Floating Solar for Clean Hydrogen Production

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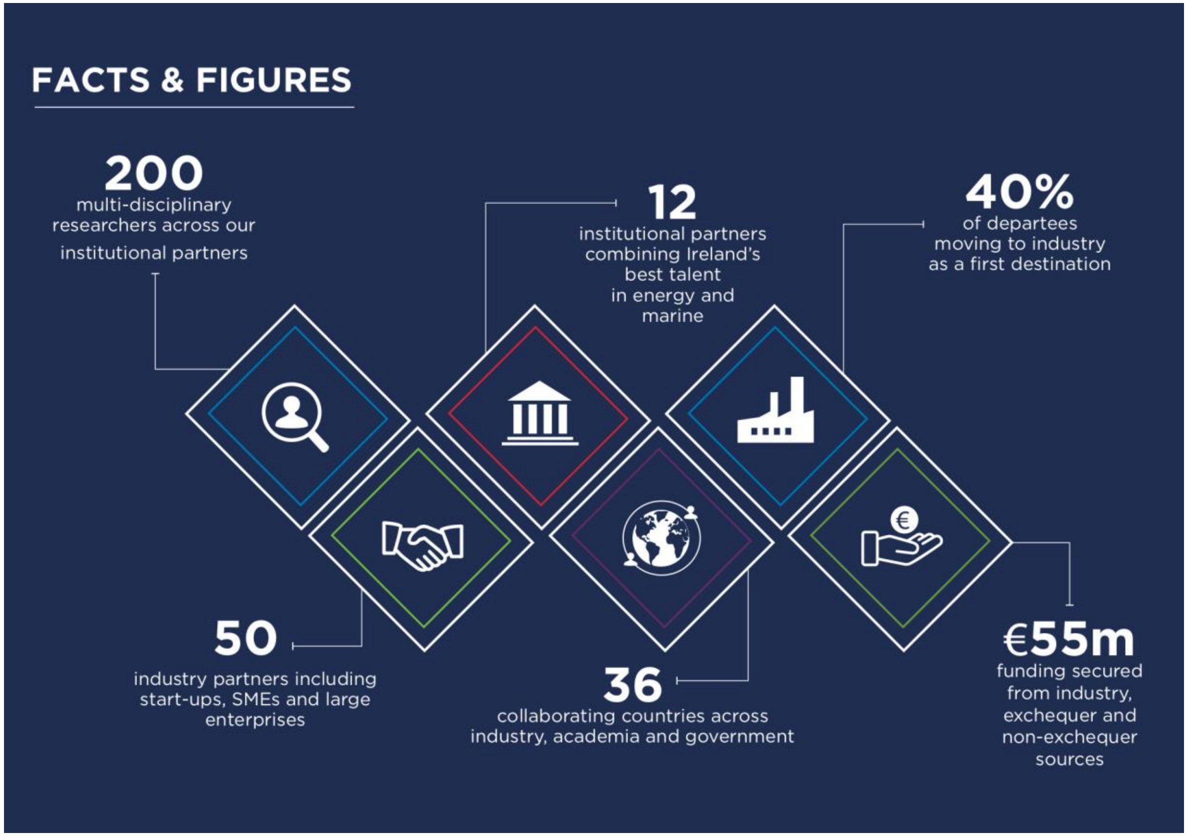
Example of Floating Solar Plant - Godley Reservoir, Manchester – 3MW (*2.7GWhr/year*)

MARITIME HYDROGEN MARINE ENERGY
FLORØ, NORWAY 18-19 SEPTEMBER 2019

Introduction to the MaREI Research Centre



MAREI is a multi-disciplinary research centre based in Ireland

12 institutions

50 industry partners

Funded by Science Foundation Ireland, industry, EU and national agencies

HOST INSTITUTION

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

PARTNER INSTITUTIONS

FUNDED BY:

Introduction to SolarMarine Energy Ltd

Formed in 2016 to develop innovative solutions for Floating Photovoltaics (FPV) plants and marine based hybrid renewable energy projects. We are a team of highly experienced marine operations and engineering professionals.

Associate Company:

- **Upsolar Floating Systems, Italy**

PV plant design expertise with extensive experience of designing and installing FPV structures.

USP

- We are the first floating solar company to design FPV plants and their mooring systems in accordance with marine industry Best Practice and DNV GL design codes.
- We do not use light Blow Moulded Plastic Pontoons - we install properly engineered, cost effective and environmentally sound floating structures using components that can be readily sourced worldwide.

What are our Goals?

- To design and develop hardware solutions for FPV and hybrid energy plants for both the inland and nearshore markets.
- Develop FPV plants to produce green Hydrogen for use in the maritime sector.
- Develop large scale FPV plants in the nearshore/offshore environments.

What we do at SolarMarine Energy Ltd.

Engineering Design - Project Management - Supervision

We provide complete FPV and hybrid energy plant solutions for clients including:

- Structural Design and Numerical Modelling of FPV structures
- Wind and wave loading studies
- Moorings Design
- Hybrid Energy Plant design, supply and installation
- Engineering, Procurement, Commissioning (EPC) Contractor
- Operations and Maintenance

Upsolar / Solar Marine Energy FPV array in Singapore

Current R&D Project

SolarMarine Eenrgy Ltd, in collaboration with University College Cork, are providing **Front End Engineering Design** services for an FPV powered Electrolysis plant to produce $\mathbf{H_2}$ in a harbour environment.

This Industry Led Project is funded by the Marine Institute of Ireland and will be completed in Q1 2020.

The project deliverables are as follows:

Work Package 1 - Engineering Design of Floating Solar Hybrid Energy Platform and Moorings

Work Package 2 - Energy Production Technology Review & Conceptual Design

Work Package 3 - Energy Production System FEED and FPV / Hydrogen Plant Project Design

Why Floating Solar Energy?

(FPV = Floating Photovoltaics)

Drivers for Floating Solar Development

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- FPV has a 50% **higher power density** than land based solar and 40 times that of wind energy.

Energy Source	Power Density per Acre
Floating Solar	480kW
Land Solar	220kW
Wind Energy	12kW

- FPV is ideal for areas where stringent **environmental regulations** prevent land-based wind & solar developments. No land requirement.
- FPV **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 labor costs.
- FPV is **quickly installed** without the need for heavy plant and equipment or civil construction. It is modular, easily scalable and easily decommissioned.
- FPV panel efficiency increases by up to 10% as the **panels are cooled** naturally by the water.
- FPV is ideal for providing energy as a **non-grid connected power source** at remote locations.
- FPV produces Zero Carbon electricity at **cheap** long-term fixed rates. Solar panel technology is well proven, low risk and dependable.
- 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**.

Market Competitors – Blow Moulded Plastic

Recent failures - Very light plastic pontoons with inadequate mooring systems :

Ciel et Terre FPV Plastic Pontoons

Sept 2019: Typhoon in Japan – Damage to FPV

FPV Design Standards

SME uses a mix of Eurocodes and DNVGL classification codes for the design of marine structures following best international engineering practice.

Load condition	Load factor	Load/material factor reference
Design of structural components subjected to dominant environmental load	1.7	DNVGL-OS-E301 cl 4.2
Additional partial factor applied to secondary environmental loads (e.g. factor applied to snow loads when applied in combination with a dominant wind/wave load, this is in addition to the load factor given above)	0.5	Eurocode 1 part 1-3 table 4.1
Design of structural components subjected to a temporary self-weight dominated load (e.g. slow slide installation from launch frame etc)	1.3	DNV-OS-C101 table D1
Accidental limit state	1.1	DNVGL-OS-E301 cl 4.3
Material factor for steel	1.0	Eurocode 3, part 1-1, cl 6.1

What differentiates our FPV designs from competitors is the following:

- We do not use 1,000’s of thin walled Blow Moulded Plastic Pontoons for PV Panel supports. We use extruded HDPE Pipes that comply with EU Drinking Water Directives
- Our FPV structures and moorings are robust and comply with recognised marine design codes and Best Practice
- Each FPV plant is designed to withstand the wind/wave loadings for that particular location

SolarMarine Energy FPV Structure

Upsolar / Solar Marine Energy FPV array in Singapore

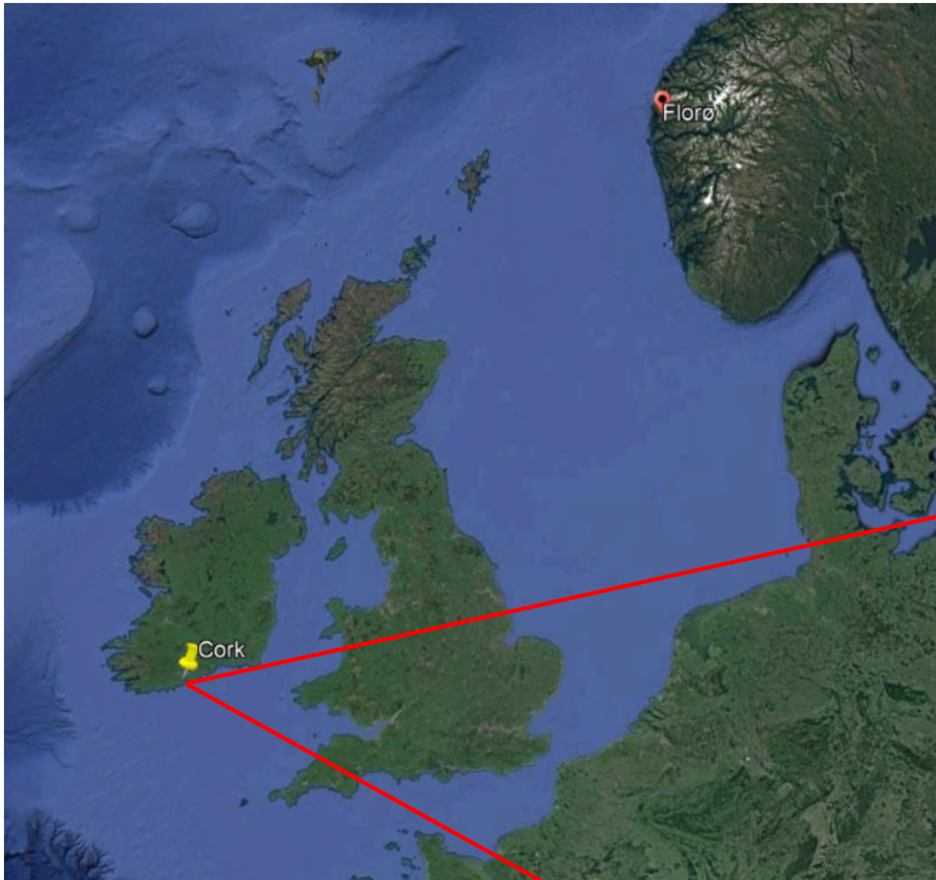
PV modules slope (deg)	5°	10°	15°	20°	25°
Max wind speed (km/h)	180	180	160	140	140
Base-Raft dimensions (60 cells PV modules)	12.000 x 3.200 x 315 mm				
Base-Raft dimensions (72 cells PV modules)	12.000 x 4.000 x 315 mm				
Floating Pipes material	HDPE - UV resistant				
Base structure material	Hot-dip galvanized steel - S235 JR				
Regulatory compliances	EN ISO 1461:2009; BS 5493/1977; EN 12666				
Life expectancy	25 years				

- Modular 'Raft' construction. Each 'Raft is designed specifically for the prevailing weather and environmental conditions of the deployment location.

- The FPVs are easily scalable as the modular construction freely allows additions/deductions to the plant footprint as required

Example:
FPV - Hydrogen Plant Location

Water Area alongside an Oil Refinery



Cork Harbour

- 2nd largest natural harbour in the World
- International marine hub
- Shipping, cruise liners, ferries, etc.
- Whitegate Oil Refinery and LNG terminal

Footprint of a 10MWp Floating Solar Development in Northern Latitudes

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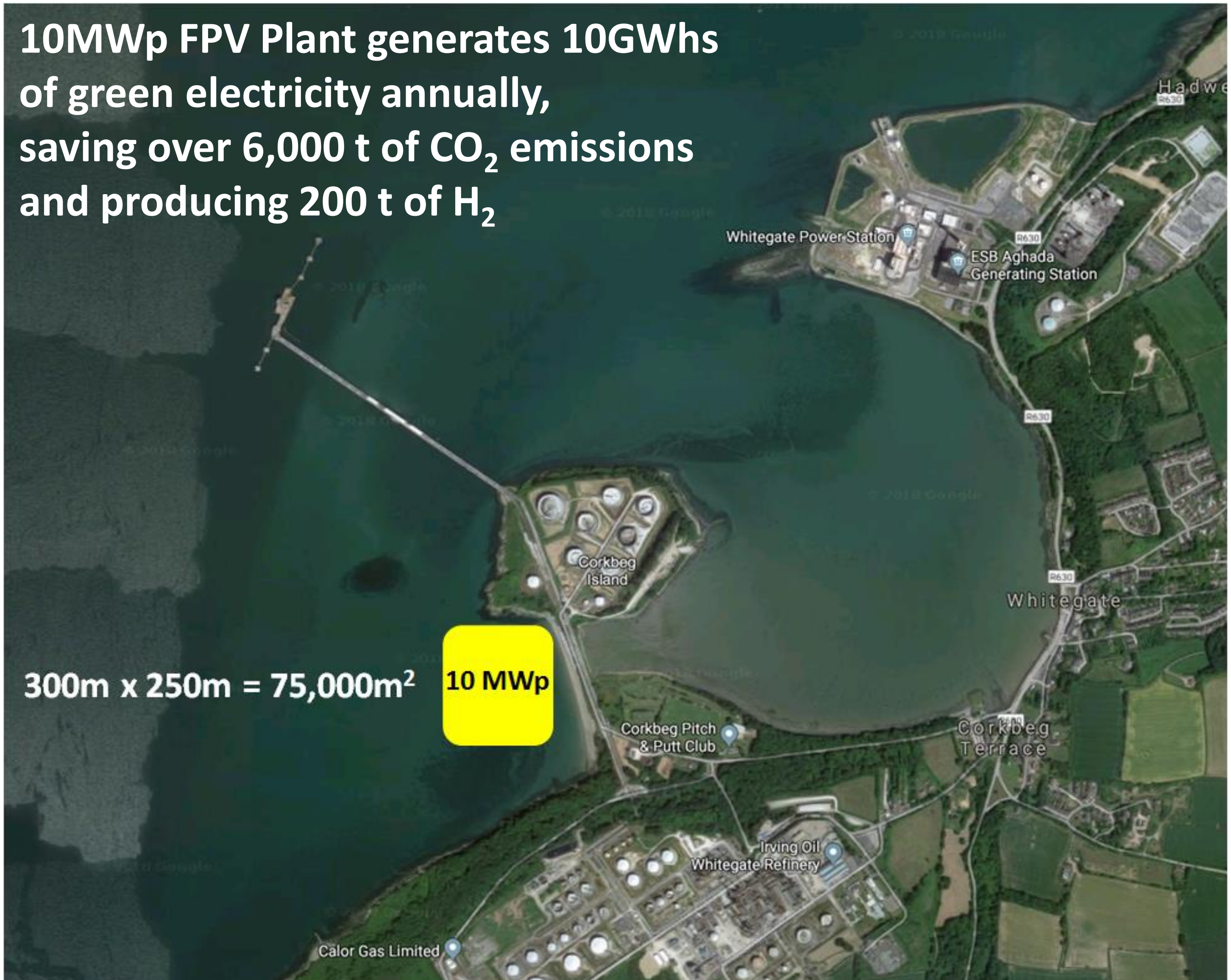
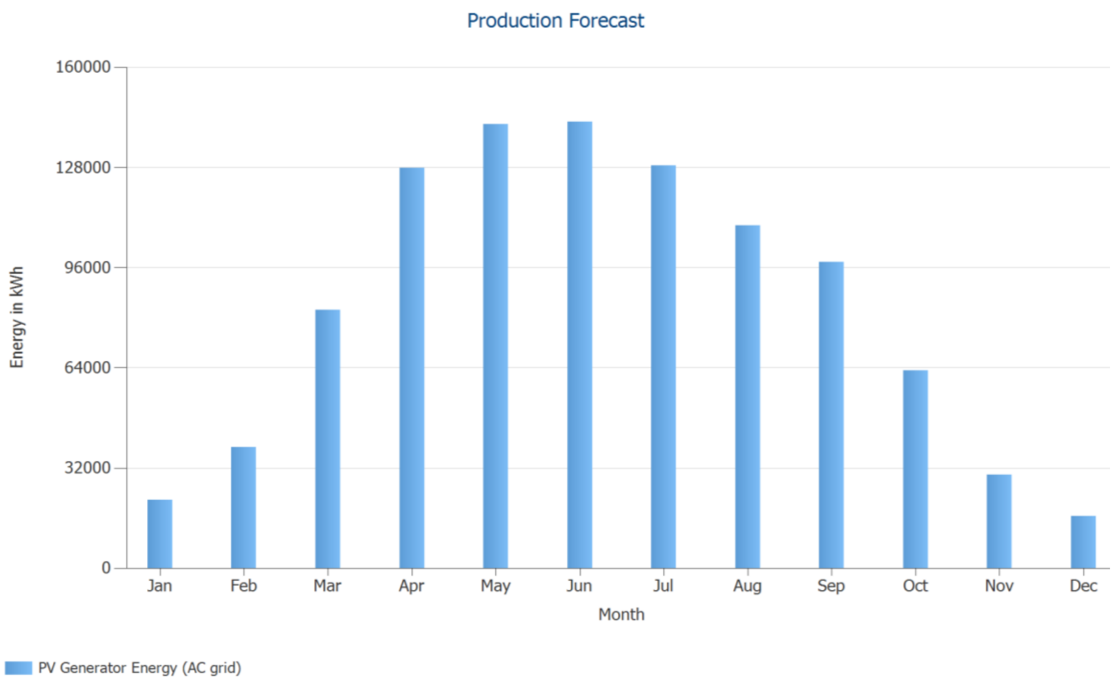


Example: 1MWp Floating Solar Plant Output

Simulation Results – Floating Solar Plant Study in **Northern Latitudes**

1MW Floating PV System – 53⁰		
PV Generator Output	**999.6**	**kWp**
Spec. Annual Yield	1,001.16	kWh/kWp
Performance Ratio (PR)	89.7	%
Yield Reduction due to Shading	5.6	%/year
Grid Feed-in	**1,000,791**	**kWh/year**
CO_2 Emissions avoided	600,475	kg/year

The table above shows some of the details for a 1MWp in higher Latitudes. These values can be taken on a pro rata basis for larger FPV plant sizes.



Seasonal PV plant output variations and changing load requirements can be accommodated through storage technologies incorporated into the FPV Plant control system

Example: 1MWp Floating Solar Plant Output

	Latitude	Rad. Horiz. Surface (NASA)	Panel slope azimuth	Rad-Yield (PV GIS)	Cooling and shading	LCOE in €/kWh
		Kwh/y/m²		kWh/y / kWp	kWh/y /kWp	
Netherlands	52°-53°	1105	20° South	930	982	6.5 cents
Cyprus (Larnaca)	34° 55’	1898	20° South	1650	1811	4.3 cents
Dubai	25° 16’	2081	10° South	1710	1940	4.1 cents
Singapore	1° 21’	1720	10° South	1220	1366	5.5 cents

Electricity costs from floating solar vary relative to the geographical location of the site. The above table shows the variance in kWh/kWp price ranging from **4.1 to 6.5 c/kWh.**

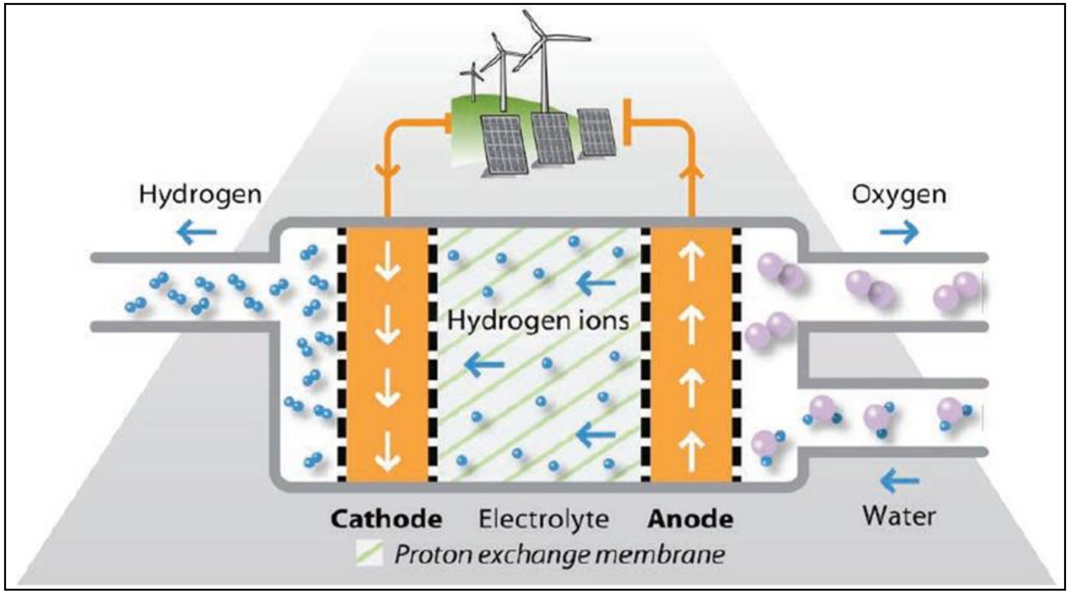
When **GOs ‘Guarantees of Origin’** are introduced under upcoming EU Legislation and the **levy price per ton of CO_2 emissions** increases to €100+ per tonne, then using FPV energy to produce Hydrogen will be will become an even stronger proposition as the playing field among potential energy sources will have been levelled.

Making Hydrogen from FPV Electricity

The Case for FPV Produced Hydrogen

- Over 80% of Hydrogen production is from SMR (**Steam Methane Reforming**) methods, a highly energy intensive and polluting process.
- EU is moving rapidly towards heavily penalising large scale H_2 producers who are solely dependent on fossil fueled based energy supply through the impending ‘Gas Package’ legislation. This will ‘level’ the playing field for companies producing **H_2 via water electrolysis and renewable energy**.
- **Decentralised energy supply** is actively being encouraged globally. Grid connected electricity supply is subject to standing costs/charges and increasing Carbon Taxes, and reduction of fossil fuel subsides. It will be cheaper to use FPV energy for the production of H_2 in the near future.
- The upcoming **‘GOs’ (Guarantees of Origin)** certification for electricity will also make H_2 production from 100% renewable energy sources very attractive.
- The **Shipping industry is looking to H_2** as a fuel source to avoid ‘Cold Ironing’ costs in harbours, as the IMO restricts NOx and SOx etc.
- There will be a **greater demand for H_2 in ports** – current supply is not enough.

PEM Electrolyser Plant for H_2 Production



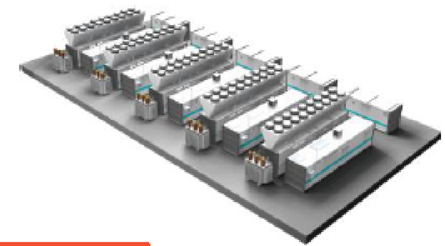
PEM (Proton Exchange Membrane) electrolysis in particularly suited for use with renewable energy sources as it can tolerate an intermittent power supply and can be started and stopped quickly, as opposed to the common Alkaline method which requires a constant electricity supply and takes time to ramp up and down. PEM electrolysis also has the following characteristics:

- High efficiency at high power density
- High product gas quality, even at partial load
- Low maintenance and reliable operation
- No chemicals or impurities
- Scalable through additional stacks

A 10MWp FPV at Northern Latitudes would generate over **10 GWh of green electricity** annually.
This is sufficient energy to produce more than **200 tonnes or 2,220,000 Nm^3 of Hydrogen per anum.**

PEM Electrolyser Plant Examples

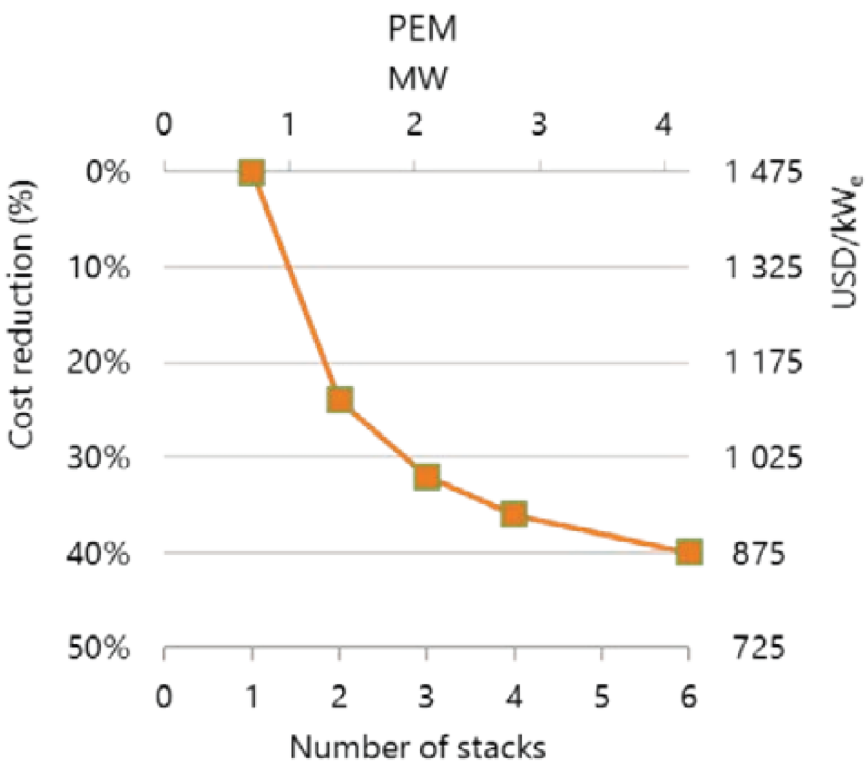
PEM (Proton Exchange Membrane)



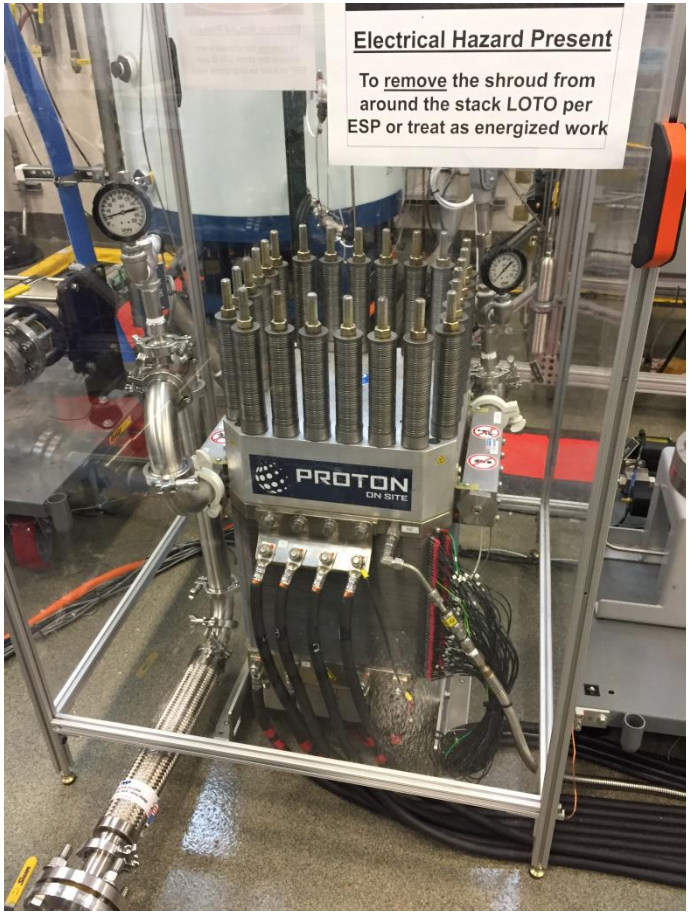
	HyLYZER® -300-30	HyLYZER® -1.000-30	HyLYZER® -5.000-30
Output pressure		30 barg	
Number of cell stacks	1	2	10
Nominal Hydrogen Flow	300 Nm^3/h	1.000 Nm^3/h	5.000 Nm^3/h
Nominal input power	1.5 MW	5 MW	25 MW
AC power consumption (utilities included, at nominal capacity)		5.0-5.4 kWh/Nm^3	
Hydrogen flow range		1-100%	
Hydrogen purity		99.998% O_2 < 2 ppm, N_2 < 12 ppm (higher purities optional)	
Tap water consumption		<1.4 liters / Nm^3 H_2	
Footprint (in containers)	1 x 40 ft	2 x 40 ft	10 x 40 ft
Footprint utilities (optional)	1 x 20 ft	1 x 20 ft	5 x 20 ft

Courtesy of Hydrogenics

PEM Electrolyser Plant Costs vs Size



Courtesy of IEA 2019



Courtesy of Nel ASA Hydrogen

Electrolyser costs decrease relative to the number of '*Cell Stacks*' installed. From 2MW in size onwards delivers best value

Advantages - PEM vs Alkaline Electrolysers

CAPEX

- PEM prices decrease with scale of $\mathbf{H_2}$ plant.
- Standard off the shelf equipment can be used for BOP equipment in processing.
- Less surface area required for installations.
- Unlike Alkaline Stacks, PEM Stacks can be 'refurbished' instead of having to be replaced.

OPEX

- Less electricity required – more efficient than Alkaline.
- No compressors required for Hydrogen liquefaction.
- No compressors means no oil contamination.
- No Potassium Hydroxide (KOH) required in process so easier maintenance.
- Low OPEX costs compared to Alkaline electrolysers (1% as opposed to 5%+).
- Better able to deal with variable power input.

Courtesy of Nel ASA Hydrogen

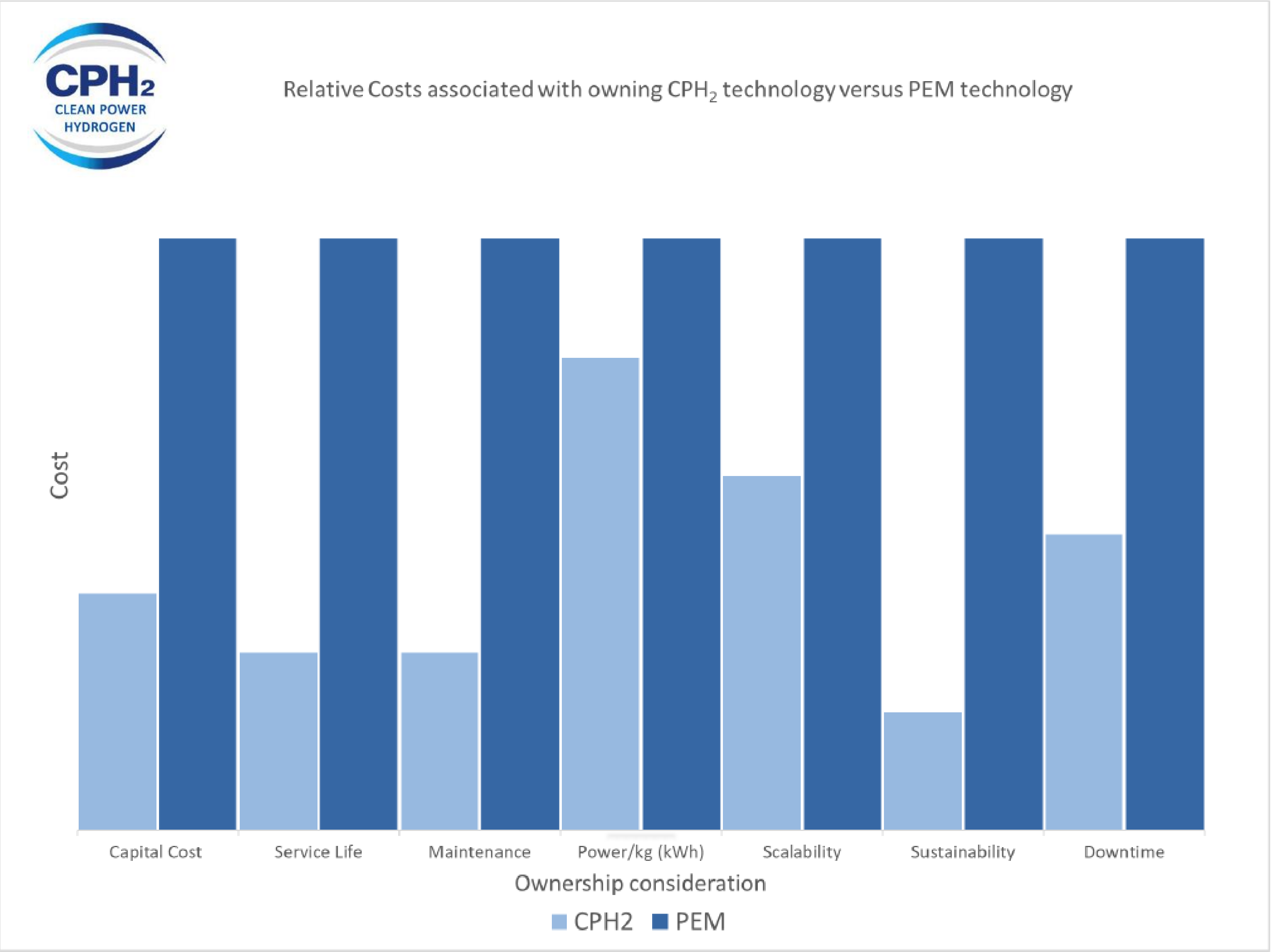
New CPH_2 Electrolysers vs PEM

A disruptive new patented electrolyser design that has 40% of the CAPEX costs of mainstream PEM electrolysers and does not require 'Cell Stack' changeout – reduces OPEX.
Potentially a market changer, currently coming out of R&D phase.

The Advantages of CPH_2 technology versus PEM

CPH_2 Negative influencers	*CPH_2 Positive influencers*
Mixed gas generation. Safety Concern.	No membranes.
Cryo-cooling system requires 6-12% electrolyser power input.	No catalytic poisoning.
	Low electrolyser (Stack) manufacturing cost.
	No precious metals needed for catalyst.
	High pressures can be generated prior to finial point of use compression.
	No Palladium filtration require. (Associated running cost & production gas losses during filter purging.)
	Low cost of Balance of plant.
	Greater electrolyser efficiency (up to 14% improvement.)
	Low maintenance requirements.
	No specialised water specification required.
	No special tools, equipment or training required for maintenance.
	Low manufacturing costs.
	No leaching of membrane materials in to gas stream that causing premature electrolyser & fuel cell failure.
	Easy to scale.
	Easy to recycle at end of life.

CPH_2 Costs versus PEM



Existing Hydrogen Market Electricity Costs

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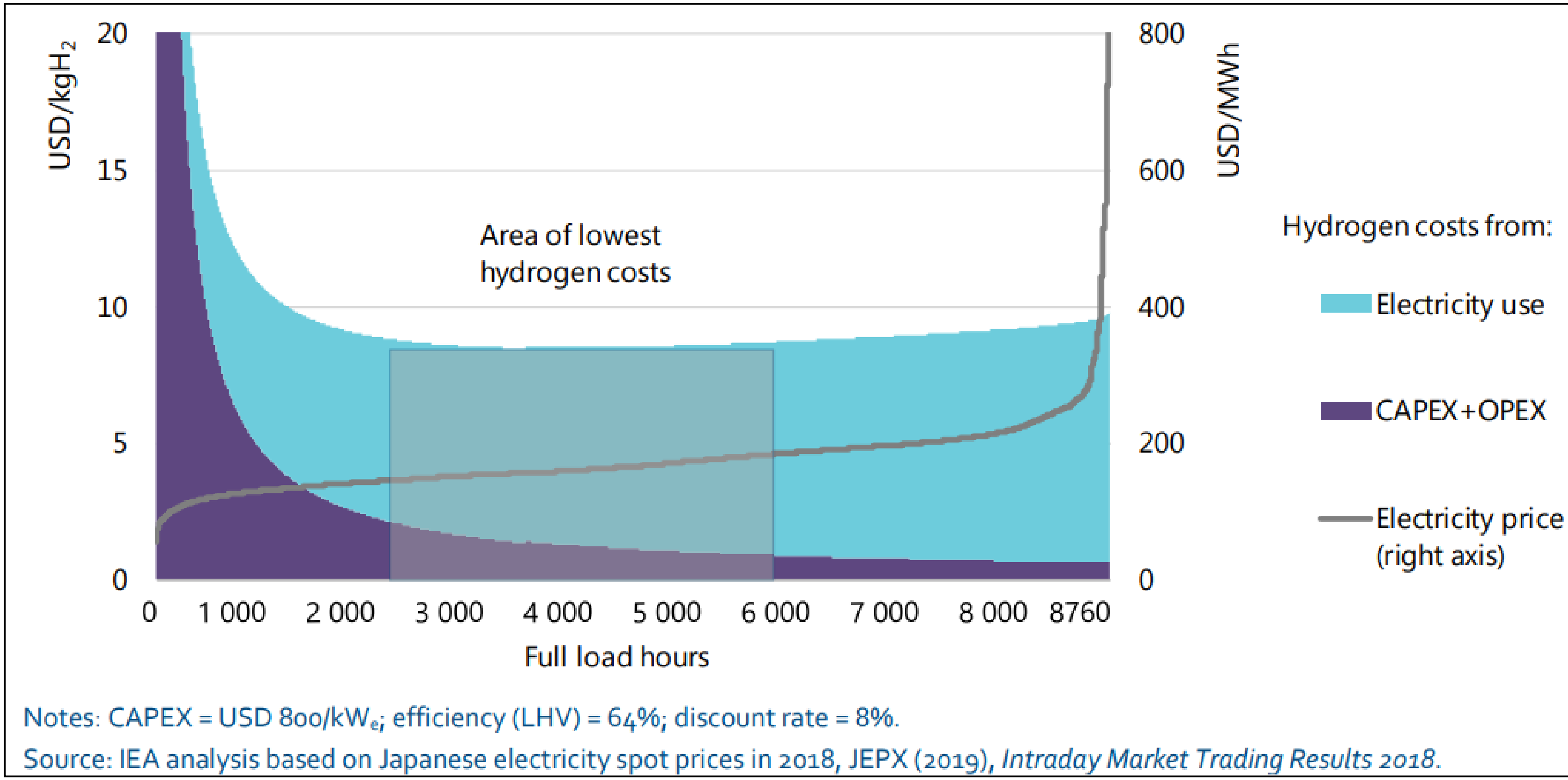


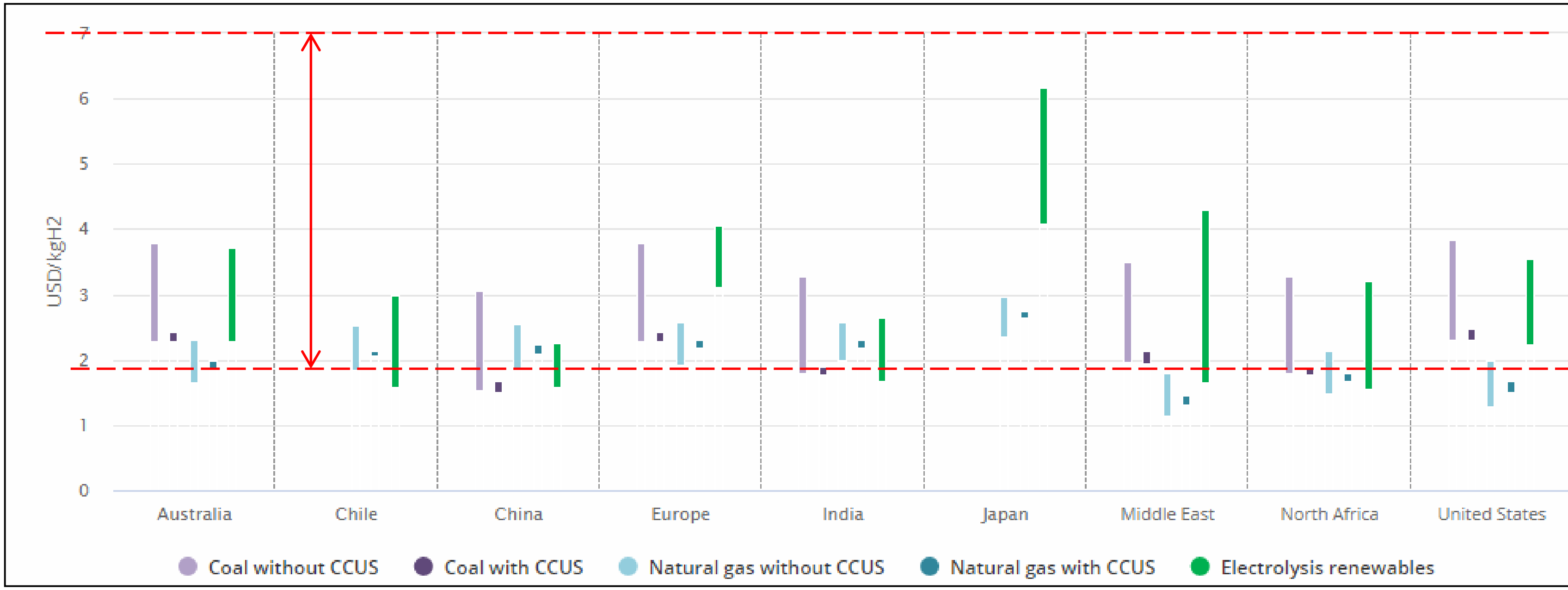
Courtesy of IEA 2019

Hydrogen Costs from Electrolysis using Grid Electricity

Above graph shows Grid connected electricity costs ranging from **20 \$/MWh up to 390 \$/MWh in Japan**

Generally to produce H_2 at 1€/kgH_2 the electricity price must be around **20 \$/MWh** to be competitive with SMR production methods

Existing Hydrogen Market Electricity Costs



Courtesy of IEA 2019

Hydrogen Costs from Electrolysis from Renewable Electricity

The lines above ($1.98/kg$H_2$ to $7/kg$H_2$) show the cost of producing Hydrogen using electricity from FPV

The big drivers for this cost band width are:

- Geographical location of plant
- Economy of scale of Hydrogen production
- Type of Electrolyser used – Alkaline / PEM / CPH_2

FPV Economics

Hydrogen Production Cost Breakdown

In High Latitudes (40^0 to 53^0) the current cost to produce H_2 using FPV plant is **€7/kg** however as Electrolyser and PV Panel costs decline so too will the cost of H_2 decrease.
At lower latitudes solar radiation values are higher so a higher power density per kWp of PV installed is achieved and this in turn lowers the cost of H_2 per kg.

Investment Costs					
Plant Size	**Lump Sum Cost**	**EPC Costs (6%)**	***Opex Costs Yr**	**20 Yr Cost**	**Unit Costs**
Northern Latitudes: 52^0 - Solar Radiation value = 982 kWh/y /kWp					
FPV 1MWp	€650,000	€39,000	€10,000	€889,000	**€44/MWh**
1MW PEM Electrolyser	€1,000,000	Included	€10,000 + Once off €550,000 (Stack refurbishment @ 55% of Capex cost)	€1,940,000	**€7 per Kg_{H2}**
****1MW CPH_2 Electrolyser**	€450,000	Included	€10,000	€650,000	**€3.84 per Kg_{H2}**
Southern Latitudes: 25^0 - Solar Radiation value = 1940 kWh/y /kWp					
FPV 1MWp	€550,000	€33,000	€10,000	€889,000	**< €40/MWh**
1MW PEM Electrolyser	€1,000,000	Included	€10,000 + Once off €550,000 (Stack refurbishment @ 55% of Capex cost)	€1,940,000	**€3.64 per Kg_{H2}**
****1MW CPH_2 Electrolyser**	€450,000	Included	€10,000	€650,000	**€1.98 per Kg_{H2}**

*Warranty costs are not included.

**CPH_2 Electrolyser is coming out of R&D phase

Summary and Next Steps

- We believe that Floating Solar (FPV) has a role in the Renewables sector.
- We see Hydrogen having a major role in future maritime operations.
- We believe that H_2 produced by FPV close to shipping hubs will be part of the required H_2 Supply Chain.
- SolarMarine Energy Ltd. is actively looking for Maritime Industry partners to install a FPV - H_2 Production plant at a suitable location.

Floating Solar for Clean Hydrogen Production

Dr Alan Henry

Comments and Questions?