Marine Research Programme

Industry-Led Awards 2018

Floating Solar Hybrid Energy Project

Final Report

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Foras na Mara
Marine Institute

Harnessing Our Ocean Wealth – An Integrated Marine Plan for Ireland (2012) sets out the Government's vision, high-level goals and key enabling actions to put in place the appropriate policy, governance and business climate to enable Ireland's marine potential to be realised.

Vision and Goals

"Our ocean wealth will be a key element of our economic recovery and sustainable growth, generating benefits for all our citizens, supported by coherent policy, planning and regulation, and managed in an integrated manner."

Harnessing Our Ocean Wealth has three high-level goals, of equal importance, based on the concept of sustainable development:

- **Goal 1** focuses on a ***thriving maritime economy***, whereby Ireland harnesses the market opportunities to achieve economic recovery and socially inclusive, sustainable growth.

- **Goal 2** sets out to achieve ***healthy ecosystems*** that provide monetary and non-monetary goods and services (e.g. food, climate, health and well-being).

- **Goal 3** aims to increase our ***engagement with the sea***. Building on our rich maritime heritage, our goal is to strengthen our maritime identity and increase our awareness of the value (market and non-market), opportunities and social benefits of engaging with the sea.

The *National Marine Research & Innovation Strategy 2017-2021* identified the need to increase opportunities for SMEs (Small or Medium Enterprise) to participate in marine research as a key implementing action for the strategy. The strategic objectives are to:

- Raise research capacity across the 15 research themes.
- Target research funding, with the overall goal of raising research maturity, to topics matching requirements articulated in state policies and sectoral plans.
- Have coherence in the approach to marine research by the various state actors involved in funding marine research.

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INDUSTRY-LED AWARD

FLOATING SOLAR HYBRID ENERGY PROJECT

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1. Project Summary

SolarMarine Energy Ltd (SME) applied under the Marine Institute's Industry-Led Awards Call 2018 and was awarded grant-aid funding to research the design of a floating solar energy (FSPV) structure and evaluate how hydrogen could be produced using power from the floating solar plant.

This was essentially a '*Power to Gas*' (PtG) project model where we designed a floating solar plant, specified the H_2 electrolyser and designed the interface between the two. Our engineers' extensive experience across the marine industry from the initial design stage to final installation enabled us to take on this challenging marine renewable energy project. We believe that a floating solar/wind/hydrogen hybrid energy plant has the potential to be a disruptive innovative technology as it leverages the technical advantages of photovoltaics and energy storage without the environmental and cost disadvantages of competitor technologies.

Photovoltaic (PV) solar energy generation capacity and contribution to global electricity supply is predicted to increase to 22% in 2025, with potential of up to 70% (40,000 TWh) in 2050, [1].Generating energy from floating solar plant is a relatively new industry with large scale commercial projects starting in 2014 in Japan, [2]. To date worldwide there is almost 2GWs of floating solar plants installed with the World Bank forecasting a 140% year-on-year growth rate for the industry, [3].

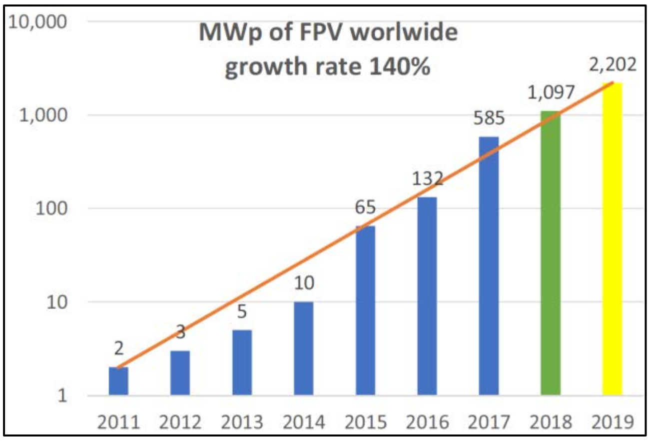

Figure 1. Yearly Growth rate of 140% for Inland FSPV (*Courtesy of World Bank)*

Our research shows that the simplicity, versatility, environmental compatibility and suitability for off-grid deployment of floating solar energy makes FSPV an ideal energy partner for island and coastal communities. Europe alone has 66,000 km of coastline bordering the Atlantic Ocean, Mediterranean Sea, Black Sea and the Baltic Sea, and more than half of the world's population lives within 100km of a coastline, [4], [5]. When coupled with battery storage those coastal communities can have 24 hour independent power supplies and the potential to use FSPV to power water electrolysers for the production of green hydrogen that can be used as a clean fuel, for heating and transport or to storage and transport energy. Green hydrogen is produced from water and renewable energy using electrolysis, whereas 'Grey hydrogen' is made from natural gas using a Steam Methane Reforming (SMR) process, 'Brown hydrogen' is made from the gasification of brown coal and 'Blue hydrogen' is made from the SMR process however the CO_2 byproduct is sequestered by means of Carbon Capture Storage. On this project the electricity used in the electrolyser is from a renewable energy source, floating PV, therefore the H_2 produced can be called 'Green hydrogen'.

In this research project we coupled hydrogen generation to solar energy and in so doing it has helped our company to develop the expertise required to manage the integration and optimisation of both power sources. Hydrogen is very suitable for large scale long term energy storage as it provides the longer term energy security not available solely from batteries or other traditional storage mediums, [6]. Our research has shown that a hydrogen production facility, primarily powered by floating solar, can also be used to capture spilled wind energy through curtailment avoidance and provide sustainable reliable back up fuel reserves whilst enhancing the value and power utilisation of floating solar, land solar and wind energy generation plants.

Renewable energy technologies like floating solar lie at the heart of the global energy transition away from fuelled power generation and lead the way towards more sustainable energy systems and new economic development. According to an IEA (*International Energy Agency*) 2020 report by 2050 the renewable energy industry will employ 42 million people worldwide, energy efficiency businesses alone could employ 21 million people and power grids and energy flexibility sectors another 14.5 million jobs, floating solar energy and green hydrogen production are included in those sectors. This is an emerging industry that will be worth billions of dollars in the next 10 to 20 years, [7]. Knowledge gained under this Industry-Led grant study will help our company be part of this newly developing industry, both at home and abroad and provide new opportunities.

There are typically 3 types of FSPV structure in use today on inland sites:

Type 1 – PV Panels on Steel Structure and Floatation Tanks (Nemo-Eng)

Type 2- Steel Supports on HDPE Pipes - Suvereto plant (Koiné)

Type 3 - HDPE Blow Moulded Lightweight Pontoons (Ciel et Terre)

Although there is over 2GW installed capacity of floating solar in the world today, it has mostly been deployed in relatively sheltered inland bodies of water (such as lakes, water reservoirs in hydropower stations), [8]. Solar, power and utility companies want floating energy plants engineered & manufactured to high standards that can survive outside of inland waters and operate at coastal locations in tandem with other renewable energy technologies such as H_2 production, our research project addresses this need for more robust floating solar plant design. This opens up a whole new market for producing solar energy and PtG projects in various locations. As 40% of the world's population lives within 100km of coastlines the deployment of solar arrays on coastal waters is an obvious next step, so that the generation of electricity is close to the end users to reduce grid transmission and distribution costs.

The advantages of Floating Solar Energy Plants can be summarised as follows:

- FSPV has a 50% higher power density than land based solar. This is because floating PV does not have a minimum height restriction unlike height stipulations for land PV and the panel tilt angles are lower at around 10^o for FSPV as opposed to 35^o for land-based PV). This means that there is less shadow cast so rows of panels on FSPV plants do not require as much separation, hence more power density per square meter. Also FSPV does not have to allow access for grass cutting or the passage of small animals between rows of PV panels, this again decreases the overall footprint. On FSPV arrays the distance between rows of PV panels is dictated by operations and maintenance requirements for personnel access.
- FSPV is ideal for areas where stringent environmental regulations prevent land based wind & solar developments.
- FSPV reduces evaporation on water reservoirs and improves water quality by shading the water which reduces algae growth and so minimises the associated water treatment and labour costs.
- FSPV produces nearly Zero Carbon electricity at cheap long term fixed rates, [9].
- FSPV is quickly installed without the need for heavy plant and equipment, it is modular and therefore easily transportable, scalable and easily decommissioned.
- The seasonal variation in wind and solar complement each other. The combined systems of solar and wind have a higher capacity factor. At night when there is no light off-peak rate wind energy can be used to supplement supply.
- Solar panel technology is well proven, low risk and dependable. Solar panel efficiency increases on water by as much as 10% as the panels are cooled naturally by the water.
- Large scale land based PV plants increase the 'Greenhouse effect' due to a reduction in the albedo effect as their radiation balance is negative whereas floating solar plants leave the radiation balance unaltered.
- FSPV is ideal for providing energy as an off-grid connected power source at remote locations.
- By 2025 nonsubsidised solar energy grid parity will be widespread in Europe and solar is set to become the cheapest form of electricity by 2050.

To achieve the aims of this project we undertook research and engineering work in the following areas:

- Literature search and industry review of current Floating Solar Energy Plants and their design strengths and weaknesses.
- Identifying a floating solar plant design concept and then developing and engineering of that design into a 1MWp structure robust enough to withstand nearshore weather conditions.
- Performing Finite Element Analysis and Structural design studies on our nearshore floating solar energy plant structure.
- Developing bespoke calculation methods to quantify in numerical terms wind and wave loadings that the structure will be exposed to.
- Designing an Electrical Architecture for the 1MWp floating solar plant that will deliver a DC power supply to an H_2 Electrolyser.
- Producing detailed 3D drawings for the 1MWp floating solar energy plant and itemising components and producing a weight register.

- Costing of the floating solar energy plant.
- Researching existing H_2 Electrolyser technologies.
- Researching of the Standards and Rules & Regulations governing H_2 production.
- Risk Assessing the design and operation of the 1MWp floating solar plant.
- Identifying an Electrolyser technology that can be powered by a floating solar plant and liaising with the electrolyser equipment manufacturers to get data and electrolyser and Balance of Plant (BoP) specifications.
- Designing an electrical topology that allows the floating solar plant DC power output to interface in an efficient manner with the DC powered Electrolyser.
- Performing plant LCOE and LCOH cost evaluations to establish the cost of a kg of H_2 produced from floating solar power, or the cost per kg using a combination of wind energy, battery storage and floating solar energy.
- Identifying potential green H_2 markets.

2. Project Description

This R&D project aimed to design a floating solar energy plant for powering a water electrolysis plant to produce green hydrogen. Cork harbour was chosen as the location for installing the floating solar energy and H_2 plant. This research project was based on engineering a 100% renewable technology to produce carbon neutral energy in an environmentally neutral manner. The energy production technology developed has the capability to replace conventional fossil fuels burned to generate electricity with clean Hydrogen electrofuel produced from solar energy and ionised water, the only by-product being water. The floating energy platform designed can be considered as having the same positive environmental impact as any existing floating marina or Jetty as a new habitat for marine species would be created.

The project’s key objectives were as follows:

- Design a floating solar energy plant that can be installed at a nearshore location
- Find a water electrolysis technology that can use floating solar energy to produce Hydrogen
- Examine the issues associated with the installation, operation and maintenance of a floating solar and hydrogen plant
- Explore the economics of an FSPV/H_2 hybrid plant in terms of hardware costs and the projected cost of a kg of produced H_2
- Look at the market potential for green H_2

2.1 Description of issues that the project aimed to address

One of the main pain points currently experienced in the land based photovoltaic (PV) and windfarm energy generation sectors is the need for ever-increasing tracts of land to facilitate utility-scale large project deployment. PV panels are an established robust distributed power source at a decreasing cost, however at present the full development potential of this technology is curtailed by the issues surrounding land use, in particular the fact that large surface areas of land are required for the installation of PV plants. This is directly due to the low efficiency of PV panels, (typically around 17 to 18%), which means that a 1 MWp land based solar power plant requires at least 15,000m² (3.7 acres) of land whereas by comparison a 1MWp floating solar energy plant only requires between 5,600m² to 8,100m² (2 acres). The large land requirement for utility-scale land PV development has had a big environmental and economic impact since the land cannot then be used for other purposes, for example, agriculture, pasture, and industrial activities. The problem is exacerbated in extra-tropical latitudes (including all of Europe) where the solar radiation flux is lower than in the tropics. The prospect of being able to install floating solar plants at scale at nearshore and inland water locations will help alleviate the need for land based solar and wind energy developers to look for ever increasing large areas of land for projects and encourage them to look to bodies of water as an alternative.

The fluctuating nature of renewable energy supply (RES) means that an element of energy storage or overall supply/demand management is required to meet electricity demand reliably. Coupling the energy supply from a floating solar array with a hydrogen production plant not only offers solutions to the intermittency of RES but it also allows the option for other elements of the energy matrix to be decarbonised, for example, local heating schemes and mobility (transport and shipping). 95% of the world's current hydrogen production is 'grey' hydrogen (CO_2 byproduct), the demand for green hydrogen is growing. Hydrogen electrolyser plants have never been solely powered from floating solar energy to date. This project has shown that it is possible to use floating solar energy to power water electrolysis for the production of H_2 at scale given a sufficient solar energy resource. For 24/7 H_2 electrolyser operation in Ireland it would be more viable from a commercial perspective to integrate other renewable energy power supplies with floating solar plant, that would guarantee a stable power supply to the electrolyser at a reasonable LCOE. An excellent synergy exists between solar and wind energy, for example, for many periods when the wind is not blowing there is still daylight and photons of light to be harvested. The wind frequently blows at night when there is zero solar energy production and the seasonal variation of wind and solar is complementary in Ireland in terms of there being more daylight in summer and more wind in winter. Whilst electrolysers can be powered solely from FSPV by coupling FSPV plants with wind energy the combined operational plant capacity increases. The result of combining wind and solar energy is that the cost of H_2 declines relative to the increased scale of quantities of hydrogen produced.

Although floating solar technology has been in development for over twelve years with more than 1GW installed in the world to date, the technology is still in its infancy. It has progressed largely by individual developers deploying land-based PV panels on a wide variety of floating platforms with differing mooring and anchoring arrangements all located on relatively small inland bodies of water. There are no standardised methods of designing FSPV and very little scientific research into environmental loads from wave, wind and current which are the basis of the design for floating solar energy systems. As a result there have been industry failures, for example, the destruction of a 13.7MW FSPV array in Japan as a consequence of typhoon Faxai in 2019 where extreme wind loading and subsequent mooring failure was the cause. In addition as developers move to larger and more exposed bodies of water, fully understanding the effect of wind, waves and currents on large arrays of floating panels becomes much more important. Our floating PV platform structural design research work addressed these issues through our development of a detailed design concept and uses international marine engineering standards that take into consideration the combination of wind/wave loading at an exposed coastal location. Rigorous and verified design processes are an essential part of classification and hence insurance which in turn is important for investor confidence, at present there is no defined classification system for FSPV plants however DNV GL have recently undertaken a Joint Industry Project specifically to develop a set of design standards for the FSPV industry.

We have developed our floating solar design to a level of detail to that of Front End Engineering Design (FEED), which defines the structural configuration of the floating solar array. Detailed environmental (wind, wave and snow) load calculations have been developed using the internationally respected Eurocode and DnVGL suite of design codes and standards. As these standards are not specifically designed for floating solar additional engineering judgement, and previous experience from the offshore industry, has been used to develop these to include information from other sources including wind tunnel tests. Mooring calculations have been developed from first principles using catenary equations and conditions of force and displacement equilibrium to determine the 3D mooring displacements and forces under different directional wind & wave loads and also at different tidal levels.

2.2 Project aims and objectives

The project's aims and objectives can be summarised as follows:

- To develop an understanding of aero-hydrodynamic loads experienced by a floating solar platform through technical research leading to the design of a floating solar energy platform to power hydrogen electrolysis to use H_2 for fuel storage and distribution that could be used in industry, shipping and for energy supply to grid connected or non-grid connected communities.
- To understand component marinisation and corrosion issues around the deployment of a floating solar platform in the marine environment.
- To understand and establish the interface control between an interruptible energy generator (solar energy) and a hydrogen generating facility.
- To establish knowledge of how to design BOP (Balance of Plant) systems for integrating H_2 generation, H_2 electrofuel and battery storage and solar energy production.
- Research into the control and interface system requirements between an interruptible energy generator (solar) and a H_2 generating facility.
- To explore hydrogen safety regulations.
- To Risk Assess the construction and deployment of a floating nearshore system whilst operating national and international regulations.
- To calculate the volume of H_2 that could be produced from a 1MWp floating solar energy plant using water electrolysis in Cork Harbour.
- To establish the cost of a floating solar energy and H_2 production and storage plant and assess market opportunities for green H_2 sales.

2.3 Methodology/work carried out

The designing of a floating solar energy plant involved a three-stage design approach including concept, FEED (Front End Engineering Design) and detailed design stages. The activities of the FEED stage of the project were completed as part of the concept and detailed design stages of the project in order to reduce the number of design reviews required. The project was divided into a series of three integrated work packages as follows:

- ***WP1 – Floating Platform and Moorings Engineering Design***

WP1 concentrated on engineering the floating platform and moorings however it also overlapped with the concept work involved in WP2 as the final floating structure had to be compatible with the electrical power and operational requirements of the H_2 production system. Extensive detailed design calculations were completed to determine the critical load case for each of the structural members of the floating solar array. A large number of load combinations were considered for each structural component to cover all possible design conditions including various combinations of the following loads:

- Multi-directional wind forces - North, South, East & West as well as the corresponding upward and downward vertical wind load components within these.
- Multi-directional wave loads.
- Forces from mooring lines which react against the horizontal wind & wave loads from different directions. This includes both "intact" and accidental "failed mooring" conditions.
- Snow loads, "primary", "secondary" and "accidental" (extreme snow) conditions.
- Maintenance loads.
- Structural self-weight loads.

Structural calculations were completed from first principles to determine the critical bending moments, shear forces and axial loads in the structural elements of the array. These calculations were checked using a structural analysis program to verify the calculations. Extreme wind speeds with a one in 50 year return period were calculated using equations derived from the Eurocode 1 design standard including the Irish National Annex. These were combined with the distance to the nearest shore (fetch) for each direction and used as inputs to a JONSWAP calculation procedure which was developed for this project to determine the significant wave height, various definitions of wave period and other parameters in the extreme storm design case. The JONSWAP spectrum is one of the most internationally widely used wave spectrum definitions and was developed by Hasselmann et al. (1973), [10]. Consideration as to how the articulated PV array would float in a wave field and the loads this induces in the array under the extreme wave conditions were used in the structural loading calculations as illustrated in the simplified diagram below.

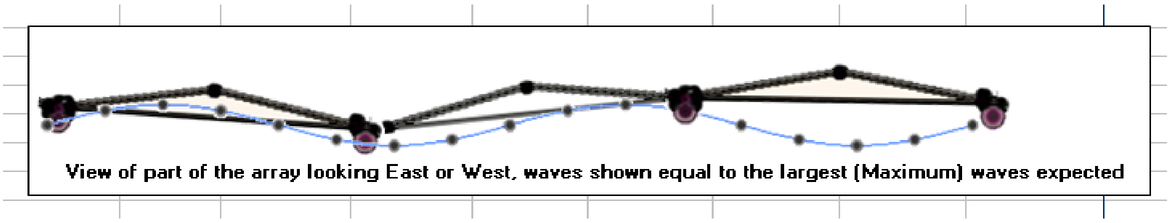

Figure 2. Illustration of floating articulated PV array floating in a wave field.

A large number of structural load calculations were completed to cover every load case and structural element in the array. This enabled the identification of load cases that produce the highest axial load, bending moment and shear force for every structural element and joint in the array, see Figure 3. We developed enveloping load conditions to cover multiple critical load cases without introducing excessive amounts of over conservatism into the analysis in order to further reduce the number of load combinations to be used in the detailed structural checks.

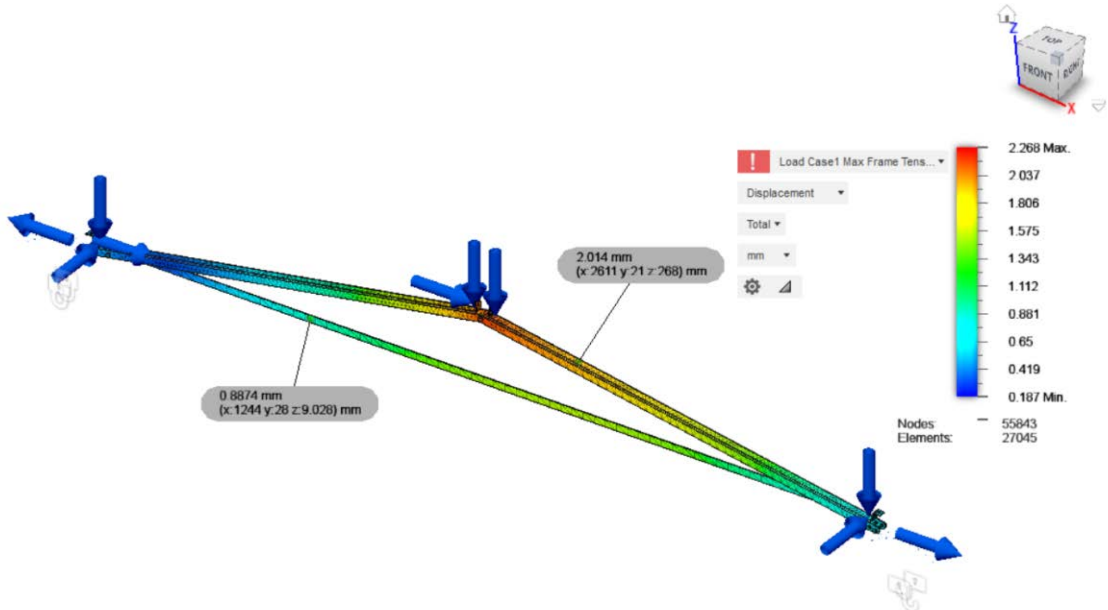

Figure 3. Identification of axial load, bending moment and shear force at Truss Pin joints

The next stage of the detailed design was to use the critical enveloping load combinations, described above, to check the strength of the structural sections and joints in the array. Structural strength was checked using a combination of hand calculations and Finite Element Analysis (FEA). The FEA software package used was "Fusion 360 simulation", this software was built on the well respected NASTRAN FEA solvers which were first developed at NASA in the 1960s. Hand calculations were made using a combination of first principles techniques and design code guidance including: Eurocode 3 design of steel structures, and also DNVGL-OS-C101 design of offshore steel structures. FEA was used to check a wide range of structural parameters under the extreme environmental loading including the acceptability of stress levels and expected displacements of the structure, as shown in Figure 3 above.

A buckling analysis was also completed to check that the slender elements of the structure will not buckle under compressive loads. Hand calculations to determine the buckling resistance of the elements were completed to complement the FEA buckling analysis. FEA buckling analysis uses a modal solution of the mass and stiffness matrices to determine the Eigenvalues & Eigenvectors of the structure, these were used to solve the buckling equations – the Eigenvalues were used to derive the load at which buckling takes place and then the Eigenvectors showed the mode shapes and shape of the buckling structure.

Drawings of the internal rafts that made up the floating solar array structure were made, see example shown in Figure 4. These were sent to fabricators for pricing and fabrication feedback. Some fabricators have limits on the size of the components they can produce. For example, some have galvanizing baths 10m long so need to "dip" longer components in two stages, others have limits on the size of steel sections they can press-break so propose welding shorter sections together after press-break forming. Welding is not preferred as this introduces additional processes, cost and potential failure points (e.g. from weld defects) so we targeted fabricators who have larger press-breaking machines and expertise in this area.

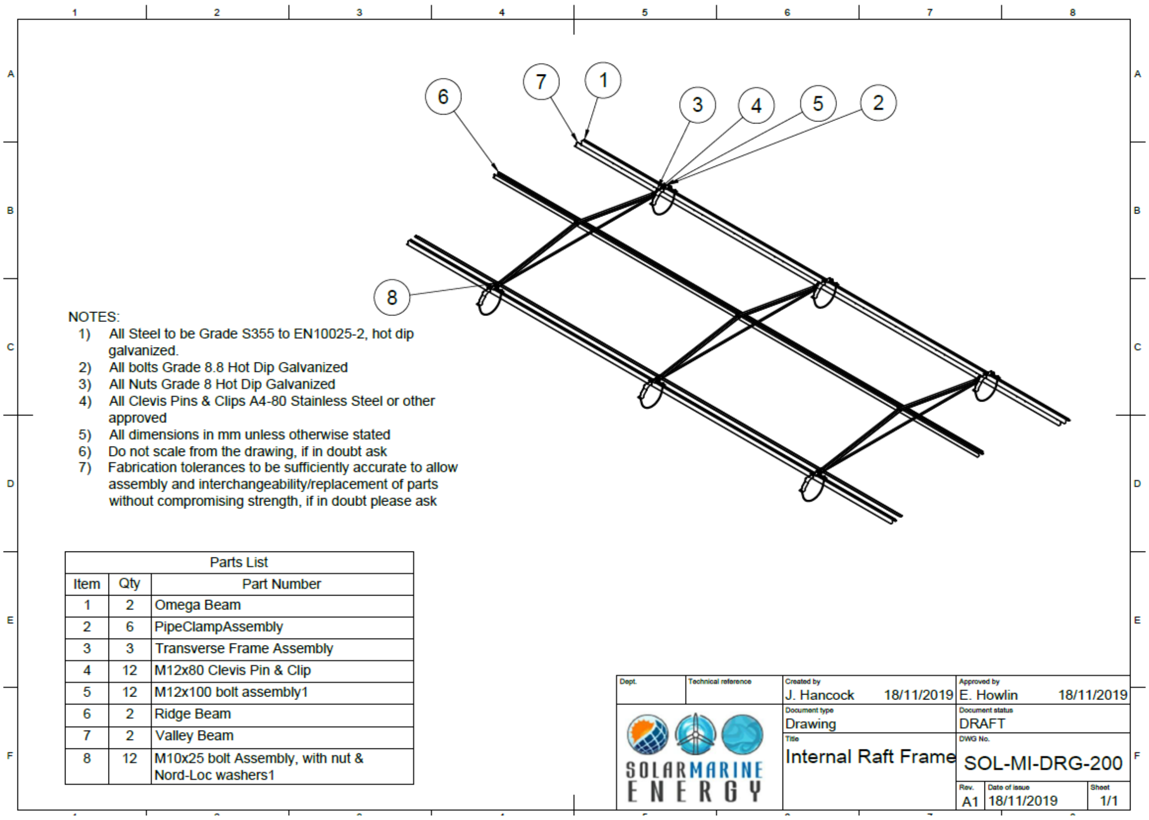

Figure 4. Drawing of internal raft of floating solar PV array

The final part of WP1 was to conduct a thorough Risk Assessment to identify all possible risks associated with the installation of a floating solar array structure. The work carried out under work package 1 can be summarised as follows.

1. Structural design of Floating Solar (FSPV) Array components
   A FEED level structural design of a floating solar array was completed checking wind, wave, snow and maintenance loads. This work determined the approximate size of the structural elements and connections.
2. Updating the array design structural configuration (including 3D model)

We updated the array design including information such as requirements for maintenance, cable trays and estimates for structural section sizes and joints. Environmental load calculations were reviewed and updated as required in light of the updated floating solar array structure configuration.

3. *The identification and development of interface definitions*
We identified and developed interface definitions, for example, between array structure and moorings, maintenance requirements, solar panels, cables & electrical system, hydrogen generation equipment etc.
4. *Carry out Risk Identification and Assessment for FSPV Array & Moorings*
All risks for the floating solar array and mooring system covering manufacture, installation/construction, operation, maintenance and decommissioning were examined with risk mitigations identified to reduce risks to ALARP (as low as reasonably possible).

- ***WP2 – Energy Production Technology Review and Concept Design***

WP2 concentrated on a review of currently available water electrolysis technologies through a combination of literature search, attendance at hydrogen conferences and electrolyser technology workshops, and direct communication with academics and OEMs (Original Equipment Manufacturers). Electrolysers are basically electrochemical reactors that use electricity to "split" water into oxygen and hydrogen (H2). SMR, the most common method of H2 production is bad for the environment due to methane slip and (from Natural Gas) and CO2 emissions, 'blue hydrogen' is less polluting but more expensive. Water electrolysis has been around a long time, for example the Norwegian company Nel has been producing hydrogen in commercial quantities since 1927 with its *Alkaline* electrolyser and it is only in recent years that non-Alkaline electrolyser technologies such as *Polymer Exchange Membrane* electrolyser technology have become mainstream. The oil and gas industry uses a *Steam Methane Reforming* distillate cracking process from natural gas to produce H_2, what we call 'grey hydrogen'. This is the cheapest way to produce H_2 however for every 1 tonne of H_2 it also produces between 9 to 12 tonnes of CO_2. Emission taxes will push up the cost of dirty hydrogen in the future. Industrial scale water electrolysis is generally not economical at current electricity prices, but this paradigm will change in a renewable energy future where electricity prices will be very low, or even free, for parts of the day when there is excess electricity produced by RE sources, [11]. In this scenario, the economics of water electrolysis will be dominated by the capital costs of the electrolysers.

An electrolyser technology that could be best integrated with a floating solar energy power supply was selected. We looked for an electrolyser technology that could deliver clean 'green' H_2 from non-synchronous power supplied from a floating PV array. The main selection criteria that we examined for choosing a suitable electrolyser were as follows:

- Power requirements – what are the amounts of power required to start H_2 production and would the H_2 be produced at a linear rate thereafter?
- What are the start up times of the electrolyser and how does it respond to variable electrical input?
- How much electrical energy is required per unit volume of hydrogen production?
- What are the Capex and Opex costs?

- What are the recommended running hours before cell stack maintenance?
- What is the design lifetime of the electrolyser?
- What volume of water and of what quality is required?
- How complicated is the electrolyser to operate and are specialised technicians required for routine operation and maintenance?
- Are there any precious metals or toxic substances used in the electrolytic process?
- What are the likely decommissioning issues and associated costs?

This set of criteria led us to a new company called *CPH_2* who manufacture an innovative type of electrolyser that is neither Alkaline or PEM based, CPH_2 use a 'membrane free' technology. Membrane-less electrolysers generally rely on a pumped flow of the fluid along with buoyancy forces to induce separation of O_2 and H_2 molecules as opposed to using a separation membrane or diaphragm as in the cases of PEM or Alkaline. In membrane-less electrolysis we get a 'mixed gas stream' that is then fed into a Cryocooler which separates the O_2 and H_2. Membrane-less electrolysers have less Capex and Opex costs than alternative designs and are less complicated to run, [12]. A big advantage of membrane-less electrolysers is that in the 'Cell Stacks' where H_2 and O_2 are separated from water, an optimum voltage per cell can be sized to suit the incoming power profile (IV curve, Voltage against Amperage) which means it can be matched to the expected output of the PV array. Many industry commentators believe that if membrane-less electrolysers can be successfully optimized and scaled up then they could become a disruptive technology for producing lowcost H_2 in a renewable energy future, [13]. We established through discussions with electrolyser companies that the efficiency of an electrolyser can only be assumed, as it is predicated on a number of things, one of which is optimisation of the input power. There is always a 'sweet-spot' at which everything works at its greatest efficiency. This changes as the power profile changes, and the way the power profile is used within the system to (e.g.) switch cell stacks in and out and, in the case of the CPH2 membrane-less electrolyser, even reduce how much of the stack is given power (this cannot be done with PEM). Additional to this is the recognised post-initial commissioning reduction in efficiency which takes place over the first month of running on PEM systems. After a variable number of weeks of running – dependent upon how well the flow-circuit is designed – the efficiency will be seen to have irreversibly deteriorated until eventually failure ultimately occurs. This is due, in PEM systems - to membrane degradation and (resultant) catalyst poisoning, in which the adsorption sites on electrodes become blinded over time. As a result of this, it is very difficult to predict efficiency and resultant gas output for any given system over time. According to Dr. Nigel Williamson of CPH2 the opposite occurs in their membrane-less technology, as he states that their electrolyser cells have empirically been proven to improve in efficiency over time, so the start-up efficiency that they quote normally improves as opposed to becoming less efficient over time.

CPH_2 were directly contacted for electrolyser specifications and operational information and from the data provided we designed an electrical interface between the electrolyser and the floating solar energy plant under WP3.

WP2 also investigated the design of H_2 plant and studied the BOP (Balance of Plant) and process systems required to produce and deliver H_2 using CPH2 electrolyser technology.

The BOP for a membrane-less electrolyser includes a water purifier, a pump and a cryogenic cooler all of which require power. The combined electrolyser and BOP power requirement was calculated with regards to how many running hours per day the floating solar plant could power H2 production. The pros and cons behind membrane-less and other electrolyser technologies in relation to our specific application were examined. One of the downsides of this technology compared with PEM electrolysers is lower voltage efficiency at high operating current densities due to higher solution I^2R losses (Ohmic resistance due to distance between the electrodes). However, in the CPH2 electrolyser design the spacing between electrodes is kept to a minimum and this seemingly alleviates I^2R losses.

Hydrogen plant design and safety regulations associated with producing a H_2 supply safely were also studied in detail as part of this work package. This aspect of the study again involved a literature search to identify both national and international government, industry regulations and international best practice. In Europe many safety studies have been carried out by organisations such as *Hydrogen Europe*, and have culminated in European legislation, Directives and Recommendations that can be found in online repositories such as the EU *HyLaw* website[1].

Finally under WP2 we looked at the potential market for selling and where the current and future opportunities lie for the sale of green H_2 that has 100% renewable *Guarantee of Origin* credentials. The study for this part of the project involved looking at data and projections from institutions such as the *International Energy Agency*, *Hydrogen Europe*, *DNV GL* and reading academic articles and renewable energy publications.

The work carried out under WP2 can be summarised as follows:

1. *A Review of Hydrogen systems designs*
   Design requirements, ATEX regulations and maintenance procedures for H2 plant, external interface systems, fire protection and pressurised vessels.
2. *Conceptual designs of BOP and process systems*
   Piping and instrumentation, water treatment requirements, Cryogenic liquefaction of H2 and storage, system redundancy and safety.
3. *Literature survey of safety standards and design codes required*
   Collection of information that would be needed for a safety file and to conduct design and standards reviews. Complete Risk Assessments.
4. *Review of green hydrogen potential markets, studies and projects*
   Techno-economic appraisal of the *Levelised Cost of Hydrogen* and identification of market opportunities.

[1] https://www.hylaw.eu

➢ *WP3 - Energy Production System Feed and Project Design*

Under WP3 we produced the final overall plant design showing how the hydrogen electrolysis unit and storage facility hardware interface with the floating solar power supply and how the power plant would be operated to produce green H_2. We designed an EMS (*Electrical Management System*) that optimises the match between the electrolyser and BOP load demand and the energy generated by the floating solar energy plant. This was a staged design process the main phases of which were as follows:

1. *Establish the Solar Irradiation available for the Cork site*

To establish the solar radiation output for our theoretical site location we consulted PVGIS; Solaris; World Bank and SERIS; PVSol and other solar radiation information websites that provide retrospective solar data. Data is received from the Copernicus Heliostat service and others where geostationary satellite images are processed using proprietary methods to retrieve cloud cover and solar irradiance at ground level with a kilometric resolution. Table 1 below shows the predicted energy output over a year for different times of the day expressed in kWh for a 1MWp FSPV in Cork harbour. Adequate prediction of system generation requires the input of accurate solar irradiation with its subcomponents:

- Direct normal irradiation (DNI)
- Diffuse horizontal irradiation (DHI)
- Global horizontal irradiation (GHI)

Then the irradiance data was fed into simulation software (e.g. *SAM* provided by National Renewable Energy Laboratory (NREL)) to get the figure of 714MWh total energy produced for a year, this is the equivalent of 983kWh/m². We also explored the solar radiation values provided by *MERRA 2*, through *NASA* and the *Global Modelling and Assimilation Office* (GMAO). They estimate 714MWhs total per year, these values are considerably higher than those provided by *PVGIS* and the *World Bank*.

Table 1. Average hourly profiles of photovoltaic power output for Cork Harbour, 1MWp array, Ireland. (Source, PVGIS).

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						2						
4 - 5					18	40	23	1				
5 - 6				27	90	116	85	44	5			
6 - 7			19	117	203	223	187	131	65	7		
7 - 8		15	95	233	280	297	257	229	156	68	10	
8 - 9	24	74	177	289	329	348	304	276	213	139	61	19
9 - 10	74	140	224	334	362	370	326	311	258	176	116	62
10 - 11	107	181	262	358	394	400	354	334	283	219	138	89
11 - 12	112	190	271	355	394	398	363	333	280	190	129	88
12 - 13	93	156	231	322	362	373	340	312	249	155	100	69
13 - 14	62	117	189	277	327	349	322	276	207	116	64	41
14 - 15	32	78	145	223	272	296	276	234	162	75	29	14
15 - 16	5	35	86	152	197	227	213	170	97	29	4	
16 - 17		4	33	78	119	149	139	97	38	2		
17 - 18			3	27	55	76	70	39	4			
18 - 19				1	16	29	25	6				
19 - 20						1	1					
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	508	989	1736	2795	3419	3696	3286	2793	2017	1176	650	382

2. *Designing the Electrical architecture for floating solar energy array*

This first step was to choose a PV Module (panel) that would be suitable for deployment in the marine environment. We were guided in our selection procedure by referencing existing literature on the subject from academia and industry. For example, SERIS (*Solar Energy Research Institute of Singapore*), produced a developers guide to floating solar plant design and installation as part of the test bed for FSPV that they set up in 2016 when they invited 10 FSPV developers to each install a 100kWp FSPV. The lessons learned from the test-bed work highlight the need to use PV modules that have good encapsulating qualities to prevent moisture ingress. We concluded that the basic properties that the PV modules must have for the Cork site were: be able to withstand the high mechanical loads imposed by storm force winds; have excellent low-light performance properties; salt mist and Ammonia resistant; and be PID (*Potential Induced Degradation*) resistant to minimise cell degradation in the harsh environment. All cables, connectors and junction boxes must have IP69 Waterproof ratings and the whole system has to be properly grounded. Our design includes the installation of an LPS (*Lightning Protection System*), and we recommend from our research that a *Rolling sphere radius* method is used.

In our system design our target was to provide enough power for 24/7 operation of a 143kW MFE30 membrane-less electrolyser from CPH2 that uses 6 stacks of cells in parallel, each stack requiring 80VDC at 200A for optimum H2 production, then we could produce on average 57.25kg every 24 hrs or 20 tonnes of H2 annually. As can be seen from the solar irradiation (Table 1), the distribution of energy produced throughout the year is uneven with productivity predictably higher in summer than in winter.

To mitigate against the variable nature of the PV power supply we designed the system in such a way that the energy is stored in a battery bank and released to the electrolyser once the optimum power value for running the electrolyser at maximum efficiency has been reached. The battery bank also supplies power to keep both the BOP and background process equipment running 24/7 and importantly it enabled us to consider feeding in power supply from other renewable energy resources such as wind. Our solar irradiation study clearly showed that to maximise H2 production we would require a complementary power supply. That would enable us to run the electrolysis plant at night and on days when solar irradiation values are low. Particularly in winter when PV output is low we would look to complement power supply to the electrolyser with a grid supply taking advantage of cheap curtailed wind energy at night and using battery banks to store sufficient power for 24/7 operation. In view of our PV output simulations at the 1MWp scale we concluded that it would not be feasible to use floating solar energy for frequency response services as a demand side electricity generator because it would not be suitable for providing a dispatchable load as a demand ramping service and curtailment avoidance tool. It is possible that a larger scale array, >50MWp FSPV, could be a realistic option to provide such services.

Many electrolyser systems use the standard 400V, 3 Phase, 50Hz, AC power supply however the electrolysers generally require a DC current supply so inverters are used to convert AC to DC. The MFE30 electrolyser uses DC power, and therefore is consistent with the DC output from solar modules once the PV power supply is converted to the electrolyser's voltage and current requirements. This electrical system design using a DC to DC configuration will mitigate against energy losses which would be incurred if we were using standard topology where inverters would be required to convert solar DC output to AC.

3. Design a Topology to deliver the power profile required

In this phase we looked at various topology designs for the FSPV that would interface with an electrolyser using a DC power supply. We choose a direct 'Parallelised DC to DC' conversion architecture as it maximises the solar energy output by avoiding inverting to AC, see Figure 5.

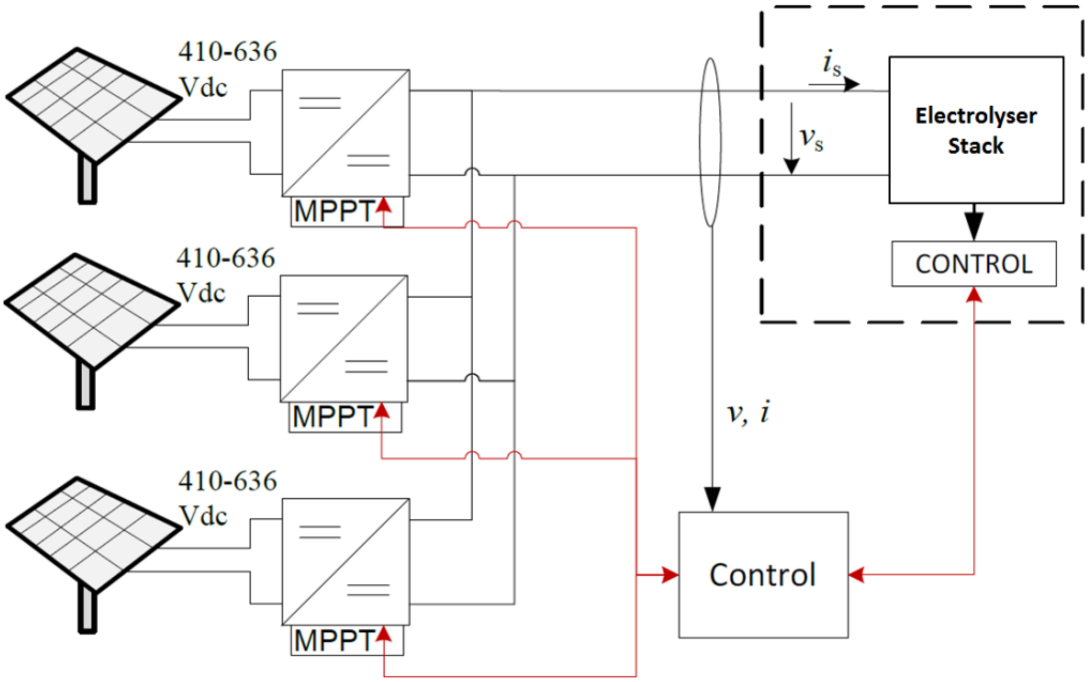

Figure 5. Parallelised DC to DC conversion architecture.

For a system topology we chose a DAB-SRC (Dual Active Bridge Series Resonant Converter) topology based on the work carried out on the EU ELY4OFF project which looked at the development of subsystems for offgrid integration, [14]. The DAB-SRC is a transformer isolated resonant DAB derived topology. It consists of eight power electronics transistors, four on the primary side and four on the secondary side, plus a capacitor and inductor for the resonant tank. This topology is well suited to high power conversions and very high input/output voltage fluctuations. Importantly reverse energy conversion from the low-voltage side to the high-voltage side is possible, as this would be very useful for our H_2 electrolyser's Balance of Plant where process equipment such as pumps require high-voltage supply. The schematic for a DAB-SRC topology system is shown in Figure 6:

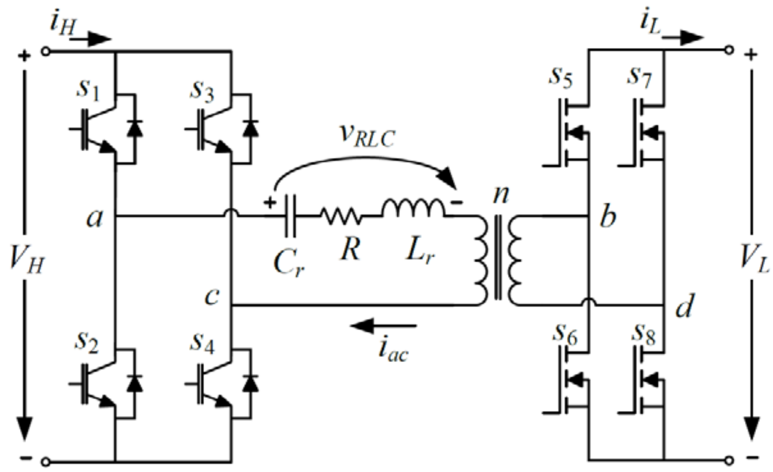

Figure 6. DAB-SRC (Dual Active Bridge Series Resonant Converter) schematic

Also under WP3 the standards and procedures associated with H_2 plant pressure testing, operations and maintenance were investigated. Background consultation with EU Directives such as: *RCS-19 Pressure Equipment Directive* (PED) 97/23/EC; *RCS-25 Simple Pressure Vessels Directive* (SPVD) 2009/105/EC and *RCS-2 ATEX Directive*, provided us with a baseline knowledge that was applied when studying CPH2 electrolyser P&ID and other piping and process diagrams, [15].

Both the floating solar and hydrogen plant components were costed to give the cost of producing one kilogram of H_2. Using the modelled 1MWp floating PV power supply alone we calculated that we it would produce 8,230kgs/ of green H_2 annually, based on running the six electrolyser stacks of the 143kW electrolyser at optimum capacity. The same exercise factoring in using wind energy for a complementary power supply and battery banks for storing energy to increase the electrolyser *'Duty cycle'* running hours to 24/7 was then carried out, this was the most cost efficient solution. A theoretical large scale FSPV plant to produce H2 in tandem with Wind and Battery storage was also looked at. The calculated range for FSPV LCOE was between 75 to 85MWh depending on what the size of the FSPV plant and importantly what *Discount Rate* was used. These are reasonable costs when compared to the cost of offshore wind energy being around 75MWh, *(European Wind Energy Association)*, and that is the subsidised cost. The LCOH for hydrogen that we calculated ranged from <€5 per kg to >€10 per kg, again very dependent on the *Discount Rate* finance terms and importantly the cost of the kWh of electricity. Plants at larger scales, (>10MWp for FSPV and >2MW for electrolysers), produced lower cost hydrogen. A 10MW electrolyser with a kWh supply cost of 4.5 cents€, at a *Discount Rate* of 10% over 15 yrs will produce a kg of hydrogen for €5.65.

In summary, the work carried out under WP3 delivered:

1. *A Front End Engineering Design study for the Energy Production System and Electrical Architectural design*
2. *A Study of information required for H_2 Safety & system design reviews*
3. *A Costing for a FSPV / H_2 Production Plant and a projected cost per kg of H_2*
4. *A Costing for a Wind / Battery / FSPV/ H_2 Production Plant and projected cost per kg of H_2*

2.4 Difficulties encountered and solutions identified

The following technical and scientific challenges were encountered on this project:

1. *Change in size of Floating Solar Array*

Initially a 30kW FSPV array size was proposed. This was found to be too small to be of practical use (due to the small quantities of hydrogen that would be produced), so we increased the array size to 1MWp. At this size it is feasible to produce significant volumes of H_2. As the scale of FSPV plant was increased the cost per kg of H_2 decreased, this was due to the direct effect of power cost on H2 production costs.

2. *Finite Element Analysis during Structural Design of the FSPV Platform*

Some results of our finite element analysis (FEA) were found to be fundamentally incorrect. Further investigation of this indicated that this was due to a number of issues including non-convergence (or unstable convergence) of the finite element solution; this is a common problem in FEA analysis irrespective of the analysis software package used. To avoid these issues we used trustworthy engineering hand calculation checks to verify the results and techniques developed to help numerical convergence.

3. *Large number of load combinations to be considered*

There were many different load cases that had to be considered for the structural design of the floating array because of the directional wind and wave loads, the possibility of snow loads, and the various mooring conditions including the possibility of a failed mooring condition. All of these factors multiply together to lead to a vast amount of load combinations which make the design process longwinded. To mitigate against this we developed techniques using first-principles engineering calculations to assess all of the required load combinations and develop enveloping load cases which could be used in detailed analysis thus streamlining the design process.

4. *Calculation of wave heights and the effect they have on the structure*

Determination of wave loads on floating solar arrays is a key area and a subject of ongoing research. For this project a methodology was developed to calculate expected wave heights at the site using the widely-used JONSWAP wave spectrum. Wave loads on the structure were determined using equations given in the DNVGL offshore design codes. Further research is being completed in collaboration with a number of universities based on the results of physical wave tank testing to further develop these techniques.

5. *Location of H2 Electrolyser Plant*

Initially the "raft" containing hydrogen generation & storage equipment was proposed to be directly moored adjacent to the solar raft. It became clear from discussions with manufacturers that if an electrolyser was installed out on the water close to the floating solar array then the H_2 equipment warranty would become void and the H_2 plant could not be insured. Therefore, in light of that fact we placed the Hydrogen plant onshore and the electricity supply from the floating solar plant is distributed directly to an onshore Hydrogen plant.

6. Finding a Suitable Electrolyser

One of the big challenges we encountered on the project was matching a suitable electrolyser technology and sizing of the electrolyser relative to the specific electrical energy output of the floating solar plant. There are many variables to be considered as certain types of electrolyser are not suitable for operating under a variable renewable energy power supply. Not only had we to consider the electrolyser power requirements but also the power needed to operate the Balance of Plant process equipment and all 'parasitic' loads. Many electrolyser companies were not interested in supplying the level of detailed information that we required as they have their own in-house R&D studies ongoing and do not share data readily due to commercial sensitivities. Members of our team attended workshops and conferences hosted by electrolyser manufacturers to find out firsthand what their respective technologies could deliver. We also attended international Hydrogen conferences to learn about the latest electrolyser technologies available. It took almost a year to find the electrolyser manufacturing company, CPH2 (Clean Power Hydrogen), a UK company with an Irish office. CPH2 were coming out of the R&D phase with an innovative new 'membrane-less' electrolyser and they were willing to share information at a level that enabled us to properly assess whether or not a power supply from FSPV could be used to produce H_2 using their equipment. After many meetings and much consultation and exchange of data, both parties agreed that a power supply from floating solar energy can be used to operate their electrolysis plant. To help we reach this conclusion we had to consider many variables and whether FSPV could deliver the power required. These variables included: ramp-up/ramp-down times; establish optimum IV Curve Voltage/Amperage requirements for Cell Stack operating; H_2 production relative to the minimum and maximum power inputs; all background parasitic loads; all Balance Of Plant loads.

7. Electrical Architecture to Integrate FSPV with H_2 Electrolyser

Designing an interface between the floating solar plant and electrolyser equipment to guarantee maximum efficiencies was a challenge. This work involved looking at how renewable energy sources can be integrated under various topologies to provide power to electrolysers and process plant within the operational constraints. We could not find any example of an electrical architecture using floating solar to power H_2 production. The closest integration model we found was under the EU *ELY4OFF* project which used a land based solar plant to power a PEM (*Proton Exchange Membrane*) electrolyser. The power profile requirements for a membrane-less electrolyser are different to those for a PEM, however with the assistance of outside experts we designed a topology that will deliver the power required from our 1MWp FSPV plant using battery storage/distribution whilst also having the system designed to use wind energy as another additional power supply option.

8. Lack of official recognition of FSPV in Ireland within Planning Legislation

Currently in Ireland there is no official recognition of Floating Solar Energy within marine planning legislation, this is an obstacle to obtaining a Foreshore license for the development of floating solar projects. To rectify this we would encourage Irish policy makers to provide the following:

- An expansion of the definition of ocean energy in the Irish context to include FSP, for example in the new post 2020 OREDP. This would allow for targeted Government actions to support the development in Irish waters of FSP, which is technically and economically well-placed to contribute to Ireland's decarbonisation goals.
- Clarification of the consenting arrangements for FSP developments, as with other marine renewables [we presume this should be covered by the Marine Planning and Development Bill].
- Specific financial incentives for blue hydrogen, from 100% renewable energy origins, to close the price gap with unsustainable fossil-derived hydrogen.

3. Results and Outcomes

As part of the project, SolarMarine Energy Ltd has developed: 1). A new more robust floating solar energy structure based on an existing design and 2). A systems electrical architecture and topology to enable production of Hydrogen from floating solar energy.

The project's key outcomes and results can be summarised as follows:

- Developed a world class floating solar structure. This modular structure is light yet strong, easy to fabricate, install and maintain.

- Developed techniques to calculate site specific environmental loads including wind, snow and waves on the floating solar array in accordance with internationally respected codes and standards.

- Created methods to solve the mooring equations and calculate mooring forces on the array under a wide range of different environmental loads, water levels and mooring conditions including the accidental failed mooring condition.

- Established procedures to determine forces within the floating solar structure, assess a wide range of load combinations and find the critical load conditions.

- Used advanced Finite Element Analysis and first principles Engineering calculations to ensure the floating structure is robust enough to withstand all applicable environmental loads and conditions including the possibility of a failed mooring.

- Designed an electrical architecture for the floating solar energy plant that will facilitate a DC to DC Topology between the floating solar energy plant and the H_2 electrolyser and it's associated process equipment.

- The creation of a topology design that integrates floating solar energy, battery bank storage and wind energy for power supply to H_2 electrolyser and BOP.

- Realistic LCOH and LCOE models for H_2 production and FSPV using: 1). Floating Solar / battery storage. 2). Floating Solar and Wind energy with Battery Storage.

3.1 Networking and Collaborations

SolarMarine Energy personnel and UCC attended several conferences and workshops on hydrogen production specifically in relation to producing it using renewable energy power sources, the conference and workshop details are in the table below. At every opportunity SolarMarine Energy Ltd informed audiences and prospective clients about the possibilities of using floating solar energy to power H_2 electrolysis. SolarMarine Energy joined Hydrogen Ireland and registered with Hydrogen Europe to follow both national and international developments in the industry. In addition, new collaborations and relationships were established over the course of the research project with electrolyser manufacturing companies, *Hydrogenics* in Belgium and *Clean Power Hydrogen* in the UK. We are very hopeful that we will get the opportunity to collaborate with *Clean Power Hydrogen* on a commercial scale project to showcase floating solar as one of two renewable energy power sources for the production of hydrogen. In addition, UCC developed a collaboration with the *Western Norway University of Applied Sciences* on electrolyser and FSPV applications.

SolarMarine Energy Ltd and UCC project personnel attended the following national and international Hydrogen workshops and conferences:

Conference / Workshop Title	Dates	Venue / Location
Power 2 X - Innovation Forum - World Energy Council	17th June 2019	Norton Rose Fulbright, London
Hydrogenics Electrolyser Workshops	4th, 5th September 2019	Oevel, Belgium
Maritime Hydrogen & Marine Energy	18-19th September 2019	Floro, Norway
Engineering the Energy Transition Conference	27th, 28th February 2020	Titanic Hotel, Belfast
MaREI & Hydrogen Ireland Workshop	19th February 2020	Lapps Quay, Cork
GenComm's Community Hydrogen Forum	21st October 2019	DCU Alpha, Dublin
MaREI Biofuels Symposium	29th April 2020	Online

4. Impacts and Benefits

SolarMarine Energy Ltd (SME) has received many benefits from this academic research project. At the start of the project SME had a solid foundation in designing floating solar structures for inland water areas. This project has enabled our company to graduate from solely designing floating solar energy plants for inland waters to creating feasible FSPV designs for nearshore coastal locations. Also very importantly this project has enabled us to build a new skills base in how to integrate renewable energy sources to produce hydrogen. Specific benefits and impacts for SolarMarine Energy include:

- This research project will be used as a marketing tool to give prospective clients confidence that the company can deliver a project from concept to production, whilst proving our commitment to the highest standards of engineering design due diligence and ability to collaborate with other leading institutes and industry partners. This confidence will help leverage future investment opportunities in the company leading to a strong sales pipeline.
- SolarMarine Energy as a direct result of this project has developed a strong network of contacts within the hydrogen industry. The impact of this has already been seen when we were invited to collaborate with an innovative electrolyser manufacturer and an international Hydrogen consultancy on a *Power to Gas* project for an island community.
- One of the many benefits of this project is that it has provided our company with the platform to build bespoke industry knowledge on how floating solar energy plant electrical system architectures can be specifically designed to integrate with complex topologies required for DC to DC power transfer. The direct impact of this is the fact that we have been allotted a work package on an upcoming H2020 grant project led by an international consortium of academic and industry partners, our task is to evaluate how floating solar and wind energy can be integrated in an offshore environment for the production of green hydrogen.
- In terms of economic impact, this research project will help accelerate the development of an indigenous industry which has a vast export potential. By positioning Irish companies at the engineering forefront of this technology, many skilled new jobs could be created in the emerging marine renewables and hydrogen industries, both direct and indirect via supply chain and support services. The generation of local employment has a compounding effect both in terms social and economic returns.

As a result of this project we now have a broader skillset that will enable our company to get involved on projects that before we would not have been able to consider participating on. At this point in time we are the only company nationally and internationally that is looking at using floating solar energy in tandem with other renewable power source combinations to produce green H_2 by electrolysis. We will build on our research base to ensure that we are at the vanguard of technology developments in this new and exciting strand of renewable energy generation.

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Appendix 1 - Company Description

Established in 2016 SolarMarine Energy Ltd was formed by a group of engineering professionals to develop innovative solutions for marine based hybrid renewable energy projects. This work includes the design of Floating Photovoltaics (FSPV) plants for renewable energy supply and for powering water electrolysers to produce Hydrogen.

The company currently employs 4 staff, but has plans to grow the employment base following on from this research that will open new markets in nearshore floating solar energy plant design and deployment. Also we will leverage our research into how electrolysers can be powered from floating solar energy plants and wind energy to generate consultancy and project work.

The following is an overview of our personnel and consultants:

Eamon Howlin – CEO*:* A Chartered Marine and Civil Engineer - MSc. in Offshore Technology - 30 years' experience across the maritime industry including founding a successful marine services company & working internationally in project engineering for oil & gas, Civil infrastructural developments and marine renewable energy companies.

Dr. Jon Hancock – Structural Engineer: Ph.D. in Civil Engineering - Chartered Civil Engineer - 20 years' experience in a broad range of disciplines in the oil & gas and construction industry - Lead Structural Engineer on cutting edge Wave energy projects from concept design through to detailed engineering, fabrication and operation & maintenance.

John Crowley – Energy Manager: MSc Energy Management, BSc Engineering, 20 years' experience in power generation and energy markets in thermal CCGT, Fuel handling, Hydrogen production, Onshore and offshore wind. John is an experienced Project Engineering and Program Manager leading energy projects worldwide.

Mike Whelan – Operations Manager: 40 years' experience working in the marine sector including oil & gas, wave energy and marine salvage. He founded and successfully ran a number of companies specialising in marine support/towage, pollution control and salvage operations working from Cobh harbour.

Dr. Richard Montague – Mechanical Engineer: 14 years' experience designing and delivering full scale marine renewables devices. At Nova Innovation, he helped deliver the world's first offshore tidal array in Shetland. He was previously Lead Mechanical Engineer at Aquamarine Power and Principal Engineer at Marine Current Turbines.

Dr. Kenneth Doherty – R & D Manager: Ph.D. in Applied Mathematics and Experimental Physics – An experienced R&D manager in the marine renewable energy industry with an esteemed track record in Tank Testing of prototype marine devices, Mathematical modelling and writing complex Algorithms.

Capabilities

The company has developed expertise in:

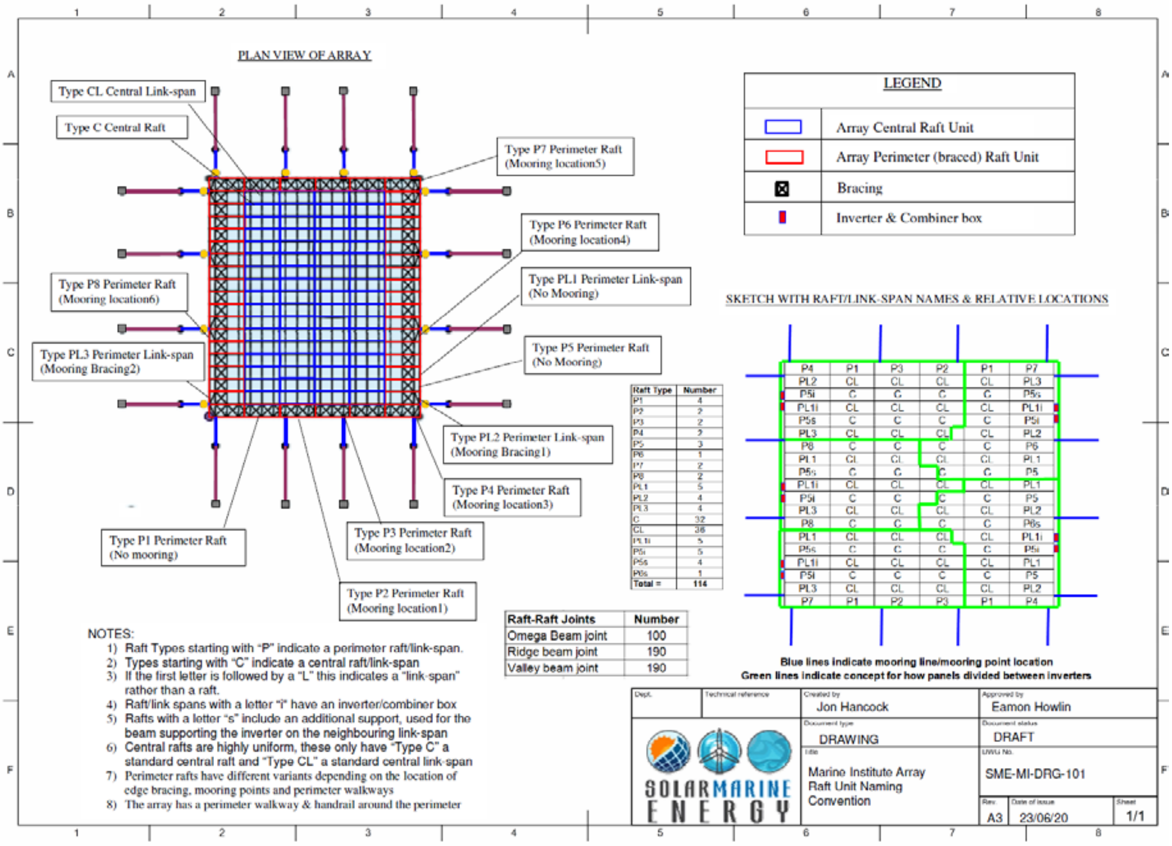
- Technical Advisors for Marine Renewable Energy projects
- 3D Modelling, Analysis and Design of marine renewable energy structures (floating PV, wave & tidal) including moorings and foundations
- Mooring Analysis, Design and Installation
- Calculation of Environmental loads, e.g wind, wave & snow, and mooring loads using in-house expertise and Eurocode & DNVGL codes/standards.
- Installation of marine structures including: Floating Solar Energy Plants; Wave and Tidal Energy devices
- Marine Installation and Site Supervision
- Feasibility Studies and Proposal preparation
- Fabrication consultation and procurement services

Appendix 2 – Extracts from FSPV Design Work

Reference SolarMarine Energy Ltd Project Design document: ***Floating Solar / Hydrogen Hybrid Energy Project Design MI Industry-Led Grant_SME-MI-REP-001 - Rev A1***

- *Site chosen for FSPV location*

- *FSPV 1MWp Array Design made up of different 'Raft' types and sizes*



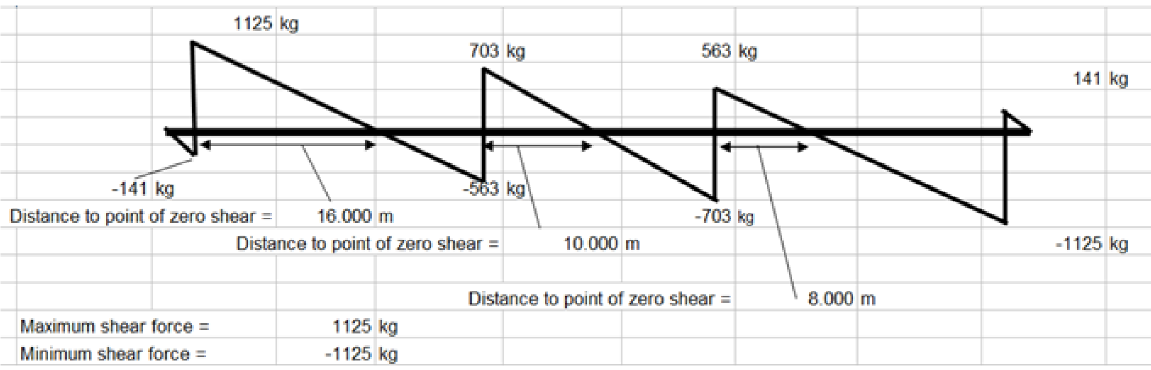
- *Table of Wind Load calculations for FSPV in North / South direction*

Loading direction (wind from, array co-ordinates)	North				South		
Component of wind load on array (global co-ords*)	**Horizontal**	**Upwards***	**Downwards**		**Horizontal**	**Upwards***	**Downwards**
Total wind load on panels (kg) =	2709	-493	1858		3564	-650	2445
Total wind load on "non-panel" structure (kg) =	1110	0	0		1461	0	0
Total load on Array (kg) =	**3819**	**-493**	**1858**		**5025**	**-650**	**2445**
Total load on Array (tonnes) =	3.82	-0.49	1.86		5.03	-0.65	2.45

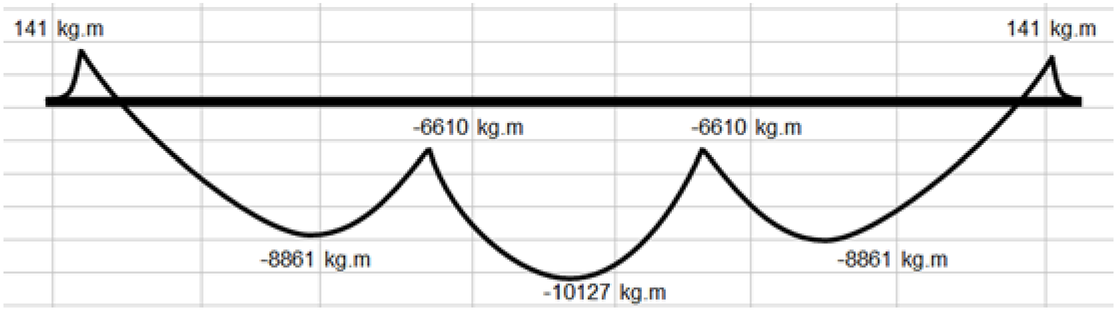
- *Table of Wind Load calculations for FSPV in East / West direction*

Loading direction (wind from)			East		West	
	A ref (m^2)	Cf	qp (N/m^2)	Force (N)	qp (N/m^2)	Force (N)
Friction on panels =	5309	0.01	260.6	8980	467.5	16110
Drag on array "non-panel" structure	4.463	2.1	260.6	1585	467.5	2844
Total horizontal wind load on array (N)				10566		18953
Total horizontal wind load on array (kg)				**1077**		**1932**
Total horizontal wind load on array (tonnes)				1.08		1.93

- *Shear Force Diagram for Northern Truss when FSPV Array under Northerly Loads*

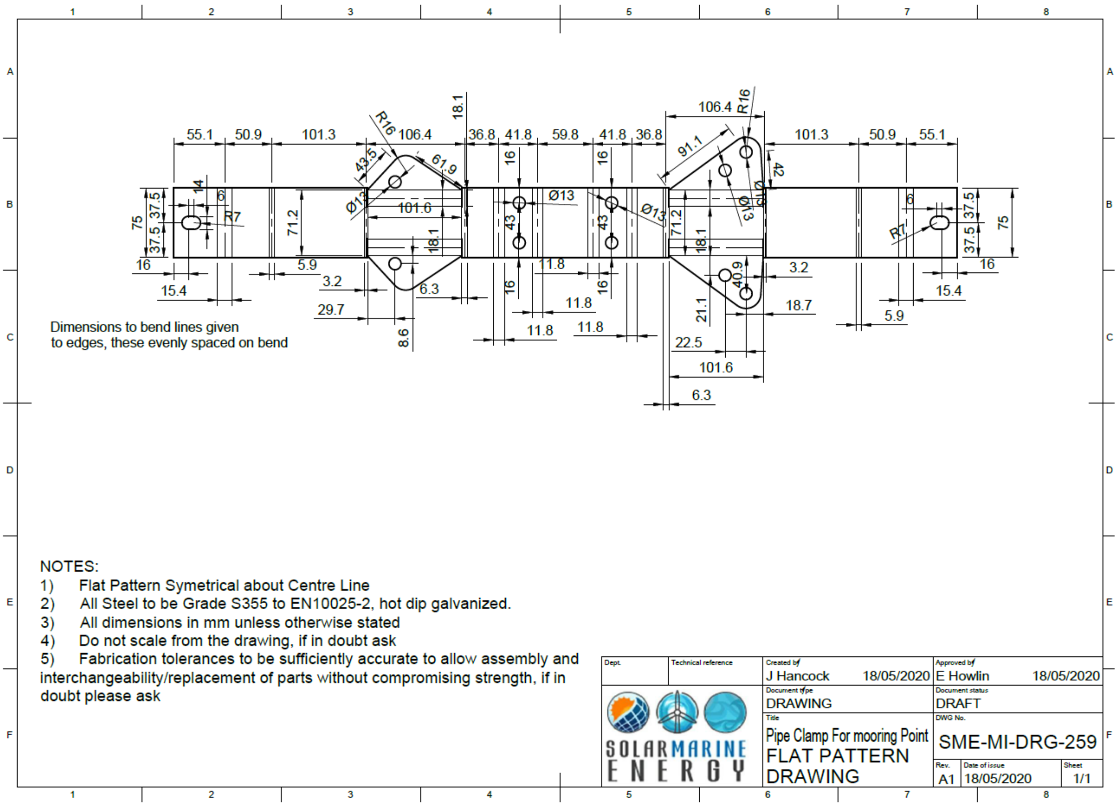


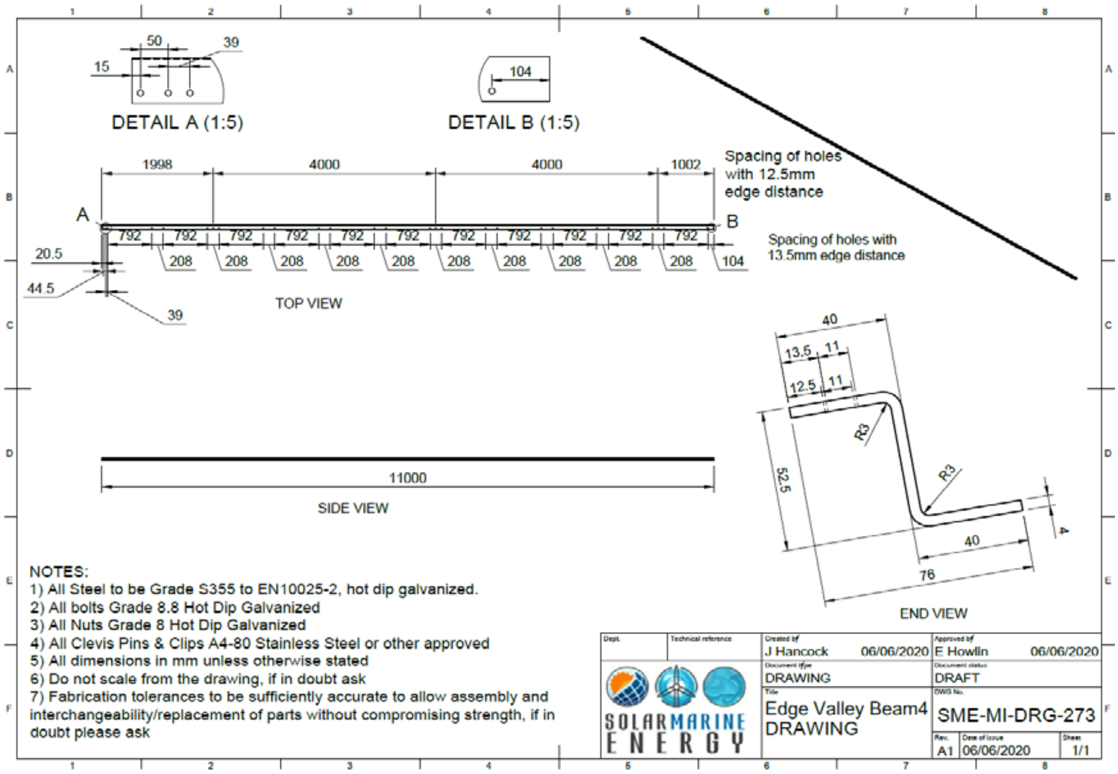
- *Bending Moment Diagram for Northern Truss when Array under Northerly Loads*



Appendix 3 – FSPV Drawings

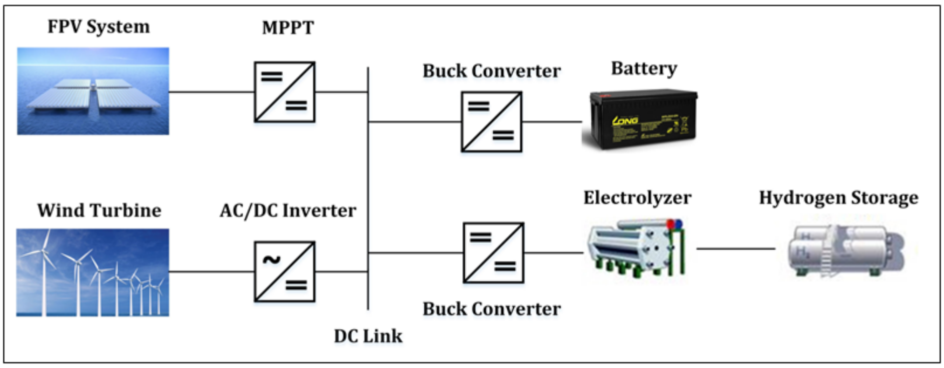
The following drawings are representative of the **102** number engineering drawings of the 1MWp Floating Solar Energy plant structural design that were produced by SolarMarine Energy Ltd for this project:

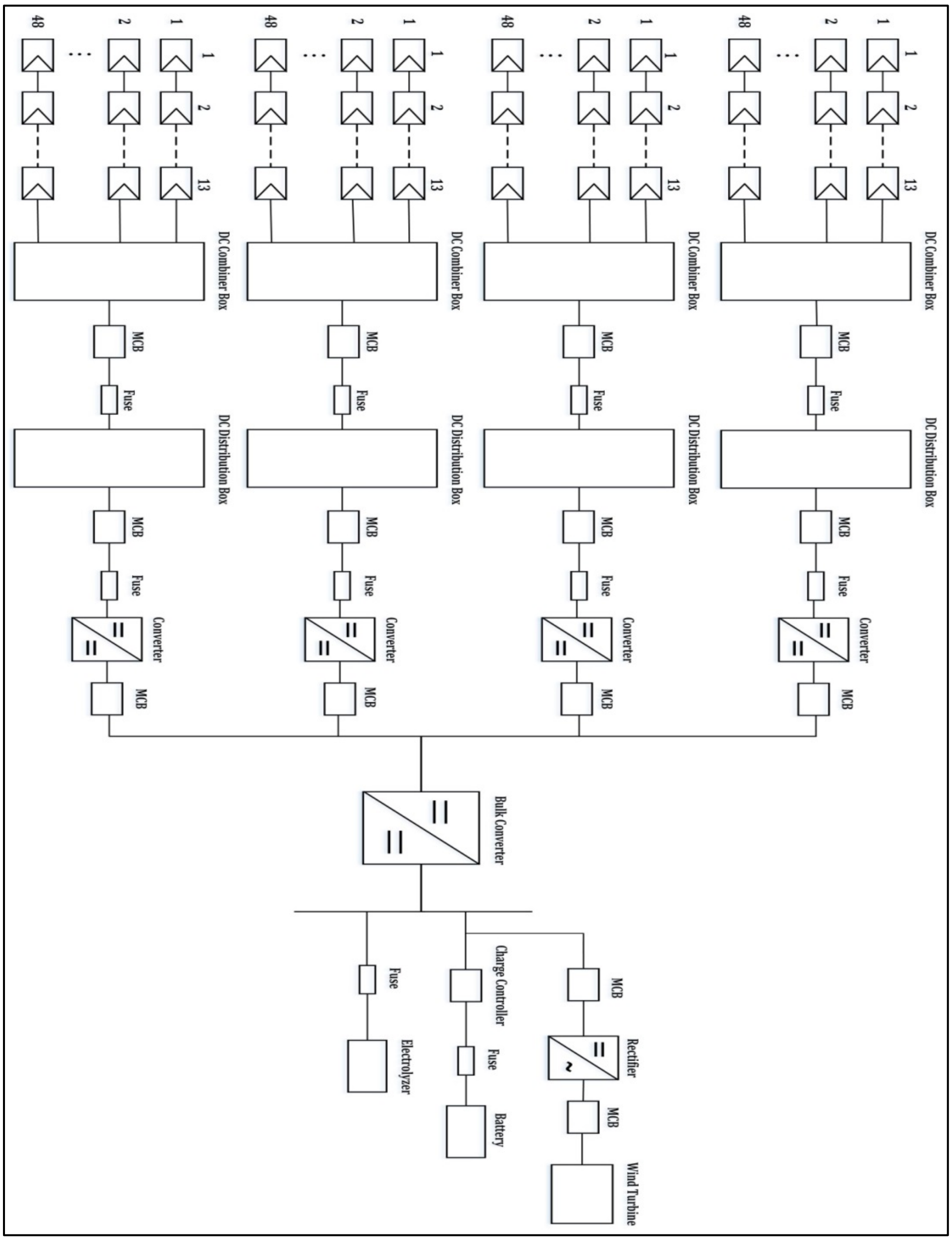




Appendix 4 – FSPV / H2 Plant Electrical Design Work

Reference SolarMarine Energy Ltd Project Design document: ***Floating Solar / Hydrogen Hybrid Energy Project Design MI Industry-Led Grant_SME-MI-REP-001 - Rev A1***





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