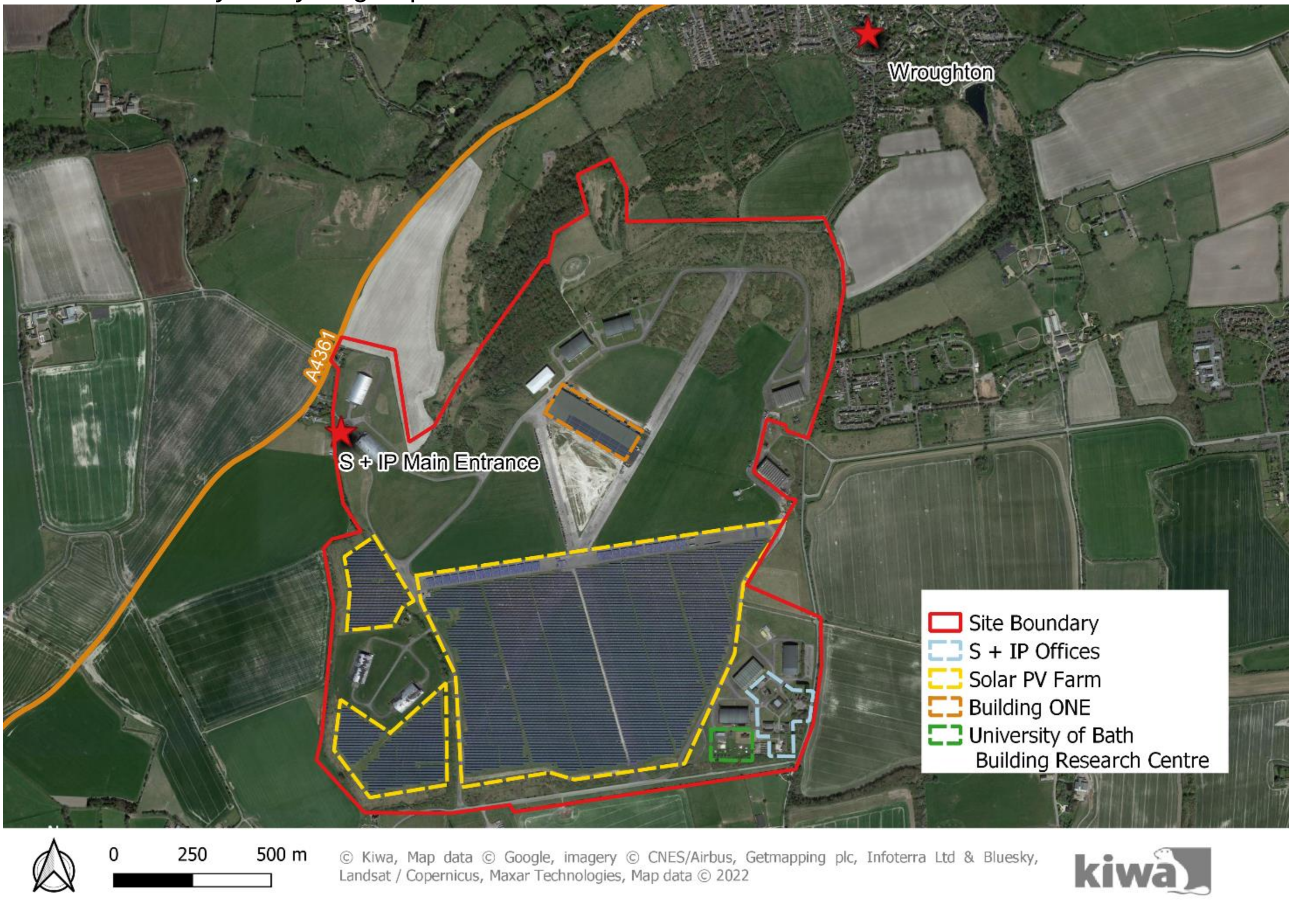


Figure 16: S+IP site showing current activities and layout

4.2 Stakeholder Engagement Workshop

In the first weeks of the project, a provisional review of potential green hydrogen use was carried out and combined with the first stages of a market and demand Assessment. This early analysis was used to identify potential green hydrogen uses, users and local/regional stakeholders critical to project success. To maximise impact and accelerate the formulation of feasible concepts, a two-day workshop at S+IP was scheduled, and key stakeholders invited (a full list of participants is included in Appendix B).

4.2.1 Purpose

Engage key stakeholders and industry experts from both public and private sectors, and from Swindon and the wider Swindon and Wiltshire LEP area:

- Brief and inform key stakeholders on the overall scope and deliverables of the S+IP Green Hydrogen Feasibility Study.
- Capture insight, challenge, and expertise from stakeholders efficiently (given the compressed timescales of the project) and enable exchange and development of input and ideas.
- Through expert facilitation, develop and discuss ideas around: a) opportunities and risks, and b) aspects of sustainability and commercialisation and – from that base – formulate coherent green hydrogen concepts as a basis for recommendation.

4.2.2 Methodology

The workshop was facilitated by BOLD Innovation, an agency PHC has worked with on previous occasions. BOLD used a structured, modular, and consultative approach previously deployed extensively in guiding new and innovative energy projects from conceptualisation to implementation.

- Insights and experience from the South Wales Hydrogen Centre and the Teesside Transport Hub were presented and incorporated into the working sessions.
- The" building blocks" of the S+IP project were presented, including considerations and options around the production and usage of 'green' hydrogen from water, using renewable energy.
- Given the uncertainty and difficulty of securing Government Grant funding, the workshop considered how green hydrogen production at S+IP could potentially be commercially viable, both a) for a developer to obtain financing and b) to generate revenue for the Science Museum Group (SMG).

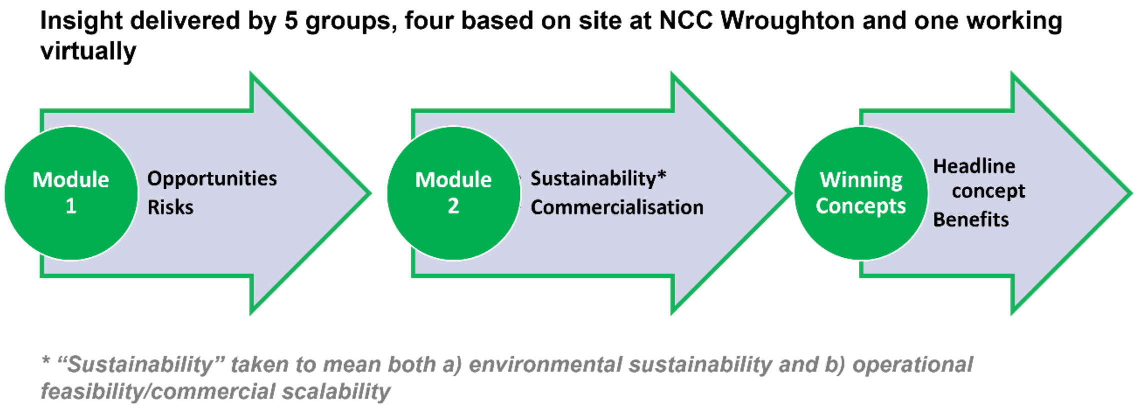


Figure 17: Process for developing the key project concepts.

4.3 Outcomes: Summary Workshop Recommendations

The outcomes detailed below are the distilled output of participating groups at the workshop. The recommendations listed (including specific opportunities, risks, sustainability, and commerciality evaluations) are extensively covered in other sections of this report.

Full and detailed workshop output from the group work is attached in Appendix B.

SOUTH WEST ENERGY HUB

kiwa

1.1.1 Production of Green Hydrogen at S+IP

Concept

Maximise use of the solar farm already in place at the S+IP, using it alongside other new renewable sources to produce green hydrogen on site. Support local and regional public and private sector operations in their transition to net zero and build on S+IP's pioneering role in renewables in the region.

Opportunities

- Possible option to bring electrolysers from a) hydrogen refuelling site at Honda (South Marston), which is decommissioned, and b) ITM facility at Johnson Matthey's site at Royal Wootton Bassett (M4 Jct. 16).
- Potentially enables development of a network of green hydrogen production sites across the Southwest region, in line with the strategic plans of the Western Gateway and Bristol Consortium.
- Supports Swindon Borough Council (SBC) in meeting the environmental and community commitments in both its Local Plan and Local Transport Plan (LTP3).
- Opportunity to capture supply contracts with Swindon's two bus service operators as "early adopters"
- Re-power the S+IP solar farm with newer technology > to increase capacity and achieve greater scalability
- Support time-shifting of electricity production (see Supply of Electricity to the Grid)

Potential Risks

- Might not be feasible to renegotiate contracts with operator of solar farm, so need to build new renewables. Planning constraints on type of new build renewables.
- Low/seasonally unpredictable supply from solar farm if no other renewable types added.
- Local sensitivity to transport operations into/out of S+IP site.
- Wholesale market for hydrogen moves to "long" as manufacturing develops at scale and depresses market prices

Sustainability

- **Circularity:** S+IP's ambition is to use own energy to power its vehicles and heat its buildings, becoming a net zero operator in its own right
- **Market growth:** all forecasts suggest that the hydrogen economy will grow, thus creating stable and growing demand

Commerciality

- Capable of attracting funding from: the Net Zero Hydrogen Fund; the Public Sector Decarbonisation Fund, the Renewable Fuel (Non-Biological) Obligation (RFNBO) certificates for new renewables, and from new BEIS funding sources
- Secure green hydrogen supply contracts with local municipal fleets (buses and local services)
- Supply hydrogen wholesale to market distributors (Air Liquide, BOC, and smaller players)

© Kiwa Ltd 2022

4.3.1 Supply to Transport Sectors

Concept

Supply S+IP green hydrogen to local public transport operators and to transit commercial road transport traffic using the M4 corridor. Leverage partnership with Local Authority (SBC) and other agencies to encourage uptake of hydrogen among public service fleets.

Opportunities

- Working with Swindon Borough Council, secure contracts with Swindon's Bus Company and Stagecoach West to convert a proportion of their fleets to H2 operation. Grow that proportion over time in line with SBC's Local Transport Plan and Environmental Plan.
- Identify commercial transport and logistics firms either a) based in Swindon or b) operating along the M4 corridor who have high public profile and brand equity/sustainability commitments: encourage those companies to test and pilot hydrogen operation at S+IP /using S+IP -produced transport-grade fuel
- Build a two-sided refuelling station at the entrance to S+IP: on the S+IP side, this would be used to supply "resident" companies involved in research and testing, plus S+IP's own vehicles. On the "public-facing" side, it would be used to supply early hydrogen adopters from various transport sectors (see Demand Profile in section 5.3)
- Supply S+IP hydrogen by tanker off-site to local/regional transport refuelling locations (bus depots/M4 services/Swindon Truckstop/A419 services)
- Opportunity to spearhead the development of a network of hydrogen refuelling stations serving the UK's commercial transport sector

Potential Risks

- Hydrogen as a transport fuel is in its infancy: future demand is unpredictable, and many variables and dependencies are in play
- Bus companies are early adopters, but are evaluating a) funding pathways and b) relative operating efficiencies and cost-effectiveness of battery electric and hydrogen fuel cell fleets. Hydrogen buses offer significant benefits but require higher up-front investment than battery electric vehicles (see Appendix C). If there are significant Capex constraints/lower levels of funding support, the Local Authority may be persuaded to migrate predominantly to BEV
- While major energy firms (Shell, BP and Total) have announced plans to develop hydrogen propositions for the commercial transport sector, transition from diesel/LNG to hydrogen remains embryonic. Private operators of diesel HGV fleets in the "general haulage" segment will not convert until regulation forces them to do so
- Commercial road transport (CRT) in the UK is a national business – with most goods being moved between the UK's industrial hubs. While the mid M4 corridor is a CRT refuelling node, unless a UK-wide network of hydrogen supply points on similar transport" golden routes" is built in parallel, supply opportunity to a refuelling site supplied from S+IP will be confined to fleets operating in a local/regional radius (<100kms)

Sustainability

- Public sector transport is committed to decarbonisation, and the case for hydrogen as a fuel for heavy municipal vehicles and buses is a clear one (see Appendix C). Hydrogen is not a "step on the journey" as a fuel for buses: it is a destination fuel: contract volumes should be long term

 © Kiwa Ltd 2022

- Industry forecasts suggest that inland goods freight will remain road based over a 20-year period, maintaining moderate (0.5-1.0%) year-on-year growth, as a result the overall energy market for commercial transport will grow in line
- Most forecasts plot CRT's decarbonisation journey not as an electrification roadmap, but as a transition from diesel towards liquefied and compressed gases. As truck manufacturing, conversion funding and hydrogen infrastructure develop, hydrogen will become the default fuel for heavy goods vehicles
- The mid M4 corridor between London and S Wales, with its A34/M3 (Southampton/Portsmouth) and A419/A417 (Gloucester/M5) tributaries, will remain a vital refuelling node for commercial road traffic

Commerciality

- Bus companies will be the first fleets to convert to hydrogen, and contracts with them are likely to hold the early commercial promise for a developer
- Fuel economy/efficiency and range potential of hydrogen contribute to a strong business case for use in trucks
- Truck conversion is largely reliant on 3rd party and grant-based funding

 © Kiwa Ltd 2022

4.3.2 Supply of Electricity to the Grid

Concept

- The workshop discussed the S+IP vision to have more long-term contracts for renewable electricity, covering the whole Science Museum Group electricity use. The current contracts are mainly onsite sleeving for their own sites; the solar park is deliberately oversized to allow this.

Opportunities

- There is a commercial opportunity for value adding, ‘time shifting’ of energy i.e., both importing from, and exporting electricity to the Grid. S+IP have commissioned separate work around optimisation of onsite electricity production and usage for the site, but an important link was identified with this hydrogen production and storage feasibility study work. Practically this means either a) installing additional hydrogen storage bullet(s) from the outset to store more hydrogen (to be able to meet the long-term hydrogen transport fuel contracts) and to be able to ‘divert’ some renewable electricity from hydrogen production to the electricity Grid- in order to take this opportunity from the outset, or b) space and position the hydrogen storage to allow for additional hydrogen storage bullets to be added to exploit this opportunity later.

Potential Risks

- The risk of additional investment to take advantage of this opportunity from the outset is that rather than an opportunity, some Developers might see providing support to the Grid as an added complexity and thus risk. Mitigate by building space for additional storage (option b).

Sustainability

- There is expected to be a long-term need for balancing of the electrical grid, and thus such an opportunity could be long term sustainable from this location in the South of England.

Commerciality

- The commerciality of building such ‘mismatch’ between the storage requirements to meet transport fuel contracts and building extra hydrogen storage to supply renewable electricity to the Grid can be explored by the developer who takes the project forward

© Kiwa Ltd 2022

4.3.3 Green Hydrogen for Heating

Concept

Use hydrogen for heating demands or use waste heat from the electrolysis process for (substantial) S+IP onsite heating and dehumidification requirements.

Opportunities

- Burning high-grade hydrogen for heat may have small applications, potentially to demonstrate hydrogen for heat onsite and in nearby housing.
- Could also supply hydrogen for heat to local estates and schools, and/or build a community heating scheme.
- A break-even hydrogen for heating project based on saved carbon and the Green Book price assumptions for carbon price may be attractive from the perspective of local government.

Potential Risks

- Using hydrogen for combustion would, on a 'normal' market basis, require very low costs to be competitive with natural gas (and with heat pump technology?)
- Overall local demand for hydrogen is unknown; it would need to be incentivised/created.
- Hydrogen production during winter periods (when there will be the highest hydrogen demand for heat) would be heavily constrained by low seasonal solar output- in the absence of other sources of clean electricity for hydrogen production.

Sustainability

- Opportunity for S+IP to meet its "circularity" aims, meeting its energy demands with its own energy (see also 3.5.1 **Sustainability**)

Commerciality

- Use of waste heat for S+IP building heating and dehumidification generates savings for S+IP buildings and nearby housing
- Associated revenue streams available as S+IP will be able to demonstrate energy re-use/circularity as part of its Skills & Education package (see 3.5.6)

 © Kiwa Ltd 2022

4.3.4 Green Hydrogen Science & Innovation Park

Concept

Hydrogen research and innovation hub, with S+IP operating as a cutting-edge science park for public- and private-sector hydrogen R&D activity.

Opportunities

- A hydrogen "science park" or innovation centre as a basis for work in numerous sectors across the hydrogen economy: construction, contract logistics, bus, rail, mail, household heating and appliances
- Builds on existing technical knowledge in the area and encourages multi-stakeholder cooperation
- Enables SMG to encourage SMEs developing new electrolyser technologies to establish bases at the site, making use of facilities and storage available to help with both testing and commercialisation
- SMEs developing new fuel-cell technologies encouraged to establish research bases at the site
- Opportunity for university hydrogen research teams to be based at S+IP (universities have budgets for hydrogen research and are looking to place them)
- Development and hosting of commercially marketable green hydrogen skills, training, and education packages at the hub. Operational and technical capability for the storage, handling and transport of hydrogen is scarce, and industry bodies view the development and certification of such skills as critical to the growth of the hydrogen economy. Commercial organisations invest heavily I in technical and operational training.
- In line with the innovation associated with S+IP, various new renewable technologies could be considered within the hydrogen production plans. Potential opportunity for innovative renewable energy pilots and scale-ups to be carried out at S+IP (e.g., bladeless wind turbines or the Norwegian kinetic energy innovation- Ki-tech https://www.ki-tech.global)
- Demonstrate hybrid energy models "in action"

Potential Risks

- Funding (private and public sector) for hydrogen research and innovation does not come onstream, reducing innovation activity
- Battery technology and cost improves faster than expected: buses and trucks move decisively towards battery-electric operation, limiting the use of hydrogen in transport and stopping the development of H2 refuelling infrastructure/network

Sustainability

- Outlook for both private and public sector funding is strong given BEIS commitments to rapid expansion of the hydrogen economy
- Activities across the Science & Innovation Park will be undertaken by players from multiple sectors, thus dispersing both growth opportunity and risk

Commerciality

- A hub for public and private sector seed funding
- Revenue generation from commercial sponsors and corporate partners

 © Kiwa Ltd 2022

- Potential to attract investment, funding & commercial interest across the South West region, the country, and the rest of the world
- Revenue from the hosting and provision of green energy/green hydrogen training packages and associated certification.
- A magnet for SMEs to base hydrogen innovation

4.4 Other opportunities

- SMG could collect royalties from additional hydrogen production: 'merchant'- short term contracts or speculative sales of hydrogen above long term contracted hydrogen volumes. This income would be incremental to land rents from the hydrogen Developer.
- SMG to reduce energy costs in multiple ways: through capture & direct use of waste heat from the electrolyser; by using 'at cost' hydrogen from developer for on-site cars, forklifts, and for a future own-branded S+IP shuttle bus
- S+IP to make commercial use of the oxygen bi-product (e.g., local sewage treatment, sell to local CGT to reduce levels of nitrous oxides) [46]
- S+IP to provide agricultural jobs in hydroponic or wall-based farming, using waste heat and part of oxygen bi-product[26]
- Dale Vince, the South West regional "green" entrepreneur who owns Ecotricity, Forest Green Rovers FC and Sky Diamond, is to establish a new "Eco Park" at junction 3 of the M5 motorway (Stroud/Dursley). This will contribute significantly to the SW region's green infrastructure, and is a potential source of collaboration

4.5 Local Authority Workshop Follow-up

After the workshop, Councillor Sumner organised a project briefing session of relevant Swindon Borough Council (SBC) officers. Those involved in the briefing session were:

- SBC Deputy Leader & Manager - Planning, Infrastructure &
- SBC Planning Manager
- SBC Service Manager, Passenger Transport
- SBC Economic Development Officer

As a result of the briefing, SBC officers confirmed (without prejudice) the following:

- That the workshop concepts and recommendations are aligned with both the SBC Local Plan and Local Transport Plan (LTP3), and support SBC in achieving some of the plans' objectives
- That there are no planning concerns arising from the concepts and recommendations which cause immediate concern or are misaligned with the Local Plan or Local Transport Plan
- That SBC officers are willing to support the project team in facilitating negotiations with the following key stakeholders:
- The two buses companies operating routes within Swindon, and to and from its neighbouring villages and towns (Stagecoach West and Swindon's Bus Company), concerning the potential conversion of vehicles to hydrogen operation and use of the S+IP for testing

---

- [46] https://hortamericas.com/blog/news/dissolved-oxygen-improves-plant-growth-reduces-crop-time

 © Kiwa Ltd 2022

- the logistics, warehousing, and distribution companies with major regional hubs a on the A419 bypass (Amazon, FedEx, B&Q, Panattoni), concerning hydrogen research, testing and potential sponsorship opportunities at the S+IP.

Project Alignment with SBC's LP and LTP3

In the follow-up consultation to the Feasibility Study Workshop, SBC's officers responsible for Economic Development, Public Transport, Planning and Infrastructure and councillors were supportive of the feasibility study at S+IP and confirmed in principle that the proposed development of green hydrogen production and supply at S+IP as "completely aligned with the Local Plan".

Swindon's population will rise from ca 180,000 to ca 220,000 with completion of the ongoing expansion projects in Wichelstowe, Tadpole Village and the "Eastern Villages". This will present considerable challenges for both public transport and road traffic management, and present barriers to achieving more sustainable transport in the town. Building green hydrogen operation of local bus fleets into its transport planning (if powers allow/bus operators agree), SBC could find hydrogen from S&IP one compelling answer in meeting those challenges.

3.6 Recommendations Taken Forward

The outcomes of the workshop were a series of recommendations to be taken forward into the feasibility study. This focussed on five areas with three outcomes taken through to the design phase of the feasibility study, see below:

- Production of Green Hydrogen at S+IP
- Supply to Transport Sectors
- Green Hydrogen Science & Innovation Park

Electricity production and hydrogen for heat have not been taken forward into the design stage. These opportunities have not discounted and may be exploited by a developer if it is commercially viable. There are however challenges around how this could be implemented at the S+IP. For electricity generation it is not clear if the additional storage and generation equipment could be viable at the site due to the capital cost of equipment, efficiencies, and complexities with how this might be operated. Hydrogen for heat has been limited due to the price required for heat energy. Even with recent increases in gas prices hydrogen is unlikely to be competitive with other technologies.

 © Kiwa Ltd 2022

5 Economic Case - Hydrogen Markets

Despite the embryonic nature of the UK's industrial and transport hydrogen markets, market leaders in liquefied and compressed gases – BOC and Air Liquide – confirm that market supply and demand are in imbalance. The UK is short on low carbon hydrogen supply and expected to remain so in the short term, and throughout the 2022-2027 period of this study's demand forecast (shown later in this section). A developer constructing and operating a green hydrogen production plant will find direct supply to transport sectors grows steadily from a low base (see below): however, there will be robust demand in wholesale markets as current suppliers continue to seek incremental supply sources

Growing demand for hydrogen as a net zero transport fuel underpins the market and demand evaluations of each segment of this study. However, demand drivers in each transport segment differ widely, resulting in vastly different segment-by-segment growth projections, and key dependencies (public sector contracts, wholesale demand, migration of pilot partners to full scale hydrogen operators).

5.1 Public Transport: status of technology

Fuelled by clean hydrogen, the use of Fuel Cell Electric Buses (FCEBs) for public transport has been demonstrated and major trials have been conducted in Aberdeen, and in multiple cities across the EU. These trials have provided real data on the performance of FCEBs. Future trials are planned in the UK, including one in Birmingham. Swindon LTA has been selected from ZEBRA Phase 1 for the standard track.

FCEBs have been shown to have:

- Operating, single fuelling ranges that are similar to that of a diesel bus - over 350-415 km.
- Refuelling times typically of less than 10 minutes, usually accommodating a refuelling frequency of more than 5 vehicles per hour. The 10 minutes compares to 4-6 hours recharge time for battery-electric operation.
- Fuel efficiency of 9.9kg/100km (equivalent to 30 litres of diesel/100 km) – 26% more efficient than an equivalent diesel bus (40.9 litres of diesel/100 km on average)
- CO2 emissions reduction of 85% compared to diesel buses over the bus life-cycle when the hydrogen fuel is produced, as at S+IP, from renewable energy sources
- Whilst issues surrounding the unreliability of the technology affected the availability of earlier FCEBs, they have now been shown to have an availability of 89%
- 98% availability of FCEB refuelling stations
- The hydrogen tank and drivetrain combination do not negatively impact on bus design and passenger experience (which bulky batteries do in equivalent EV buses).

More information on trials of FCEBs can be found in Appendix D.

5.1.1 Local bus operations and hydrogen demand

Two bus operators operate in Swindon's urban area and the surrounding villages: Stagecoach West (focused on the suburban and rural routes, and on longer range services to Oxford, Reading, Chippenham, and Cheltenham) and Swindon's Bus Company (whose routes typically serve the town itself).

Swindon's urban configuration, with the mainline railway dissecting the town and numerous low railway bridges characterising the town, make some urban routes unsuitable for conversion to battery electric operation- due to the increased height of a BEV bus. Growth and conversion assumptions in the demand model reflect this.

5.1.2 Commercial road transport and hydrogen demand

The commercial transport sector is decarbonising, but private sector general haulage will move only at the pace of regulatory frameworks. Battery technology and weight/size, component availability, operating ranges and recharging times all suggest that a move to Battery Electric Vehicle operation is on a 20-year horizon, if it happens at all. Perceived non-viability of battery-electric solutions will drive the hydrogen opportunity in Commercial Road Transport.

Most previous analysis suggested that much of commercial road freight could decarbonise through stages: biodiesel to liquefied and compressed natural gas in internal combustion engines towards a destination fuel of hydrogen in FCEVs. Solid national and international infrastructure, product availability, price parity and operational readiness are all significant factors in moderating the pace of change in the whole segment. However in segments where the pace has been increased for example in certain commercial transport segments – where public visibility and brand perception are high priorities – decarbonisation is likely to move faster and move to hydrogen sooner. These segments are:

- Parcels and logistics (e.g. FedEx/DHL/Amazon/UPS)
- Branded fast mover consumer goods (FMCG) (e.g. John Lewis/M&S/IKEA)

Demand projections in this study are therefore focused on supply to operators in the above segments.

5.2 Markets and growth

The markets considered in the context of electrolytic hydrogen production on the S+IP site are transport related uses.

Swindon Rail works closed in 1986 and currently no Light Maintenance Depot for rail is in the Swindon area so provision of hydrogen for fuelling rail units of locomotives is not a possibility.

Public Transport	**Initial conversion of vehicles in bus fleets (see demand projection)**	**Wider adoption across bus fleets.**
Commercial Road Transport* **	Initial testing and piloting by local logistics and LMD firms	Supply to local truck stops for growing CRT demand; possible supply to own depots
Emergency Services	Potential hydrogen pilots, especially for heavier vehicles	Limited rollout

NOTES: In this context:
‡ Includes all types of road transport: private cars, taxis/minicabs, buses, etc.
** service includes such activities as waste collection, school transport, local minibuses
*** CRT is transport of goods at all scales (HGVs, LGVs, etc.) including ‘final mile’ delivery by couriers

5.3 Demand Forecast

5.3.1 Hydrogen for Transport Demand: Buses

Operated under local authority contracts and with access to established funding pathways, municipal and suburban bus operations will be the first and fastest transport segments to move away from diesel. Complete replacement of diesel fleets by BEV and hydrogen buses is anticipated by the DfT Zero Emission Bus Regional Areas (ZEBRA) scheme by the relatively early date of 2027.

Operators are studying the comparative economics and operating benefits of battery-electric vehicles (BEVs) versus hydrogen fuel cell electric vehicles (FCEVs). There is a current difference of 35-40% in vehicle replacement cost in favour of battery-electric, which has encouraged the early adoption of BEV over hydrogen FCEVs.

However, in-depth interviews with UK bus companies who have a) already migrated away from diesel operation and b) have operational experience of both BEV and hydrogen FCEV fleets underline the following factors which support a projection of growth for hydrogen in bus fleets (detailed notes on these consultations are attached in the appendices):

- Hydrogen is far better suited to suburban and rural route patterns than BEV, given battery range and overall economy calculations
- Bus battery recharge times are in the range of 6-8 hours, meaning entire bus fleets would have to be charged overnight, implying considerable space requirements for recharging bays.
- Current battery size invades the bus cabin and decreases the maximum number of passengers a bus can carry
- Bus OEMs have vertically integrated into the parts market, constricting choice of parts suppliers, and driving up parts costs
- Bus cabin heating in winter and cooling in summer significantly drains a battery and decreases range by up to 40%

BEV buses are further along the product maturity lifecycle than hydrogen fuel cell alternatives (FCEVs). As such, production economies of scale have already been captured and, while battery cost and size are likely to decrease over the 5 years from 2022, the difference between the replacement vehicle cost for BEV ca. £240k and the replacement cost for hydrogen fuel cell (FCEV) ca. £325k will close and sharpen the business case for hydrogen bus operation.

Buses in the Swindon area cover on average 225-275 km per day. Trials have shown that hydrogen fuel cell buses can achieve consumption figures of 10 kg hydrogen per 100km (exact fuel requirement will vary with the type of bus, the distance travelled, the way it is driven, its loading and the number of stops along its route etc). This equates to a daily requirement of ca 25kg hydrogen per bus per day (or a daily bus energy demand of some 500kWh per day). An assumed 25kg/bus/day is therefore built into the demand forecast.

5.3.2 Demand: Trucks

The hydrogen economy for trucks is estimated to grow substantially from 2022-2027 in the UK and Europe based on several critical drivers:

- Most studies conclude that battery technology will not evolve sufficiently within a 10-year timeframe to provide sufficient range, fast enough recharging, and a light enough battery to avoid compromising performance. Cost and availability of alkaline metals and other components also limit projected growth of battery-electric operation for trucks.
- The HGV truck industry is on a decarbonisation journey. Increasing engine efficiency, AdBlue legislation and advanced diesel additive packages have contributed to lower CO_2 and NO_X emissions. The last 3-5 years have seen a rapid increase in the conversion of

 © Kiwa Ltd 2022

trucks to liquefied and compressed gases (most notably LNG), particularly in mainland Europe.

- Comparable economies in North Western Europe have relatively mature LNG (liquefied natural gas) and CNG (compressed natural gas) supply and distribution infrastructures for commercial road transport. Both major and independent energy suppliers have focused on the development of a network of supply locations which, in 2022, is expected to grow to around 5,000.
- As an example, NGVA Europe estimates that liquefied and compressed gases accounted for 30% of all commercial road transport fuelling in the Netherlands in 2021. Operating to the same 2030 decarbonisation targets, UK penetration of LNG and CNG in the overall road transport fuel mix was just 0.3%. Between 2022 and 2030, the UK will therefore see much faster growth than in low carbon commercial road transport fuels than its North West European neighbours as it catches up.
- Shell's LNG volumes in the commercial road transport sector in Europe have grown consistently over the 5 years from 2016-2021. While its LNG division emphasises that growth is off a very low initial 2016 base, Compound annual growth rate (CAGR) in low carbon LNG supply has been circa 75% in the period. Shell is now seeing a flattening of LNG demand and is repositioning its commercial road transport towards hydrogen: Shell sees hydrogen as the only viable solution for long-range heavy goods transport.

Trucks are not typically converted from diesel to hydrogen operation – instead, on scheduled replacement of a truck, an operator will usually consider alternatives, including hydrogen. HGV operators replace vehicles every 8-10 years on average, and stagger replacement across fleets. Given the low penetration of LNG in the UK, and the projected growth of the hydrogen economy, it is foreseen that the UK may well "leapfrog" LNG in the decarbonisation journey and move directly to hydrogen, given fulfilment of the following conditions:

- Transport-grade hydrogen availability across the UK's transport and industry hubs
- A stable and competitive hydrogen price
- Governmental grants and subsidies for conversion
- Vans and light commercial vehicles (LCVs)

Smaller vans (Transit/Sprinter/Traffic-style, usually operating in tight radii and in urban environments, are predicted to follow the same course as passenger cars and electrify quickly, providing availability of express/rapid charging increases as expected.

Larger vans and LCVs will, where they operate across wider regions or nationally, make longer journeys and, where there is a network of available hydrogen, may convert to H2 where business cases support.

5.3.3 Demand: Cars

Hydrogen is not expected to gain traction as a fuel for passenger vehicles or small vans. Over the period 2022-2027 a) production costs of battery-electric vehicles will fall; b) advancing battery technology will reduce the comparative costs of BEV's and increase operating ranges and c) charging infrastructure density will increase. Hydrogen cars are not viewed by the automotive industry as providing a large-scale consumer alternative to BEVs. To that extent, except for those vehicles operated by S+IP itself, cars are mostly excluded from the demand forecast.

Given the high intensity and low-radius operation of taxis, moderate demand from the taxi sector will emerge in areas where hydrogen refuelling is available at competitive cost.

 © Kiwa Ltd 2022

5.3.4 Supply Constraints

Dialogue with the management team of Air Liquide UK in the context of this study has revealed the following:

- UK hydrogen supply is constrained/short and suppliers (Air Liquide itself and BOC) are seeking new sources.
- Air Liquide would consider a) adding new hydrogen supply sources to its own manufacturing and supply base in Runcorn and b) adding additional rolling stock (hydrogen containers) to its existing trailer fleet to collect and distribute hydrogen from the S+IP.
- There are growing numbers of specialist H2 transport and distribution companies in the market which are also seeking supply sources.

Consequently, over and above the segment-based demand forecast set out in the analysis below, we see the potential for the establishment of wholesale contracts with Air Liquide and other distributors.

- Disappearance of local H2 supply alternatives
- Decommissioning of the small hydrogen refuelling facility next to the former Honda manufacturing plant at South Marston (A419) has been confirmed by SBC.
- ITM has announced the closure of its H2 refuelling station at the Royal Wootton Bassett Johnson Matthey site (M4 Jct. 16). The rationale for this closure is critical – ITM rightly sees the future of road transport hydrogen in the heavy goods freight rather than the light passenger vehicle segment, and from 2022 will focus on sites which can accommodate heavy goods vehicles and the required supply volumes.

As a result of the closures, moderate existing H2 demand in and around Swindon can be transferred to NC S+IP.

5.4 Core Demand Assumptions

5.4.1 Buses (see also 4.3.1)

- Core assumption: 20% bus conversion to hydrogen in Swindon in year 1 rising to 60% conversion in year 5
- Supply contracts with Swindon's two contracted bus operating companies (Stagecoach West and Swindon's Bus Company) underpin the demand case in Y1.
- Benchmark studies with early adopters of net zero bus fleets - Metroline West (London) and Translink (Belfast) - suggest that bus fleet decarbonisation will happen in two ways:
- 1) vehicles will be gradually/progressively replaced as lifecycles expire (they will not be converted "wholesale" to net zero).
- 2) based on early operational experience, it is likely that bus companies with a mixed urban/suburban/rural route mix will convert partially to BEV and partially to HFC to achieve operating efficiency.
- The case's overall dependence on bus company hydrogen demand falls from ca 35% in year 1 to below 20% in year 5, as demand grows from the commercial road transport sector.

5.4.2 Commercial Road Transport (see 4.3.2)

- Core assumption: 0.5% of M4 corridor transit HGV traffic in year 1 rising to 2.5% in year 5

 © Kiwa Ltd 2022

- As infrastructure develops and comparative economics improve, organic local demand for hydrogen as a transport fuel grows at 100% in year 1 (from a very low penetration base) and flattens to 25% in year 5. These forecasts mirror the demand curve development of LNG/CNG over the period 2016-2021).

5.4.3 Wholesale

- Core assumption: 200kg/day wholesale demand in year 1 rising on a flat line to 600kg/day in year 5
- Wholesale hydrogen supply will be short in year one and is forecast by Air Liquide to remain short over the 5 years 2022-2027 as demand accelerates faster than supply. Air Liquide has indicated that it will a) add additional vehicles to its supply fleet to unlock incremental hydrogen supply sources and b) seek new wholesale supply sources.

5.4.4 Research and testing

- Stakeholders confirm the potential of S+IP as a Science & Innovation Park, and in particular its credibility as a hub for hydrogen research, testing and piloting.
- Three groups of “customers” will use hydrogen produced at S+IP for research and testing purposes:
- **University research departments:** Business West confirms that the universities of Bath and UWE (Bristol) have established hydrogen research programmes, have research budgets to place, and would be potential on-site hydrogen users renting facilities and space from SMG. Reading University is also active in H2 research and can be similarly engaged.
- **SME’s:** Business West also emphasises that there are small enterprises experimenting with innovative uses for hydrogen who could also be part an S+IP innovation hub and community. Beyond hydrogen use, this community would also generate rental income for SMG.
- **Local and regional logistics firms:** the demand case sees a sharp increase in hydrogen volumes from local/regional logistics operators over the period 2022-2027. This is not built on rapid expansion of a testing fleet, but on the transition of large local (B&Q, FedEx, Amazon) and regional M4 fleets (IKEA contractors) from limited vehicle testing to broader hydrogen operation as vehicles are replaced. In total, ca 40% of projected year 5 hydrogen demand is made up volumes supplied to local and regional logistics operators, making early engagement critical to the overall case.

 © Kiwa Ltd 2022

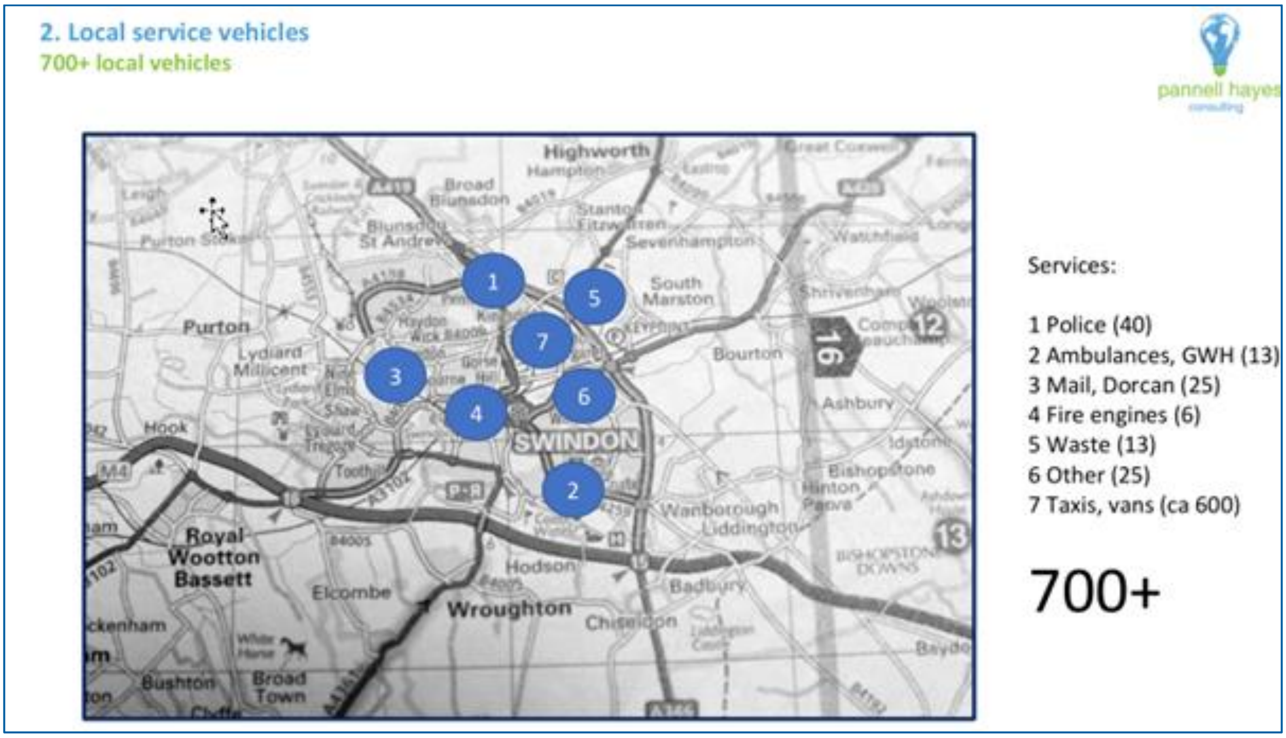


Figure 18: Locations of local service vehicles in the area

5.5 Supply Rationale

5.5.1 S+IP Site

A “two-sided” refuelling facility should be built on site (and operated by a third-party fuel supplier). The site would supply the following groups:

- on-site vehicles operated a) by the S+IP itself and b) by S+IP research entities and SMEs (see above)
- on its public-facing side, hydrogen cars and vans from the area (including small numbers of commercial vans, taxis and minibuses testing hydrogen operation)

Early-stage conversations are under way with both Watson Fuels (part of World Fuel Services, with a head office in Brinkworth, Swindon) and with energy majors as potential operators of the site.

Despite the proximity of the site to S+IP electrolyser(s), it is unavoidable that hydrogen will need to be bulk-tankered to the on-site refuelling location (a business case for piping H2 to an on-site refuelling location is unlikely to stand up).

5.5.2 Local supply

Bus companies have confirmed that hydrogen will need to be stored at their own depots. Based on projected growth in the demand model, 1-2 full tanker loads of hydrogen per day would be required in year 1 rising to 4-5 loads in year 5 to meet the demand model assumptions.

Logistics companies based around Swindon (B&Q, FedEx, Amazon), are assumed to take an aggregate of 75 kg/day on average for testing purposes. Once they migrate from testing to operational use, these fleets would either a) require supply of hydrogen to their own depots or b) would use 3rd party truck refuelling locations that may or may not be supplied by S+IP (see below).

 © Kiwa Ltd 2022

5.5.3 Truck refuelling

Commercial transport traffic using the M4 corridor between London and Bristol/South Wales and the A419/417 link between Swindon and the M5 (Gloucester) refuels in the following locations in the Swindon area:

- M4 services at Chieveley (Jct. 13 – Moto/BP), Membury (Jcts. 14-15 – Welcome Break/Shell) and Leigh Delamere (Jcts. 17-18 – Moto/BP)
- Swindon Truckstop (A419/A420 (Oxford) interchange
- North- and Southbound A419 services at Cricklade (Esso/Eurogarages and BP)

To meet projected demand from the commercial transport sector, which in year 5 makes up 60-65% of overall hydrogen demand from S+IP, storage and dispensing facilities will need to be built at some/all of these locations; supply contracts will need to be negotiated with site operators and hydrogen will need to be tankered between 10 kms (Swindon Truckstop) and 50kms (Chieveley).

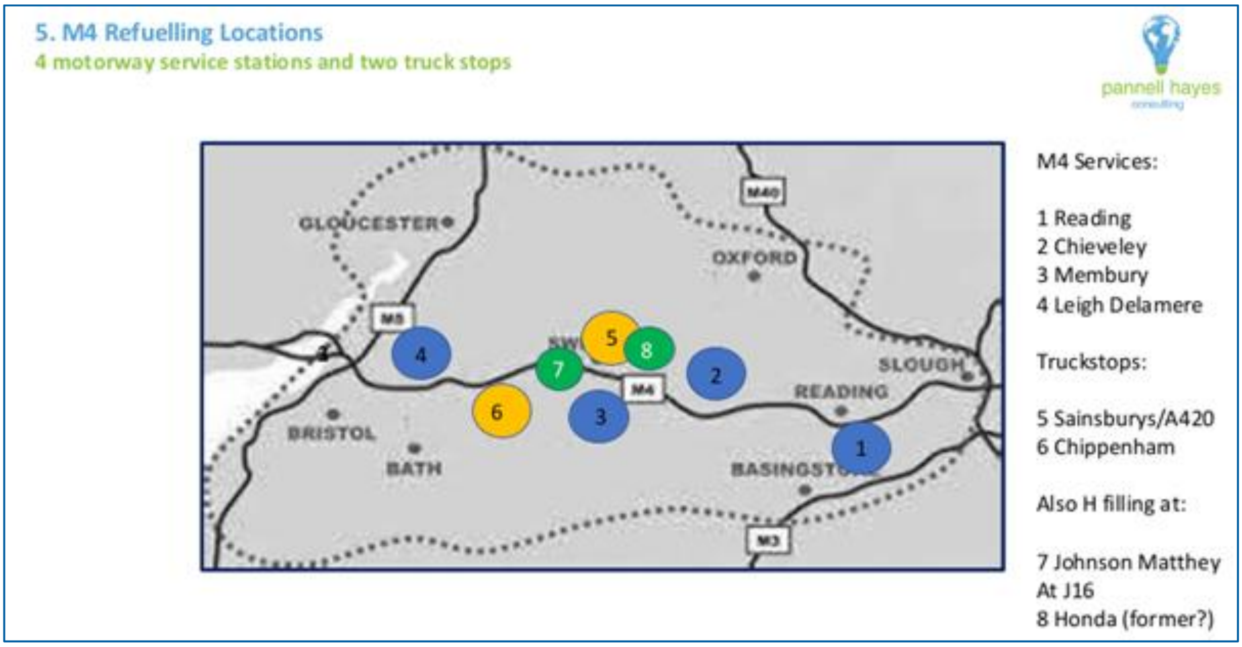


Figure 19: M4 Refuelling locations

5.6 Demand Forecast

Over and above the segments described in above sections, which form the lynchpin of the demand forecast, several other segments are included in the model. While these will not drive the substantial five-year growth modelled in the demand forecast, Swindon Borough Council's leverage and influence as the contracting party for some of these service providers offers potential to convert vehicles to hydrogen as early as years 1 and 2 of operation and have been assumed in the demand profile with demand assumptions noted per service:

S+IP -owned/operated vehicles: A total of 15 vehicles already operated by S+IP on site, plus a shuttle minibus used to bring groups to the site for educational tours, visits, and events.

SBC-owned/operated vehicles: 6 school minibuses and an "Access" bus for disabled mobility.

SBC-contracted coach company: Estimated total of 40 coaches owned and operated by Barnes Coaches (Swindon), and substantially contracted to SBC for school transport services across the Borough.

SBC waste collection: 13 bin lorries operated by environmental services contractors and contracted to SBC.

Emergency services: 40 police vehicles operated by Wiltshire police, 13 ambulances operated by Great Western Hospitals Foundation Trust and 6 fire engines operated by Dorset & Wiltshire Fire Service.

Aviation testing: Zero Emissions Flight Initiative and ZeroAvia. Both these organisations are researching and testing Sustainable Aviation Fuels (SAF), as well as hydrogen, and could be attracted to the Science and Innovation Park (especially with its test track, space/hangars; and airbase history) for guidance, supplies etc in addition to the green hydrogen and electrolyser being built at Cotswold airport.

Local taxi firms: A total of over 200 taxis licensed by SBC, overwhelmingly operated by two firms – V-Cars and Cross Street Cars.

Other Waste collection: Bin lorries operated under contract to SBC.

Local last mile delivery: 10 delivery vans owned and operated by JLP/Waitrose (Online) from its store in Wichelstowe, next to Wroughton and ca 25 mail vans operated by Royal Mail from the Dorcan depot in SE Swindon

Given that this multi-segment demand a) spreads any contracted supply risk and b) offers the potential for early adoption by a small number of vehicles in much larger fleets, a critical success factor in building the demand-side case is gaining agreement from Swindon Borough Council's officers to engage its contracted parties in hydrogen operation for a proportion of their vehicles.

Figure 20 shows a summary of the demand forecast for hydrogen for the next 5 years. A detailed version of the demand model is attached in the appendices.

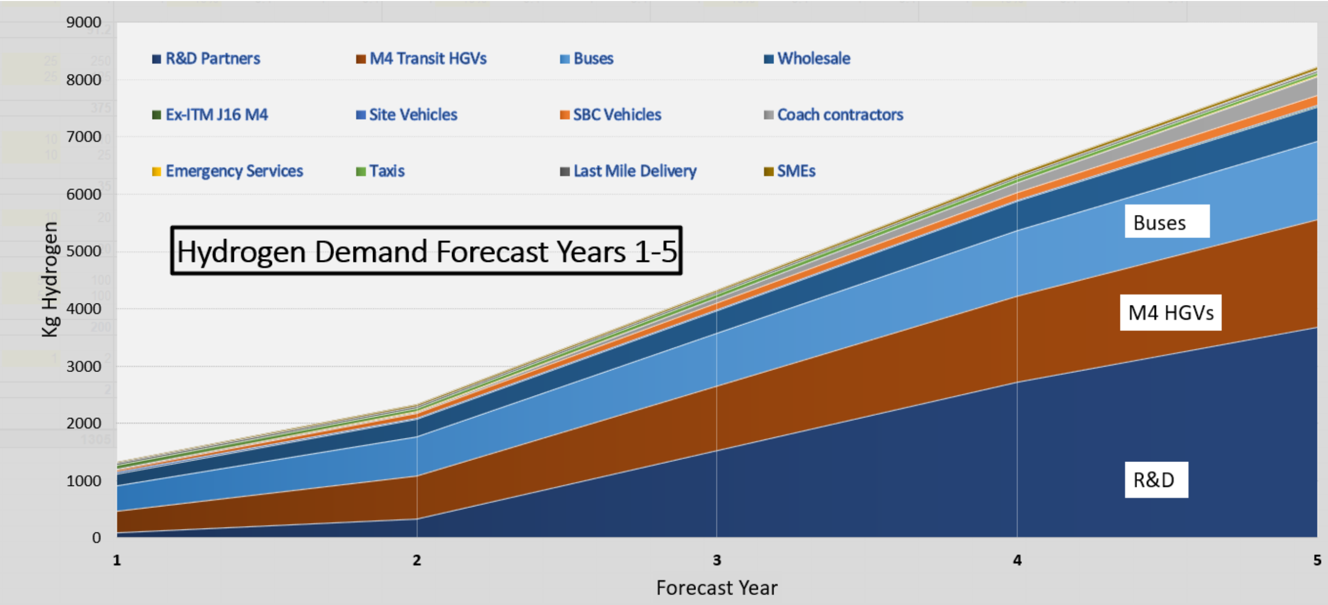


Figure 20: Hydrogen demand forecast for the next 5 years

 © Kiwa Ltd 2022

6 System Design

The following section sets out the commercial case for the project where a system design is undertaken for the opportunities identified in the project workshop. The following section sets out the production technology choice, the system sizing and the selection of the demand that can be met by the system. The system design and layout is also set out in this section as well as a potential location at the site for the production system.

6.1 Workshop Outputs Impacting System Design

The workshop outputs specified that maximising the use of the solar farm already in place and S+IP and using it alongside other new renewable sources to produce green hydrogen on site was a priority. However, one of the biggest risks identified with this plan is that the current renewable solar generation at S+IP may not be available due to commercial realities. As renewable energy is a key requirement for the study to reduce this risk two options for the energy supply have been included in the system design. This has been possible as additional renewables has been explored as part of the S+IP development. Through the S+IP's conversations with the DNO, it is understood that the headroom for additional renewables to export into the grid is 45MW. If required, this would enable a new solar installation close to the existing site making use of the existing export infrastructure whilst also providing power to the hydrogen production system. Option A is the use of existing solar whilst Option B is a new 45MW installation. As 45MW is close in output to the 50MW system already installed at S+IP the modelling of available solar energy for both options A and B has only been completed once for the existing site with the results used in both options.

Another requirement from the workshop is a stable system on which to build upon to enable further opportunities to be developed. As green hydrogen is the main requirement of the project the renewable energy which is currently produced at S+IP through the existing solar farm has been used extensively in the production modelling. This has been done as any project at S+IP would benefit if this energy could be utilised due to the co-location of renewable energy with hydrogen production and the simplification and cost savings of using existing infrastructure. The detailed modelling of the system has used 20 years of solar data to show that the system design is robust enough to deal with renewable energy constrains such as periods of low renewable energy output.

Additional renewable energy production (other than solar) is also an option for the site explored in the workshop and has been included in the system design through investigations of the scale of additional renewable energy production required to produce hydrogen at the site.

There are other opportunities that have been identified in the workshop which will be able to utilise renewable hydrogen production at the S+IP however, these demands will require a base case or base demand already in operation from which to build on. This is due to the nature and uncertainty in some of these demands and their timescales for development. As the main opportunity for the site has been identified in the workshop as being for transport applications a base system design has been set on the transport demands.

Due to these additional opportunities which can be built upon the system base design, the sizing of the system and system layout also considers future expansion of the system by providing opportunity for expansion of the electrolyser and the storage required on site.

 © Kiwa Ltd 2022

6.2 Hydrogen Production Technology - Electrolyser Review

The review of electrolysers concerns the requirements of production and hydrogen use. The hydrogen purity required by the different demands and its carbon intensity is also important when considering the choice of electrolyser. Resources for hydrogen production and limitations on storage are also discussed. The total capital and operating costs will not be discussed here as they will be discussed later in this report. Technology choice for electrolyser is an important part of the feasibility study as the choice of using renewable energy for generation does have a considerable impact. The way that different electrolysers operate will have a bearing on not only the technical viability but also on the capital cost and operating cost of the systems.

Although this section is a summary of the electrolyser technologies considered, there are a few possible routes to clean hydrogen production that stretch across a wide range of technology readiness levels. One thing that all hydrogen production routes have in common is that they all need to be supplemented by additional technologies, for example: purification, carbon capture & storage (CCS), gas compression. Main examples for hydrogen production:

- Reformation of methane + CCS
    - Steam methane reforming (SMR)
    - Autothermal reforming (ATR)
- Production from wastes
    - Gasification
    - Pyrolysis
- Electrolysis
    - Alkaline electrolyser
    - Proton Exchange Membrane (PEM) electrolyser

Within the technologies listed, production from the reformation of hydrocarbons is the most developed, although CCS has less at-scale operations (Norway, Canada, US, UAE, Brazil etc.). However, the S+IP is far from the coast and the industrial clusters at which CCS will be developed. The CO_2 produced from burning waste for renewable electricity generation should also be collected- using CCS. Thus, it was not considered. Thus, electrolysis is the focus of production at the S+IP, also because relatively low cost (no grid connection charge) electricity is already available on site, and expansion is feasible.

6.2.1 Electrolysis and its Role in Hydrogen Production

Electrolysis is a hydrogen production method which uses a direct current to split water molecules into hydrogen and oxygen. A voltage is applied between a negatively charged electrode (anode) and a positively charged electrode (cathode). The overall reaction that occurs:

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2$$

There are many types of electrolysis for hydrogen production: alkaline water electrolysis, polymer electrolyte membrane water (PEM) electrolysis, high temperature steam electrolysis, solid oxide electrolysis and anion exchange membrane electrolysis. Only alkaline electrolysis and PEM electrolysis will be considered in this review as the other technologies do not have commercial availability that is suitable for the S+IP application.

 © Kiwa Ltd 2022

6.2.2 Hydrogen purity requirements

Standards exist which define hydrogen grades in terms of permitted levels of various contaminants and these are assigned for different types of use. Fuel cell technologies, are believed to be highly sensitive to the presence of compounds such as CO, S-compounds, etc. At S+IP the opportunity is for production of hydrogen of sufficient quality for fuel cell uses. The principal standards are:

- 'BS ISO 14687:2019 Hydrogen fuel quality — Product specification'
  Grade D is applicable for proton exchange membrane (PEM) fuel cell road vehicles application and Grade E is for PEM fuel cell stationary applications
- 'BS EN 17124:2018 Hydrogen fuel. Product specification and quality assurance. Proton exchange membrane (PEM) fuel cell applications for road vehicles'
  This defines the approach to production and quality control for the Grade D specification hydrogen defined in BS ISO 14687

Most commercially available electrolysers can produce hydrogen which meets the strict requirements of the hydrogen standards most notably ISO 14687 Hydrogen fuel quality — Product specification. Typically the contaminant most likely to be present in the hydrogen product is water which can be removed post production.

6.2.3 Electrolyser Choice

The electrolyser choice for the feasibility study has been based on the electrolyser technology's ability to deal with variable input from renewable electricity sources and the impact of parasitic loads on the performance of the electrolyser. Considerations such as the efficiency and operating pressure are also important however there are fewer differences in the performance of the electrolysers chosen for comparison. Four commercially available electrolysers were chosen for comparison in this study these were:

- A low-pressure alkaline system
- A medium pressure alkaline system
- Two high pressure PEM electrolyser systems

PEM electrolysis is more responsive to a change in power input as proton transport is not limited by inertia; this is something that is important during periods of low energy input into the electrolyser system. The solar inputs modelled in this feasibility study have periods of rapid changes in power output which impact on the performance of electrolyser systems. This is particularly true at the beginning and end of the day where ramp rate in the electrolyser causes energy wastage.

The challenge of solar energy inputs from the solar array at the S+IP also presents challenges with some technologies and parasitic loads on the electrolysers. These parasitic loads are particularly challenging for electrolyser technologies which have energy demands when they are not in operation. These loads are required to keep the electrolysers operating correctly and to ensure that they are available when called on. Whilst all electrolysers have some of these parasitic loads, some technologies have higher parasitic electrical demands than others, particularly during periods of no demand or renewable energy availability. Over an annual period, this can result in a significant amount of annual energy demand being provided from non-renewable sources. Alkaline systems that were modelled and shown in Appendix A were shown to always have parasitic loads which had to be maintained even when there was no renewable energy available.

A PEM electrolyser has been chosen as the main technology for hydrogen production in this study due to the benefits of ability to deal with variable input and parasitic loads.

6.3 Resources at S+IP

To minimise the carbon emissions from hydrogen production system and processes, the energy inputs need to be renewable resources available at S+IP. Other resources which are important are the availability of water for electrolysis and space needed to enable the production to be developed.

6.3.1 Renewable energy

As Blue or Green Hydrogen is required for carbon reduction in the city, a renewable source of energy would provide carbon reduction in the production of hydrogen. Renewable energy is in short supply in conurbations. however, in Swindon and Wiltshire there has been a strong push to install significant levels of solar PV generation. There is a significant solar farm located on the site, which was reputed as one of the largest in the country when built. This is renewable energy which could be used to generate 'green hydrogen' by electrolysis. As solar has been installed on site the basis for the modelling has been to utilise solar energy to supply the electrolyser.

6.3.2 Water and Power

Electrolysis needs a steady water and electricity supply to be able to produce hydrogen. The site has a basic supply of both power and water due to its use as an airfield it has bever had the need for large scale power and water supplies. For periods of no renewable energy production grid electricity is needed to ensure security of supply. The high voltage supply which is in a ring around the site (Figure 21) is not designed for large loads required by the hydrogen production. However, there is a large grid connection from the solar farm system to the grid which could provide grid power. Mains water supply also runs around the site. This supply is not built for large demands. The electrolyser system needs around 1.5 m^3 of water per hour (25 litres per minute) when operational which should be able to be supplied by this system. This is equivalent to 3 domestic households. If this rate cannot always be met water storage at the production site may be required.

6.3.3 Integrating on site resources into a hydrogen production facility

Hydrogen production is an energy intensive process, regardless of the manufacturing route taken. Hydrogen production at a large scale therefore requires large amounts of energy and resources which presents a significant challenge, especially when the requirement is to produce green hydrogen requiring renewables. There are a range of resources at S+IP which are unique to the site. The site's history as an airbase means that no large water, gas, connections are readily available. The sites energy production has mean that electricity infrastructure has been installed connecting the site to the main electricity grid so there are opportunities for energy import and export. This energy production has become an integral part of the S+IP, and will be for the foreseeable future, which provides opportunities for low or zero carbon energy to be used in the production of hydrogen. However, as the only renewable energy source currently available at S+IP is the solar energy, production from renewables can only be achieved when the power is available. The scale of production needs to take this power availability into account. Additional renewable capacity for electricity generation would provide additional power unless it was diversified to provide additional sources of renewable energy when the solar panels are not generating sufficient power for hydrogen production needs.

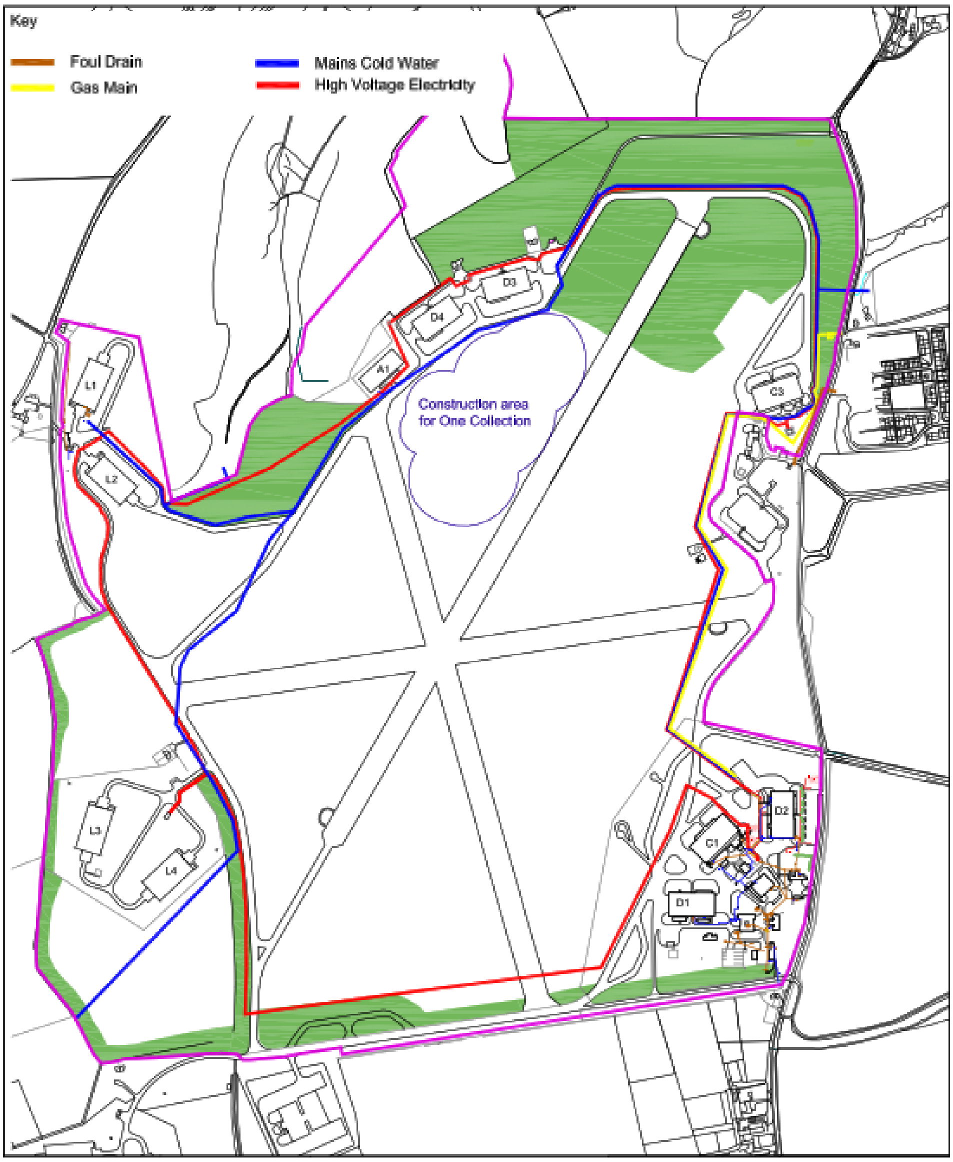


Figure 21: Approximate locations of onsite infrastructure.

6.4 Renewable energy - Solar PV

For use in the study the existing solar farm has been used as this asset exists and is currently in operation on the site. This allows us to model the availability of renewable electricity produced from the solar farm using 20 years' worth of data which was obtained from www.renewables.ninja [47] [48] which used simulated direct and diffuse irradiation to model the theoretical output from a 50 MW PV array located at S+IP. The 20 years of irradiance data was chosen so that we can include in our model many different weather patterns which will impact on solar output. This use of irradiation data for the actual area of the feasibility study also allows us to demonstrate and model real renewable energy inputs and to quantify the impact on hydrogen production.

---

[47] Pfenninger, Stefan; Staffell, Iain - Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114, pp. 1251-1265

[48] Staffell, Iain; Pfenninger, Stefan - Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239

Average hourly output when the PV was outputting power (ignoring non-daylight hours) is shown in Figure 22. The seasonal variation in the output is clearly visible as well as the variation from one year to the next can be seen.

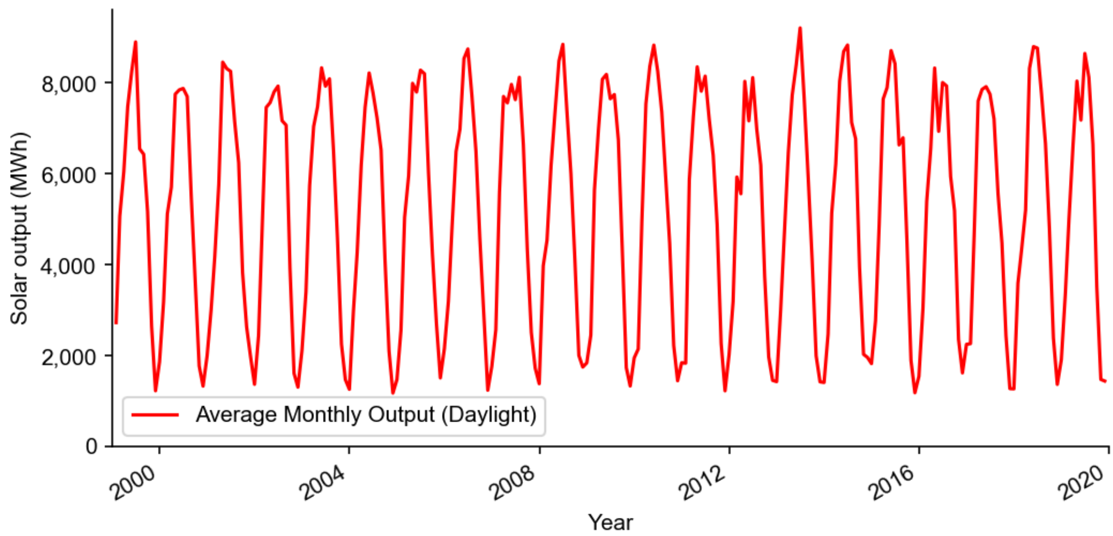


Figure 22: Simulated average monthly l output of a 50 a MW PV array at S+IP for last 20 years

Overall, the shape of the output from year to year was consistent however there is some variation in the annual output over the 20 year period. This variation is consistent with what is expected from solar PV in the UK and shown in Figure 23.

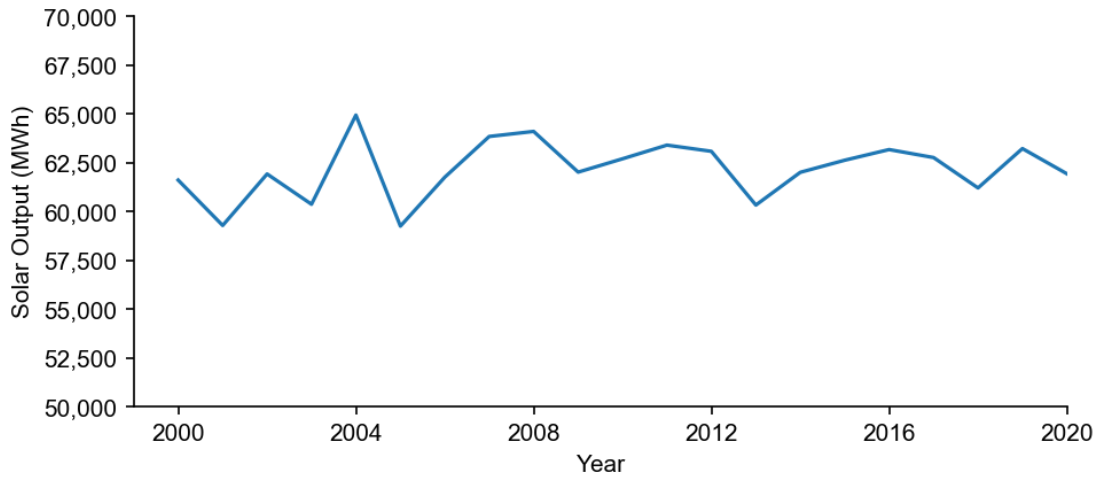


Figure 23: Total Annual Output in MWh from 1999 to 2020

Average hourly profiles

Total photovoltaic power output [kWh]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5					1	8	2					
5 - 6				3	32	39	32	9				
6 - 7			3	57	97	103	91	65	27	0		
7 - 8		0	79	173	211	212	197	170	138	55		
8 - 9	11	80	194	292	321	313	304	280	248	186	59	8
9 - 10	79	197	283	373	397	391	386	358	323	266	139	71
10 - 11	138	272	357	442	444	435	427	409	392	330	227	120
11 - 12	206	327	420	478	478	468	465	446	424	389	282	155
12 - 13	219	344	434	476	478	469	473	446	422	337	271	158
13 - 14	169	291	373	436	437	437	444	418	375	285	195	122
14 - 15	108	233	302	371	392	399	408	365	311	226	110	79
15 - 16	49	166	240	295	315	328	332	300	240	156	43	16
16 - 17	1	52	143	193	213	228	239	199	141	31		
17 - 18		0	32	82	106	124	129	95	38	0		
18 - 19			0	12	37	49	48	25	0			
19 - 20					5	17	13	1				
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	980	1,962	2,860	3,681	3,966	4,021	3,991	3,587	3,080	2,260	1,326	727

Figure 24: Simulated average hourly and monthly PV output of 1 MW array.[49]

Average solar output for the S+IP area can also be simulated (Figure 24) with what could be expected from a 1MW solar array. The heatmap in Figure 24 shows the variation month to month but also throughout the day as the shortened daylight hour take effect in the winter months. This seasonal variability in PV generation poses a challenge to renewable hydrogen generated via electrolysis as the electrolyser size connected to the system is restricted by the minimum outputs of the solar farm output.

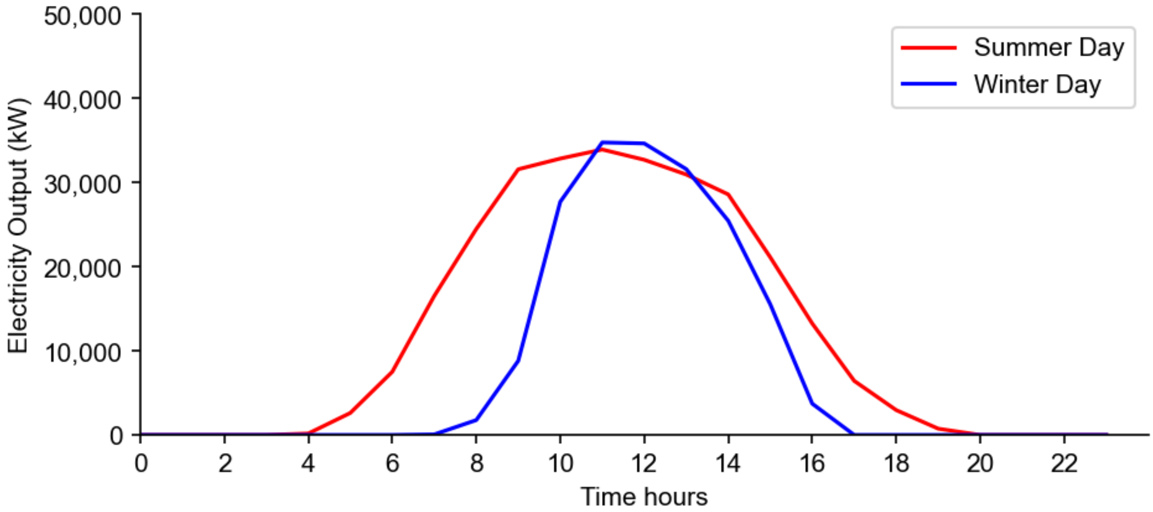


Figure 25: Within day PV output - comparable winter and summers day

[49] Ref: https://globalsolaratlas.info

© Kiwa Ltd 2022

A detailed view of a comparable summer and winter days (Figure 25) shows the impact of these shorter days on the electrolyser. Although the peak electricity output is comparable on the days shown the energy available is reduced in the winter as shown by the reduction in the volume under the winter curve vs summer curve. This limits the amount of hydrogen that can be produced during winter periods even when it is sunny. Typically, there is also a reduction in winter outputs due to inclement weather where clouds reduce the solar irradiance. By using actual irradiance data in the modelling, we can model and identify periods of particularly low output due to poor weather. This allows us to identify periods of interest for the modelling where the hydrogen production system will be under the most stress as it tries to meet demand. These periods are summarised in Table 4.

Table 4: PV output - periods of interest within the last 20 years

Maximum PV output		Minimum PV Output		Median years	
5-day period	Max Year	5-day period	Max Year	Lower	Upper
06/06/2015 to 10/06/2015	2003	12/12/2015 to 17/12/2015	2004	2019	2013

The periods above are important for the modelling of the system. The sizing of the electrolysers, storage and therefore any constraints on the demand that can be met are determined by these periods of minimum PV output. The costing however is based on median years to give an average costing and hydrogen price for the system.

6.4.1 Electrolyser sizing

The electrolyser needs to make the most from renewables whilst ensuring that it is not oversized for the energy input. There is a careful balance that must be made to ensure the benefit of the renewables can be used effectively without oversizing the electrolyser. An oversized system would struggle to be utilised properly during periods of low solar output and an increase in the consumption of grid electricity if no other renewables are available.

Ultimately the electrolyser size is limited by the renewable energy available. As the system has been modelled on 50MW maximum of solar PV output the optimum balance has been found to be 15% of annual output as shown by the black dashed line in Figure 26. This line at 5MW is the sizing of an electrolyser that can potentially be supplied by the system for most of the year. It should be noted that there are some periods where the power output is lower than 5MW which does mean that the solar output may not be able to meet the 5MW output for at least 15% of the year. However, as there are always periods of no solar output the system cannot be sized on the minimum output of the system. Although this 5MW number is much lower than the peak output of the system which is 50MW this size is much better matched to the lowest winter output periods.

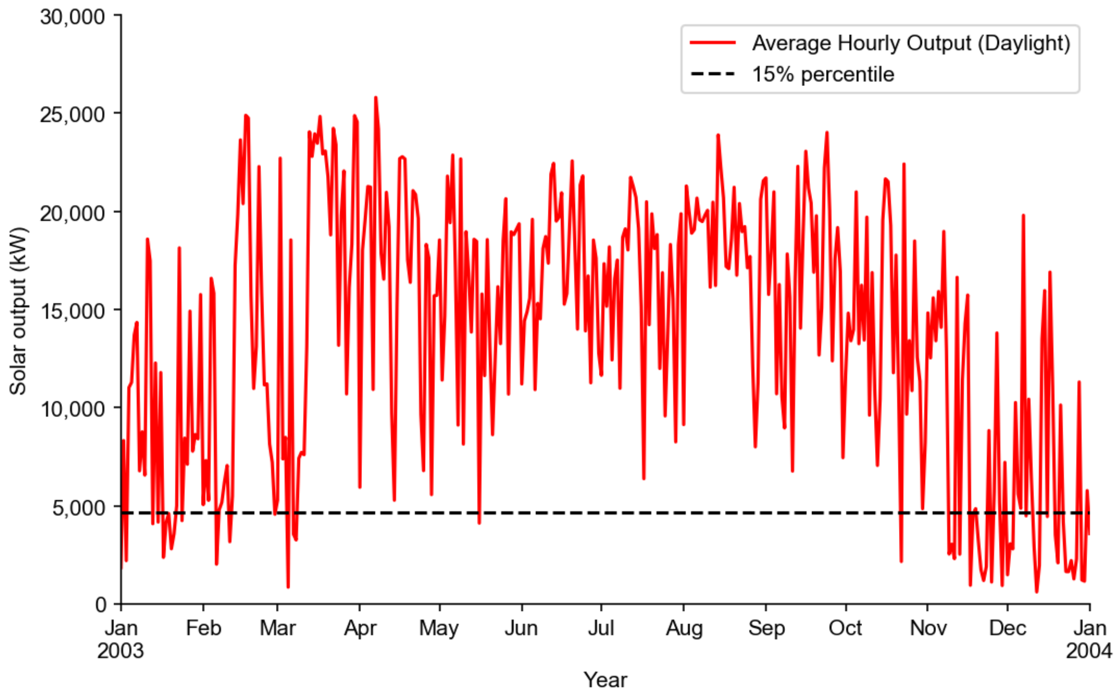


Figure 26: Average hourly output for each day in 2003 with the 15-percentile shown.

6.5 Storage and distribution

Key for the initial development of the project will be ensuring that balance is achieved between hydrogen supply and demand and that supply commitments can be met reliably. At the same time, any system developed needs to have the flexibility to respond to variations in availability of renewable energy.

6.5.1 Hydrogen storage options

Most production technologies operate best (i.e. with the highest efficiency and lowest cost) at full continuous output. Modulating production up or down, or on-off operation tends to increase costs and reduce plant lifetime. Electrolysers are more forgiving in this respect as they have peak efficiency at partial loads however, the utilisation of the electrolysers does have an impact on the cost of hydrogen. Higher utilisation of the asset reduces the overall price of the hydrogen as overall the impact of fixed operating costs on the price is reduced. As the supply of compressed hydrogen for vehicle fuelling will involve distribution by road tankers in pressure vessels the demand is well known and the variations in demand which require greater storage requirements are limited.

Storage options assessed in this study have been limited to gaseous hydrogen due to the energy penalties and the risks associated with liquified hydrogen storage. At this location above ground storage is the only feasible option as there are no geological formations that could be taken advantage of. The scale of storage required also makes the cost of exploring geological options further afield unfeasible balance between fixed storage and storage in tube tankers prior to delivery has also been considered however it has been determined that this is impractical as it limits the availability of the production system. The most feasible option for storage at the site is bulk pressurised hydrogen storage.

 © Kiwa Ltd 2022

6.5.2 Stationary above ground storage of hydrogen

Hydrogen storage above ground uses pressurised hydrogen containers. At small scale, bottled gas supplies or small hydrogen vessels are used at high pressures up to 700 bar for FCEV and 350 bar for larger fuel cell vehicles. For larger scale storage such as the intraday storage required at S+IP using these small storage vessels is not practicable due to the number required. Larger storage vessels however are not able to operate at such high pressures due to limitations in the wall strength, these larger storage vessels use lower pressures typically 30-35 bar.

Cylindrical vessels, "hydrogen bullets" are used for larger scale above ground storage. They can be any size, however they are typically manufactured offsite and therefore the maximum size is governed by the ability to deliver the units to site. An example of one of these cylinders is shown in Figure 27. The unit is 25m long with a 4m diameter and has a volume of 314 m^3. At 30 Bar this equates to 850 kg of hydrogen or 28.2 MWh which is just under one day's average production of hydrogen. They can cost around £250,000 per bullet.

Figure 27: Low pressure hydrogen storage bullet, 25m by 4m diameter.

6.5.3 S+IP storage strategy

Gas storage is key to successful implementation of the project, as well as to provide attractive commercial opportunities to the project. [In the wider sense, gas storage as currently used in the natural gas network provides capacity for inter-seasonal and diurnal fluctuations.] In the context of this project, storage is needed to meet any intraday variations and to ensure that there is security of supply for a defined period in the event of the electrolyser system not being able to produce hydrogen. This could be for various reasons including plant maintenance but also in the unlikely event of a failure or loss of on-site electrical supply.

For some types of demand there is a generally agreed level of security of supply (for example for domestic heating or public transport, where there may be health and safety or national infrastructure considerations). Security of supply for this project is related to business continuity, and an assumption was made that reserve supply of hydrogen was needed to meet 2 days' worth of hydrogen demand, based on the ability to recover the production system if there is a fault. This would allow for the backup equipment to be switched to and alternative operation to be initialised. Storage was therefore selected so that a minimum of 2 days' worth of full demand was always available. This would allow for any system issues to allow the site time to rectify them.

Above ground hydrogen storage (in the form of bullets, as shown in Figure 27) costs around £250,000 per bullet, so the base model was optimised for the number of bullets required. This optimisation allowed for the modelling and costing of the base scenario. Additional space has been included into the layout of the site to allow the expansion of storage as additional production will also require additional storage installed.

The modelling has been achieved by setting the minimum level of storage throughout the year to be 80% of the total capacity i.e. the storage is maintained at above 80% levels to ensure supply can be delivered for 2 days in the event of system failure. Remaining 20% provides intraday storage as a buffer for when hydrogen was produced outside the period of demand or withdrawn during a period of low power input. This results in the requirement for 3 bullets to provide the intraday storage and 2 days' worth of reserve hydrogen.

Allowing bigger swings in the variation in the storage was found not to benefit the base project as savings in energy costs were offset by the increased cost of the storage (for example a minimum level of 0.33 full capacity factor) was shown to increase the number of bullets required without significantly increasing the percentage of PV output utilised. This sizing was completed for the base case scenario and the benefits of additional storage for additional hydrogen demands have not been assessed. There may be commercial opportunities that can be developed by increasing the amount of storage however this is outside the scope of the modelling.

6.5.4 Storage for onsite refuelling

Although most of the hydrogen produced onsite would have to be sent to the refuelling location i.e. the fuelling stations for cars, LGVs and HGVs or to a fuelling station at a bus depot, a fuelling station on the S+IP has also been considered.

It is not envisaged that demand from onsite vehicles will be significant compared with offsite refuelling. The workshop outputs suggest that limited refuelling will occur at the site. Such on site refuelling demands will therefore not significantly increase the variation in final demand profile which is dominated by offsite refuelling demands and therefore onsite transport use will be a small percentage of the overall demand. The demand profile from the site will also likely be intermittent and so suitable amounts of on-site storage capacity will be required from the bullets but can be managed using the buffer capacity available in the storage system.

6.6 Production, storage, and demand modelling

To assess the feasibility of and costs associated with a hydrogen production facility it is important to determine the size of each of the major components of the system (i.e. production plant and storage) needed to meet the demand.

It must also be demonstrated that the system is suitably sized to reliably meet the needs of the end users under most foreseeable situations. An additional requirement of the system at S+IP is that it should be able to make good use of the electricity generated from the Solar PV array.

A detailed model was created which took as input, data such as solar irradiation, technical plant specifications and simulated demand profiles to create a 20-year, minute-by-minute model of hydrogen production, storage, and end usage.

By tweaking various parameters of the model, it was possible to establish the size of system that would reliably meet the pattern of demand whilst operating efficiently.

6.6.1 Demand

The model that has been used for demand is that the hydrogen produced was for supply to a nearby road tanker refuelling station. Demand has been modelled as discreet daily tanker refills distributed evenly across the working day (from 8 am until 6 pm), with the assumption that hydrogen would be transported to refuelling depots throughout the day for refuelling at localised deports. From a supply perspective this demand is predictable and allows for the system to utilise storage onsite to allow these hydrogen draw offs to be made. Refuelling of buses and HGVs is generally carried out when services are not being operated and could be over night. Where public refuelling stations are supplied there could be requirements for supply at specific times. The delivery points will operate with local storage and so the time of restock deliveries can have flexibility. Therefore, if they are made daily these hydrogen tanker refills can happen at any point in the 24 hours as the storage is sized to allow for a buffer of these demands.

A refill of a delivery tanker was modelled to be equal to 200 kg of hydrogen and assumed to be of ½ hour duration. This gave a demand of around 260 kWh / minute during a half-hour draw-off period. Many different scenarios were investigated involving between 1 and 20 refills per day. Figure 28 shows the daily demand profile for 5 and 10 refills as an illustration for when these draw offs could occur. Currently this demand is spread evenly which is expected due to the time constraints of refilling each vehicle as it arrives to the site.

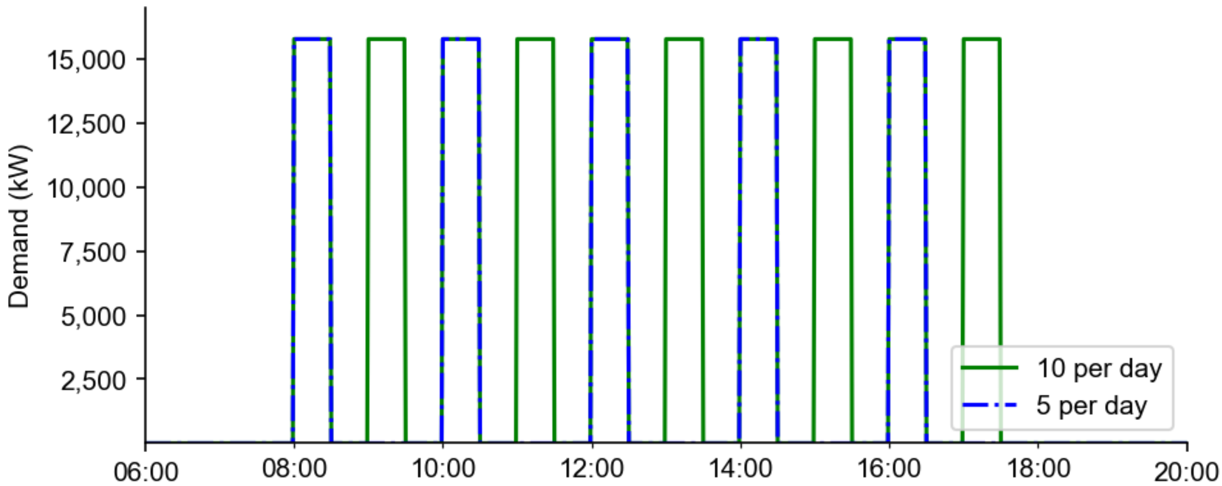


Figure 28: Daily demand profile showing 5 and 10 tanker refills per day

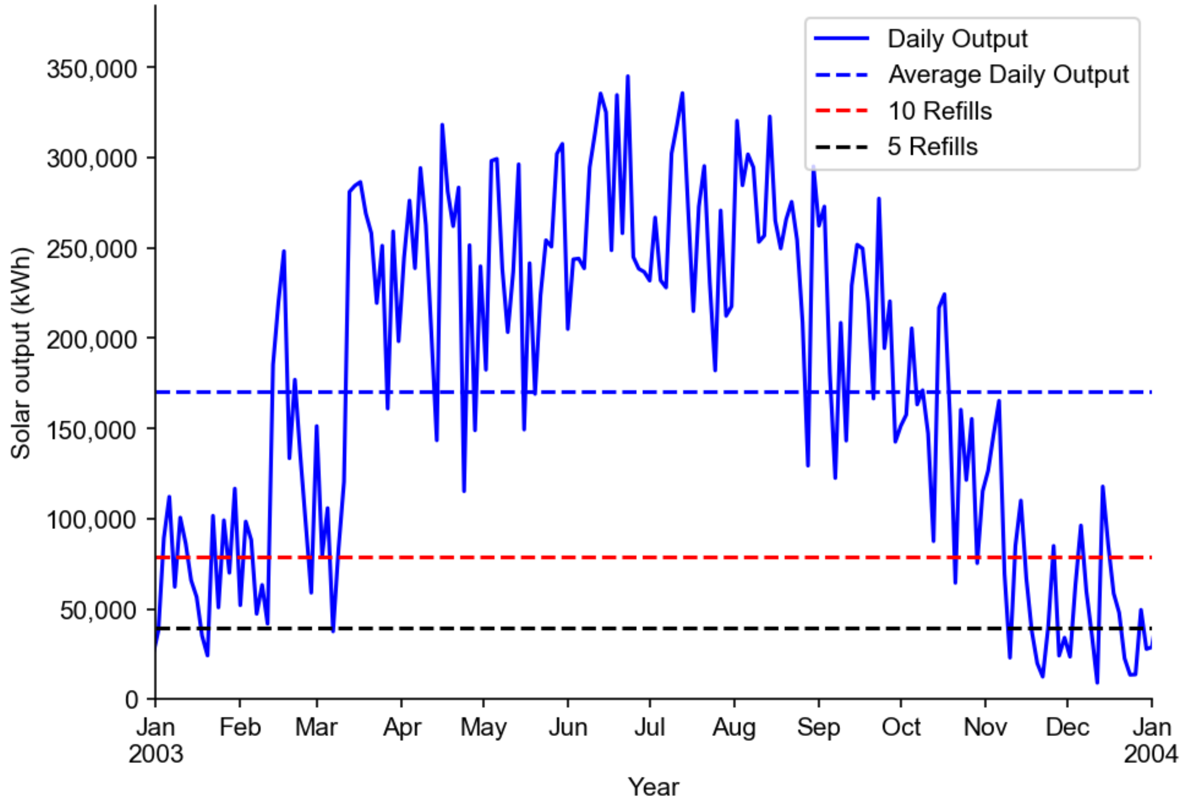


Figure 29: Demand of 5 daily tanker refills against daily PV output

Figure 29 shows the demand of 5 refills (1000kg) and 10 refills (2000kg) per day in relation to the daily PV output. The figure also shows the average output for the solar array show by the blue dashed line. Either side of the blue dashed line represents where on you could expect 50% of the days to produce more energy and 50% of the days to produce less energy. Logic may suggest that this is a good point to set the demand level, however as the energy produced drops quickly in the winter periods and the demand would not be close to being met for a significant period of the year.

The bottom dashed line (Figure 29) represents 5 refills which as it is close to the bottom of the daily outputs you could assume that on most days there should be enough solar to provide the energy for hydrogen production. This number of refills was chosen for the modelling as it makes use of most of the available PV electricity (i.e. the hydrogen produced is as “green” as possible) whilst still producing a reasonable amount of hydrogen to meet the utilisation needed to justify the CAPEX. Meeting the demand of 5 daily refills returns a lower percentage use of grid electricity as a percentage of the overall electricity input (Figure 29) than all the other refill patterns. This is due to the availability of solar and the increased proportion of parasitic electrical losses for smaller demands. The historic demand pattern was repeated every day for 20 years, to match the 20 years’ worth of PV data.

The utilisation of the electrolyser system is also an important factor in the sizing as a 1000 kg a day demand corresponds with a 50% utilisation of the electrolyser asset. This is important for ensuring security of supply. As at 50% utilisation of the whole system 1 electrolyser can meet the entire

 © Kiwa Ltd 2022

demand if running continuously throughout the day and night. This allows an electrolyser to be offline for maintenance or repair whilst the system can operate and continue to meet the demand.

6.6.2 Hydrogen production technology

As stated in section 6.2, due to the requirement for green hydrogen, the hydrogen production technology at S+IP would be via electrolysis. Whilst new technologies are emerging, the point of the selection is for it to be a well tried and tested "off the shelf" commercially available units to produce hydrogen. This will be a requirement for a developer to secure third party financing. A 5 MW sized electrolyser was chosen as optimal for modelling as this gave options around using existing, upgrading existing and/or adding new renewable energy.

Section 6.2 explains the operation of each electrolyser technology in more detail. Key considerations for the modelling were:

- Speed of the response of the electrolyser to a change in power input
- Maximum and minimum rated power draw of electrolyser and balance of plant (BoP) (percentage operating range). Also included was the definition of BoP equipment.
- Maximum and minimum hydrogen production amounts (percentage operating range)
- Relationship between power input and hydrogen output (efficiency curve)
- Modes of running, power in each mode and transition time between modes
- Operating pressure

A grid connection will be included, enabling the system to draw grid electricity in the exceptional circumstances where insufficient solar (or other renewable) energy is available. The system was (naturally) optimised to preferentially use renewable energy to meet demand, if available. The model was run using the following parameters (Table 5)

Table 5: System sizing

Component	Value
Electrolyser type	High Pressure Polymer Exchange Membrane
Electrolyser output	5 MW (2 2.5 MW units)
Storage (number of bullets)	3 required for maintaining supply
Demand pattern	5 refills (1000 kg/day)

6.6.3 Results of the modelling

The following is a summary of the results output from the electrolyser modelling. For the modelling the periods that are shown are the most challenging periods of operation. This is done so that it is possible to highlight areas where the model may be struggling or to show where any issues are occurring. This is different to the costing modelling later in this report which uses median years for the reporting. The first graphical output (Figure 30) shows the result of the modelling and the operation of the electrolyser over the worst year for solar output. This has been chosen as the year during 2004 where solar energy was at its lowest.

 © Kiwa Ltd 2022

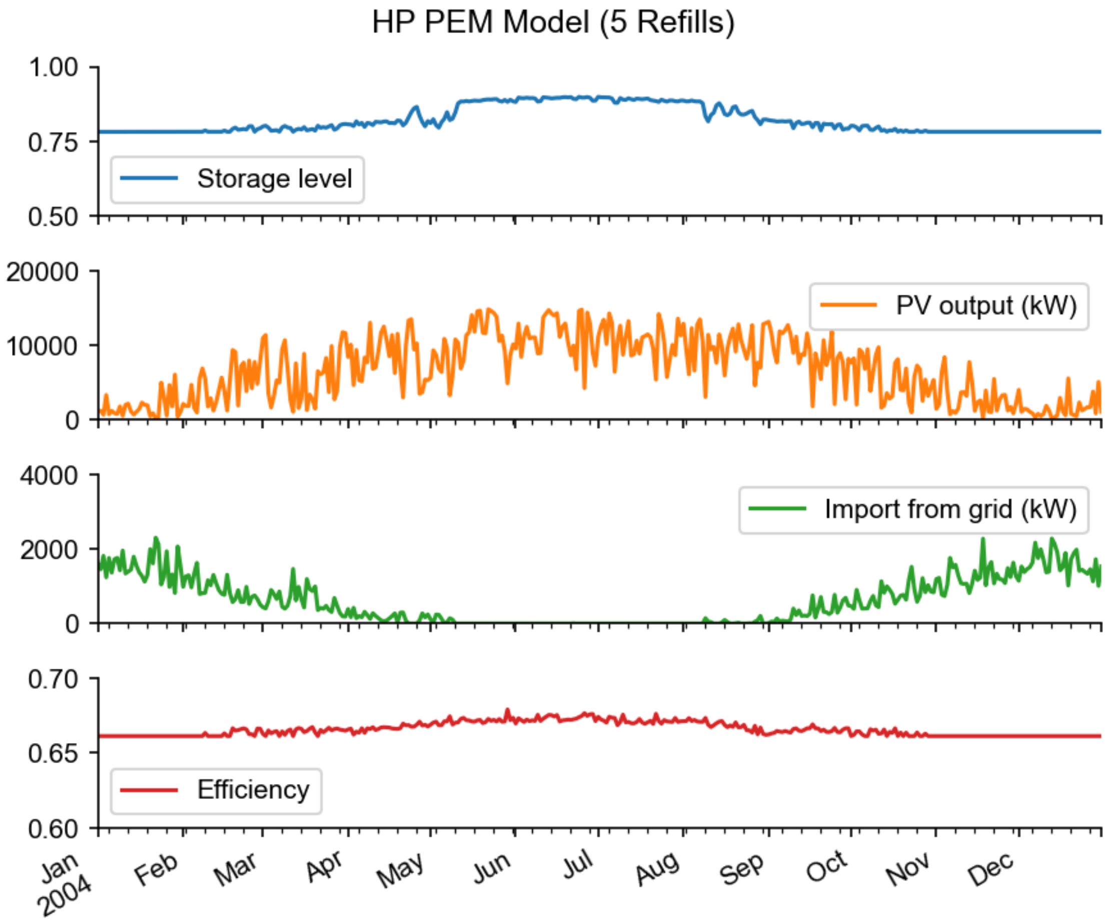


Figure 30: Model output for 5MW electrolyser with 5 refills

The whole year is shown in Figure 30 with the graph showing the daily average for the values. The storage level does not vary too much over the year as it goes from 0.75 to 0.9 which are its upper and lower limits of operation. The daily average efficiency also does not vary much as the pattern of operation of the electrolyser is stable across the year. One parameter that does change is the import from the grid which is very low in the summer but rises steadily on either side of the summer period towards the middle of the winter period where the import from the grid is at its highest.

6.6.4 Worst 5-day period in last 20 years

This period provides an indication of when the solar energy is lowest and the most grid electricity must be used for hydrogen production. It is also the period where the hydrogen produced will have the highest marginal cost (Figure 31). The model output for 5 days shows the import required from the grid to ensure the supply remains available for transport applications. The reduction in import can be seen when there is a small amount of solar PV available which peaks on day 5 of the period (16th December 2002) at around 6MW, around 10% of the 50MW capacity of the system.

 © Kiwa Ltd 2022

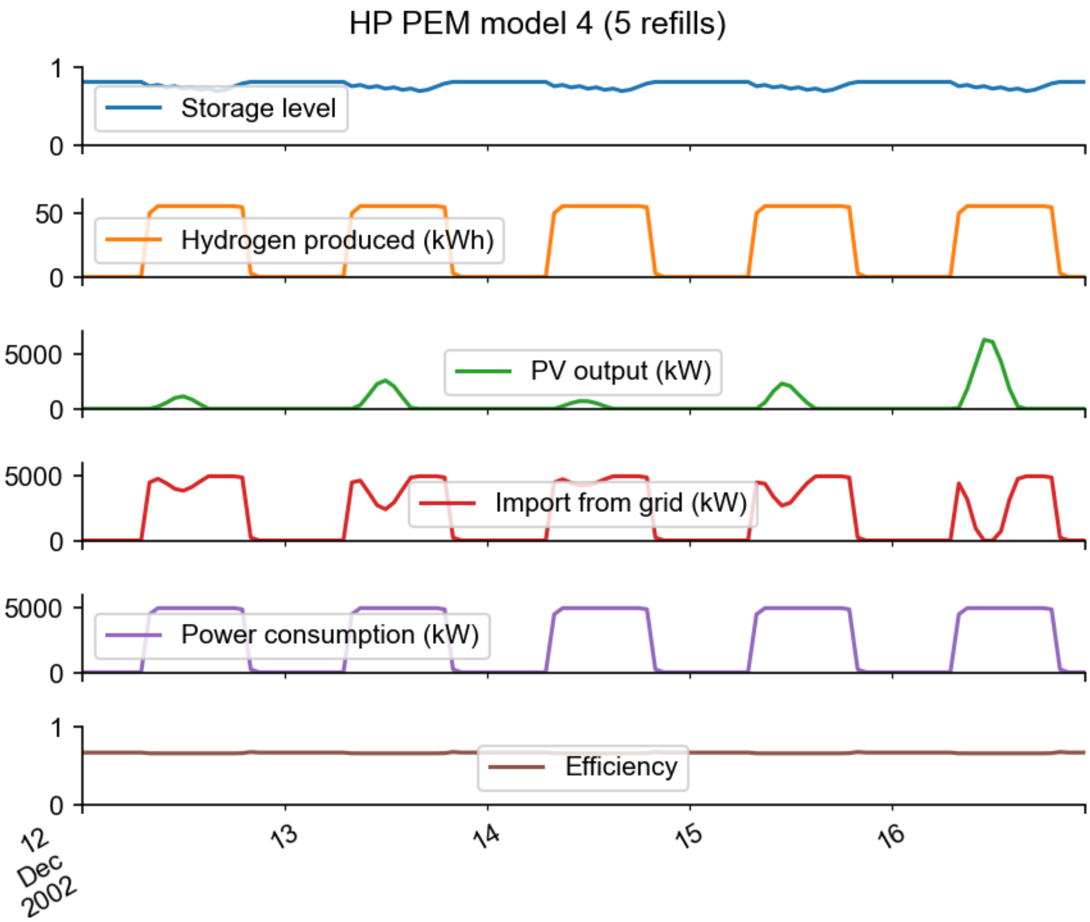


Figure 31: Worst 5-day period of solar PV. Model output showing 5-day operation from the electrolyser system

Table 6: Performance of hydrogen production during the worst 5-day period

Period	Total PV output (MWh)	Total import from grid (MWh	% of PV used	% Input from Grid	H2 produced (kg)
12/12/2002 to 16/12/2002	49.4	299.0	98.0	84.0	5,000

Table 6, shows the same 5-day period shown in the graph that during the worst 5-day period, although almost all the available solar energy was utilised (98%), the percentage of total energy used for hydrogen production that came from the grid was 84%. Given the relative high cost of grid electricity compared with solar PV this electricity demand needs to be met with new renewables installed at the site.

6.6.5 Best 5-day period (period of highest PV output)

This period provides an indication of when the solar energy is highest, and the least grid electricity used for hydrogen production (Figure 32). The model output for 5 days shows the import required from the grid is almost zero.

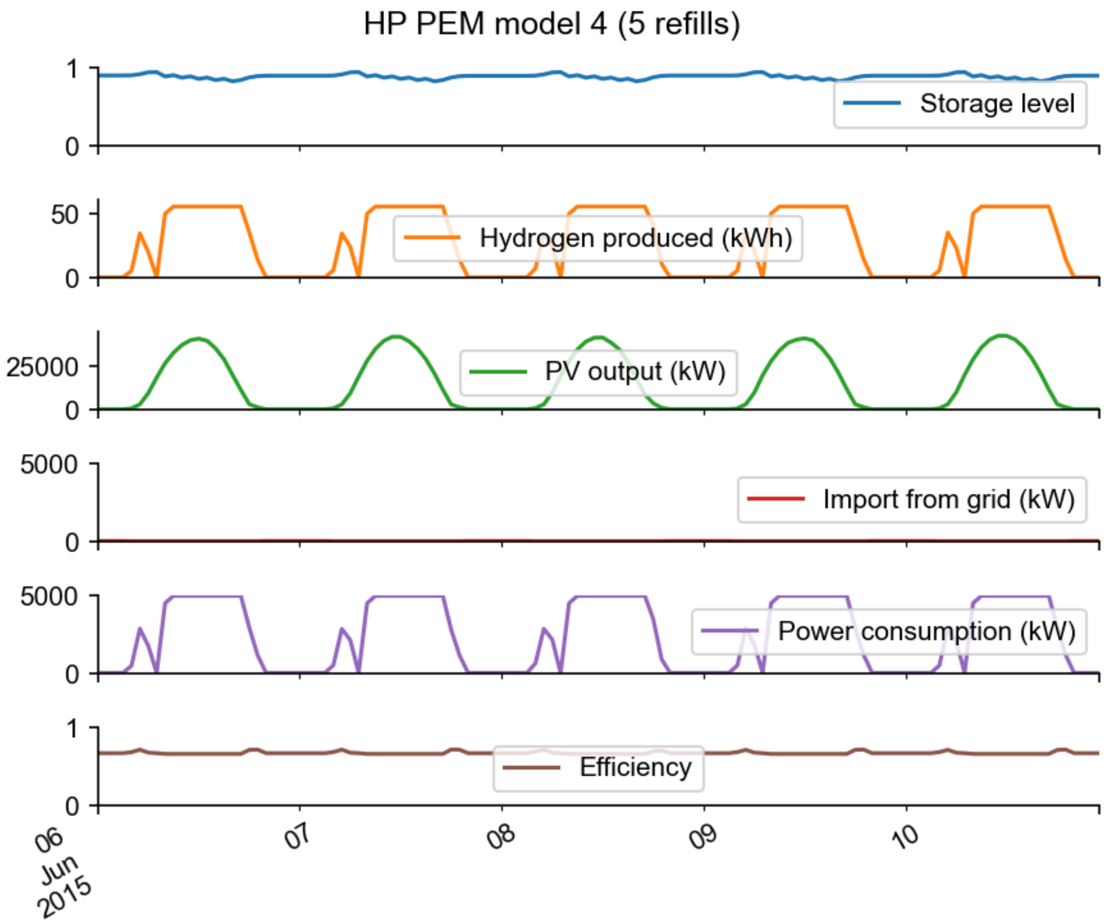


Figure 32: Best 5-day period of solar PV. Model output showing 5-day operation from the electrolyser system

Table 7 during the best 5-day period almost all the electricity used for hydrogen production comes from the PV array with only 0.8% coming from the grid.

Table 7: Performance of hydrogen production during best 5-day period

Period	Total PV output (MWh)	Total import from grid (MWh)	% of PV used	% Input from Grid	H2 produced (kg)
06/06/2015 to 10/06/2015	1793.0	0.5	16.5	0.0	5,000

6.6.6 Seasonal performance

The worst and best 5-day periods show the electrolyser during periods of high availability of solar energy and low availability of solar energy. To fully understand the seasonal differences between the winter and summer we need to show the seasonal performance of the system.

 © Kiwa Ltd 2022

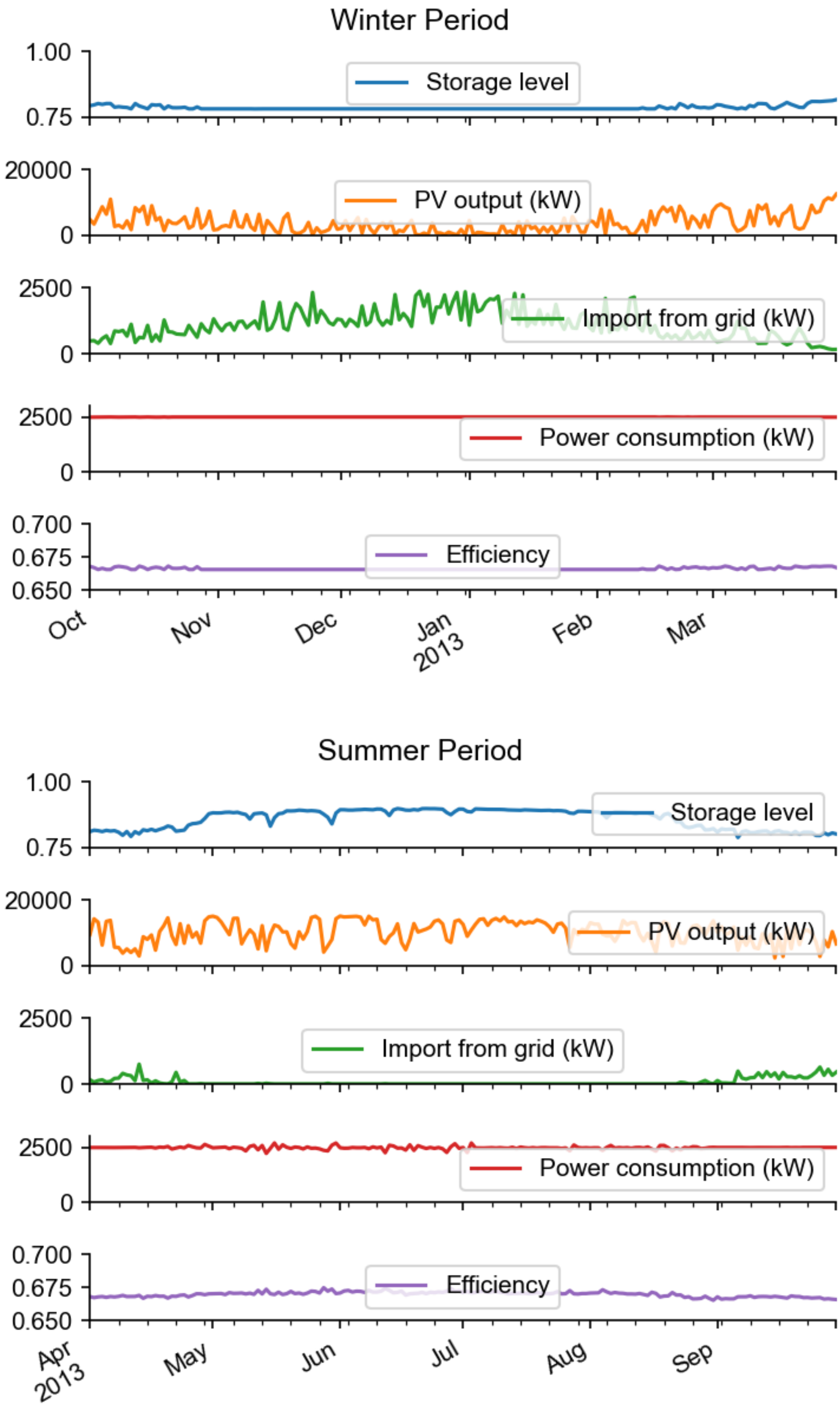


Figure 33: Comparison of electrolyser performance in the summer and winter

Section 6.4 showed the variability in the solar from summer to winter and that there is reduced solar output in the winter periods. Figure 30 also shows this difference between summer and winter with reliance on non-solar electricity increasing in the winter periods. Graphical outputs for the summer and winter periods have been shown in Figure 33 for comparison. The graphs for the 2012-2013 winter (Figure 33) show storage at the minimum level of 80% for almost the entire period as the amount of solar energy available is not enough to run the electrolysers. As electrical input not from solar is kept to a minimum the storage is not able to fill to capacity. This minimum input requirement is also why the power consumption and efficiency are constant during this period.

The actual monthly power consumption for winter and summer can be seen in Table 8. By comparing the blue sections (winter) with the orange sections (summer) it can be seen how the solar availability can be utilised by the system. Up to 63% of the energy used by the system in December 2012 would be non-solar due to the lack of energy available from the solar farm.

Table 8: Monthly energy usage of the electrolyser system – solar vs non-solar energy requirements

Season	Month	Energy (MWh)	Non-Solar (MWh)	Solar PV (MWh)	Non-Solar (%)	Total Solar Utilisation (%)
Winter 2012-2013	October	1852	622	1230	34%	32%
	November	1794	984	810	55%	52%
	December	1854	1177	677	63%	51%
	January	1854	934	920	50%	41%
	February	1673	614	1059	37%	32%
	March	1850	402	1449	22%	24%
Summer 2013	April	1791	93	1698	5%	24%
	May	1849	8	1841	0%	24%
	June	1780	3	1777	0%	22%
	July	1837	5	1832	0%	23%
	August	1836	18	1818	1%	22%
	September	1789	196	1593	11%	25%
				ANNUAL AVERAGE	23%	31%

6.6.7 New sources of renewable energy

The models have shown that due to periods of low solar output in the winter and due to parasitic loads, there are challenges around providing the required renewable energy to the electrolysers. The modelling has shown that a 5MW system on average will use 31% of the total solar output of the 50 MW solar farm (Table 8). Despite this utilisation 22.6% of the annual electricity demand cannot be provided from the solar farm. The amount of renewable energy available especially in the winter periods therefore needs to be increased to enable green hydrogen to be produced all year round. During the lowest periods of solar output around 2.5MW of additional renewable energy is needed. This new renewable energy resource needs to be diversified away from solar as increased solar would not provide the additional electricity required. Wind energy is an example of a diversified source of energy which would allow for a greater share of renewable energy to be

© Kiwa Ltd 2022

used whilst also allowing increased utilisation as hydrogen could also be produced outside daylight hours. Assuming a 40% capacity factor[50] this would require 6 MW of wind power. Designing and sizing the additional renewable energy capacity required to provide this energy is outside the scope of this report.

Even with new resources of renewable energy available, because of the intermittent nature of generation from renewables there will always be periods where no renewable electricity generation is available. Grid backup is an important part of the project to enable the system to operate during these periods. The limit for grid import into production should be set at around 5% of total electricity used. The reasons for this are presented later in this report on carbon intensity of the hydrogen (section 8.5).

6.7 Specification of The Complete System

There are two options that are considered in the system design, although this has not had an impact on the renewable energy available. There are some minor differences which do impact the specification of the whole system (Table 9).

Table 9: Resource requirements for Option A and Option B

	OPTION A	OPTION B
Renewable Solar	Existing 50MW system Option for expansion	New 45MW system
Additional Renewables	2.5MW	2.5MW
Size of Electrolyser	2× 2.5MW electrolysers Future option for 7.5MW total	2× 2.5MW electrolysers
Storage	3 Bullets Future option for 5 bullets	3 Bullets
Compressors	2 Compressors	2 Compressors
Refuelling station	350 Bar tanker refuelling station	350 Bar tanker refuelling station
Personnel cabin	1 personnel cabin for site staff	1 personnel cabin for site staff

As stated above the additional renewables required have not been designed; rather a price has been assumed for the electricity that meets the current price for PPA contracts in the UK. For clarity for the purposes of this feasibility study, the following system components have been specified (sized and costed) for the S+IP site.

- Electrolysers
- Storage (in the form of bullets)
- Compressors

[50] https://www.eci.ox.ac.uk/publications/downloads/sinden06-windresource.pdf

 © Kiwa Ltd 2022

- Refuelling station
- Personnel cabin

This section sets out the final design whilst also including room for future expansion which is available in Option A. This allows for development of the hydrogen production. A simple flow diagram has been included to show how the specified equipment fits together. The physical layout of the hydrogen production system is also shown in this section.

6.7.1 System Flow Diagram

Figure 34 is a diagrammatic representation of the basic components of the proposed system. The electrolyser is supplied with green electricity from the PV array was much as possible, with electricity being supplied from the grid when solar electricity is unavailable. Hydrogen is produced and then must be compressed prior to refuelling the road tankers. Outside periods of demand and to maintain backup supply, hydrogen is produced and sent to storage. Any hydrogen removed from storage must also be compressed prior to refuelling.

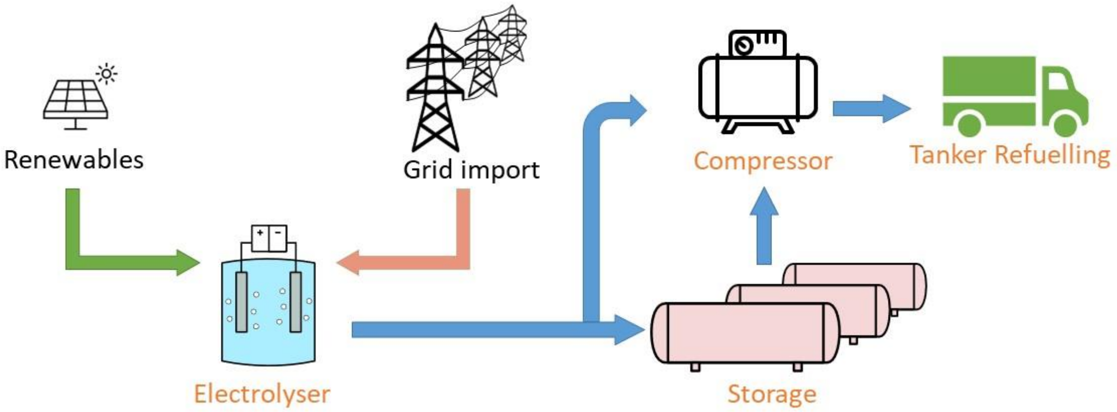


Figure 34: Block diagram of proposed system

6.7.2 Electrolysers

As previously specified a Polymer Electrolyte Membrane (PEM) has been selected as electrolyser type for use with the renewable energy supply at S+IP. As well as being able to respond to changing electrical supply more readily than alkaline electrolysers, this type of electrolyser has the additional benefit that hydrogen can be produced at a high enough pressure (30 bar) to be injected to storage without further compression. This is particularly useful as the hydrogen can be sent directly to storage without further compression required. Two electrolysers have been specified in the system design. This has been done to ensure that there is backup hydrogen available in the event of unplanned failure or scheduled maintenance. The proposed plant layout includes room for an additional electrolyser, allowing room for future expansion. Each containerised electrolyser has a footprint of 75 m^2, giving a total footprint of 225 m^2 for the electrolysers.

 © Kiwa Ltd 2022

6.7.3 Compression

The PEM electrolyser will produce hydrogen at around 30 bar which is suitable for storage without further compression. However, refuelling of hydrogen tankers takes place at around 350 bar, so hydrogen supplied from storage or direct from the PEM electrolyser would require further compression prior to refuelling. The system has been designed with 2 compressor trains so there is redundancy in the event of planned or unplanned outages.

Allowing for the footprint of the compressor skids and a firewall to maintain the required safe distance zone, the compressor trains are to be housed behind rectangular firewall of area 430m^2

6.7.4 Storage

Each storage bullet is approximately 25 metres long from tangent line to tangent line, and 4 metres in diameter. The bullets will be housed in a 600 m^2 area surrounded by a permitter fence. This will protect the minimum save distance between and around bullets and associated valves. This area has been sized to accommodate a total of 5 bullets, allowing room for future expansion.

6.7.5 Security of supply

The basis for the system design work is security of supply. The system design has implemented redundancy in the system design so that faults with the system and breakdowns can be covered by backup equipment. For example, two compressor trains have been included to allow for constant supply for the refuelling system even during equipment breakdown. The decision to install multiple electrolysers also allows for continued operation of the system even if one electrolyser goes down (maintenance or system fault) as the system is operating at 50% utilisation with two electrolysers one electrolyser will be able to provide all the hydrogen by running overnight to ensure security of supply.

6.7.6 Plant layout and importance of ATEX Zoning.

In the sections above, the footprint for each piece of equipment-based on manufacturers' information have been used for the study to set out the physical footprint of equipment, which are shown in the system layout design and in Table 10. However, the plant layout is not just dependent on the equipment size and operation of the site. The distances between equipment are also dependent on the hazardous zones needed to ensure that operation of the plant remains safe even in the event of equipment failure. These distances set out the minimum distances which need to be maintained between equipment.

Table 10: Plant layout for the hydrogen production and refuelling system

Equipment	Length (m)	Width (m)	Area (m^2)
Electrolysers	15	15	225
Compressors	23.8	18.8	447
Storage bullets	40	40	1,600
Refuelling station	15	5	75
Personnel cabin	10	10	100
Total size	41.5	84	3,486

The Modelling using Quadvent has showed that a minimum safe distance of 5 m should be observed around any potential leak points, such that a flammable atmosphere of 25% LEL cannot be reached.

 © Kiwa Ltd 2022

This minimum distance was used when designing the plant layout and applied to valves, flanges at to the outlet from the storage bullets (located in the centre line of each bullet). The compressors also had a minimum distance associated with them but, due to the elevated pressures, also have a wall around them for additional protection.

The total area that is required for the site is 3,486m^2. The space requirements and layout have been sized for Option A. This is the total area and includes all equipment excluding the access road required by the filling tankers. The site also includes area for expansion by allowing additional equipment to be put onsite if required in future with room for two additional bullets and an additional electrolyser.

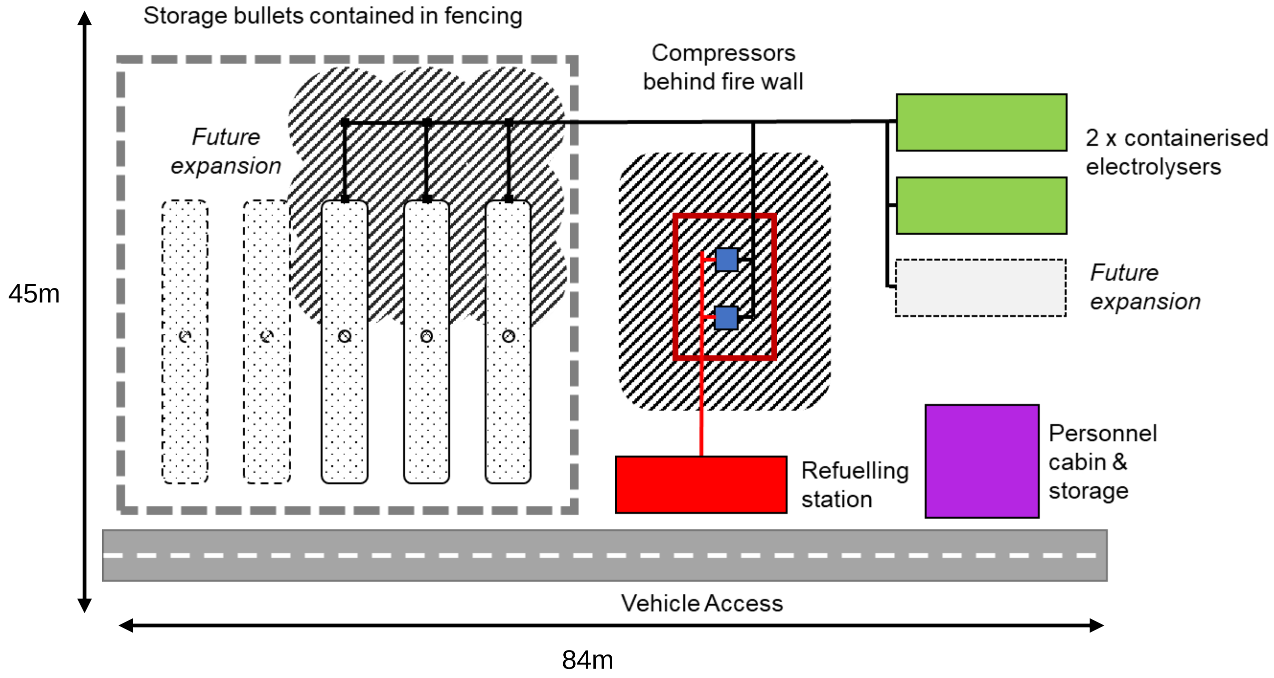


Figure 35: Hydrogen production plant layout

Figure 35, is a suggested plant layout, showing the relative sizes of each component and the necessary spacing between each component to maintain safe distance. The drawing is to scale to show how the site would look with the required separation distances. For context to the site Figure 37 shows how the proposed production plant may be situated on land at S+IP. The area has been chosen due to the colocation of the solar farm which would reduce electrical connection costs. Information from the site has also shown that utilities required by the production plant are also available at the location. The suggested location is within a currently empty field within the site, earmarked for development and would sit just to the North of the runway.

Tankers would have access to a refuelling layby or slip road from off the runway. The location of the proposed location and suggested field can be seen in the context of the wider site, in Figure 36.

 © Kiwa Ltd 2022

Figure 36: Suggested plant location in context of the wider site

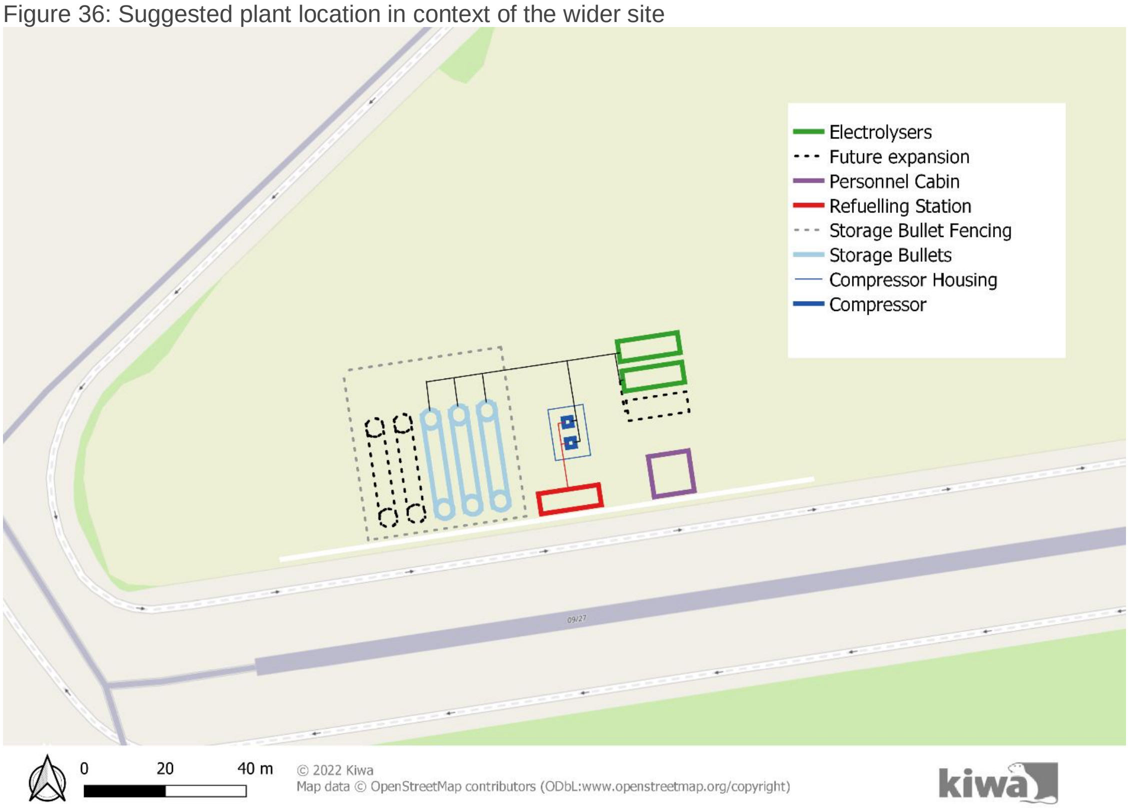


Figure 37: Suggested plant location at S+IP

7 Commercial and Financial Case

It has been shown through modelling of the production and storage of hydrogen that it is technically possible for an electrolyser to produce renewable ('green') hydrogen for transport demands at the S+IP. The final part of the feasibility study is to show how the hydrogen produced at S+IP has the potential to be economically viable. The first part of evaluating this viability is to assess the price of hydrogen. This is important to understand how the acceptability of hydrogen produced to the end users. Due to the production cost, hydrogen produced at S+IP will be more expensive than the status quo diesel, but on a life cycle cost basis the hydrogen vehicles can be cost competitive with electric vehicles, as well as fitting specific requirements of longer distances covered per day. The price of hydrogen does play a big part in making hydrogen a cost competitive choice of fuel.

7.1 Scope of the costing study

For simplicity, the costing models discussed in this section are for an initial phase of the development of hydrogen at S+IP and are based on a minimum case for hydrogen production. Any additional revenue from hydrogen at the site has also not been included. This includes increased revenue for hydrogen produced through increased utilisation of the asset in the summer months with additional daylight hours and due to the introduction of wind energy to the site allowing the production to be utilised outside daylight hours. The costing study has included all the equipment required to deliver the hydrogen up to the point of the filling tankers for transporting hydrogen to end users. The boundary of the costing for transport therefore stops at the site and does not include the infrastructure required to refill any transport vehicles off site or the vehicles themselves. The full costing of all the equipment required by the production technology has been included in the sections below.

7.2 CAPEX of the production technologies

The capital cost of the production technologies chosen have been developed by using the optimised scale of production, storage and the main ancillary equipment needed to provide hydrogen for tanker refuelling at S+IP. To develop the estimates, Kiwa has worked with technology providers to gather the costing information required and has based some costs on available information. As a hydrogen facility at the 5 MW scale is large for electrolyser installations in the UK (2 x 2.5MW), the cost information has been used alongside accepted industry costing factors which allow estimates to be made of the installation and maintenance costs. This method of cost modelling has been widely shown to provide an estimate of in the range of ±30% which will allow the economic viability and ultimately feasibility of the project to be assessed. More accurate costing can be achieved through work to produce detailed designs of the proposed production, storage, and distribution technology. This detailed work is outside of the scope of this study and would be completed in a subsequent project.

The capital expenditure (CAPEX) of the electrolyser system has then been validated with information available in literature to ensure they fit within the ranges found in other projects. In particular[51] and the IEA GHG 2017[52] report provided useful comparison cost information for electrolysis technologies. The installation costs which form part of the CAPEX have also been calculated using factors (Table 11) which are based on the equipment costs. As the installation

51 "What is needed to deliver carbon-neutral heat using hydrogen and CCS?" https://pubs.rsc.org/en/content/articlelanding/2020/ee/d0ee02016h
52 https://ieaghg.org/exco_docs/2017-02.pdf

 © Kiwa Ltd 2022

costs are dependent on the equipment every effort has been made to provide accurate equipment costs for the technologies.

Table 11: Factors used to calculate the installation costs

Item	Factor
Permitting	FIXED
Installation	0.1
Electrical	0.1
Buildings	0.02
Site	0.05

The equipment CAPEX also included common items which are utilised most notably the storage, distribution, and filling infrastructure. These items were also costed using quotes for equipment and values from literature.

Table 12: Total CAPEX including installation costs and cost per kW installed capacity for the Electrolyser system

CAPEX	Development
	PEM Electrolyser System (5 MW)
Equipment Cost (£)	£6,010,000
Installation Cost (£)	£1,773,000
Total Capex (£)	£7,633,000
Equipment (£ / kg equipment)	£1,828 £/kg (hydrogen output)
Total CAPEX (£ / kg installed)	£2,322 £/kg (hydrogen output)

The figures presented (Table 12) represent the costs in 2020 for purchasing and installing the required technologies. There has been discussion around the installed cost of electrolyser systems and increased adoption if the technologies will see the price of this technology fall in price over the next few years. The costs presented are the current costs of the technology chosen to produce hydrogen at the S+IP.

To assess how the costs in this work compare to other pieces of work £/kW figure can be used. The equipment £ / kW of installed capacity is an important figure as it allows the comparison with literature values for the installation costs of these technologies. Accepted costs for electrolysers from literature is around £880 / kW. The costs for the equipment used in this work when we take away additional equipment from the electrolyser the projects equipment cost comes to be around £1000 per kW. This is slightly greater than literature costs however as the system design is for 2 units, the cost increase fits with the costs associated with duplicate equipment that would not be required when purchasing one individual unit.

7.3 OPEX of the production technologies

The operating costs have been calculated from the energy and utility use but also factors using the capital cost to estimate some fixed operating costs. Energy use dominates the operating costs for the electrolyser technology as it requires large amounts of electricity to produce the hydrogen. The

 © Kiwa Ltd 2022

energy costs for the production technologies have been based on expected utility figures for 2021. Energy figures do fluctuate year to year and has seen some recent price increases however the prices used allow for the economic viability and ultimately feasibility of the project to be assessed

The operating expenditure (OPEX) of the production technologies have been estimated from factors based on equipment CAPEX - Fixed Costs) and energy and utility requirements (Variable Costs). The Fixed and Variable Costs together make up the total OPEX of the project.

The Fixed operating costs have been calculated from the Equipment and Installation CAPEX and as a factor of the total operating costs. The following factors have been used for the Electrolyser (Table 13) OPEX calculations.

Table 13: Factors used to calculate the fixed operating costs

Item	Factor	Factor of
Maintenance	0.03	3% of Equipment CAPEX
Labour	0.15	15% of The Total Operating Cost (Excluding Utilities)
Monitoring	0.02	2% of The Total Operating Cost (Excluding Utilities)
Overheads	0.5	50% of the Labour Costs

Table 14: Utility cost per unit, variable, and total fixed costs

Utility	Cost	Annual Operating Cost
		Electrolyser (5 MW)
Electricity	5p (p/kWh)	£1,124,000
Demineralized water	188 (p/m^3)	£14,000
Instrument Air	0.4 (p/m^3)	£2,000
Misc.	N/A	£18,000
Total Variable Cost		£1,158,000
Total Fixed Cost		£239,000
Total OPEX		£1,397,000

The Variable operating costs are based on consumption of utilities. This has been taken from information provided by the technology vendor and checks made of plant efficiency so ensure it matches the values found in literature. The costs are then calculated using prices based on data for utilities from 2021. These prices can be seen in Table 14.

The total OPEX for the Electrolyser is dependent mainly on the cost of electricity, the main input into the plant. The sensitivity of the Electrolyser to the price of electricity can be seen in the total OPEX cost which is mostly made up of this cost. This sensitivity is not unexpected and has been reported in previous work completed on electrolysers. From the demand modelling we know the annual hydrogen production for the system. From this we can calculate a very basic break-even cost based on the total OPEX of the plant (Table 15).

 © Kiwa Ltd 2022

Table 15: Simplified OPEX break even estimates for the price of hydrogen

Utility	Annual Operating Cost
Total Hydrogen produced kWh	14,381,000 kWh
Total Hydrogen produced kg	365,000 kg
Technology	PEM electrolyser
Total OPEX	£1,397,000
OPEX Break Even (£ / kg)	£3.83 kg
OPEX Break Even (p / kWh)	9.7 p/kWh

7.4 Electricity prices

As the OPEX has shown in the co sting study the sensitivity of the cost of hydrogen to electricity prices is very high. The lower the electricity price that can be paid for the hydrogen production the more economical the site will be. The current price of electricity paid by the purchaser via a power purchase agreement (PPA) from the site is unknown as this is confidential contractual information between the parties. It is known however what the average PPA price is for renewable solar and wind electricity. This price is determined by the value of the renewable electricity is to the purchaser and therefore there is variation in the price between solar systems. Typically, in the UK these prices are around £50 /MWh on average and have been stable in recent years (Figure 38). The cost of electricity for the electrolysers should therefore closely match these costs as the project requires electricity before it has been exported to the grid (behind the meter). This “direct” connection to the renewable generation is an important consideration for the project as once electricity has been exported into the grid there are additional costs associated with using the electricity network which drive up the electricity costs.

As the electricity that the project requires is behind the meter, electricity is provided directly to the electrolyser system, with excess exported to the grid; this allows a low cost of electricity to the system of 2 x 2.5 MW. For the cost modelling, an electricity price of 5p/kwh has been used for the electricity price at the site. This is in line with expected selling prices in PPA contracts to the grid. This price should also be in line with expected prices for future renewables when connected to the grid as the prices are expected to fall over the next few years. These prices are much lower than could be expected from grid electricity where the expected cost for large demands can be around 11p/kwh (2021).

Table 16: Impact of electricity price on the breakeven cost of production

Utility Price (p/kWh)	OPEX Break Even (£ / kg)
4.50	£3.51
4.75	£3.67
5.00	£3.82
5.25	£3.97
5.50	£4.13

 © Kiwa Ltd 2022

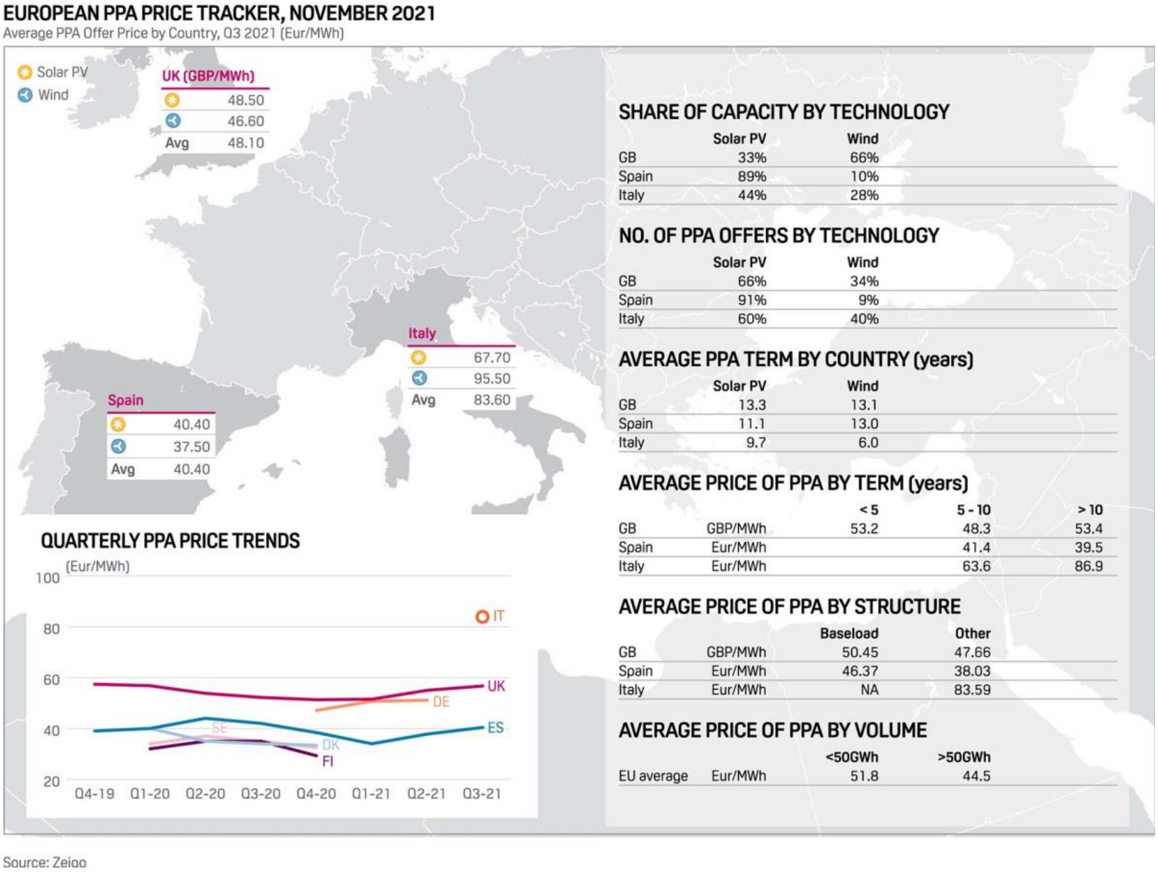


Figure 38: Average PPA price tracker for the UK Spain and Italy Q3 of 2021[53].

The sensitivity of the hydrogen production with electricity price is shown in Table 16. As expected, being the single largest cost of production even a small increase in the cost has an important impact on the overall cost of hydrogen. A 20% rise in the electricity cost gives a 16% rise in hydrogen break even cost.

One of the risks that should be noted here is that there is an emerging risk with the instability of energy prices that has occurred in recent months. The forward price for electricity markets as this report is being written are showing high volatility. Should there be long periods of high prices in the UK it is likely that PPA cost would also increase. This is due to purchasers who will look to fix their electricity at a lower cost willing to pay a higher price per unit of energy. It is not known how the market will move long term and whether higher prices will impact the project long term. This is due not only to energy costs causing the price of hydrogen produced to rise but rising energy costs also driving up the cost of counter factual technologies which offset the increase

7.5 Discount rate and final hydrogen price

The simplified OPEX break even estimates presented in the previous section do not consider the profit required when producing the hydrogen. Therefore, we need to add on some cost to get a calculation of the overall price of hydrogen. This is done by using a discount rate for the capital investment required for constructing the plant.

[53] Source www.zeigo.com

7.5.1 Plant lifetime

For the lifetime of the plant, a 15-year life has been assumed as this fits with the timescales expected for project using the government pricing models. This timescale also fits with expected development of hydrogen infrastructure as hydrogen produced by the plant could play an important part in the region's energy supply. The end of the plant's lifetime will be when national scale hydrogen infrastructure is available in the region, and whilst the plant could continue to support hydrogen transport in the region after this period it is likely to be less cost effective than national infrastructure. The plant will eventually be phased out when cheaper alternative sources are present in the region which is why extended lifetimes have not been used in this work. Due to the geography of the area national scale infrastructure is unlikely to be in place until the late 2030s.

7.5.2 Discount / Hurdle rates

As this report is a feasibility study, we are not able to represent the financing cost as a £ / MWh component of the hydrogen price directly. However, as financing a project requires capital that which will come at a cost, we do need an acceptable methodology which allows us to take account of this cost. To enable us to do this a discount rate is used to account for the cost of the capital. The discount rate is used to set as the minimum financial return that a project developer would require over a project's lifetime. This is because the discount rate allows the cost of money to be assessed over the lifetime of the investment and is set to include the cost of the money invested (cost of borrowing the money or the return the money could earn in an alternative investment with similar risks). When technology and business risks are unproven the risks to the project require higher discount rates to be used to ensure that the correct rates are used. When assessing new technologies these rates are often also called hurdle rates. Hurdle rates consider the higher risks associated with new technologies or business models and include both the cost of money and the risk taken on by the developer.

Increasing the discount rate increases the price of hydrogen product by discounting the future revenues from production. Lower hurdle rates give less weighting of the upfront CAPEX and therefore would result in lower hydrogen prices, with later year volumes being discounted less. Lower discount rates would also be used if the project can be shown as being low risk, and that the production throughout the project's lifetime will generate a sufficient rate of return with a very high certainty. The rate is set individually by the developer and reflects their analysis of the risk. The more certain a developer can be in the project the lower the hurdle rate. The rate used in this study therefore represents the investor's minimum required return (hurdle rate), given the investment risks.

These hurdle rates are often specified for certain technologies and are therefore used in many studies looking at future hydrogen costs. As the project's discount rate or hurdle rate is a measurement of the risk of the project a low social discount rate of (3.5%) used for well proven investments cannot be used. Due to lack of knowledge on technology specific hurdle rates at this early stage the government's recent work on hydrogen production costs has been used [54]. This work sets a 10% hurdle rate to discount costs and output across time as a sensible hurdle rate for hydrogen production. Future work may of course update this assumption and lower this rate. A value of 10% has therefore been chosen to match the government's discount rate specified in the Green Book and the government's report on Hydrogen Production Costs 2021.

[54] Hydrogen production costs 2021 - GOV.UK

© Kiwa Ltd 2022

To calculate a hydrogen price the revenue needed to set Internal Rate of Return (IRR) equal to the discount rate has been calculated. This is when the net present value NPV of the project equals zero. This sets the IRR as equal to the Discount Rate. Setting the NPR to zero allows a hydrogen price to be calculated which provides the minimum return for the investor. The Internal rate of return for the project and cash flow are shown in Table 17.

Table 17: Calculations of Depreciation and Annual ROI and NPR for the Electrolyser

Item	Annual Cash Flow
Life of plant	15 Years
Discount rate / minimum IRR	10%
Total OPEX	£1,397,000
Total CAPEX	£7,633,000
Additional Revenue to Meet 10% IRR	£1,036,000
Total Revenue	£2,433,000

The return on investment for the Developer is also a key output and a result of optimisation of a base case. The potential work and upsides to sell hydrogen under short and attractive spot contracts have not been included in the pricing work here, and increased utilisation of the asset for hydrogen demands other than those modelled is not included. It is likely that this additional revenue would provide further revenue for the developer. Access to hydrogen volumes above the fixed contracts that will likely be required to secure FID on a project further attract the interest of private investors to fund the Developer.

7.6 Price of Hydrogen

The price for hydrogen in the base case has been calculated from the OPEX, Capex and revenue required to meet the 'hurdle rate' of 10%. This is also the minimum IRR required by the project. It is assumed that the facility operates at full system capacity from day 1. The hydrogen price shown (Table 18) is the price for the company collecting the hydrogen from the site. This accounts for the energy needed to get the hydrogen up to the delivery pressure for tankers transporting the hydrogen away from the site but not the cost of the transportation to the end user. More information on transport costs is provided in the following sections.

Table 18: Price of hydrogen

	Cost of Hydrogen
Technology	Electrolyser (5 MW)
Transport Hydrogen Cost	£6.66 per kg 17.0 p / kWh

The price of hydrogen specified in Table 18 is the minimum price that would need to be charged by the developer of the hydrogen system. As discussed in the previous sections 10% has been used as the required IRR to match the 10% hurdle rate specified. The impact on hydrogen price for different IRR has been presented to show what the price is for different IRR (Figure 39). This

 © Kiwa Ltd 2022

allows the price variation to be assessed and for developers that require higher or lower hurdle rates to be met to assess the viability of the investment.

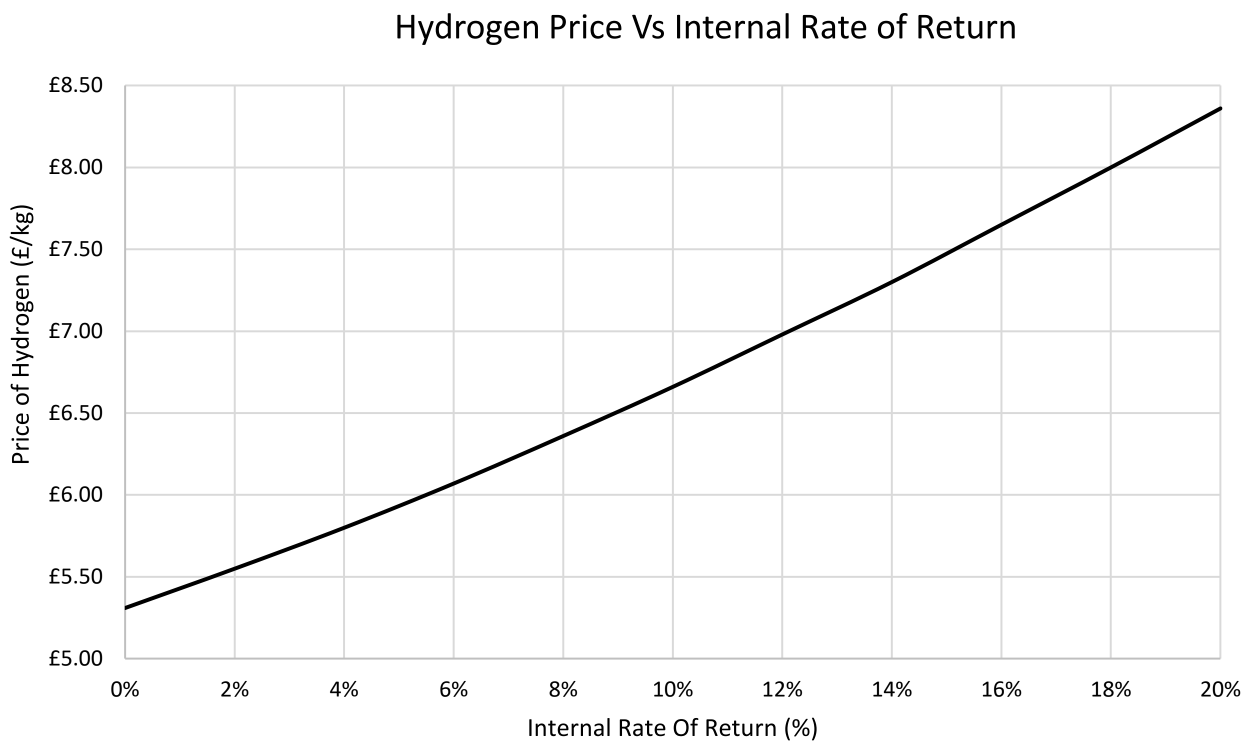


Figure 39: Hydrogen price vs internal rate of return

7.7 Government support

As previously stated, for the project to be feasible, the use of hydrogen must be economically viable. Ultimately, the acceptability of the final price of hydrogen depends on the end use, in this study transport, must be able to operate with these costs of energy. There are several government support mechanisms which could be used by the developer to lower the price of hydrogen for the end user. Grant funding could be used to reduce the risk to the developer by lowering the CAPEX costs. As 40% of the hydrogen price covers the CAPEX, investment grant funding could have a significant impact on lowering the hydrogen price required by the developer to meet their minimum return by reducing the revenue required. The level of government support and the impact on the hydrogen price (Figure 40). Grant funding for a project would reduce the risk to the developer but also reduce the capital required to build the production facility. This results in lower prices for the hydrogen product. With 50% grant funding reducing the hydrogen price to £5.24 per kg at a 10% IRR.

Further support for the production could be found in the RTFO scheme which could provide income for each kg of hydrogen produced through the ability to claim RTFCs which when traded would provide at current prices £1.374/ kg of hydrogen produced. This could rise to a maximum of £2.29 / kg which is the current cap in the scheme. By including grant funding at 50% of the CAPEX (matched funding) and RTFOs using current RTFC prices of £1.374/ kg the price of hydrogen could be as low as £3.86/kg or 9.8p/kWh at a 10% IRR.

 © Kiwa Ltd 2022

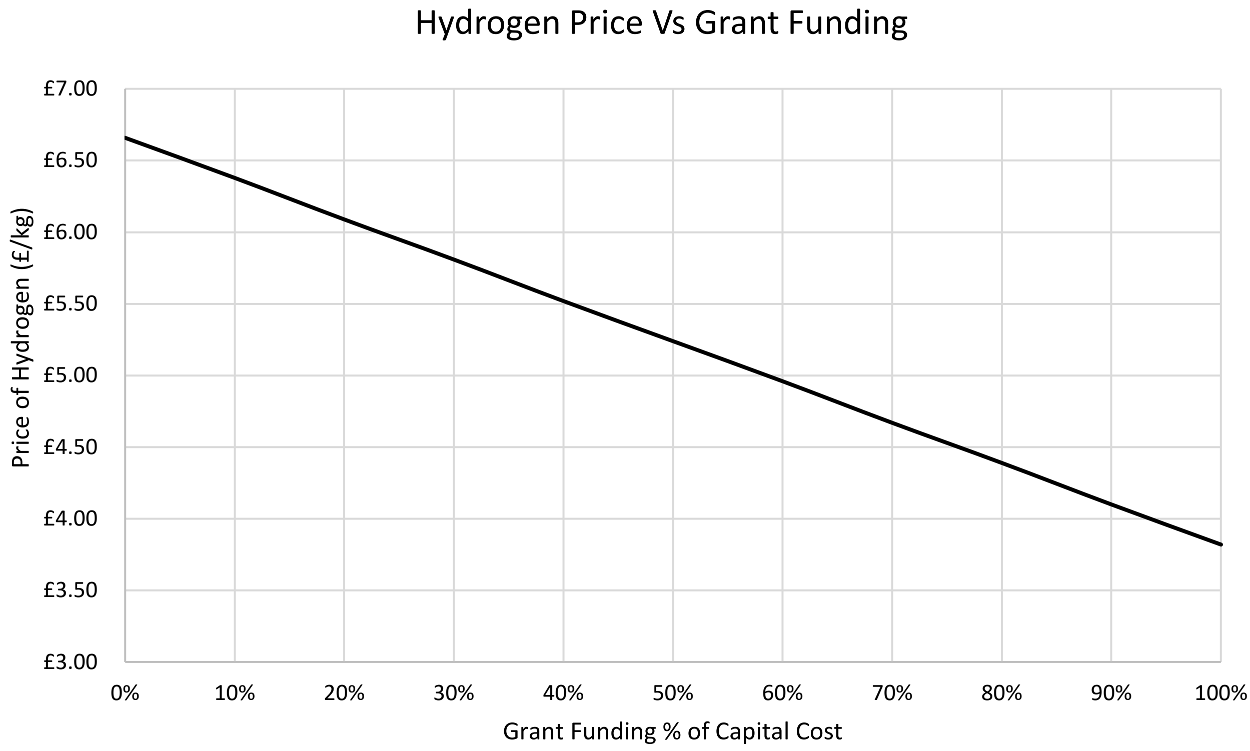


Figure 40: Hydrogen price vs grant funding of capital cost

7.8 Cost of hydrogen

As this project has multiple social benefits around reduced carbon emissions, cleaner air, less noise pollution etc. any estimated target hydrogen prices should be compared with EV prices rather than compared with current diesel costs. In other words, public and most private transport providers are not going to buy new diesel vehicles. However, there are applications which cannot be met with current battery electric technologies for example some bus routes, HGVs, and heavy on-site vehicles, which does allow for some comparisons to be made.

For hydrogen from electrolysis, the achievable price is largely dictated by the price of the electricity used and the way in which the hydrogen production system is operated i.e. usage/uptime. Previous work with electrolyser technologies have shown that hydrogen costs for transport applications are typically based on the electricity price that can be achieved. A large factor in favour of the S+IP is that Grid Connection / sleeving charges are avoided for all the renewable electricity provided which is why the minimum price of £6.66 per kg is lower than typical values.

The price for hydrogen in the UK has been variable over the past 3 years, this is mainly due to the supply constraints discussed in previous sections. This has led to high demand for hydrogen with the cost of bottled hydrogen increasing by 300% since 2018. This has been caused to some extent by a lack of infrastructure in the UK for delivering hydrogen. Europe on the other hand has seen stable prices for hydrogen over the same period as it has not had the same constraints. Bottled deliveries do tend to be at a much higher cost than can be used for transport applications at around £50 per kg of hydrogen with recent prices peaking at over £100 per kg.

Bulk deliveries of hydrogen on a larger scale have not had the same volatility in pricing and are usually delivered at a lower overall cost compared to bottled hydrogen. The price for these deliveries depends on the location and the quantity required but do benefit from efficiencies due to scale. The market has recently seen some challenges where the increase in the price of gas which has impacted industry across the UK also pushing up the manufacturing costs of hydrogen impacting bulk hydrogen costs.

When hydrogen is not produced and consumed on site, the price of hydrogen is also impacted by the delivery cost of transporting the hydrogen and the end use compression to supply pressure. This price is very dependent on the distance that the gas is transported as long distances can have a significant impact on the overall price. This has not been included in the costing and will need to be assessed by the end user. The cost of delivering large amount of hydrogen over short distances has not been the focus of many studies which often focus on large-scale long-distance deliveries. The costs for shorter distances do have an impact as the fuel consumed is recued on such trips. Distribution costs for hydrogen up to 50km from production have been estimated to be around £0.8 per kg of hydrogen delivered[55]. Studies looking at refuelling station deliveries have identified gaseous deliveries as the best solution for short distance deliveries with costs of around £1.5 per kg [56]. Both these studies assessed larger quantities of hydrogen deliveries than would be possible from S+IP however as gaseous hydrogen deliveries do not scale well these number could provide an estimate of delivery costs of around £2 per kg.

Current hydrogen prices for transport applications are not easy to evaluate as the market is small in the UK with a limited number of refuelling stations providing hydrogen at commercial rates. Typical prices ranges found are between £10 - £15 per kg of hydrogen with reported prices of around £12 per kg typically accepted as the price at the limited number of UK refuelling stations. Supply for bulk deliveries is variable due to demand and location however it is unlikely to be lower than £10-£15 per kg.

The price hydrogen can be sold into the market ultimately depends on the end user of the hydrogen. As discussed, there are some applications in the UK using bottled hydrogen at above £50 per kg but these are small demands typically for specialist use but which may be attractive to some users bringing SMEs to the S+IP. To meet the scale required to make the system technically and economically feasible the production from the site will have to meet the bulk hydrogen market for transport demands. The transport use will therefore set the minimum price which can be charged for the hydrogen. To understand what the market will pay we can compare energy prices to get an understanding of the price the end user could pay. We can levelise the fuel cost across technologies by converting for technology efficiency. Here energy conversion efficiency has been normalised so the technologies can be directly compared (Table 19) with hydrogen both with and without government support.

Table 19: levelised price of usable energy for different transport fuels (excluding transport to filing sites).

Energy Type	Energy Price (p/kWh)	Efficiency of Energy Conversion	Levelized Price (p/kWh usable)
Electricity	15.0	0.80	18.8
Hydrogen (No gmt support)	17.0 (£6.66/kg)	0.44	38.9
Hydrogen (With gmt support*)	9.8 (£3.86/kg)	0.44	22.3
Diesel**	14.9	0.32	46.6

*50% of the CAPEX (matched funding) current RTFC prices of £1.374/ kg

[55] Competitive Hydrogen Delivery: The cost of trucking. https://www.greenbox.global/post/hydrogendelivery
[56] Determining the Lowest-Cost Hydrogen Delivery Mode. Yang, Christopher;Ogden, Joan M 2008

 © Kiwa Ltd 2022

**diesel price of £1.50 per litre

These costs do not consider the differences in infrastructure and operating costs of the different technologies so have limited use as a direct comparison of the technologies themselves. It is useful to understand some of the differences in the operating costs between the technologies and current energy costs compare to hydrogen.

 © Kiwa Ltd 2022

8 Management Case for H2 Production at S+IP

Whilst the Feasibility Study seeks to define a ‘main’ business case of sufficient interest for a Developer to take the project forward, it is vital that there is sufficient attractiveness perceived in the project from the other two principal participants: the owners of the site, the Science Museum Group (SMG) and the Government - represented locally by the SW Energy Hub and supported by the SWLEP. Attractiveness to these overlapping and well aligned three main interested parties are summarised in the following diagram (Figure 41), before going into more detail on each.

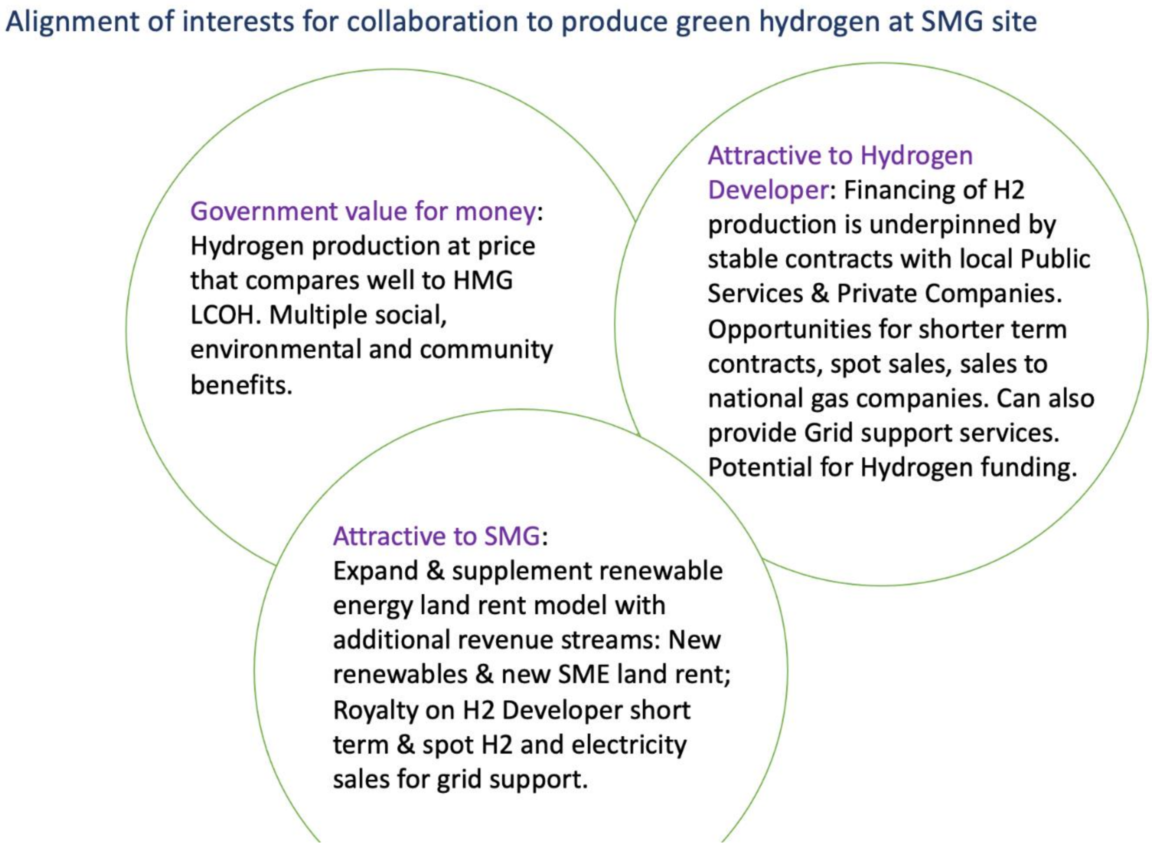


Figure 41: Alignment of interests for collaboration to produce green hydrogen at SMG site

8.1 Business Case/Attractiveness for the Developer

A particularly attractive structure for a Developer of the hydrogen production facilities would be to enter into a Partnership Agreement with a Developer of new renewable energy. With such a strategic partnership alignment, the Hydrogen Developer would not then in practice be beholden to the market electricity price- a key input assumption of the Green Book Methodology for green hydrogen production. Instead, the Partnership could optimise their ‘private-wire’ (within the site) electricity price arrangements to maximise their combined profitability from the hydrogen sales. In any case, the Grid supply charges would not be incurred whenever the renewable electricity remains on the site.

A further optimisation in structure and commerciality could come from the new renewable energy Partner being committed not to a single technology, but to multiple and innovative clean energy generation technologies. Examples would be technologies involving harnessing kinetic energy from wind[57]. The Partnership would then be incentivised to incorporate innovative technologies that will improve their commerciality; this in turn will encourage wider 'roll-out' from the S+IP of the new technology by other projects and regions.

Following on from the relative favourability of the site, and crucial to the attractiveness to a Hydrogen Developer, the initial size of the project was optimised both for technical reliability e.g. two, rather than one electrolyser, and to provide some additional volumes to have high confidence to be able to supply contracted volumes and to provide (limited) opportunity to take advantage of short term and spot supply contracts.

In other words, whilst the project is expected to be underpinned by relatively long-term contracts with local transport companies, it is not optimal for either the Developer or the buyers to be locked into 100% of the output from electrolysers that are mainly powered by renewable energy. Examples of 'merchant' (shorter term and on the day, 'spot') contracts include SMEs onsite at S+IP who use hydrogen for testing or for use all the way up to national carriers of hydrogen by road who have short term demands to meet. In addition to initial contracts with HGV logistics companies, hydrogen could be made available for testing by additional logistics bases in the Swindon area. Both being on the 'right side' of being able to supply hydrogen to meet long term contracts and some potential for economic upside increases the interest for a Developer, as well as helping a Developer to attract at least part private financing- an important Feasibility Study Workshop group output.

Whilst the ideal would be for a Developer to secure funding and to be able to press on with the development of the project without being dependent on securing government funding, there are a number of attractive schemes for which the project is eligible (4.1 - Opportunities for Government Funding).

8.2 Business Attractiveness for the Science Museum Group

Incremental revenue streams can be generated for SMG through development of S+IP as a green hydrogen Science and Innovation Park. At the same time, the proposed S&I Park builds significantly upon SMG's profile as a leader in scientific research, technological leadership, and education:

- Development of a hydrogen Science & Innovation Park is fully aligned with SMG's policy of "**F*ostering a Research Culture***", as witnessed by the group's commitment to: "E*xtend research networking activities, events and seminar programmes across all SMG museums and the National Collections Centre at Wroughton, to engage with regional and national partners and enhance SMG's position as an important part of the UK research infrastructure"*.
- Development of a hydrogen Science & Innovation Park at S+IP contributes to SMG's aspirational positioning. Establishment of a research and innovation hub for the SW green hydrogen economy contributes to the opportunity for SMG *"**to gain influence by delivering a world-class and sector-leading research programme** as a fully-integrated part of how the group works, expressing our international status, with an appropriate commitment to the highest intellectual standards".*
- Development of a hydrogen Science & Innovation Park at S+IP furthers the SMG cause of ***education and inspiration of the next generation through research***. The proposal to use the park for educational visits, training and testing contributes to SMG's aim of

57 . https://vortexbladeless.com

"enabling us to deliver the group mission of inspiring futures through the creative exploration of science, with the aims of building scientific literacy and inspiring the next generation".

8.2.1 Additional income from use of space at S+IP

The overall S+IP site extends over an area of some 220 ha. To build an expandable green hydrogen production and storage facility to the specifications included in this report, a relatively small area of c.0.35 hectares (0.07%) will be used, and rent will be received for this land use from the Developer of the hydrogen production facilities.

8.2.2 Income from tarmac testing track at S+IP

The S+IP contains a tarmac road test track made up of the former airbase runway(s) and aircraft apron routes. The test track has been used in the filming of Jeremy Clarkson's "Grand Tour" series as the test track for a wide variety of vehicles, confirming its serviceability. Two prototype hydrogen-fuel cell vehicles owned and operated by the S+IP itself have already been extensively tested on the track.

In the context of the Feasibility Study Workshop group output and recommendations for the site's use as a centre for research, piloting and testing of commercial hydrogen vehicle operation (see Appendix A), the availability of an existing, serviceable, fit-for-purpose test track boosts the credibility/perceived suitability of the site as an effective centre for hydrogen transport research and development activities and is highly likely to increase its attractiveness to locally/regionally-based commercial logistics operators interested in testing and piloting hydrogen-fuelled vehicles before scaling up hydrogen operations. Income to MSG would be generated from these track activities.

8.2.3 Exploitation and potential upgrade

Exploitation and potential upgrade and/or extension of existing solar farm at S+IP could be achieved by building on the Science Museum's Groups sustainability commitment and previous sustainable energy innovation activities. Through its development of photovoltaic solar energy at S+IP, the Science Museum Group has already taken a lead in net zero energy innovation for the local economy. The incremental development of green hydrogen production and storage capability using renewable energy is a) entirely consistent with SMG's purpose and b) further supportive of the sustainable energy commitments made by Swindon Borough Council through its Local Plan and Local Transport Plan (LTP3) – see also section 4 We would expect, in keeping with the Innovation Centre, taking a lead role in testing and using new renewable generation technologies, such as those using bladeless turbines and kinetic energy.

Attracting new zero-carbon business

In the context of the workshop's recommendations for the use of the site as a centre for commercial hydrogen transport research, piloting, and testing – space and facilities can be provided at S+IP for both public and private sector organisations to establish research and development bases.

New companies could come in and pay land rent, following the existing model, and make their own investments for buildings/facilities. Alternatively, and potentially more efficiently, SMG could invest to make one or more of the currently empty hangars ready for commercial occupation and use, it should be noted that:

 © Kiwa Ltd 2022

- Rental income from SMEs using such facilities would go to SMG; this would be additional to the rental income that would go to SMG as part of the hydrogen Developer costs.
- Planning permission for re-purposing would be expected to be uncomplicated given broad SBC support for the project (see section 4.5).

This could provide increased income from land use and/or upgrade currently some of the empty hangars and buildings at S+IP. In the context of the Feasibility Study Workshop's recommendations for the use of the site as a centre for commercial hydrogen transport research, piloting, and testing – space and facilities can be provided at S+IP for both public and private sector organisations to establish research and development bases.

In the context of the Feasibility Study Workshop's recommendations for the use of the site as a centre for a) commercial hydrogen transport training and b) green hydrogen economy education (See section 8.5) – space and facilities can be provided at S+IP for the development and provision of both private (training) and public (education) services. For these purposes, also, while moderate investment would be necessary to make commercial training facilities ready and to prepare and develop educational capacity and capability, it should be noted that:

- Rental income from training and fees for services would go to SMG.
- Significant reputational benefit would accrue both to S+IP locally and to SMG nationally, and this would increase interest and demand over time

8.3 Attractiveness for public sector investment

The project is fully aligned regarding the UK Hydrogen Strategy. The project would both be eligible, and in terms of timing, 'dovetails' well with the timing for national hydrogen grant funding. This is as mentioned in section 4.1.

As well as calculating full project costs, we have followed the Green Book supplement provided by HMG in calculating a Levelised Cost of Hydrogen (LCOH) that has enabled the favourable comparison of the estimated costs of this project with those in the document [58].

The project makes a significant contribution to Local and regional growth and to carbon reduction targets, as outlined in Section 4.1, and now detailed in the following section on the Environmental and Community Benefits. Specifically, the project fits the vision for a SW Net Zero Economy, playing a leading (catalysing) role in building the regional hydrogen economy for transport. Furthermore, the project will provide a multi-sector regional hydrogen cooperation hub. The project also fits into Western Gateway strategy and planning.

Because of the very high alignment between the three main participants, this makes the project more attractive. This is because, due to the limited time and resources of local government and public service bodies, projects need to be realistic in their requirements and risks at the outset, but also scalable – in this case as the demand for green hydrogen grows.

The possibility of funding the project with both commercial and government part-funded routes again adds to its attractiveness.

[58] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011506/Hydrogen_Production_Costs_2021.pdf

 © Kiwa Ltd 2022

8.4 Top 3 identified Risks & Opportunities

Many opportunities and risks were identified at the workshop and summarised in Section 4.3. Many of these considerations fed into developing the option for hydrogen production based upon long term contracts with transport companies that was developed in this Feasibility Study. As this option is taken forward, what are the top three remaining Risks and Opportunities?

PPA Contracts - There is a key risk that a deal cannot be agreed with the current owners of the solar park, to make use of existing solar capacity to produce hydrogen. Making use of existing capacity is a good first step and would appear to be easier than building new renewables. Discussions with the current owners of the solar park can also include the opportunity to re-power the S+IP solar farm with newer technology to almost double the capacity. However, as outlined above, building new renewables may offer far greater opportunities for strategic alignment between the new renewables Developer and the Hydrogen Developer.

Uptake of Hydrogen Vehicles - There is a risk that if the upfront CAPEX cost of hydrogen vehicles buses remains higher than that of alternatives, then the range, space and fast charging advantages of hydrogen buses may not outweigh the additional costs in the eyes of bus companies and HGV fleet operators. The 'whole life' sustainability of hydrogen fuel cells, compared to batteries, was identified as an important element to highlight in the project. This risk is being mitigated as further specifics on government funding for the bus companies are announced, in order that they may be leaders in the growth of the hydrogen economy. Thus, the bus companies may wait for specifics on their own funding before signing up to long term hydrogen contacts. Currently, strong evidence that such contracts will be signed is required for the Developer themselves to also apply for funding. Whilst signed long term contracts will likely be required before investor funds are fully released, the approach taken in the Feasibility study was to aim for a project that is likely to attract development funding i.e. the project is of sufficient attractiveness to a Developer, that it does not have an absolute need for full clarity on government funding for the Developer at each stage of the development.

National Hydrogen Developments - Whilst interest in purchasing hydrogen has been expressed by locally based international companies, there could be a risk that the supply opportunity to a refuelling site supplied from S+IP will be confined to fleets operating in a local/regional radius (<100kms). This is because commercial road transport in the UK is a national business – with most goods being moved between the UK's industrial hubs. While the mid M4 corridor is a commercial road transport refuelling node, unless a UK-wide network of hydrogen supply points on similar transport "golden routes" is built in parallel, supply opportunity to a refuelling site supplied from S+IP will be confined to fleets operating in a local/regional radius (<100kms). Whilst this project is viable with a focus on local areas with local opportunities, the project could in turn eventually generate national market/changes required in national developments to prevent FCEV assets would become stranded in the region and limiting further development of the site.

8.5 Environmental and Community benefits

There are numerous benefits to hydrogen production at the site that are not just related to the financial and site development business cases which relate to commercial benefits. As written in the previous section the main driver for this project is decarbonisation of transport applications. Hydrogen from renewables has the potential to make considerable carbon savings but also reduce other pollutant emissions such as NO_x which are harmful to humans and the environment. There are also local community benefits from putting hydrogen production at S+IP with hydrogen vehicles

 © Kiwa Ltd 2022

providing improvements over diesel alternatives resulting in improved public services. Developments at the S+IP also have the possibility to improve education around renewable and low carbon systems by engagement with the hydrogen production facility at the S+IP. All these benefits also align with local government strategies as covered in Sections 4 and 8.1.

8.5.1 Carbon intensity of hydrogen

It is common to use colours to identify the source of the energy used to produce hydrogen. In terms of green hydrogen, the UK standard is still being developed. For this report, we have defined the low carbon threshold to be in line with the work published as part of the European CertifHy project [3] i.e. 36.4 $gCO_{2(e)}$/MJ H_2 - around 10g/kWh. This would then set the limit for scope 1 emissions produced directly from hydrogen production.

Green hydrogen is hydrogen that meets a low-carbon threshold and is generated using renewable energy sources (such as biomass, solar, or wind). In the case of 100% of the electricity being generated from renewable sources of energy, then no carbon emissions are deemed to come directly from the hydrogen production process.

For the hydrogen produced at S+IP to be classed as green hydrogen it will need to meet the (yet to be defined) UK threshold. The Scope 1 emissions have been further investigated for energy and water consumption of the electrolyser production technology. The calculations show that the carbon intensity for the electrolyser is from water use. With 4 tonnes of CO_2 coming from water consumption each year 344g CO_2/m^3. This equates to 0.28g/kWh of hydrogen well within the European limits for low carbon hydrogen of 10g/kWh.

The electrolyser was modelled to use 100% renewable energy, so the scope 1 emissions are determined to be zero. It is expected that small amounts of grid electricity will be used each year to cover periods of maintenance or breakdowns, the maximum share of energy from the grid in the supply to the electrolyser - to still stay below the European threshold has been calculated. To do this, carbon intensity of grid electricity was taken from UK 2021 figures. The carbon intensity for UK electricity produced in 2021 was 212.33g CO_2/kWh. At this level only 4.6% of the annual electricity used in the system would be able to come from the grid to be able to still meet the European low carbon definition. This equates 17 days per year where no renewable energy is available due to breakdown or maintenance.

Green hydrogen production at scale would thus require additional diversified renewable electricity generation onsite e.g. wind to make good use of the electrolyser. Of course, renewable electricity can also be purchased through the grid, however as shown in the sensitivity pricing the cost of this electricity is likely to be high from this source and will significantly increase the price of hydrogen.

8.5.2 Carbon savings

A Hydrogen production facility at the S+IP meeting the hydrogen demands up to 1000kg per day would result in a reduction in Swindon’s carbon footprint of 5,000 Tonnes CO_2 / yr. This is based on the replacement of diesel engines with hydrogen FCEV. Based on ONS estimates of carbon emissions this equates to 2% of transport emissions from the Borough of Swindon’s emissions in 2019[59] (most recent year data is available). This is a significant reduction in CO_2 but would also lead to reductions in other pollutants, particularly NO_x and particulates associated with combustion of diesel and natural gas. Future developments of hydrogen production supplying the area would

[59] https://naei.beis.gov.uk/laco2app/

result in further reductions in carbon emissions, which could help the city meet its overall CO_2 reduction ambitions.

8.6 Planning / Regulation

8.6.1 North Wessex Downs AONB

Much of the land to the south of Swindon, including the disused airfield site at Wroughton where the S+IP is located, sits within the North Wessex Downs AONB.

While the AONB has equal status to a National Park in terms of landscape value and protection under law, it does not have an independent planning function or authority. Authority for planning decisions rests uniquely with the Local Planning Authority (SBC). Given that Natural England's policies include a caveat on all consultation responses to seek the advice of the relevant AONB, SBC are not obliged to consult AONB Partnership on planning applications – yet it still has a non-statutory, advisory role. (There are recommendations within the Glover Review which propose that AONB's are made statutory consultees).

North Wessex Downs' own Planning Policy does not exclude development within the boundaries of the AONB, but takes the position that "any development should complement the character of the landscape, be **sustainable** and of an appropriate scale and nature".

The "Development" section of the AONB's Management Plan references the principle of "net gain", where development which may have an impact on landscape and traffic can be considered positive if it brings with it substantial community benefit. It also outlines the need for reduction of greenhouse gas emissions, framing its support for renewable energy initiatives. In the context of additional renewal energy source requirement to produce hydrogen at consistent scale, the NWD AONB Plan is specific about wind turbines' potential to adversely impact the natural landscape: any plan to use wind energy at S+IP may need to be based on small, high-efficiency turbines.

This study provisionally concludes that the North Wessex Downs AONB would, for the reasons outlined above, be unlikely to raise concerns or objections over the proposed green hydrogen production at the S+IP.

8.6.2 SBC Local Plan and Local Transport Plan context

Local Plan and LTP

SBC officers were broadly enthusiastic about the S+IP green hydrogen proposals in the follow-up call to the workshop. However, this cannot be taken as support.

Nonetheless, Swindon Borough Council's Local Plan contends with several urban planning initiatives which have received planning approval and result in the following:

- Through the Eastern Villages, Tadpole Village and Wichelstowe developments an increase in the town's population of ca 20% (181,000 to 221,000)
- A subsequent increase in the amount of private and public transport traffic in Swindon Borough
- Severe pressure on SBC's target to become "one of the most sustainable communities in the UK by 2030"
- Increasing development of the land surrounding Swindon's circumference for warehousing, logistics and distribution activities

Swindon's greenhouse gas emissions are above both regional and national per capita averages. This gap is forecast to increase with the completion of the new developments above, and without direct intervention.

With regards to the site itself policy RA2 in SBC local plan mentions the S+IP site and the policy states that SBC will maximise opportunities associated with the Science Museum to benefit Wroughton and the Borough through:

- realising tourism benefits associated with the Science Museum
- Allow expansion of museum related activities and enabling development providing the benefits of the development are delivered sustainably and do not conflict with other policies in the Local Plan;

In that context, Swindon Borough Council's Local Transport Plan quotes the following commitment: "Contributing towards carbon emission reduction targets by achieving a shift towards more sustainable transport networks".

In other sections, the Plan is explicit about "the role of technology in safeguarding the environment"; "reducing the dependence on fossil fuels" and driving town centre regeneration.

The study concludes that Swindon Borough Council would deem the proposed hydrogen development at S+IP as not only aligned with, but supportive of its transport and environment targets.

Brownfield Site

The SBC Local Plan makes clear the preference for incremental residential and/or commercial development on disused "brownfield" sites.

As a disused airfield, with several existing hangars and other, currently unused buildings, SBC would consider further development at S+IP – insofar as not erecting high-rise buildings, new constructions which offend the natural landscape - as "brownfield development".

Standard planning procedures would need to be followed, with the necessary period of consultation required to engage local residents and stakeholders. However, the only likely planning objections would come from residents of Wroughton village and would be based on increased tanker traffic.

As such, the study concludes that Swindon Borough Council would deem the proposed hydrogen development at NCC as development on a brownfield site, and would raise few, if any, objections.

8.6.3 Health and Safety Executive (HSE) and Environmental Regulations

Planning issues for handling hydrogen (HSE requirements)

There are four pieces of regulation that are important considerations for the hydrogen production system. These are:

- Regulatory control under the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002
- Pressure Systems Safety Regulations (PSSR) 2000
- The Planning (Hazardous Substances) Regulations 2015
- Control of Major Accident Hazards Regulations (COMAH) 2015

 © Kiwa Ltd 2022

DSEAR puts responsibility for safety on operators of sites and it is their responsibility to ensure that it has been safely designed. It requires that control measures are in place to either remove risks or, where this is not possible, control them. This is done through system design and the ATEX zoning done in the system layout is an example of this work. As this impacts the design of the system it will need to be included in future detailed system designs.

As the system that has been designed with high pressure storage and pressurisation equipment for transport demands at high pressure the PSSR regulations apply to the production facility. This regulation covers the safe design and use of pressurised systems. In summary the regulation requires a specific assessment of the system by a competent person which is required in accordance with the PSSR, this also results in the preparation of the Written Scheme of Examination which ensures that the facility is correctly maintained.

The storage at site will be greater than 2 tonnes which is above the controlled quantity of Hydrogen for The Planning (Hazardous Substances) Regulations 2015, which is 2 tonnes. Consent will be required from the Hazardous Substances Authority (HAS) in accordance with the Regulations. This is usually the local planning authority although they often receive advice from the HSE. To gain this approval there are various notification requirements that are needed.

The COMAH regulations have been prepared to prevent major accidents involving dangerous substances and to mitigate the effects on people and the environment of those that do occur. It is the regime controlling the operation of large hazardous establishments such as chemical plants, oil refineries, nuclear power stations etc... with Installations divided into tiers. As this is meant for major installations it's a very complex and time-consuming process. It is recommended that sites avoid COMAH if possible, by reducing their inventory. For hydrogen the minimum tier is 5 Tonnes. The system has been designed so that its storage does not exceed 5 Tonnes and the site stays out of the COMAH regulations.

Transport of Hydrogen

Transport legislation, including the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations, will be reviewed to ensure compliance of the proposed road transport supply arrangements. As the gross weight, external dimensions and high-pressure system ratings of the road transport will be comfortably within the maximum threshold of these regulations, approval is expected to be straightforward. The amount of hydrogen that can be transported will be less than 1 tonne per delivery. Accordingly, all additional relevant transport regulations issued by UK national (and international) competent authorities will be respected.

Environmental Regulations

Hydrogen production, as any chemical manufacturing, must operate within the regulatory regime of environmental permits. The regulations do apply for hydrogen production at the S+IP due to the production of 100 kg per annum of hydrogen product. Part A1 of The Environmental Permitting (England and Wales) Regulations 2016 – sets out the requirements and a full Environment Agency application and approval will be required. A low impact assessment will not be possible as the site is larger than 3 MW of energy consumption. Environmental permitting for electrolytic generation of hydrogen is considered a light touch due to the lack of hazardous chemicals in production. This is because the feedstock is water which is not a hazardous chemical and the hydrogen product whilst hazardous from a safety perspective is not damaging to the environment. Environmental permitting whilst required is not expected to be a risk to the project.

© Kiwa Ltd 2022

9 Conclusions

The Feasibility study into renewable hydrogen production at the S+IP has shown that it is feasible to produce competitively priced hydrogen at scale for use in the surrounding area. Hydrogen supplying transport demands would also significantly contribute to the delivery of the region's zero carbon ambitions.

By integrating energy supply from renewables produced at the site with hydrogen transport demands in Swindon and demands of heavy traffic using the M4, hydrogen produced on the site can be feasible. The requirement for diversified renewable energy supply may pose some risks to the feasibility of the overall system, as this will need to be developed at S+IP. As the requirement is for green hydrogen, there is no other option as using significant grid electricity would result in the hydrogen being produced falling short of the (yet to be announced) UK definition of green hydrogen. The integration of predictable transport demand contracts has been shown to be vital for large scale production, particularly since this site does not have large scale underground storage. Long term contracts are currently a requirement for Government funding, and so these contracts are also making an optional funding route available to the project.

The concept developed in this study is potentially replicable across other renewable energy production sites in the region. This would enable additional hydrogen production in the area, allowing additional demands for green hydrogen to be met. This could be done at other locations where there are large transport energy demands close to large renewable energy sites. S+IP is the ideal first, or early location for such a system in the UK because of its strategic location close to major transport infrastructure and demands in the UK. This would allow S+IP to make innovative and substantial carbon reductions via hydrogen, whilst supporting its existing ambition to develop its S+IP site.

The analysis of the demand for hydrogen in the region has shown that there is a strong potential for growth in the adoption of hydrogen technologies year on year over the next 5 years. Early predictions show that 1300kg per day could be the potential demand within a year in the region with buses and HGVs making the largest proportion of this demand. This is scheduled to grow to up to 8000kg in the region in the next 5 years. The planned closure of other hydrogen production infrastructure on the region also provides an opportunity for the site to develop 'at pace' and to provide hydrogen to the existing hydrogen users in the region. The demand modelling looked at many diverse demands including demands other than transport. This was done to ensure that the demand can, if necessary or desired, be spread between many different users as required to reduce the risk to the developer. The demands for the hydrogen also included assessments of hydrogen for heat, power and for use in buildings in the S+IP. These assessments have shown that whilst there are no immediate opportunities to developing hydrogen for heat and power on the site, use in buildings in the S+IP could be exploited if an appropriate demand arose in the future.

The modelling of production focussed on the transport base demand. The amount of production available was set by the availability of the solar energy on site. The system has been sized at 5MW producing 1000kg per day with a potential expansion designed into the system layout that would enable a 7.5MW system with production of 1500kg per day. This was done to enable the integration with different demands to allow the developer to reduce project risks and allow additional demands to be met by expanding the system. Choosing local transport demands over which local authorities have some control has enabled a real deliverable project allowing continued hydrogen development in the region.

Using stable consistent transport demands provides an opportunity to quickly achieve a scale of production not possible for smaller production sites, providing a route to cost effective production of

 © Kiwa Ltd 2022

hydrogen, driving down costs and creating greater flexibility and resilience. Cost is one of the major barriers to hydrogen as an energy vector as the low cost of fossil fuel energy used for transport and other demands make commercialisation of hydrogen supply a significant challenge. The CAPEX and OPEX of the production have been calculated to enable the minimum hydrogen price to be assessed. This has been done using the Green Book requirements and setting a hurdle rate of 10%. The price of hydrogen in the base case was shown to be a minimum of **17.0p/kWh** or **£6.66/kg** without government support. The focus of the cost modelling has been undertaken to show that hydrogen production can be supported without government funding, and this is the basis of the prices shown above. However, as there are several mechanisms for government support being developed for hydrogen production a scenario which includes government support has also been presented. By also including 50% CAPEX and RTFCs under the RTFO scheme (providing £1.374/ kg of hydrogen), this would further reduce the price of hydrogen charged by the developer to meet there required return on investment making the hydrogen more competitive for the end users. This minimum hydrogen price was shown to be **9.8p/kWh** or **£3.86/kg**.

Green hydrogen production from renewables is not possible without a diversified renewable electrical supply at S+IP. This is due to a lack of capacity in the solar energy from the site and a lack of geological hydrogen storage to cover the period of no renewable electrical supply. The winter periods have a significant reduction in solar energy output due to reduced daylight hours and inclement weather impacting solar irradiance. **Green hydrogen at scale is therefore not possible without diversified renewable electricity production**. An additional 2.5MW of electrical energy supply to the electrolysers is needed to cover the 20% of annual energy demand which is not expected to be covered by solar energy in the winter periods.

The system could prevent 5,000 Tonnes CO_2 being emitted to atmosphere per year if replacing diesel from transport demands. Based on ONS estimates of carbon emissions, this equates to 2% of transport emissions of the Borough of Swindon (2019 figures, 0.5% of total emissions). This is a meaningful reduction in CO_2. Importantly, it would also lead to reductions in other transport related pollutants, particularly NO_x and particulates associated with combustion of diesel. Future developments of hydrogen production supplying the area would result in further reductions in carbon emissions, which could help the city meet its overall CO_2 reduction ambitions.

Whilst this study has been successful at identifying a route to implement hydrogen infrastructure at an appropriate scale for decarbonisation of transport at a reasonable cost, there are risks to the project which will have to be addressed:

PPA Contracts - There is a key risk that a deal cannot be agreed with the current owners of the solar park, to make use of existing solar capacity to produce hydrogen. Making use of existing capacity is a good first step and would appear to be easier than building new renewables.

Uptake of Hydrogen Vehicles – For the project to become viable there needs to be an uptake of hydrogen demand from transport operators in the region. This needs to happen at the same time as the developments at S+IP. If the upfront CAPEX cost of hydrogen buses remains higher than that of electric buses, then the range, space and fast charging advantages of hydrogen buses may not outweigh the additional costs in the eyes of bus companies. There are risks that the barriers to developing demand are too high to allow the development at S+IP to take place. This will have to be addressed before the developments at S+IP can take place.

Next steps – A base case hydrogen production system at S+IP providing transport demands in the area has been proven to be technically and financially feasible. There are now steps required to optimise and take this project to the stage where a full front end engineering design (FEED) study can be carried out. As a full FEED study will require local and national support before it can be funded, it is proposed that a preliminary front end engineering design (PreFEED) project is required to bring together a project consortium, provide the final technical evidence, strengthen the business case, and manage project stakeholders. This PreFEED once will allow the selection of the optimum design option and project consortium to be taken forward into the full FEED study.

To be successful the PreFEED would require the following steps:

1. Identification and engagement with potential developers and operator for hydrogen production at the S+IP site. To take the project into the next stage the project will require a developer identified to operate the hydrogen production facility. The PreFEED should therefore identify, approach and select the best candidates to operate the system.
2. Direct engagement with the end users identified in this study to identify and outline the demand and locations for supply of hydrogen from the S+IP. This includes council fleets, bus operators and HGV fleet operators. This stage is required for the business case to be strengthened enough to allow a developer to have the confidence to get involved.
3. Provide the final technical evidence required for technical aspects of the study. Some areas identified in this study are outside of the scope of work to be considered at this stage. This includes additional diversified renewable energy production and the commercial contracts for energy supply to the electrolyser systems. This will allow the optimum design choice to be made regarding the hydrogen production system.
4. Bring together a project consortium to support the project into the next stage. The stakeholder analysis has identified a number of key stakeholders which will be required to support the project into a FEED project. The support of these stakeholders will be needed to enable the project to be developed further. The work completed so far should be continued to ensure ongoing support for the project.

Appendix A. Electrolyser Comparison

This section provides a commentary on alkaline and PEM electrolyser.

Alkaline Electrolysers

Alkaline electrolysis is a mature technology, with low cost and readily available construction materials. Large-scale, MW production of hydrogen through alkaline electrolysers has been common practice for decades.

Alkaline electrolysers consist of the cathode and the anode suspended in an aqueous liquid hydroxide solution, normally NaOH or KOH, separated by a diaphragm. The diaphragm allows the passage of hydroxide ions between the electrodes. Hydrogen and oxygen gas cannot pass through the diaphragm. When a voltage is applied between the electrodes, electrons are delivered from the cathode to the water molecules, producing hydroxide ions and hydrogen molecules. The hydroxide ions pass through the diaphragm and the electrons are collected from the hydroxide ions by the anode to produce oxygen and water.

Cathode: $2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^-$

Anode: $2\,OH^- \rightarrow \frac{1}{2}\,O_2 + H_2O + 2\,e^-$

The electrolyte is recirculated in separate loops, one for each electrode, to prevent cross mixing of gasses. The operating temperature is between 60 ºC and 80 ºC.

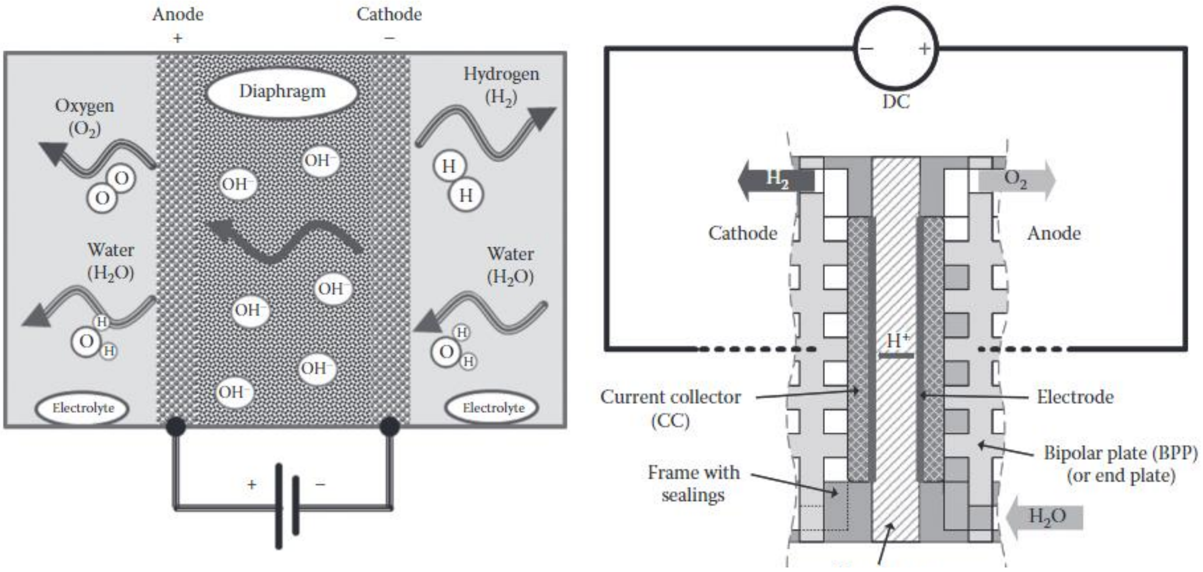


Figure 42. Schematics of electrolysers60 (left) alkaline electrolyser, (right) PEM electrolyser

Polymer Electrolyte Membrane (PEM) Electrolysers

Polymer electrolyte membrane electrolysis, also known as proton exchange membrane electrolysis, is a relatively new technology which is only just emerging as a MW scale commercial product.

The PEM cell consists of the solid polymer membrane as the electrolyte, with each side coated with porous layers of electrocatalyst, which act as the electrodes. The membrane and electrodes are fixed between two bipolar plates which support the structure and supply the current[60]. The ohmic resistance across the membrane is low as the high proton conductivity allows the membrane to be very thin. This allows the anode and cathode to be very close together [61].

Whilst the overall reaction is the same as alkaline electrolysis, the partial reactions at the electrodes are slightly different. The anode collects electrons from the supplied water to produce hydrogen ions and oxygen gas. The solid polymer conducts the hydrogen ions across to the cathode. The cathode delivers electrons to the hydrogen ions to form hydrogen gas. Channels are used to supply water and remove liquid-gas mixture, which can then be separated to extract the gasses.

Cathode: $2\,H^{+} + 2\,e^{-} \rightarrow H_2$

Anode: $H_2O \rightarrow 2\,H^{+} + 2\,e^{-} + \frac{1}{2}O_2$

The operating temperature is between 60 ºC and 80 ºC. PEM electrolysers are relatively a new technology and whilst there are many manufacturers producing them commercially, larger scale non-modular options are less available.

Comparison of PEM and Alkaline Electrolysers

Operating Pressure

Alkaline electrolysers are operated under atmospheric and low pressurised conditions, up to about 12 barg. Advantages of pressurised operation include the reduction of gas bubble size within the electrolyte which decreases the ohmic resistance[60]. The system used to remove the gasses from the electrolyte is complex, as the valves must ensure external gasses do not enter the electrolyte. Under high pressure operation, there is inefficient gas removal resulting in a large differential pressure across the gas separator valves. This causes cross-mixing of gasses across the diaphragm[62].

Cross-mixing is when oxygen permeates into the hydrogen electrolyte side and hydrogen permeates into the oxygen electrolyte side. The lower flammability of hydrogen is around 4% by volume and the upper flammable limit is around 94% by volume, both in oxygen. If the concentration of hydrogen gas within oxygen gas falls within this, there is a significant safety risk. Oxygen present in the hydrogen gas side decreases purity the final hydrogen product. The total system efficiency will be reduced if separation processes are required for purification.

Due to complexity associated with pressurised operation, alkaline electrolysers are commonly operated at atmospheric pressure. There is inherently less risk of hydrogen leakage, which may cause jet fires. Less energy is required to run the electrolyser. The technology is more developed and the large capacity units are much more developed. These electrolysers are not containerised and vent to the atmosphere, reducing parasitic costs. The units tend have a large footprint, which may be disadvantageous in some applications but should not be an issue in Wroughton.

60 Godula-Jopek, A., 2015. *Hydrogen production by electrolysis.* Weinheim: Wiley-VCH.
61 Bessarabov, D., Wang, H., Li, H. & Zhao, N., 2015. *PEM Electrolysis for Hydrogen Production Principles and Applications.* Boca Raton: CRC Press.
62 Roy, A., Watson, S. & Infield, D., 2006. Comparison of electrical energy efficiency of atmospheric and high-pressure electrolysers. International Journal of Hydrogen Energy, 31(14), pp. 1964-1979.

 © Kiwa Ltd 2022

PEM electrolysers are atmospheric or low pressurised, up to about 30 barg. Higher pressure PEM electrolysers exist but are still in the development phase and are not available on a commercial market. High pressures cause greater cross mixing of the gasses. As a result, thicker and more expensive membranes are required to prevent this transfer of gas, which have yet to be extensively developed. Internal recombiners must also be used to maintain safe concentrations of hydrogen in oxygen. Although overall system efficiency may be reduced, high pressure operation can also improve cell efficiency through increased gas mass transfer[63].

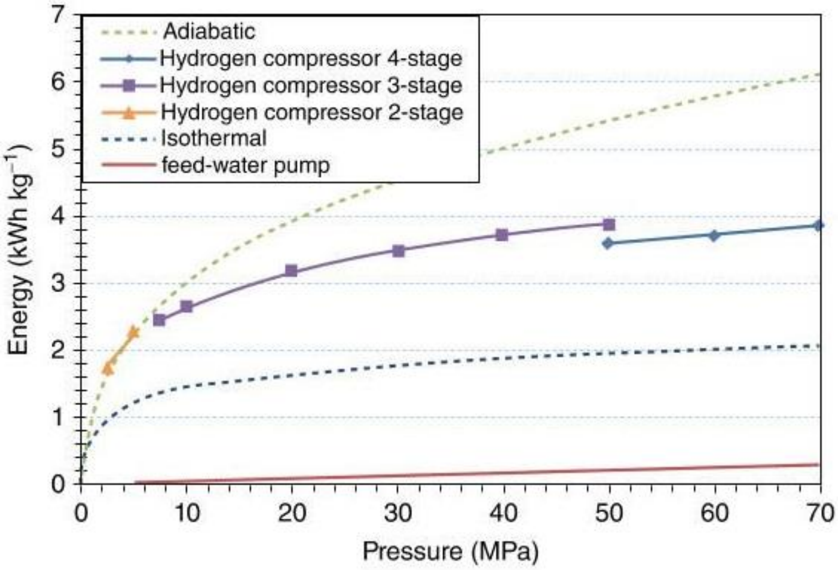


Figure 43. Energy consumption for water pumping against hydrogen compression under isothermal, adiabatic and multistage conditions[60].

Figure 43 shows the energy required to pump this water is considerably lower than energy requirements for hydrogen compression. By electrolysing with high pressure water the hydrogen output pressure is increased.

It can be advantageous to operate at 30 barg as hydrogen can be produced and delivered without the need for a compressor. With pressurised PEM electrolysis, water must be pumped to a high pressure before it is used in the system.

Efficiency and Variable Current Densities

For both alkaline and PEM electrolysers, efficiency increases at part-load operation compared to full load.

Alkaline electrolysers tend to operate at current densities of 200 – 400 mA cm^{-2} The lower limit of operation tends to be 10-40% of the nominal hydrogen operation[64]. Any lower and the diffusion of hydrogen into oxygen is high enough to exceed the flammable limits.

---

63 Millet, P., Ngameni, R., Grigoriev, S. A. & Fateev, V. N., 2011. Scientific and engineering issues related to PEM technology:Water electrolysers, fuel cells and unitized regenerativesystems. *International Journal of Hydrogen Energy,* 36(6), pp. 4156-4163.
64 Buttlera, A. & Spliethoff, H., 2018. Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review. *Renewable and Sustainable Energy Reviews,* Volume 82, pp. 2440-2454.

PEM electrolysers have the capability of operating at higher current densities, 0.8 – 1.0 A cm[-2][60]. There tends to be no lower limit for operation as the membrane has a very low gas permeability so cross-mixing of gasses is not a significant risk. However, at higher pressures and low current density, the cross-mixing of gasses may be large enough to cause a safety risk[64].

Renewable electricity sources result in a variable input to the electrolyser. PEM electrolysis is more responsive to a change in power input as proton transport is not limited by inertia, unlike liquid electrolytes in alkaline technologies[65]. On a commercial scale, large alkaline electrolysers take around 10 minutes to adjust from minimum to maximum output, although often this is less in newer models. Contrastingly, PEM electrolysers take less than 10 seconds.

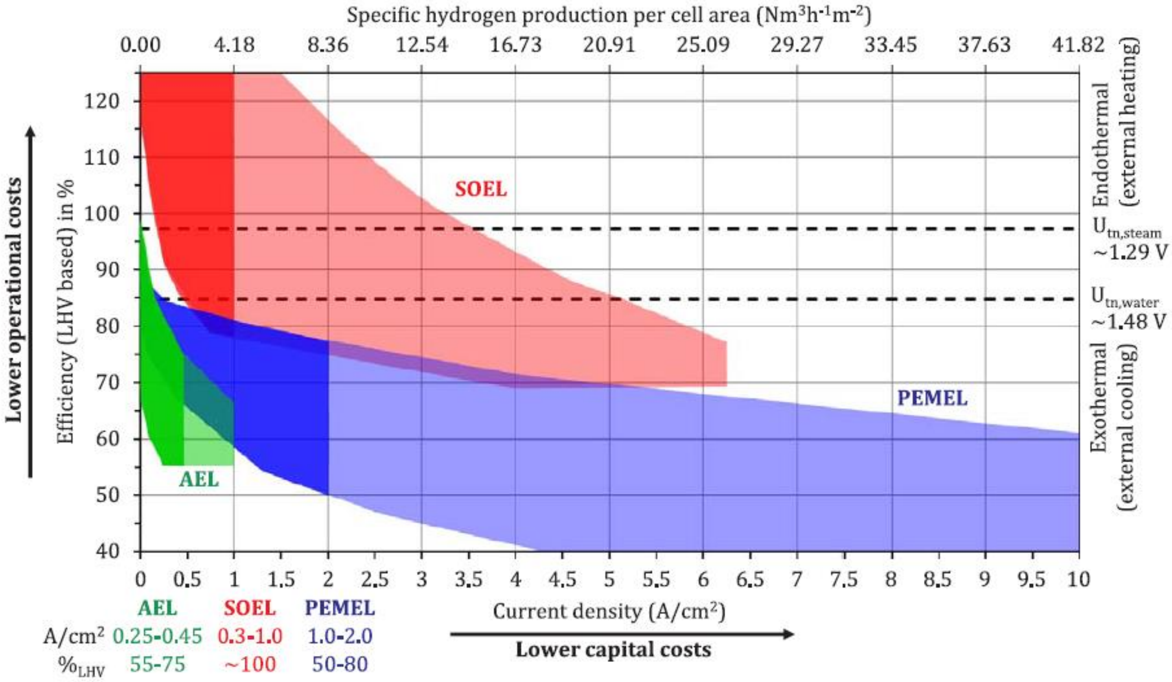


Figure 44: Efficiency assuming 100% Faraday efficiency against current density of alkaline electrolysers (AEL), polymer exchange membrane electrolysers (PEMEL) and solid oxide electrolysers (SOEL)[64].

Figure 44 is based on cell voltage and theoretical output data. Current density is proportional to hydrogen production capacity. The darker colours in Figure 4 represent the current operating range of available electrolysers of that type. The efficiency is based on the lower heating value (LHV) of hydrogen and is defined as the energy in the hydrogen vs the electricity input. The general trend is as the current density is increased, the efficiency decreases, supporting the argument that efficiency increases with part-load rather than full load operation. Any electrolyser would have a unique efficiency variation based on its operational design and set-up. This data from the manufacturer does not tend to be publicly available.

A high current density decreases the capital costs as more compact systems can be used to deliver the same hydrogen output.

65 Carmoa, M., Fritza, D. L., Mergela, J. & Stolten, D., 2013. A comprehensive review on PEM water electrolysis. *International Journal of Hydrogen Energy,* 38(12), pp. 4901-4934.

 © Kiwa Ltd 2022

Nominal current density is a compromise against increased hydrogen production when operating at higher current densities but which also decreases cell efficiency (higher losses). High current densities yield reduced specific capital costs per cell but increased operating costs[64].

For PEM technologies, current densities greater than 2 A cm^{-2} cause degradation of cell performance due to ohmic and mass transfer resistances66. As a result, there are currently no commercially available PEM electrolysers that operate at these current densities.

Low load operation of an alkaline electrolyser increases the risks associated with cross mixing. Whilst the rate of diffusion of the hydrogen into the oxygen through the diaphragm remains constant, low production rates decreases the amount of oxygen so there is a greater proportion of hydrogen present in the oxygen[65].

Cost

Given that alkaline electrolysers are a more established technology, materials required to manufacture them are low cost and readily available. Contrastingly, the precious metals required for the electrocatalysts within PEM cause a significantly higher cost.

Whilst PEM seems advantageous in many scenarios, the CAPEX of a large enough scale PEM electrolyser is very high. The large-scale commercial PEM electrolyser products are still being developed, with very few on the market that have been tested for long term use. The sustainability and reliability of the PEM products is not well known, making a potentially risky capital investment.

Most PEM electrolysers tend to be containerised due to their small size. For the scale of S+IP, a number of these containerised units would be required. High parasitic costs are associated with having lots of these units; each unit would have its own fan for ventilation, its own control system, its own cooling system and more. Compared to a large system with several stacks, many containerised units can add additional cost and energy usage.

Commercially Available Electrolyser Comparison

A large spectrum of electrolysers exists in today's commercial market. Many companies' electrolyser products were investigated, and a comparison made. Both company name and product model name are included in the graphs. The electrolysers are presented in 4 separate plots for clarity.

There are more PEM electrolysers products available on the commercial market than alkaline electrolysers. Most of these are small scale, containerised electrolysers designed for small applications. This was likely due to alkaline electrolysers being built on a much larger scale than PEM electrolysers. These do not tend to be offered as a product like the containerised PEM electrolysers but are designed specifically to the client's needs. Like a chemical plant, the different components of the plant may be sourced from different companies, so the system is not sold as a complete package.

Due to the profile of the hydrogen demand for supplying hydrogen refuelling stations and PV generated electricity supply, the hydrogen production facilities at S+IP need to have a variable input and output. In addition to varying the power input of the electrolyser, the number of electrolyser stacks allows for the greatest range of hydrogen production output. This also ensures

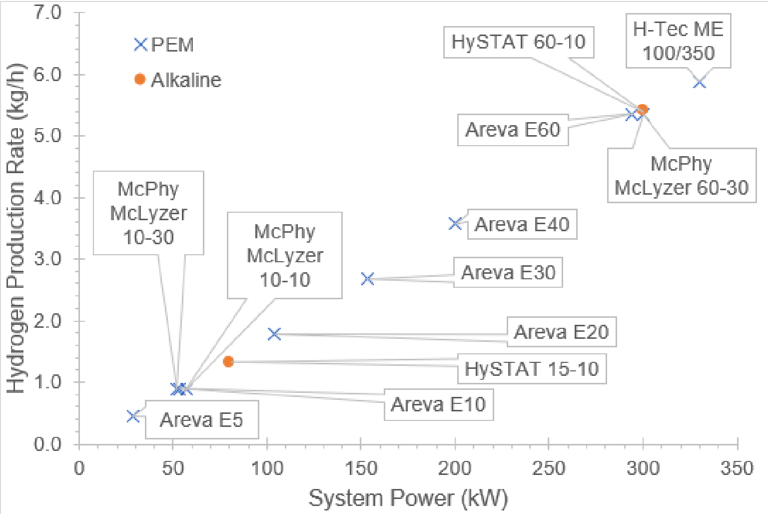
66 Carmo, M. et al., 2018. The stability challenge on the pathway to high-current-density polymer electrolyte membrane water electrolyzers. *Electrochimica Acta,* Volume 278, pp. 324-331.

security of supply if an electrolyser must be taken offline. Resultingly, electrolysers that allow for multiple stacks of a lower power is more desirable than one large power stack.

When operating below maximum output, temperature must be considered for alkaline and PEM electrolysers. When a unit is not being used, it is kept at the required temperature whilst on stand-by as the time for heating may be too long to be practical and the electrochemical reactions do not perform well at sub-optimal temperatures[64]. For large scale alkaline electrolysers, leakage of the electrolyte can occur at low temperatures, so during low usage, the system must be kept above a minimum. This can result in high power consumption when the electrolysers do not have high utilisation. This is especially important when considering systems connected to renewable power such as solar farms where output is dependent on weather and daylight hours. Energy used to ensure that the electrolyser is available and at temperature when renewable energy resumes is often therefore required with electrolyser systems. This energy when sourced from the grid increases the cost of production. Modelling has shown that the percentage of grid import can make up a high proportion of annual energy use from systems which have low utilisation due to the availability of renewable energy.

Most of the models in Figure 45 have a production range, which depends on the size and number of electrolyser stacks chosen for the final design. The data displayed is the maximum electrolyser output based on maximum possible stacks. Therefore Figure 45 should be used as a guide and the original collected data should be referenced if a smaller capacity is required for a particular model. Figure 45 to Figure 48 show that the general trend is that production rate increases linearly with system power, as expected. There are no deviations from this trend at low- or high- power ratings which is to be expected.

© Kiwa Ltd 2022



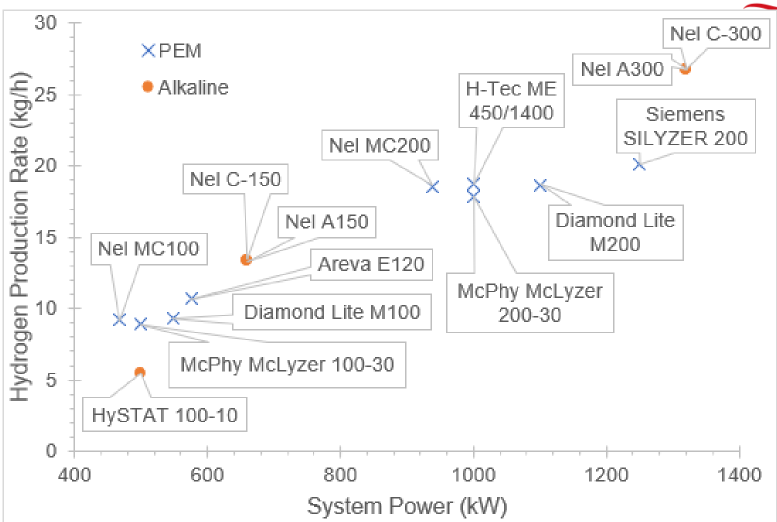
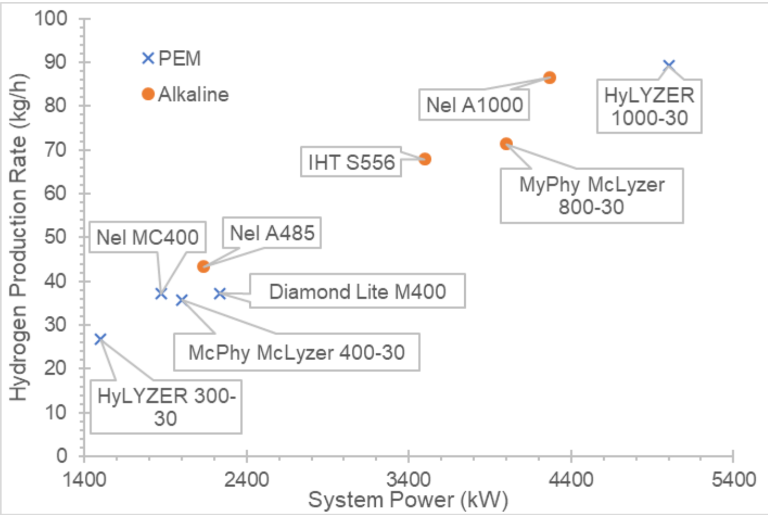


Figure 45: Relationship between power & hydrogen production rate for 0 - 350 kW

Figure 46: Relationship between power & hydrogen production rate 400 - 1400 kW



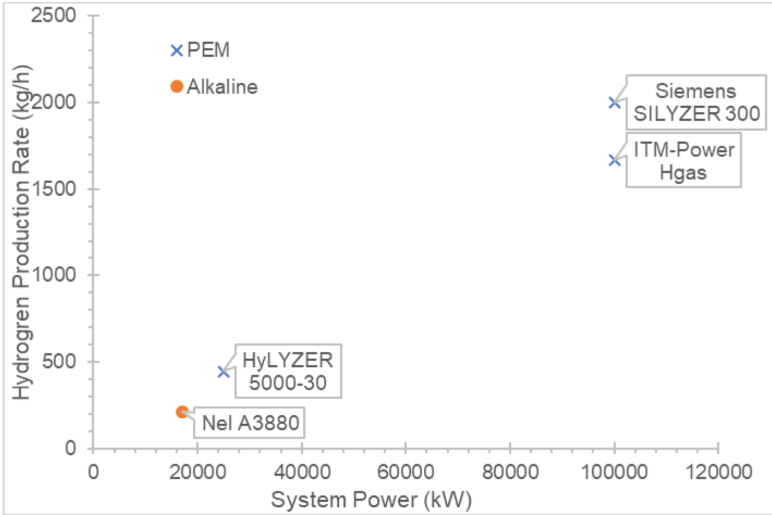


Figure 47: Relationship between power & hydrogen production rate 1.5 - 100 MW

Figure 48: Relationship between power & hydrogen production rate 0 - 120000 MW

© Kiwa Ltd 2022

Appendix B. Stakeholder Engagement

Participating stakeholders

Together with input and attendance from S+IP, SW LEP and the SW Energy Hub, participants were from all sectors considered potential end users: public and commercial transport; industrial and domestic heating, power generation and National Grid as well as delegates from renewable energy companies and hydrogen vehicle marketers (Figure 49). Participants included representatives bringing valuable implementation experience from both the South Wales Hydrogen Centre and the Teesside Hydrogen Transport Hub. A representative from the locally based Public Power Solutions and a developer of electrolyser projects also contributed insights.

Councillor Gary Sumner, deputy leader of Swindon Borough Council and its Head of Planning, Infrastructure and Transport attended in his various capacities and provided an important "bridge" to the local authority (see Local Authority Follow-up in Section 4.5).

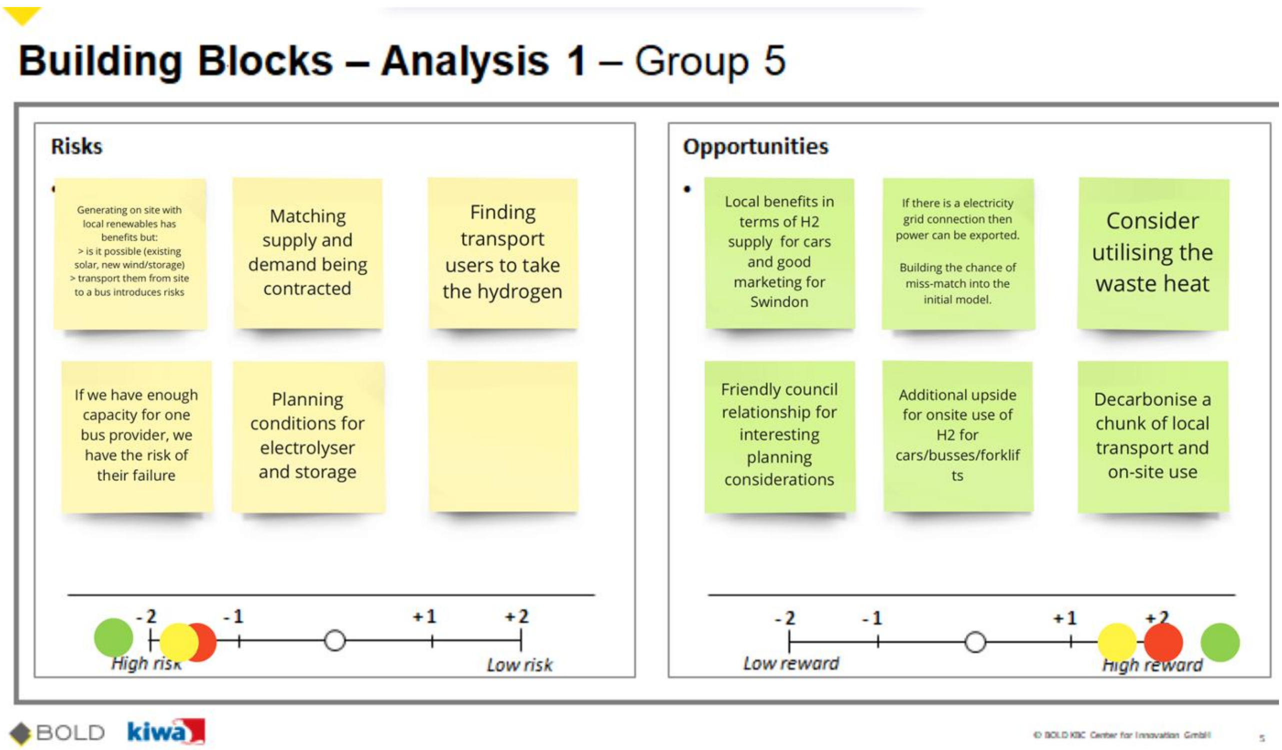
TITLE	ORGANISATION
Senior Partner	Pannell Hayes Consulting
Director	Pannell Hayes Consulting
Senior Partner	Pannell Hayes Consulting
Technology & Innovation Officer	Tees Valley Combined Authority
Senior Energy Consultant	Kiwa Gastec
Director of Strategy and Policy	SWLEP
Investment Manager	Thrive Renewables
Marketing Director	Roadgas Limited
General Manager	Go South Coast
Managing Director	Pebley Beach Group (Hyundai & Suzuki)
Research Fellow	University of South Wales
Managing Director	Business West
Deputy Leader SBC	Swindon Borough Council
Technical Director	Toucan Energy
Advisor	Element 2 Limited
Development	Public Power Solutions
Director	National Collections Centre
Operations Manager	Stagecoach West
Operations Manager	Bristol Airport
Operations Manager	ITM Power
Director	KIWA
Project Manager	South West Energy Hub
Principal Transport & Development Manager	Wiltshire
Head of Spatial Planning	Wiltshire
Manager	Toucan energy

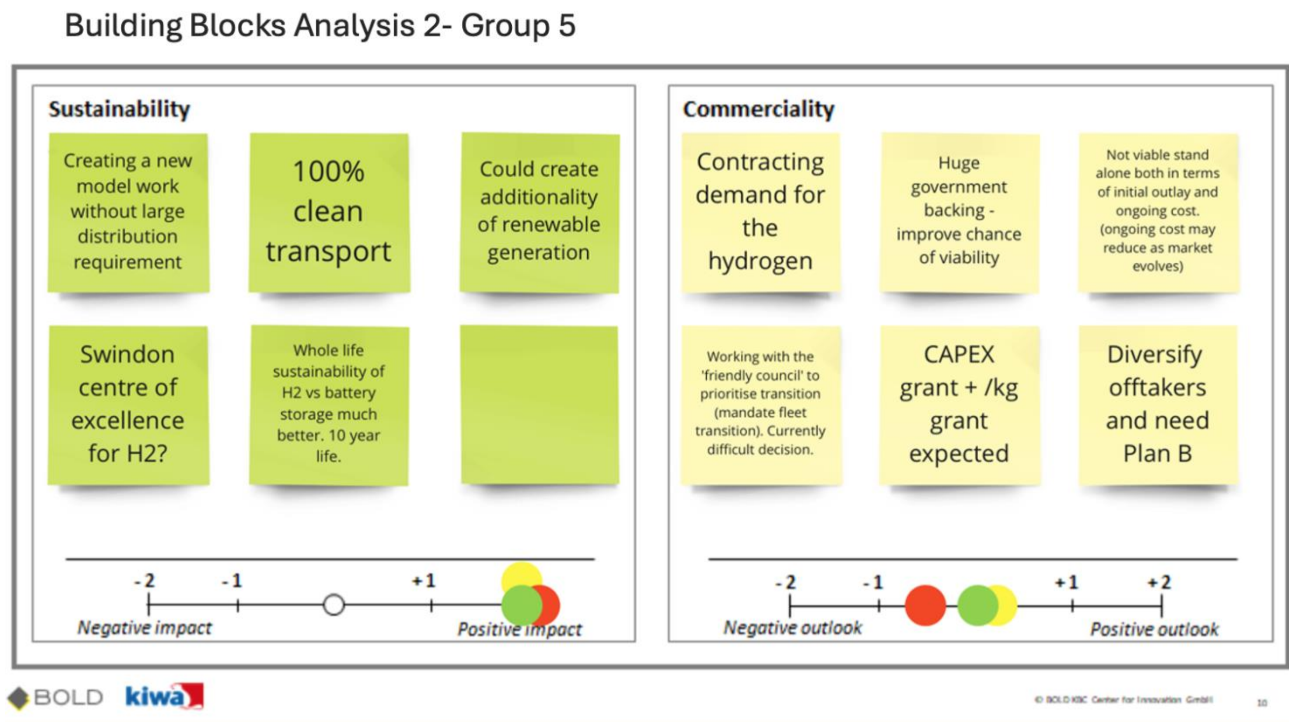
Figure 49: list of participating stakeholders and organisations

Workshop Write-up

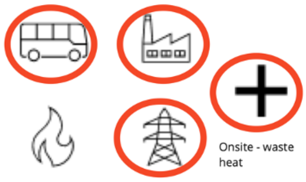
Starting with the online Group (named 5), who were using the Miro package and working with a second Bold Group facilitator, we capture below the output from the Groups.

Note: there were 5 Groups on the first day and 4 groups on the second day; thus, below can be found the final output from all 4 Groups on the second day.


Building Blocks – Analysis 1 – Group 5
Risks
Generating on site with local renewables has benefits but: > is it possible (existing solar, new wind/storage) > transport them from site to a bus introduces risks
Matching supply and demand being contracted
Finding transport users to take the hydrogen
If we have enough capacity for one bus provider, we have the risk of their failure
Planning conditions for electrolyser and storage
-2
-1
+1
+2
High risk
Low risk
Opportunities
Local benefits in terms of H2 supply for cars and good marketing for Swindon
If there is a electricity grid connection then power can be exported.
Building the chance of miss-match into the initial model.
Consider utilising the waste heat
Friendly council relationship for interesting planning considerations
Additional upside for onsite use of H2 for cars/busses/forklifts
Decarbonise a chunk of local transport and on-site use
-2
-1
+1
+2
Low reward
High reward
BOLD
kiwa
© BOLD KBC Center for Innovation GmbH


Building Blocks Analysis 2- Group 5
Sustainability
Creating a new model work without large distribution requirement
100% clean transport
Could create additionality of renewable generation
Swindon centre of excellence for H2?
Whole life sustainability of H2 vs battery storage much better. 10 year life.
-2
-1
+1
Negative impact
Positive impact
Commerciality
Contracting demand for the hydrogen
Huge government backing - improve chance of viability
Not viable stand alone both in terms of initial outlay and ongoing cost. (ongoing cost may reduce as market evolves)
Working with the 'friendly council' to prioritise transition (mandate fleet transition). Currently difficult decision.
CAPEX grant + /kg grant expected
Diversify offtakers and need Plan B
-2
-1
+1
+2
Negative outlook
Positive outlook
BOLD
kiwa
© BOLD KBC Center for Innovation GmbH

Hydrogen Concepts- Highlights Group 5



Description of the key concepts:

Production: New renewables generation on-site (Solar + Wind (+ Storage?) + grid connection. Primary demand being bus and delivery fleets. Pump for:

> Use on site
> Sale on site
> Distribution to demand centres - diversifying buyers.

Novel Opportunities (3)

> Marketing of high % renewables.
> Introducing new renewables technologies - championing smaller scale/scalable models
> Non-critical upsides of onsite use (waste heat)

Risks (open)

> Need for contracted hydrogen usage - counterparty risk
> Renewables aren't viable - use grid connection
> Distribution being cost prohibitive - consider production in-depot
> Renewables are cheap enough - oversize (managing contract)
> Risks associated with break in supply -

Top 3 Commercial Ideas

> Scaling production with over sized generation
> Resilience through modular design
> Enable busses which are more developed as a technology as the initial customer.

Top Sustainability Aspects

> Enabling the additionality of renewables.
> Decarbonise/air quality improvement for local bus/HGVs

© BOLD KBC Center for Innovation GmbH

Building Blocks Analysis 1 – Group 1 (penned by Mark)

RISKS	OPPORTUNITIES
TRANSPORT Risk that Electric bid for local buses was a missed opportunity to introduce hydrogen buses	TRANSPORT – Opportunity for NCC hydrogen shuttle buses
-Risk that EV (uptake) rate is much higher (then hydrogen)	Opportunity for bus trial support
-Risk that Autonomous Cars are EV and people use these rather than buses.	Opportunity to improve air quality (incl. in Swindon)
	Opportunity for low emission longer bus routes
HEATING Risks- Consumer perception re repurposing of the (domestic) heat network	Opportunity for Commercially viable project
	HEATING- Opportunity to use & supply heat from hydrogen production and from electricity production
-Cost concerns and desire for UK self sufficiency	HEATING- Opportunity for demonstrations at NCC and at houses on the site
GRID risks- (will there be) sufficient HMG support for hydrogen	GRID- Opportunity for new renewable electricity production at NCC
PRODUCTION Risks- (Getting a hydrogen) PPA for 8 years	Opportunity around grid services (based on storage availability). To help manage grid constraints or problems. Use solar PVs to provide extra capacity short term to the grid to manage frequency and voltage of supply.
Risk of (outages or) failure of production	Opportunity to support the grid (by supplying hydrogen to) local homes
Risk of insufficient storage	Opportunity for value adding time shifting of energy (producing hydrogen and then supplying the grid when required)
	PRODUCTION OF OXYGEN- sell to a local CGT to reduce levels of nitrous oxides
Note: Bus trials and Time shifting of energy seen as having highest reward; heating lower; oxygen lowest	INNOVATION- Use waste heat from electrolyser for site needs to grow (high yield) crops

 © Kiwa Ltd 2022

Building Blocks Analysis 2 – Group 1 (penned by Mark)

SUSTAINABILITY	COMMERCIALITY
CIRCULARITY – Align with NCC site ambition to use their own (or substituted) energy, including all vehicles at NCC running on hydrogen	BUSINESSES- brings companies to the site due to availability of hydrogen
LOW CARBON-Create plan for all NCC to be low carbon; improve air quality & land management	-Can run education away days- (on history of transport, including hydrogen)
TELL THE STORY OF THE SITE – from higher to low carbon usage for storage of National Collection	NCC Visitor Centre can benefit from hydrogen production and demonstrating usage. Showcase hydrogen technology (including appliances)
SCALABLE- Can envisage (continuing) the phased transition to low carbon site, in line with site developments	COSTS- Create sufficient revenue streams to cover costs of hydrogen production; include public hydrogen refuelling. Hydrogen for heating or power might contribute less.
SUSTAINABLE- (supporting) transport is long term sustainable; (can start with) buses	CIRCULARITY reduces costs and increases efficiency and thus a focus
	VEHICLES- Include full range, include rail companies
	VEHICLES- Hold special events for hydrogen vehicles
	REFUELLING- Help create a network of hydrogen refuelling points in this crucial area for distribution
	REFUELLING- Co locate hydrogen refuelling station with EV charging and other commercial activities
	TIMESCALES- opport to contribute to UK 2030 targets

Hydrogen Concepts- The Highlights- Group 1 (penned by Mark)

Description of Key Concepts	
NCC has multimodal refuelling for EV, Hydrogen cars and buses, including shuttle buses to site	
NCC heats and dehumidifies the site using heat produced in the generation of hydrogen	
NCC is actively supporting time shifting of electricity production	
Top 3 Novel opportunities: i) Create an onsite heat network using a hydrogen storage system; ii) Be a showcase of sustainable activities- around transport and in homes	Top Risks: Securing the 'backbone' PPA; Uncertainty of funding and the hydrogen business models to support hydrogen producers and users (2022 announcements); How much development could be done with existing PV site versus what is needed (need more/new renewables)
Top 3 Commercial Ideas: i) Use hydrogen production and usage to increase site attendance and make a commercial return on this; ii) reduce energy costs for site operation; plus all from previous page	Top Sustainability Aspects: Focus on Circularity; Carbon reduction; Multi use of the site and the energy; Leverage partnership between Local Authorities and NCC Site

© Kiwa Ltd 2022

Building Blocks Analysis 1 – Group 2 (penned by Nick)

RISKS	OPPORTUNITIES
TRANSPORT Risk of people increasingly planning on using cars due to lack of buses in rural and suburban areas.	TRANSPORT – Opportunities for more buses to outskirts of the town and rural areas.
	TRANSPORT- HGVs; reach out to companies who have made Net Zero announcements (Amazon, Ikea etc.); also to Earthline, (and other) local HGV companies
	TRANSPORT: Lots of hydrogen & transport expertise in Swindon; opportunity to test multiple and varied hydrogen vehicles- from go-carts to F1 hydrogen testing
PRODUCTION: risk that buyer of existing solar sales contract is not open to renegotiate; would then need new renewable energy of sufficient size	PRODUCTION: opportunity to repower the solar site with latest solar panel technology
	PRODUCTION: by raising local production and demand, also increase demand at JM site
	HEATING- Opportunity to supply heat from hydrogen production for onsite heating. Potentially also to few houses on edge of site + Housing Association houses

Building Blocks Analysis 2 – Group 2 (penned by Nick)

SUSTAINABILITY	COMMERCIALITY
The hydrogen economy will build and grow and thus the project is fundamentally sustainable	
A hydrogen "science park" or innovation centre provides opportunity to start work in numerous sectors across the hydrogen economy: construction, contract logistics, bus, rail, mail, housing (heating?)	A hydrogen exploration centre, science park can potentially attract investment, funding & interest across the SW region, the country and the rest of the world.
A hydrogen "science park" or innovation centre is commercially sustainable as a focal point in the SW for hydrogen skills, knowledge, exploration and testing. The technical knowledge already exists in the area. Education & PR Centre for schools & colleges.	Needs to be of commercial scale, but project can also expand as demand grows and hydrogen economy matures.
A hydrogen "science park" or innovation centre has long term feasibility for clean energy innovation. Little companies doing innovative things with hydrogen.	The site can be a hub for public and private sector seed funding in embryonic hydrogen projects.
Huge positive impact potential for Swindon; can change its very identity from Burmah/Honda to Hydrogen Centre.	Some commercial opportunity as an expanded training and education centre, potential to offer hydrogen certification.

 © Kiwa Ltd 2022

Hydrogen Concepts- The Highlights- Group 2 (penned by Nick)

Description of Key Concepts	
Hydrogen innovation centre Swindon: Pilot, test, Demonstrate and Educate. A focal point for hydrogen skills, knowledge and training	Attract innovative companies to test, explore & pilot hydrogen initiatives. A blend of different sectors (public & private) and segments (transport/industry)
The top 3 novel opportunities, all of which build expertise, knowledge, skills & experience to boost hydrogen economy growth: i) Create a hybrid energy production model: demonstrating how renewables plus hydrogen (& battery) storage can lead to viable fuel sources ii) Use these renewable fuel sources (principally hydrogen) to demonstrate viable applications across the hydrogen economy iii) Bring electrolysers from JM or ITM (& Honda) to Wroughton.	Risks around current uncertainty re government commitment to hydrogen at government level. Risk around what to do with surplus energy (sell as short term and spot market or to grid); renewables are not reliable energy supply without storage (post meeting note: significant hydrogen storage is included in Feasibility study, plus can draw from the grid)
Top 3 Commercial Ideas: i) Companies come to NCC to pilot, explore and test. They invest in facilities, space & expertise. ii) A potential hub for transportation refuelling is created (offsite) for mail & parcels, buses, construction. iii) Generate revenue from education & training; visitors from schools, universities, businesses, seminars, conferences	Top Sustainability Aspects: Ensure appropriate sponsors & corporate partners; Need solid local authority backing (both financial and in term of public sector piloting & testing). The Hydrogen Innovation Centre will add to the long-term identity of Swindon.

© Kiwa Ltd 2022

Building Blocks Analysis 1 – Group 3 (penned by Matt/Belinda)

RISKS	OPPORTUNITIES
Hydrogen can be difficult to meter, which leads to risks around pricing and fair charging of customers	PRODUCTION – Opportunity for some scale, in line with LEP desire to stimulate larger volumes of H_2.
Risks around uncertainty of Government position around hydrogen. How will different sized projects be treated (5-50 t/day)?	-Opportunity to team up with Earthshot prize winner- Enaptor- with their (small scale) AEM Electrolysers; grow the hydrogen innovation concept on the site
Risk that Energy Company renews existing solar contract without taking the opportunity to modify the contract and to consider upgrade of solar panels	Opportunity to replace existing solar panels with latest technology (already almost double the capacity is available 280W to 540W) as well as to build new solar.
The risks around any hydrogen leakage in terms of the impact on climate change are not currently well understood.	Opportunity for renewable energy new technology trials e.g. bladeless turbines or Norwegian kinetic innovation- Ki-tech- https://www.ki-tech.global
	Opportunity for University research around hydrogen- some Uni's have money for hydrogen research and are looking to place it.
	-Opportunity for transport (and other) demonstrations at NCC
	GRID- Opportunity for 'behind the grid' solutions; Museum group vision is to have long term contracts for renewable electricity, mainly onsite sleeving, but also opportunity for value adding time shifting of energy. i.e. import from, and export to the grid.
	HEATING- Opportunity for CHP at the site – using waste heat generated during production of hydrogen
	COSTS: opportunity to optimize electrolyser running time and availability of storage.

 © Kiwa Ltd 2022

Building Blocks Analysis 2 – Group 3 (penned by Matt/Belinda)

SUSTAINABILITY	COMMERCIALITY
GREEN-Create plan for long term transition away from existing Gas/Biomass plant for heating and dehumidification and to 'green heat'; adds to the concept of a 'green' Conference Centre	Aim for commerciality around the production of hydrogen- consider grants as a bonus. [Grants from Innovate UK, Net Zero Hydrogen Fund, Public Sector Decarbonisation Fund.]
Plenty of water for electrolysers on site- water sustainable	-Universities and/or SMEs pay to use the site for hydrogen research and testing; encourage fuel cell technology as well as new electrolyser technology companies. Carry out fuel cell reconditioning/repurposing as one SME on site.
OUTPUTS OF THE SITE – low cost, stable decarbonised energy; public engagement; development of the site	Use Western Gateway mapping, Bristol Consortium, Hydrogen Eastern Gateway; review hydrogen for Oxford-Reading Buses; hydrogen aviation fuel testing on site;
SITE AS PLACE TO ENGAGE & OPERATE: As landowner, bring SMEs, Uni partners, research, commercial partners, testing	
Check distances and costs of connections to the grid; whether any upgrades to switchgear required	

Hydrogen Concepts- The Highlights- Group 3 (penned by Matt/Belinda)

Description of Key Concepts	
Produce green hydrogen commercially from onsite renewables- driven by commerciality, not dependent on grants. Multiple revenue streams for the produced hydrogen. Transport offsite by tanker. Modular and scalable- increase volumes as new opportunities emerge/are developed. Identify O2 opportunities too.	Top Risk: There is a risk that if the volumes start too small, the site will be unattractive as an investment proposal. There is a risk that the location/hydrogen demand/price sweet spot is hard to find
The most novel opportunities were i) to encourage Skydiamond manufacturing on site; ii) use oxygen for hydroponic farming (and local sewage treatment). iii) A hydrogen airship could even be considered- to help dispel old concerns around safety of hydrogen.	Top Sustainability Aspects Price parity potential in near future (considering Total Cost of Ownership); multiple revenue streams; its commercial focus; research and innovation potential, plus manufacturing & job opportunities; the flexibility of supply and demand options from the outset
Top 3 Commercial Ideas: i) Sell the high-quality green hydrogen produced on site (without paying grid connection charges) to transport companies. ii) Reduce cost uncertainty and volatility of onsite energy (for the Museum group/public purse) by using (waste) heat from electrolysers to heat buildings and reduce current energy costs. Iii) Whilst potentially not highly commercial, consider supplying hydrogen to local estate, schools or building a community heating scheme.	

© Kiwa Ltd 2022

Appendix C. Demand Forecast

Detailed demand forecast assumptions per transport segment shown in section 5.5.

NCC Wroughton Green Hydrogen Demand Profiling

Segment		Sub-segment	Year 1 Fleet #vehs	Year 1 Conv %	Year 1 H2 op #vehs	Year 1 H2 use kgs/veh /day	Year 1 H2 use total/kg /day	Year 2 Fleet #vehs	Year 2 Conv %	Year 2 H2 op #vehs	Year 2 H2 use kgs/veh /day	Year 2 H2 use total/kg /day
1 **On-site vehicles**	1.1	HFC cars	2	100%	2	1	2	2	100%	2	1	2
Owned/operated by SMG/NCC	1.2	HFC forklifts	7	100%	7	1	7	7	100%	7	1	7
	1.3	HFC vans	5	100%	5	1.5	7.5	5	100%	5	1.5	7.5
	1.4	HFC shuttle bus	1	100%	1	5	5	1	100%	1	5	5
		Subtotal on-site vehicles	**15**		**15**		**21.5**	**15**		**15**		**21.5**
2 **SBC vehicles**	2.1	School minibuses	7	50%	4	2	7	7	100%	7	2	14
Owned by SBC	2.2	"Access" minibus	1	100%	1	2	2	1	100%	1	2	2
	2.3	Waste collection	13	20%	3	12	31.2	13	40%	5.2	12	62.4
		Subtotal SBC vehicles	**8**		**7**		**40.2**	**8**		**8**		**78.4**
3 **Coach contractors**	3.1	Barnes Coaches	40	2.5%	1	16	16	40	5%	2	16	32
SBC contract												
		Subtotal coach contractors	**40**		**1**		**16**	**40**		**2**		**32**
4 **Emergency services**	4.1	Police vehicles (Wiltshire Police)	40	2.5%	1	3	3	40	2.5%	1	3	3
	4.2	Ambulances (GWH Foundation Trust)	13	2.5%	0.3	5	1.6	13	2.5%	0.3	5	1.6
	4.3	Fire service (Dorset & Wilts FS)	6	2.5%	0.15	5	0.75	6	5%	0.3	5	1.5
		Subtotal emergency services	**59**		**1.5**		**5**	**59**		**2**		**6.1**
5 **Public Transport: buses**	5.1	Swindon's Bus Company (Go Ahead Group)	85	20%	17	20	340	85	30%	26	20	510
SBC contracts	5.2	Stagecoach West	30	20%	6	20	120	30	30%	9	20	180
		Subtotal public transport: buses	**30**		**6**		**460**	**115**		**34.5**		**690**
6 **Licensed taxi operators**	6.1	V-Cars	100	5%	5	5	25	100	5%	5	5	25
SBC-licensed	6.2	Cross Street Cars	50	5%	2.5	5	12.5	50	5%	2.5	5	12.5
	6.3	Others	100	5%	5	5	25	100	5%	5	5	25
		Subtotal licensed taxi operators	**250**		**12.5**		**63**	**250**		**12.5**		**62.5**
7 **R&D + Companies Testing**	7.1	Bath University	2	50%	1	2	2	2	50%	1	2	2
Research & testing at NCC	7.2	Reading University	2	50%	1	2	2	2	50%	1	2	2
	7.3	UWE @Bristol	2	50%	1	2	2	2	50%	1	2	2
	7.4	RWE Technology	2	25%	0.5	2	1	2	25%	0.5	2	1
	7.5	Inter-IKEA	20	5%	1	25	25	20	10%	2	25	50
	7.6	Fedex	100	1%	1	25	25	100	5%	5	25	125
	7.7	B&Q	80	1%	0.8	25	20	80	5%	4	25	100
	7.8	Amazon	40	1%	0.4	25	10	40	5%	2	25	50
	7.9	ZEFI	1	10%	0.1	2	0.2	1	10%	0.1	2	0.2
	7.10	ZeroAvia	1	100%	1	4	4	1	10%	0.1	4	0.4
		Subtotal R&D partners	**250**		**7.8**		**91.2**	**250**		**17**		**332.6**
8 **M4 transit HGV traffic**	8.1	General Haulage	2000	0.5%	10	25	250	2000	1%	20	25	500
	8.2	Contract Logistics	1000	0.5%	5	25	125	1000	1%	10	25	250
		Subtotal M4 transit HGV traffic	**3000**		**15**		**375**	**3000**		**30**		**750**
9 **Last mile delivery**	9.1	Waitrose Online (Wichelstow	10	10%	1	10	10	10	10%	1	10	10
	9.2	Royal Mail (Dorcan)	25	10%	2.5	10	25	25	10%	3	10	25
		Subtotal last mile delivery	**35**		**3.5**		**35**	**35**		**4**		**35**
10 **SME's**	10	SME innovation (BusinessW	20	10%	2	10	20	20	15%	3	10	30
		Subtotal SME's	**20**		**2**		**20**	**20**		**3**		**30**
11 **Wholesale**	11.1	Air Liquide	1	20%	0.2	500	100	1	30%	0.3	500	150
	11.2	Other H2 distributors	1	20%	0.2	500	100	1	30%	0.3	500	150
		Subtotal wholesale	**2**		**0.4**		**200**	**2**		**1**		**300**
12 **Ex ITM M4 Jct 16**	12	Volume from ITM customers (estimated)	2	100%	2	1	2	2	100%	2	1	2
		Subtotal Ex ITM M4 Jct 16	**2**		**2**		**2**	**2**		**2**		**2**
		TOTAL NCC H2 DEMAND FORECAST	**3711**		**74**		**1305**	**3796**		**129**		**2216**

Appendix D. Bus Company Consultation

CONSULTATION NOTES: UK H2/BEV FOR BUSES

External participants:

Metroline Travel/Metroline West – London

Translink – Belfast & NI

Objectives

Opportunities were taken to:

i. learn from clean transport advocates who had blazed the trail with battery electric and hydrogen fuel cell buses.
ii. sharpen understanding of the transition process from initial plan to implementation
iii. gain deeper understanding of financial and operational elements

Context

The individuals consulted have led the commercial and operational aspects of urban/suburban bus fleet transition to BEV and HFC operation. As such, both offer deep experience of the costs of transition and of "clean fleet" operation; the constraints involved in transition and operation, and the increased capability requirements brought about by transition.

The detailed illumination of "the three C's" (Cost, Constraints and Capability) was a detailed, commercially realistic, and highly useful breakdown of the leadership challenges of clean fuel transition for bus fleets. The following notes are structured along the lines of the C's.

Summary of Learnings ("the three C's")

Participants highlighted the "commercial and operational naiveté of central/local government planning and funding". In a comparison with London, which attempted to switch 9000 buses to BEV-operation in a "switch and go"-style transition, Singapore was highlighted as an example of more "joined-up" planning ("*government agencies should talk to each other*"), greater foresight and more considered implementation.

In Singapore, buses were migrated into a transitional hybrid model – supported by an extensive backbone of digitised metrics and interactive fleet management. With hybrid buses having a 14-year cycle, and capable of responding to the different needs of inner city and suburban route patterns with ease, a more solid and versatile foundation was built for cleaner operation, and a platform built for ultimate conversion to BEV or H2 (or both), while experience is gathered, funding requirements assessed, and technology appraised.

Joined-up thinking", or "*arrows pointing in the same direction*" was a frequent theme of the meeting, with a clear opinion voiced that some UK projects had been ill-considered, "knee jerk" responses which had not been properly thought through. In no way dismissive of either the urgency or importance of decarbonisation, but critical of strategic, planning, funding, and operational weaknesses.

© Kiwa Ltd 2022

Costs

Base vehicle cost

- Typical new vehicle purchase prices for buses are as follows: diesel: £150k; BEV £240k; HFC £325k.
- The existence of a price differential between diesel, BEV and HFC vehicles is unlikely to disappear over time, but may narrow
- A bus has an operating life expectancy of ca 20 years, while its battery has a 15-year life expectancy: this means a battery must be swapped mid-life.
- A bus cannot be simply and cost-effectively converted from diesel to BEV/HFC, or from BEV to HFC.

Operating company margins

- Privately owned/PLC bus fleets operate on margins between 2-4% of gross revenue, making cost increases impossible to bear (see also 1.4 Elasticity).

Service, maintenance & parts

- OEM's design and tightly specify both battery packs and the surrounding equipment, giving operators no flexibility to source parts in a competitive, independent aftermarket and driving up parts prices.

Elasticity

- A funding gap is evident on diesel > BEV/HFC transition. Numbers would need to be modelled, but the meeting assumption was that the funding gap can only be closed by either higher fares or government subsidy (or a blend of both). Would passengers a) pay more or b) be more likely to use public bus transport if buses were cleaner and quieter? Again, modelling is required, but **the working hypothesis must be that this would be insufficient to close the gap**.

Constraints

Available clean energy (BEVs)

An "archaic" national grid infrastructure represents a significant stumbling block to BEV operation.

- Electricity supply at lowest rates from the national grid is neither guaranteed nor secure.
- Net zero operation is highly questionable for BEVs when marginal electricity is drawn from a grid whose power is fossil fuel-generated (*therefore HFC is the cleaner option)*.

Aftermarket parts

OEM's design and tightly specify both battery packs and the surrounding equipment, giving operators no flexibility to source parts in a competitive, independent aftermarket and driving up parts price

 © Kiwa Ltd 2022

Service & maintenance (plus positives)

- BEV's offer some limited service and maintenance advantages over diesel-fuelled buses, with oil and filter changes dropping off the cost radar.
- Is charge-and--swap an option? It is timely and labour-intensive: the battery is the size of a Ford Fiesta.
- Failures in the BEV and HFC powertrains are significantly more expensive to repair.

Cold- and high-temperature operation

In very low or very high ambient temperature operating environments (GB), 20-40% of the battery power (and therefore range, see 2.6) is drained by the need for battery warming or heating (to maintain voltage output).

Depot space

Operating both BEV and HFC buses implies greater space requirements. However, given the need to recharge most/all BEV buses overnight, the additional space required for charging bays is considerable higher than for hydrogen operation.

Battery range vs OEM claims

Significant anxiety over limited range of current batteries in BEV buses.

- Recharge time for a bus battery is 4-6 hours – expensive downtime and requires depot space.
- A HFC bus is refuelled, by contrast, in 6-8 minutes – though there is no commodity market price for either packed/bottled or bulk (67% cheaper) H2.
- OEM's overstate potential range of BEVs): claims are between 200 and 250 mile range on a single charge. Operational experience suggests a maximum battery range of 150 miles with mixed urban/suburban routing, decreased still further in very hot or very cold ambient temperature operation (see 2.4).
- Average bus schedules are 200- 250 miles/day, bringing a headache for operators of BEVs, and meaning either shorter route patterns (and more of them) or the culling of routes altogether.
- A HFC bus has a range of over 300 miles/day, so HFC's look a more attractive option to bus operators with mixed urban and suburban routes.

Capability

Wholesale changes in engineering, driving, scheduling, routing, and management capability as well as monitoring and KPI management are required for a shift to BEVs and/or HFCs.

Engineering, service & maintenance

No ready supply of trained/experience BEV or HFC skills. Means investment in re-skilling of engineering teams or recruitment of more highly paid engineers.

© Kiwa Ltd 2022

Drivers

Driver capability is a key factor with a BEV bus: battery range can reduce to 100 miles/day with "poor driving". Training and monitoring is required in "regenerative braking" (although the published battery performance benefits to be obtained through regenerative braking are "false").

Scheduling & routing

BEVs require trained teams managing vehicles, routing, range, and battery performance via telematics.

NB: when asked if any of these costs, constraints or capability challenges fall away with a move from BEV to HFC, participants maintained that many elements above are largely mitigated by HFC operation.

Factors to consider

- Participants were advocates of decarbonisation (as witnessed by their pioneering role in the introduction of both battery-electric and hydrogen fuel cell buses). What they bring is a) commercial insight and b) pragmatic experience – gained with some of the UK's leading urban/suburban bus businesses.
- The UK government is making sweeping commitments to more ambitious decarbonisation targets. In this context, however, no specific hydrogen strategy exists (despite some noise). This contrasts with the EU, where (as commented) a strategy has been outlined for hydrogen implementation: at its core, 1st Industry, 2nd Transport and 3rd Heating.

Kiwa Gastec
Kiwa Ltd, Kiwa House,
Malvern View Business Park,
Bishops Cleeve, Cheltenham,
GL52 7DQ, UK

Tel +44 (0)1242 677877
Email enquiries@kiwa.co.uk

www.kiwa.co.uk