HYBONT GREEN HYDROGEN PROJECT

Climate Change Statement

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1 INTRODUCTION

1.1.1 This Climate Change Statement has been prepared in support of the Hybont Green Hydrogen Project. This project will pair the production of green hydrogen[1] through polymer electrolyte membrane (PEM) electrolysis, with a private supply of renewable energy from a local solar photovoltaic (PV) array.

1.1.2 Both elements are proposed to be provided in parallel, with the Hydrogen Production Facility proposed to be located on land to the south of Brynmenyn, and the solar PV array proposed to be located on land to the east of Bryncethin. These sites will henceforth be referred to as the 'Brynmenyn Site' and 'Bryncethin Site', respectively. A private wire will connect the Bryncethin Site with the Brynmenyn Site, and a hydrogen pipeline route will connect the Brynmenyn Site with the local district heating network.

1.1.3 This report will detail the construction and operational emissions associated with both the Brynmenyn and Bryncethin Sites, and will consider the following:

- Embodied carbon emissions (associated with material extraction, manufacture and processing) for elements of both sites;
- Operational emissions arising from the Hydrogen Production Facility energy demand only; and
- Displaced emissions enabled by the hydrogen produced through the avoidance of more carbon intensive alternative fuels assuming a business as usual fossil fuel combustion.

1.1.4 Emissions associated with project decommissioning stage and end of life treatment have not been assessed within the scope of this report. Given the project lifetime (25 years) will result in decommissioning in the mid-21st Century, it is anticipated that progress towards decarbonisation of the UK economy, including improvements made towards circular economy principles relating to materials recycling and reuse, will allow any emissions associated with project decommissioning to be insignificant.

- The assessment of embodied, operational and displaced emissions included within this report has drawn key project-specific information from technical studies undertaken by Mott MacDonald with regards to: solar array design and yields, and hydrogen electrolyser design and energy demand.

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[1] Green hydrogen is produced through the electrolysis, by splitting water into hydrogen and oxygen. This electrolysis is fuelled by renewable energy sources (such as solar or wind power), resulting in low or zero carbon hydrogen. Blue hydrogen is the most commonly produced, often through steam methane reformation where natural gas is reacted with steam to form hydrogen. This is a carbon intensive process, improved through the addition of carbon capture and storage (HM Government, 2021).

2 POLICY REVIEW

2.1 UK Wide Policy

Energy White Paper: Powering Our Net Zero Future, 2020

2.1.1 The Energy White Paper (HM Government, 2020a) builds on the Ten Point Plan (HM Government, 2020b) to set energy-related measures in a long-term strategic vision, working towards the net zero emissions target for 2050. It establishes a shift from fossil fuels to cleaner energy in terms of power, buildings and industry, whilst creating jobs and growing the economy. In addition to this, the best solutions should be determined for very low emissions and reliable supply, keeping cost low for consumers.

2.1.2 Focusing on electricity is key for the transition away from fossil fuels and decarbonising the economy by 2050. Some relevant commitments from this white paper include the following.

- Accelerate the deployment of clean electricity generation through the 2020s.
- Invest £1 billion in UK's energy innovation programme to develop the technologies of the future such as advanced nuclear and clean hydrogen.
- Make sure that energy system information about supply and demand is used to drive greater efficiency and lower costs.

2.1.3 The Net Zero Innovation Portfolio (HM Government, 2021a) has been developed and aims to *"accelerate the commercialisation of low-carbon technologies, systems and business models in power, buildings and industry…and set the UK on the path to a low carbon future. It will create world-leading industries and new green jobs."* It looks to focus on ten priority areas, including flexibility in decarbonisation of the energy system.

2.1.4 Key commitments relating to the energy system include:

- *"Publish a new Smart Systems Plan in spring 2021, jointly with Ofgem, and define electricity storage in law, legislating when Parliamentary time allows;*
- *Through the Net Zero Innovation Portfolio, we will launch a major competition to accelerate the commercialisation of first-of-a-kind longer duration energy storage, as part of our £100 million investment in storage and flexibility innovation, with delivery from spring 2021; and*
- *We will legislate, when Parliamentary time allows, to enable competitive tendering in the building, ownership and operation of the onshore electricity network."*

Net Zero Strategy: Build Back Greener, 2021

2.1.5 The Net Zero Strategy (BEIS, 2021b) sets out the UK's long-term plans to meet net zero emissions by 2050 and gives the vision for a decarbonised economy in 2050.

2.1.6 The policies detailed in the strategy will be phased in over the next decade or beyond in order to continue decarbonisation towards net zero. They also aim to keep the UK on track to meet upcoming carbon budgets.

2.1.7 This strategy brings forward the ambition for a fully decarbonised power system by 15 years, building on the targets set out in the Energy White Paper and the Ten Point Plan for a Green Industrial Revolution. The ambition is to fully decarbonise the UK's power system by 2035, with electricity sourced predominantly from wind and solar generation, supported by nuclear power in addition to an increase in energy storage capacity, gas with carbon capture and storage (CCS), and hydrogen to increase the flexibility of supply.

2.1.8 Further, the strategy outlines aim to support the decarbonisation of the construction and building sector. Reporting on embodied carbon in buildings and infrastructure is sought to be improved, alongside reductions in embodied carbon by way of material substitution, where appropriate, and resource efficiency.

British Energy Security Strategy, 2022

2.1.9 Building on the Ten Point Plan for a Green Industrial Revolution and the Net Zero Strategy, The British Energy Security Strategy (BEIS, 2022a) references green hydrogen projects in the following statements:

- doubling our ambition to up to 10 GW of low carbon hydrogen production capacity by 2030, subject to affordability and value for money, with at least half of this coming from electrolytic hydrogen. By efficiently using our surplus renewable power to make hydrogen, we will reduce electricity system costs;
- aiming to run annual allocation rounds for electrolytic hydrogen, moving to price competitive allocation by 2025 as soon as legislation and market conditions allow, so that up to 1 GW of electrolytic hydrogen is in construction or operational by 2025;
- designing, by 2025, new business models for hydrogen transport and storage infrastructure, which will be essential to grow the hydrogen economy; and
- levelling the playing field by setting up a hydrogen certification scheme by 2025, to demonstrate high-grade British hydrogen for export and ensure any imported hydrogen meets the same high standards that UK companies expect.

UK Hydrogen Strategy, 2021

2.1.10 The UK Hydrogen Strategy (HM Government, 2021) *'takes a holistic approach to developing a thriving UK hydrogen sector. It sets out what needs to happen to enable the production, distribution, storage and use of hydrogen and to secure economic opportunities for our industrial heartlands and across the UK. Guided by clear goals and principles, and a roadmap showing how we expect the hydrogen economy to evolve and scale up over the coming decade, the Strategy combines near term pace and action with clear, long term direction to unlock the innovation and investment critical to meeting our ambitions*.'

2.1.11 Specifically referencing Wales, the UK Hydrogen Strategy states that *'Wales has significant opportunities for low carbon hydrogen production and use. Its offshore wind and tidal and wave power potential, strong infrastructure networks and ports, research and development strengths, skills base and readily available internal markets provide a platform for deployment of hydrogen and fuel cell technologies under a favourable policy environment*.'

2.1.12 '*As we scale up low carbon production through the 2020s, we expect the main production methods to be steam methane reformation with carbon capture, and electrolytic hydrogen predominantly powered by renewables*.'

2.1.13 '*System flexibility through electrolysis and storage ('Power to Gas', 'Power to Gas to Power'): Electrolytic hydrogen production can also provide grid flexibility by drawing on 'excess' renewable or low carbon electricity that would otherwise be constrained or curtailed (where power cannot be transmitted) and where there is an economic case to do so. In this way electrolytic hydrogen can allow excess electricity to flow across different parts of the system, from power to gas, to transport or industry (often referred to as 'sector coupling'). This unlocks a wide range of system benefits and can provide an additional route to market for new and existing renewables capacity. Coupling this electrolytic production with storage, including long duration storage where hydrogen is a lead option (see Chapter 2.3.2), can help integrate hydrogen further into our power system by helping to balance the grid when generation from renewables is higher or lower than demand.*'

Hydrogen Strategy Update to the Market, 2022

2.1.14 Since the publication of the UK Hydrogen Strategy, BEIS (2022b) has provided a Hydrogen Strategy Update to the Market, published in July 2022, stating the following:

2.1.15 '*Since the publication of the UK Hydrogen Strategy, we have continued to deliver on our commitments, setting out new policy and funding for hydrogen across the value chain, and bringing together the international community around shared hydrogen objectives to rapidly develop a global hydrogen economy. Hydrogen was a key component of the Net Zero Strategy, COP26 and the British Energy Security Strategy. The Hydrogen Investment Package and opening* *of the £240 million Net Zero Hydrogen Fund in April marked a major step forward in delivering government support to drive further private investment into hydrogen production in the UK.*'

2.1.16 '*To keep industry informed on the government's ongoing work to develop the hydrogen economy, we committed in the UK Hydrogen Strategy to producing regular updates to the market as our policy develops. In addition to offering an accessible 'one stop shop' of government policy development and support schemes, these updates will provide industry and investors with further clarity on the direction of travel of hydrogen policy across the value chain, so that government and industry can work together most effectively and with the necessary pace to build a world-leading low carbon hydrogen sector in the UK.*'

2.2 Welsh Policy

Net Zero Wales Carbon Budget 2 (2021-2025)

2.2.1 '*We believe strong Welsh Government commitment to a net zero pathway, backed by financial support, regulation and clear hydrogen strategies and targets, could trigger unprecedented and sustained momentum in Welsh hydrogen in the medium to longer-term. We need to understand the role hydrogen should play in Wales in the longer term – in transport, in industry and in energy – but in the meantime will take action to keep our options open. We will*:

- *Establish at least one renewable hydrogen production site 10+ MW by 2023-24: Providing stimulation and support to the demand side.*
- *Scope large-scale hydrogen production sites: Given the time required from developing a concept to implementation of hydrogen production at scale, there is a need to begin planning low carbon/ renewable hydrogen production and delivery facilities in parallel with the deployment of the initial smaller scale facilities.*
- *Support local projects and place based approaches: such as the Holyhead Hydrogen Hub.'*

Low Carbon Delivery Plan 1

2.2.2 '*If Wales is to meet its climate targets, buildings will need to operate at close to zero emissions by 2050. This will require a substantial change in how we heat and power buildings in the future. The amount of energy used in our buildings will have to be significantly lower. The electricity we use to light and increasingly heat our buildings will be from low carbon and renewable sources. When gas is needed for heating to meet demand, as a supplement to other sources, the proportion of green gas such as biomethane or hydrogen will be higher*.'

2.3 Local Policy

Bridgend Local Development Plan (LDP) 2006-2021 (2013)

2.1 The Bridgend Council LDP (Bridgend Council, 2013) is intended to be replaced by an emerging LDP outlining local planning policy from 2018-2033, although this plan is yet to be formally adopted (further detailed below). The current plan is focused on achieving sustainable development, providing a basis for rational and consistent developmental management decisions and to guide growth and change while protecting local diversity and character. Relevant policies to the proposed project are as follows:

2.2 **Strategic Policy SP8: Renewable Energy.** ***"****Development proposals which contribute to meeting national renewable energy and energy efficiency targets will be permitted where it can be demonstrated that there will be no significant adverse impacts on the environment and local communities".* This policy highlights that renewable energy developments will be supported in principle.

2.3 **Policy ENV17: Renewable Energy and Low/Zero Carbon Technology.** *"The council will encourage major development proposals to incorporate schemes which generate energy from* *renewable and low/zero carbon technologies".* This policy states that a Renewable Energy Assessment was prepared alongside the LDP to indicate potential levels of energy generation from renewable sources, and has produced an Energy Opportunities Plan as a special planning guidance document to the LDP, to spatially identify possible sources of renewable energy.

2.4 **Policy PLA4: Climate Change and Peak Oil.** *"All development proposals will be required to make a positive contribution towards tackling the causes of, and adapting to the impacts of Climate Change".* The policy indicates that means of achieving this may include promoting energy efficiency, using local materials and supplies, encouraging the development of renewable energy generation, and using resources more efficiently and minimising waste.

Bridgend County Borough Draft Local Development Plan (2018-2033)

2.3.1 The emerging draft local plan, which is to come into effect following examination by Bridgend Council, supports continued decarbonisation in line with the Welsh carbon budgets.

2.3.2 *'Under the Environment (Wales) Act (2016), Wales is required to reduce net greenhouse gas emissions by at least 80% by 2050 (against a baseline set in legislation), with interim targets and carbon budgets established to ensure this target is met. In March 2019, Welsh Government published Prosperity for All: A Low Carbon Wales that sets priorities for*:

- *reducing the amount of energy we use in Wales;*
- *reducing our reliance on energy generated from fossil fuels; and;*
- *actively managing the transition to a low carbon economy.'*

2.3.3 Within the draft local development plan, 'SP13: Renewable and Low Carbon Energy Development' will assist the County Borough transition to a low carbon, decentralised energy system that works for its individuals, communities and businesses by encouraging renewable and low and zero carbon energy projects.

3 APPROACH AND METHODOLOGY

3.1.1 Given the early stage in the design process, specific environmental product declarations (EPDs) are not yet identified. As such, the assessment of embodied carbon associated with the construction of the project, and operational emissions associated with the admin building, relies on existing published information and benchmarks. The assessment methodology and source materials are detailed further within this section.

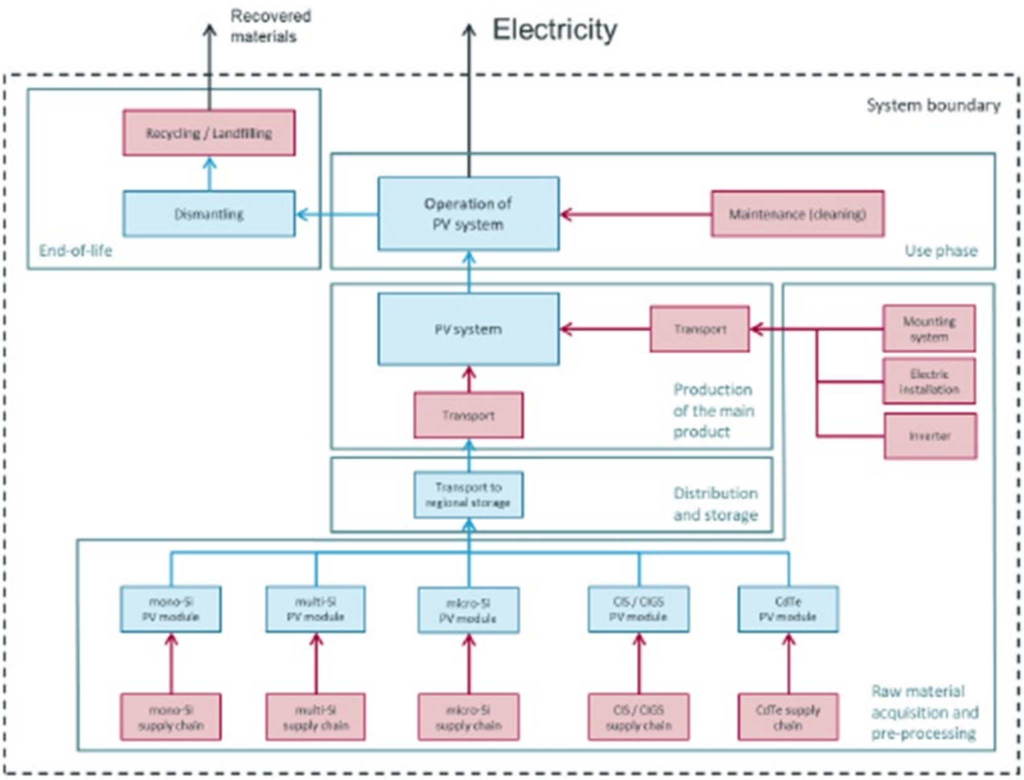
3.2 Embodied Carbon

3.2.1 Bryncethin Site – Solar PV

3.2.1 The installation of a 5.51 MW solar PV array would result in both direct and indirect greenhouse gas (GHG) emissions at all stages of its lifecycle. These emissions would occur as a result of the extraction of necessary raw materials, manufacturing of the panels and associated balance of system (BoS)[2] components, transportation of materials to the site, the onsite assembly/construction of the PV array, ongoing maintenance and end of life (EoL) treatment.

3.2.2 The quantification of the emissions resulting from these activities requires a GHG Lifecycle Assessment (LCA). Figure 1 below displays the system boundaries considered in a typical GHG LCA for a PV development of this nature.

Figure 1: System boundaries for a solar PV development (IEA, 2020)



3.2.3 Currently, 95% of total global PV production is accounted for by crystalline silicon (c-Si) panel technology (66% of which is accounted for by mono-crystalline (mono c-Si) and 34% by multi-crystalline (multi c-Si)) (ISE, 2020). Mono c-Si panels have been chosen for the proposed development, however multi c-Si panels have also been referenced in the assessment of GHG effects to provide a broader range of available LCA's, increasing the robustness and validity of research.

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[2] BoS components are predominantly comprised of inverters, electrical cabling and frames/mounting structures.

3.2.4 Emerging technologies for high efficiency c-Si panel types such as passivated emitter and rear contact (PERC), heterojunction (HJT), and interdigitated back contact (IBC) technology are becoming more readily available on the market, however, robust LCA information for such technology types is not yet available. This assessment has therefore concentrated on established first generation c-Si panel technologies.

3.2.5 The key GHG emitting process involved in the manufacturing of c-Si panels and associated BoS components are as follows.

- The extraction of quartz, from which metallurgical-grade silicon is extracted. This silicon is then further purified into solar-grade silicon, typically via the energy intensive Siemens reactor method.
- The forming of silicon ingots: an electricity-intensive process requiring 32 kWh per kg of mono-Si ingot (via the Czochralski process), or 7 kWh per kg of multi-Si ingot (IEA, 2020).
- The extraction of raw materials for and manufacturing of BoS components, e.g. silica for glass, copper ore for cables, iron and zinc ore extraction and refinement for mounting structures and bauxite extraction and refinement for module framing (c-Si modules require circa 2.1 kg of aluminium per m^2 of module) (IEA, 2015).

3.2.6 The emissions resulting from the processes described above, as well as those occurring due to the transportation of materials to site and onsite emissions occurring during the assembly of the solar PV array account for circa 70% of total lifecycle GHG emissions (not including the avoided emissions resulting from the displacement of more carbon intensive electricity generation) (NREL, 2012).

3.2.7 Solar PV LCAs are a complex process, given the large number of materials and processes involved in the production of PV modules and BoS components. Furthermore, the associated GHG emissions are dependent on the location (and associated energy mix) of where these processes are occurring. As such, a detailed site specific LCA is beyond the scope of this assessment. Instead, a robust approach has been formulated by considering meta analyses of published solar PV LCAs, thereby accounting for the likely range of magnitude of the proposed development's construction-stage GHG emissions..

Emissions factors and data sources

3.2.8 The current literature surrounding PV system LCAs is characterised by a high degree of variability in its published GHG figures, and therefore a degree of uncertainty occurs in selecting any one of these figures as a means of analysing the embodied GHGs in constructing a solar array. As a means of dealing with this uncertainty, the primary source of emissions factors used in assessing the embodied carbon effects of the proposed development was NREL's (2012) 'Life Cycle Greenhouse Gas Emissions of Crystalline Silicon Photovoltaic Electricity Generation'. The study constituted a meta-analysis of over 397 LCAs regarding C-SI PV systems, all of which were subject to a screening process, and for those which passed the screening process, a subsequent harmonisation process. Using the NREL study as a means of acquiring GHG factors for construction-stage[3] GHG emissions partially eliminated the large degree of variability and uncertainty in the published literature surrounding PV LCAs and ensured the range of construction-stage GHG emissions stated in this chapter represent the most realistic and accurate effects.

3.2.9 The screening process removed the majority of the considered studies, so that the meta-analyses considered in detail only 13 studies (containing a total of 42 Lifecycle GHG factors). The screening process ensured that minimum standards for the following criteria were met:

- Quality: the study used an accepted LCA methodology (e.g. ISO 14040 (ISO, 2006));
- Transparency: the study described its methods, sources and values of input data; and

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[3] Construction-stage – in this sense – also refers to the emissions associated with maintenance and any EoL treatment-related emissions. It excluded the GHG implication of exporting low carbon power onto the grid.

- Relevance: relevant, up-to-date technology was analysed.

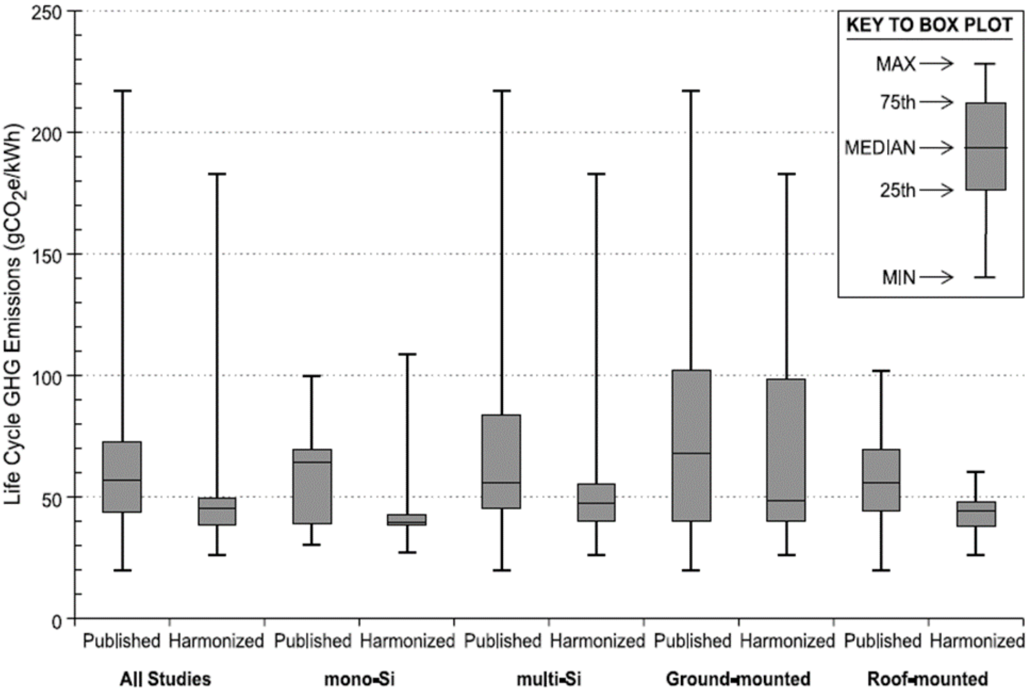
3.2.10 As well as the lifecycle GHG implications of PV systems being sensitive to the energy input/mix required for their manufacturing and production, they are also sensitive to other input parameters including module efficiency, solar insolation, system lifetime and performance ratio[4] (Pacca et al, 2007). As a means of accounting for potential variability due to these factors, the LCA studies in NREL's meta study were subject to a harmonisation process. The process involved correcting the considered LCA results following the normalisation of the aforementioned input parameters. Table 1 states the input parameters used in the harmonisation process and subsequent generation of improved lifecycle GHG factors for PV systems.

Table 1: NREL harmonised input parameters

Solar insolation (kWh/m^2/yr)	System lifetime (years)	c-Si module efficiency (%)		Performance ratio	
		Mono	Multi	Ground-Mounted	Rooftop
1,700	30	14	13.2	0.8	0.75

3.2.11 Based on the input parameters in Table 1, the NREL study generated a range of harmonised GHG impacts. These are displayed in Figure 2.

Figure 2: NREL lifecycle GHG emissions factors (NREL, 2012)



3.2.12 Based on the lower quartile ranges (LQR) and upper quartile ranges (UQR) provided within Figure 2, an initial range of 39 to 49 gCO_2e/kWh (with a median value of 44 gCO_2e/kWh) was considered. This range includes technologies not proposed to be installed, however, as detailed within paragraph 3.2.3, this is considered appropriate in order to increase the range of LCAs available to provide a more robust approach.

3.2.13 The lifetime GHG emissions factor – when expressed in terms of the system's lifetime energy output (i.e. in terms of kWh) – is sensitive to the annual insolation value used in the calculation.

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[4] Performance ratio refers to the difference in potential energy output (for a given module efficiency and annual solar insolation value), and actual energy output. The performance ratio is determined by BoS efficiency losses (namely inverter and cabling losses), cell mismatch, elevated PV module temperature, reflection from the module front surface, soiling, shading, and component failures.

The harmonized insolation value of 1,700 kWh/m^2/yr used in the NREL study is representative of the meteorological conditions of southern Europe.

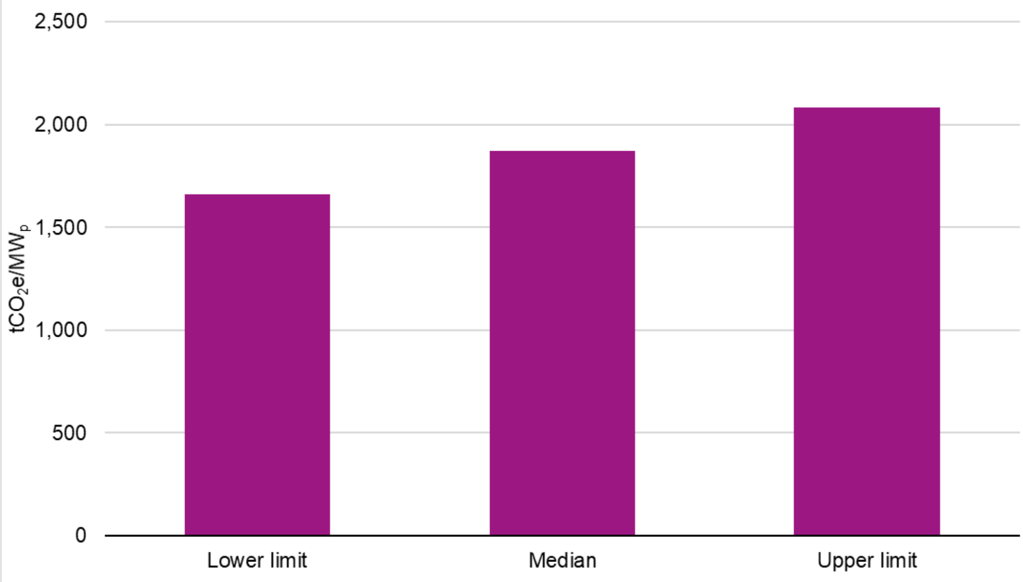
3.2.14 The IEA's (2020) 'Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems' report contains country specific annual average solar energy yields, whereby average annual energy outputs from PV systems in various countries are expressed in terms of the peak capacity of the system. An average annual energy yield (in terms of annual kWh/kW$_p$[5]) for a solar array in southern Europe was obtained by averaging the same values for Spain, Portugal, Italy and Greece. This value was then used to factor out the annual energy output for the lifetime GHG emissions factor, so that the emissions factor could be expressed in terms of gCO$_2$e/MW (i.e. in terms of installed capacity rather than lifetime energy generation), and therefore representative of the likely range of construction-stage GHG effects of the UK-based proposed development. The lifetime GHG factors, expressed as gCO$_2$e/MW could then be multiplied by the 5.51 MW generating capacity of the proposed solar array in order to calculate the construction-stage GHG impacts in tCO$_2$e.

3.2.15 Table 2 and Figure 3 display the source data used to inform calculations of the construction-stage GHG intensities of the proposed solar array, including the possible upper and lower limits, based on the NREL (2012) study.

Table 2: Construction stage GHG emissions factors and impacts (NREL Scenario)

	Lower limit	Median	Upper limit
Lifecycle GHG intensity (gCO$_2$e/kWh)	39	44	49
Average annual energy yield[6] (kWh/kW$_p$)	1,419	1,419	1,419
Operating lifetime (yrs)	30	30	30
Total GHG (gCO$_2$e/kW$_p$)	1,659,645	1,872,420	2,085,195
Total GHG (tCO$_2$e/MW$_p$)	1,660	1,872	2,085

Figure 3: Total construction stage GHG impacts (NREL Scenario)



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[5] 'W$_p$' refers to the nominal power of a solar array, i.e. its peak generation capacity.

[6] For a solar array in southern Europe

3.2.16 Using the above-described source data, and multiplying the resultant GHG emissions factors (1,660 to 2,085 tCO_2e/MW_p) by the proposed solar array's peak capacity of 5.5 MW, results in an estimated 9,145 tCO_2e to 11,489 tCO_2e embodied carbon resulting from the solar PV construction.

3.2.17 A potential limitation of this assessment is the age of the meta-analysis study that has used to inform the potential construction-stage GHG emissions. So as to provide further confidence in the results expressed in Table 2, a recent study by Milouisi et al (2019) was also considered. This study calculated the lifecycle GHG implications of 3 kW PV systems of varying panel technology in Crete, which were therefore under similar irradiance conditions to the harmonized irradiance value expressed in the NREL study. The Milousi et al (2019) study concluded that mono-Si systems have a lifecycle GHG impact of 52.4 gCO_2e/kWh, whilst multi-Si systems have a lifecycle GHG impact of 44.3 gCO_2e/kWh. These results provide further confidence that the results expressed in Table 2 are in the correct order of magnitude.

3.2.18 As the type of panel is known (mono c-Si), and the Milousi et al (2019) study is both the more recent study, as well as offering the most conservative estimation of the lifecycle GHG impact of mono c-Si panels at 52.4 gCO_2e/kWh, this has been used to establish the estimated construction GHG emissions of the proposed solar array to be **12,287 tCO_2e**.

Private Wire

3.2.19 A private wire will connect the solar PV array with the hydrogen production facility. This is likely to comprise carbon intensive materials such as copper or aluminium, in addition to insulation. However, when considering the project as a whole and the potential contribution towards the whole life carbon, the embodied carbon associated with the private wire connection is likely to be insignificant. As such, this has not been further assessed.

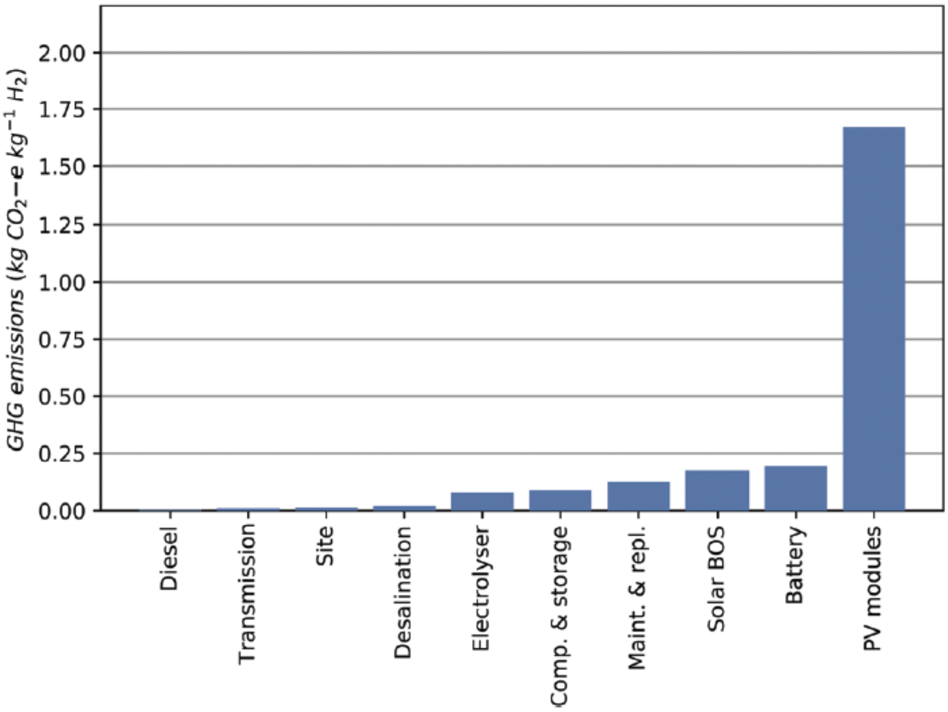
3.2.2 Brynmenyn Site - Hydrogen Production Facility

Hydrogen Electrolysers

3.2.1 Research by Palmer et al. (2021) considers a case study of hydrogen production via solar PV, and assesses the project in terms of GHG emissions, highlighting the significant embodied carbon associated with the solar panels as outweighing those associated with the hydrogen electrolysers. '*The solar components are much more significant than the electrolysis components. Comparison of the materials load for the respective system components elucidates the underlying reasons for the difference*'.

3.2.2 As can be seen in Figure 4 below, the GHG emissions (kg CO_2e kg^{-1} H^2) from the electrolysers, compression and storage facilities, are comparable to that of the solar PV BoS components, and are much less significant than that of the GHG emissions associated with the solar PV modules.

Figure 4: GHG emissions from solar-battery baseline scenario (Palmer et al., 2021)



3.2.3 An 18-fold difference (approximately 5.5%) in emissions intensity between the solar PV panels and electrolyser system components is reported by Palmer et al. (2021).

3.2.4 This is supported by further studies assessing the embodied carbon associated with hydrogen electrolysers, this time accompanied by a wind energy supply, which states the Global Warming Potential (GWP) '*contribution of the electrolyser unit is relatively small (only about 4% in wind based electrolysis including hydrogen production and storage systems)*' (Bhandari et al, 2013). Wind based electrolysis ranks as the most efficient method of hydrogen production via electrolysis, with GWP values for solar PV moderately higher than those for wind electrolysis. The higher GWP values for PV are due to the significant emissions related to module manufacturing processes (Bhandari et al, 2013).

3.2.5 Therefore, to provide a conservative estimate of embodied carbon associated with the hydrogen production and storage facilities at the Brynmenyn Site, a 5.5% uplift was applied to the embodied carbon associated with the solar PV array at the Bryncethin Site, as stated in paragraph 3.2.18. This results in a total of **676 tCO_2e** of GHG emissions.

Hydrogen Pipeline

3.2.6 Despite its length, the hydrogen pipeline is unlikely to significantly contribute to the total embodied carbon associated with the project. The hydrogen pipeline operating pressure is proposed to be low (below 7 barg), and as such is unlikely to require a carbon intensive metallic pipeline commonly used for higher pressure systems. Instead, polyethylene materials are likely to be used, which come with low carbon intensities allowing the project to achieve embodied carbon emission reductions when compared to those arising from the alternative carbon intensive metallic pipelines, resulting in embedded emission mitigation within the pipeline design. As such, this assessment will not further consider the embodied carbon associated with the construction of the hydrogen pipeline.

Supporting Infrastructure

3.2.7 Other infrastructure associated with the Brynmenyn Hydrogen Production Facility includes the following:

- Substation;
- Admin Building; and
- International Organisation for Standardisation (ISO) Containers (30 / 40 ft).

3.2.8 Site infrastructure associated with the Hydrogen Production Facility, such as roads and drainage, have not been considered within this assessment of embodied carbon. When considering the magnitude of embodied carbon emissions anticipated to result from the solar PV array at the Bryncethin Site, and those associated with the hydrogen electrolysers, it is unlikely that emissions arising from the construction of site infrastructure would be significant.

Substation

3.2.9 There is limited design data and few published LCAs from which to calculate the embodied emissions associated with the substation, busbars and BoS components. Data from an environmental product declaration (EPD) for a 16 kVA – 1000 MVA transformer (ABB, 2003) has therefore been used to provide an approximation of the potential order of magnitude of emissions, as transformers are among the major substation plant components and have a relatively high materials and carbon intensity, including the copper or aluminium winding.

3.2.10 The LCA listed a manufacturing GWP of 2,190.04 kgCO_2e per MW. This was scaled by the substation capacity incoming DNO supply of 10 MVA and incoming private wire supply of 5 MVA (total 15 MVA) to give an estimated embodied emission value of **33 tCO_2e**.

Admin Building

3.2.11 Limited information is currently available regarding the design of the admin building to be located towards the south of the site. As such, the proposed building area has been scaled by RICS industry standard benchmarks (925 kgCO_2e/m^2) to give a worst-case estimate of associated embodied carbon. This value totals **149 tCO_2e**.

ISO Containers

3.2.12 The electrolysers, compression and re-fuelling station units will be housed within 30 ft or 40 ft ISO containers. The embodied carbon of such containers has been calculated by scaling their estimated weight with an associated embodied carbon factor listed within the Inventory of Carbon and Energy (ICE) (Jones and Hammond, 2019). This value totals **68 tCO_2e**.

3.2.13 This value include lifecycle stages A1-A3.This will likely underestimate construction stage emissions. While the manufacturing emissions associated with the steel used to make the container crates is included, the emissions associated with the manufacture of the crates themselves and potential waste materials is not. However, it is considered that further inclusion of emissions resulting from manufacture and waste are unlikely to exceed those already stated for the construction of the ISO containers, and are anticipated to be negligible.

3.3 Operational Emissions

3.3.1 No operational emissions have been assessed for the Bryncethin Solar PV site – these have been accounted for within the assessment of embodied carbon emissions. The published literature used within the calculations, as described in Section 3.2.1, include maintenance and replacement of the solar PV array taking place within the operational phase its lifetime.

3.3.2 The following assessment of operational emissions focuses on those arising from the Brynmenyn Hydrogen Production Facility.

3.3.2 Hydrogen Electrolysers

Carbon intensity of energy sources

3.3.1 Although the Hydrogen Production Facility will include a private wire connection to the solar PV array at the Bryncethin Site to supply energy for hydrogen electrolysis, it will also make use of wind energy through a power purchase agreement (PPA), and a minor amount electricity from the grid. The carbon intensity of each energy source is described below.

Solar

3.3.2 As the solar energy for hydrogen electrolysis will be provided from the Bryncethin Site solar PV array, of which the construction GHG emissions have already been quantified above, the carbon intensity of such solar energy is considered to be zero. The construction carbon emissions accounts for future operational maintenance activity within the intensity used.

Wind

3.3.3 The lifecycle carbon intensity of offshore wind has been informed by Bhandari et al (2020), who compiled LCA data from secondary sources regarding the GHG impacts of offshore wind generation across the manufacturing, installation, transportation, maintenance, and dismantling lifecycle stages. The study compiled a total of six datasets ranging turbines with rated powers between 0.5 and 6 MW. While this sample size is small, LCA data for offshore turbines is limited, and as such an average of multiple studies is deemed an acceptable proxy. A lifecycle GHG intensity of 17.73 gCO_2e/kWh was established.

Grid Electricity

3.3.4 With regard to the grid electricity used to power the Hydrogen Production Facility, two figures have been utilised to provide a range of expected carbon intensity of grid electricity across the facility's operational lifetime.

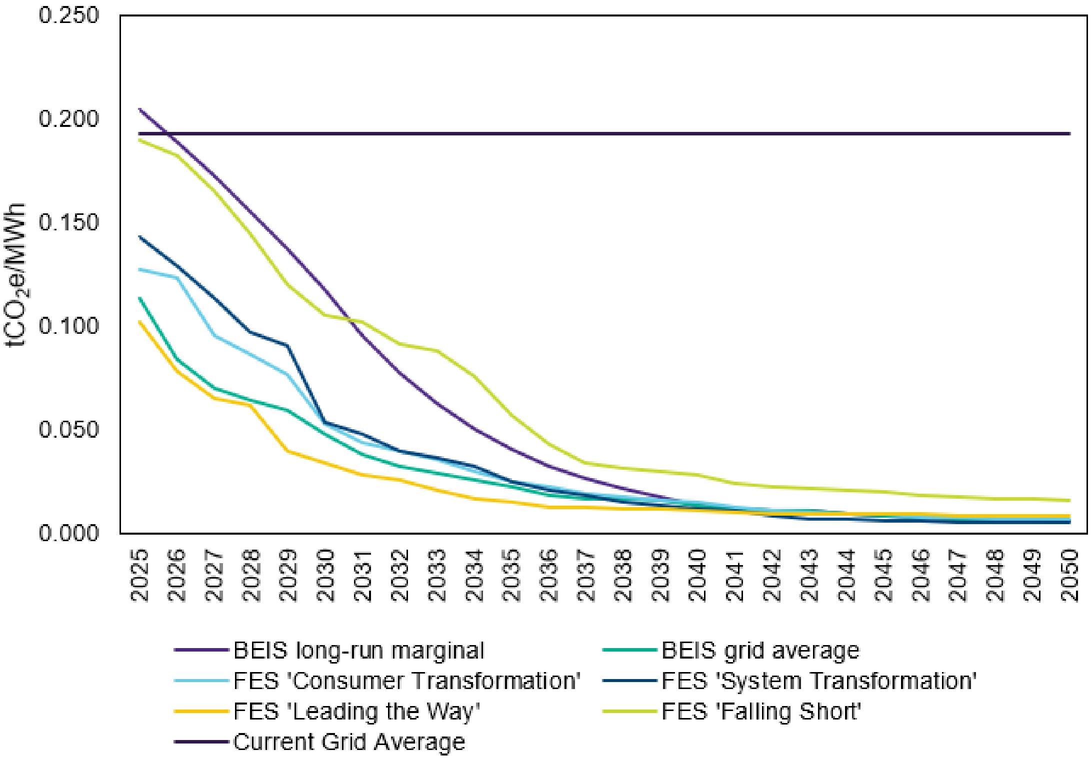
3.3.5 Firstly, the current grid average electricity carbon intensity value has been taken from published benchmarks (BEIS, 2022), and is 0.19338 $kgCO_2e/kWh$. This is a static figure which does not represent the likely scenario of an increasingly decarbonised grid over the facility's 25 year operational lifespan. As such, this figure presents a conservative estimate of the carbon intensity of grid electricity supplied.

3.3.6 Secondly, long-run marginal (BEIS, 2021) figures have been utilised. The UK government department for Business, Energy and Industrial Strategy (BEIS) publishes projections of the carbon intensity of long-run marginal electricity generation and supply that would be affected by small (on a national scale) sustained changes in generation or demand (BEIS, 2021). BEIS' projections over the facility's operating lifetime (2025 to 2049) are based on an interpolation from 2010's assumed marginal generator (a combined cycle gas turbine (CCGT) power station) to a modelled energy mix in 2030 consistent with energy and climate policy and predicted demand reduction scenarios by that point. A grid-average emissions factor is projected by BEIS for 2040 and the marginal factor is assumed to converge with it by that date, interpolated between 2030 and 2040; both factors are then further interpolated from 2040 to a national goal for carbon intensity of electricity generation in 2050 and assumed to be constant after that point.

3.2 National Grid publishes 'Future Energy Scenario' (FES) projections (National Grid ESO, 2022) of grid-average carbon intensity under several possible evolutions of the UK energy market, which have also been reviewed. The BEIS grid-average projection sits broadly in the middle of the National Grid range, and as stated above, the marginal factor is assumed by BEIS to converge with it (and hence with National Grid's scenarios) over time. Figure 5 illustrates both the BEIS and National Grid projected carbon intensity factors for displaced electricity generation over the anticipated project lifetime.

3.3 The FES projections reflect different routes to decarbonisation, with one, “falling short” not leading to near-full decarbonisation by 2050.

Figure 5: Predicted Grid Carbon Intensities under Different Scenarios



3.3.1 The future baseline for electricity generation within the UK depends broadly on future energy and climate policy in the UK, and more specifically (with regard to day-to-day emissions) on the demand for operation of renewable energy technologies, compared to other generation sources available, influenced by commercial factors and National Grid’s needs. The carbon intensity of baseline electricity generation is projected to reduce over time and so too would the intensity of the marginal generation sources.

3.3.2 In summary, the current grid average represents a scenario that lacks future renewable energy deployment to the UK national grid, whereas the long run marginal accounts for future renewable energy installation, in line with current policy, but as it is only a projection it cannot be taken with certainty. As such, both the current grid average and long run marginal projections will be used to provide a range of values for the current baseline and future business-as-usual baseline against which operational emissions associated with the facility will be calculated. It is likely that the true carbon intensity of grid electricity supplied to the Hydrogen Production Facility will fall somewhere within this range.

Energy Demand

3.3.3 As described in Mott McDonald’s report Bridgend Green Hydrogen: Basis of Design, energy demand for the hydrogen electrolysers (including demand associated with cooling and compression) will rise from 25.86 GWh to 28.38 GWh (27.12 GWh average) over the facility’s 25 year operational lifespan, due to efficiency degradation of the hydrogen electrolysers over time.

3.3.4 This demand will be met by renewable energy supplied by the Bryncethin Site solar PV array, wind-generated renewable energy, and a limited amount of wholesale grid power.

3.3.5 Yield analysis of the solar PV array, conducted by Mott McDonald, provides estimated annual solar yield from the Bryncethin Site, and accounts for year on year efficiency degradation in the assessment of whole life energy generation. Annual average solar yield from the site will total 5,194 MWh, with a total of 129,858 MWh generated across its 25 year lifetime.

3.3.6 There may be occasions where wholesale grid power must be purchased in times of abnormal demand/low renewable production (combined with an insufficient quantity of stored hydrogen). The average monthly allotment of this usage is expected to be below the 20gCO2e/MJ H2 LHV threshold required in line with the Low Carbon Hydrogen Standard. A maximum of 3,530 MWh of grid electricity is assumed to be utilised at the facility annually, with 88,250 MWh supplied over the facility's lifetime. This represents a conservative and worst case estimate.

3.3.7 With regards to the energy supplied by wind, to be secured through a PPA, it is expected that it will increase over time as electrolyser energy demand increases (due to their efficiency losses) in tandem with decreasing solar supply (as a result of degradation of the PV panels over their lifetime). The average annual electricity to be supplied by wind power is estimated to be 18,396 MWh, with a total of 459,892 MWh supplied over the facility's lifetime.

Operational Emissions

3.3.8 Table 3 summarises the above-described energy demand and operational emissions associated with the hydrogen electrolysers; utilising emissions conversion factors as detailed within paragraphs 3.3.2 to 3.3.2.

Table 3: Hydrogen production energy usage and associated resultant emissions

	Solar	Wind	Grid Electricity*
Annual average energy required (MWh)	5,194	18,396	3,530
Annual emissions (tCO_2e)	0	326	212 to 683
Lifetime energy required (MWh)	129,858	459,892	88,250
Lifetime emissions (tCO_2e)	0	8,155	5,306 to 17,066

*Emissions associated with the supply of energy from wholesale grid electricity have been calculated using both the current grid average emissions conversion factor, in addition to those supplied by the BEIS long run marginal projections, to provide a likely range of operational emissions associated with such energy supply.

3.3.9 Taking the most conservative estimation of grid electricity carbon intensity, the total lifetime operational emissions for the hydrogen electrolysis is expected to **25,221 tCO_2e**.

3.3.3 Admin Building

3.3.1 Detailed information with regards to the energy consumption at the admin building located at the Brynmenyn Hydrogen Production Facility is not yet available. As such, benchmark electricity and fuel consumption values in CIBSE Guide F – Efficiency in New Buildings (CIBSE, 2012) for a standard office were used to estimate the annual GHG emissions for the admin building. It has been assumed that all electricity powering the admin building will be sourced from the grid, providing a conservative estimate of operational emissions. As detailed within paragraph 3.3.4 to 3.3.2, both the current grid average and long run marginal projections will be used to calculate a range of likely emissions associated with the admin building over its operational lifetime.

3.3.2 Estimated energy consumption within the admin building totals 36 MWh/yr, resulting in approximately 8.8 tCO_2e/yr. Over it's lifetime, total emissions are anticipated to range between **101.6 tCO_2e to 170.4 tCO_2e**.

3.4 Displaced Emissions

3.4.1 The hydrogen produced at the Brynmenyn facility will supply local buses, refuse vehicles and light commercial vehicles, in addition to being piped into the local district heat network. The use of hydrogen as fuel for transport and heating displaces the requirement for the use of more carbon intensive fuels, such as diesel and natural gas. Emissions associated with such displaced fuels are therefore equal to those emissions avoided by the supply of hydrogen from the proposed facility.

3.4.2 A total of 443,500 kg of hydrogen is estimated to be produced per annum. Of which 290,480 kg will be used as vehicle fuel, with the remaining 153,020 kg being used to replace natural gas for heating. This is detailed below in Table 4, provided by the client, and has informed the assessment of emissions displaced as a result of the use of hydrogen produced.

Table 4: Annual Hydrogen Production

	Hydrogen use	Hydrogen (kg/yr)	Displacement type
Annual Hydrogen Production (443.5 t/yr)	Refuse Vehicles	19,880	Vehicle Fuel
	Bridgend Buses	91,500	
	Swansea Buses	91,500	
	HyHaul	87,600	
	Sarn Heat Cluster	48,770	Natural Gas
	Rockwool	104,250	
Total		**443,500**	

3.4.2 Displaced vehicle emissions

3.4.1 It has been assumed that the fuel economy of an average hydrogen bus is 0.1025 kgH$_2$/km (Penderzoli et al., 2022), and a Fuel Cell Electric Vehicle (FCEV) HGV (for use by HyHaul) is 0.090 kgH$_2$/km (Zemo Partnership, 2021). As fuelling hydrogen buses and HGVs are the largest use of vehicle fuel produced from the facility, and it is considered that refuse vehicles would not be dissimilar, these figures have been applied respectively to the total annual hydrogen (kg) diverted to bus (and refuse vehicle) and HGV vehicle fuel use. This establishes the potential hypothetical distance travelled by vehicles fuelled by this quantity of hydrogen.

3.4.2 When applying a BEIS emissions conversion factor to such distances for an average diesel bus (1.23 kgCO$_2$e/km[7]) and fully laden HGV (>33t) (BEIS and DEFRA, 2022), the resultant total value gives the emissions avoided, assuming the hypothetical distances would have been travelled by an average diesel bus or HGV in the absence of the Hydrogen Production Facility.

3.4.3 Based on the above methodology, it is estimated that replacing conventional combustion vehicles with those fuelled by hydrogen produced at the proposed Hydrogen Production Facility will displace approximately 3,481 tCO$_2$e per annum, and 87,015 tCO$_2$e over the facility’s lifetime (assuming a supply consistent with that detailed within Table 4, above).

3.4.3 Displaced natural gas emissions

3.4.1 The remaining 153,020 kg hydrogen produced at the Brynmenyn facility will replace the use of natural gas to supply heat energy. When this weight is scaled by a hydrogen higher heating value (HHV) intensity of 39.37 kWh/kg (BEIS, 2021), this equates to approximately 6,024 MWh per annum supplied as heat by the facility.

3.4.2 Should this heat energy have instead been supplied by natural gas (scaled by 0.18 kgCO$_2$e/kWh BEIS natural gas conversion factor, 2022), this would result in emissions of 1,084 tCO$_2$e per annum, or 27,110 tCO$_2$e over the facility’s 25 year lifetime (assuming a supply consistent with that detailed within Table 4, above), and as such equals avoided emissions as a result of the project.

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[7] The BEIS and Defra conversion factor for an average bus gives 0.0965 kgCO$_2$e/km per passenger. This factor was scaled by the average passenger occupancy of a bus (BEIS, 2022c) to give the resultant total emissions conversion factor of 1.23 kgCO$_2$e/km used.

4 RESULTS SUMMARY

4.1 Embodied Carbon

4.1.1 Embodied carbon emissions associated with both the Bryncethin solar PV site, and Brynmenyn Hydrogen Production Facility are summarised within Table 5, below.

Table 4: Embodied carbon associated with Bryncethin and Brynmenyn Sites

Infrastructure Item	Embodied Carbon (tCO_2e)
Bryncethin Site	
Solar PV panels	12,267
Brynmenyn Site	
Hydrogen Electrolysers	676
Substation	33
Admin Building	149
ISO Containers	68
Subtotal	926
Total	**13,213**

4.1.2 The total embodied carbon associated with the Bryncethin solar PV site totals 12,267 tCO_2e. The total embodied carbon associated with the Brynmenyn Hydrogen Production Facility totals 926 tCO_2e, this is equal to just over 7.5% of the embodied carbon associated with the solar PV construction at the Bryncethin solar site, and as such represents a minor contribution to the total project embodied carbon.

4.2 Operational Emissions

4.2.1 Operational emissions are limited to those associated with the Brynmenyn Hydrogen Production Facility, as operational maintenance emissions associated with the solar PV array at the Bryncethin site are anticipated to be negligible (as outlined in paragraph 3.3.1).

4.2.2 Operational emissions associated with the Brynmenyn Hydrogen Production Facility may be split into two categories – those associated with the energy demand, and with the emissions displaced as a result of the hydrogen produced. These are summarised within Table 6 below.

Table 5: Operational Emissions

	Annual (tCO_2e)	Lifetime (tCO_2e)*
Emissions associated with operational energy demand		
Solar	0	0
Wind	326	8,155
Grid Electricity	683	5,306 to 17,066
Admin Building	7	102 to 170
Sub-total	1,016	13,563 to 25,392
Displaced emissions		
Vehicle	-3,481	-87,015
Natural Gas	-1,084	-27,110
Sub-total	-4,580	-114,507
Total		**-89,116 to -100,945**

*Range of lifetime emissions assesses both the current grid average (assuming no further grid decarbonisation) and the BEIS long run marginal projections (assuming grid decarbonisation in line with current policy). Lifetime emissions are likely to fall within this range.

4.3 Whole Life Emissions

4.3.1 When accounting for the whole life emissions, both the embodied and operational emissions (considering lifetime emissions only) for the Bryncethin and Brynmenyn sites are considered together. The results are detailed within Table 7, below.

Table 6: Whole life emissions

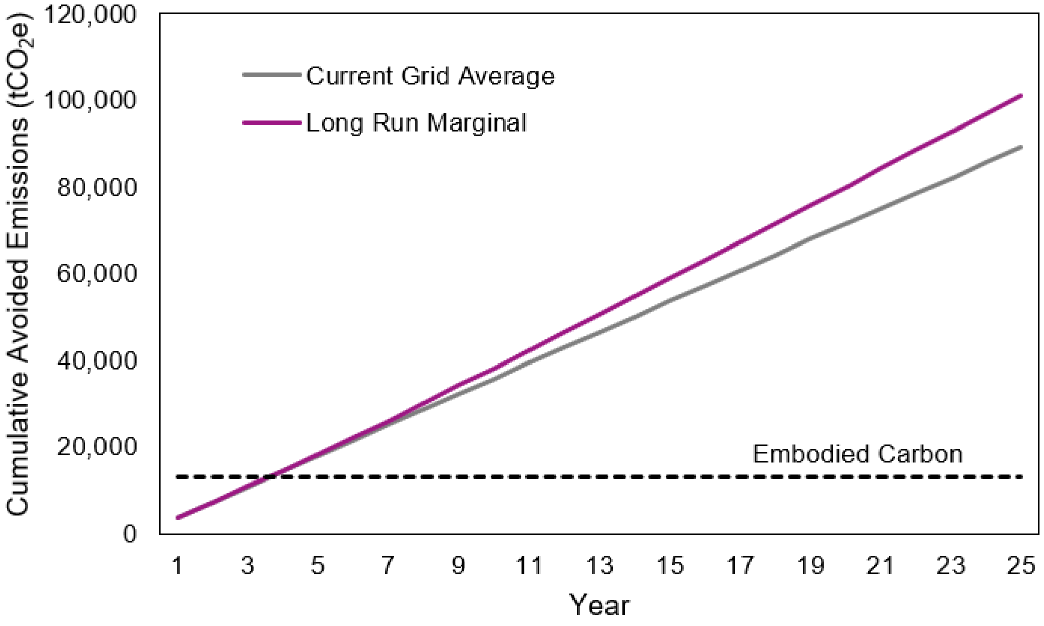
	Emissions (tCO_2e)
Embodied Carbon	
Bryncethin Site	12,287
Brynmenyn Site	926
Sub-total	**13,213**
Operational Emissions	
Brynmenyn Site	13,563 to 25,392
Displaced Emissions	
Brynmenyn Site	-144,507
Total	**-75,903 to -87,732**
Carbon Payback Period	**4 years***

*Carbon payback period achieved during year 4 under both the current grid average and long run marginal scenarios.

4.3.2 Figure 6 displays the lifetime avoided emissions associated with the Hydrogen Production Facility over it's operational lifetime, accounting for all emissions associated with energy demand from wind and grid electricity, in addition to emissions avoided as a result of the displacement of carbon intensive fuels by the hydrogen produced. Such operational avoided emissions are displayed for the application of both the current grid average and long run marginal grid electricity carbon intensity factors. It is likely that the emissions avoided by the Hydrogen Production Facility will fall between this range.

4.3.3 Also displayed is the embodied carbon estimated to result from the project's construction. As shown, the project is expected to achieve a carbon payback period during its 4th year in operation.

Figure 6: Operational cumulative lifetime avoided emissions



5 DISCUSSION AND CONCLUSION

5.1.1 As promoted within UK Hydrogen Strategy (HM Government, 2021), the project is facilitating the expansion of green hydrogen supply through the pairing of the Hydrogen Production Facility alongside a solar PV array, with remaining energy demand met largely by wind supply. Minimal energy will be supplied from wholesale grid electricity, which is anticipated to be required during periods of low renewable production combined with an insufficient quantity of stored hydrogen. It is considered that this supply is necessary for the successful operation of the facility. The allotment of grid electricity will be consistent with the threshold required by the Low Carbon Hydrogen Standard, and as such associated reported emissions should be considered a worst case scenario. Further, as the grid decarbonises in line with current policy requirements, emissions associated with grid electricity are anticipated to reduce, resulting in reduced operational emissions.

5.1.2 The green hydrogen produced will assist both the UK and Welsh Government in the achievement of power system decarbonisation targets – over its lifetime the project will result in the avoidance of 144,507 tCO_2e emissions through the adoption of hydrogen fuel for transport and heating. This will displace the requirement for fuels associated with greater emissions, such as natural gas and diesel.

5.1.3 Such avoided emissions will greatly exceed those caused as a result of the construction and operation of the project. The greatest source of emissions associated with the project over its lifetime will be from those arising from the construction of the solar PV array at the Bryncethin Site. This will result in 12,287 tCO_2e, equal to 93% of the total embodied carbon associated with both sites. Embodied carbon emissions arising from the Hydrogen Production Facility at the Brynmenyn Site has been estimated to total 926 tCO_2e, 7% of the total embodied carbon associated with both sites. All operational emissions will arise from the energy demand of the Brynmenyn Hydrogen Production Facility. A total range of 13,563 tCO_2e to 25,392 tCO_2e emissions over the facility's lifetime will result largely from the hydrogen electrolysers, alongside the cooling and compression of hydrogen produced.

5.1.4 When accounting for the above-described avoided emissions, the project will achieve a payback period of 4 years. In other words, after 4 years of operation the facility will have resulted in avoided emissions that exceed those associated with its construction and whole life operational energy demand, and as such over its lifetime the proposed facility will enable local and national energy system decarbonisation progress.

5.1.5 Additionally, the inclusion of hydrogen storage allows system flexibility – electrolytic hydrogen production during periods of increased renewable supply can allow excess electricity to flow across different parts of the energy system, allowing system benefits such as helping to balance the grid and integrating hydrogen into our power system.

5.1.6 Despite the magnitude of embodied carbon emissions associated largely with the construction of the solar PV array, the construction of such energy infrastructure should be considered necessary in order to displace the use of fuels associated with increased emissions, and provide a means for the continued decarbonisation of the UK economy.

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