Decentralised Green Hydrogen Production

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Reader in Energy Storage and Harvesting

March 2023 to Now

A collaboration journey (Cranfield and HyWaves)

Problem

Today $\mathbf{H_2}$ is almost exclusively produced from fossil fuels

Producing 2% of the world's $\mathbf{CO_2}$ emissions

- Low cost ($1-2 /kg)
- Costly to transport H_2 ($2-5 /kg per 100km)

Green $\mathbf{H_2}$

(H_2 produced using renewables):

- High production costs ($3-8 /kg)
- Costly to transport H_2 ($2-5 /kg per 100km)

Problem - inefficient and costly Green H_2 production

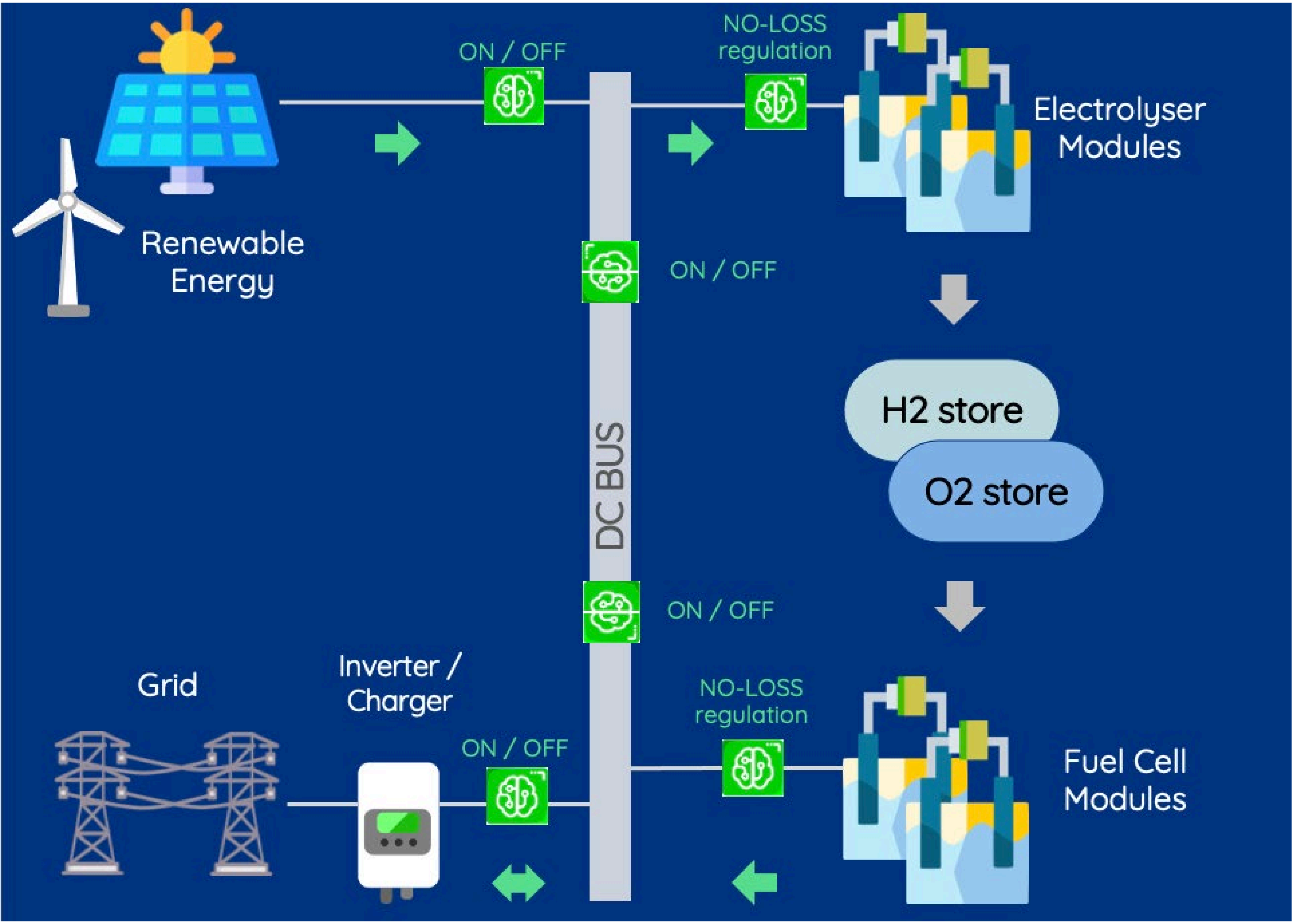
- Up to 10% in net efficiency losses between PV plant and electrolyser…

- … driven by expensive power electronics.

- Variable green energy sources reduce electrolyser lifespan and increase maintenance costs

- Expensive H_2 transportation

Decentralised (onsite) production of green hydrogen



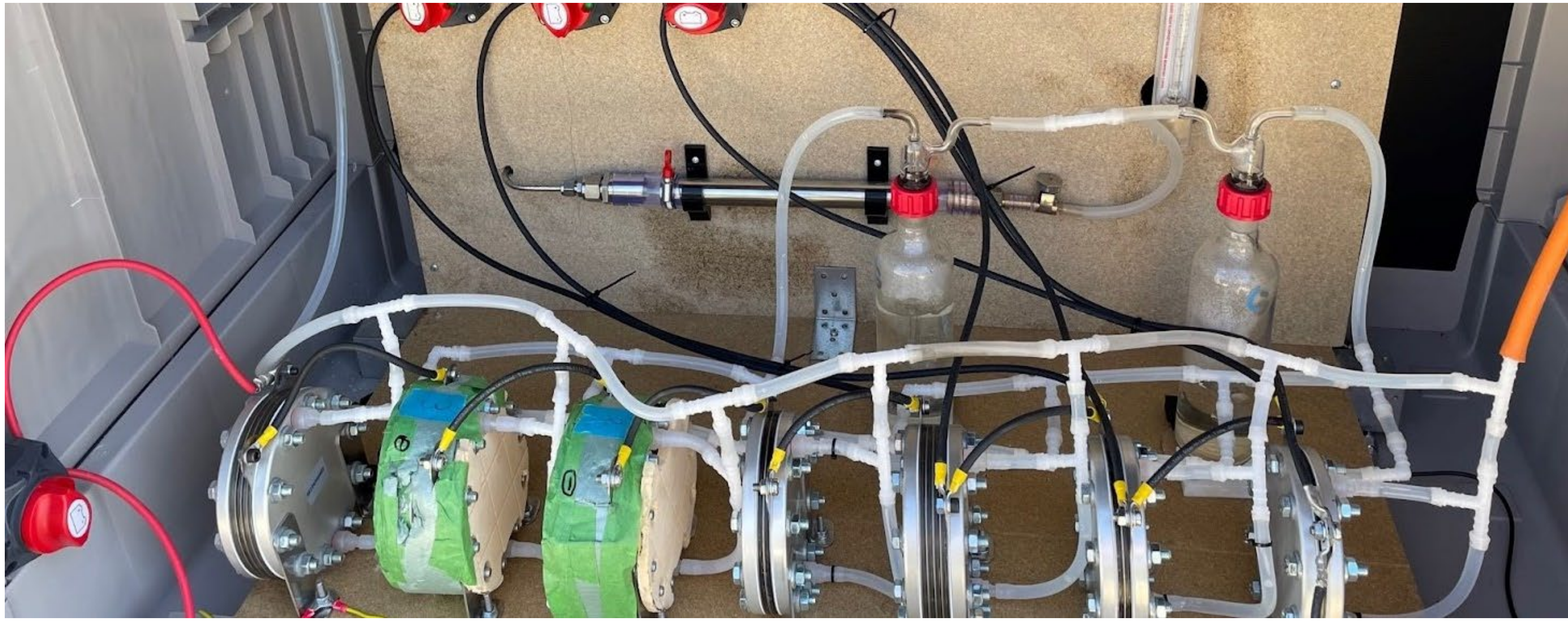
Advantages:

- Eliminate DC-AC-DC conversion loss
- Lower CAPEX on power electronics
- Lower H2 transport cost
- Increase electrolyser lifetime

Research:

- Hybridising renewable energy input (e.g., solar and wind)
- Modularised system architecture
- AI control for effective power transfer between renewable energy and electrolysis
- H2 storage

Stage of Development (currently Phase 3)



Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Validation of concept at 1kW scale	Controller for automation & software development	Scaled to commercially relevant modular 50kW (gen-2) size with automation	Add the compatibility of using a secondary green energy source, e.g. wind	System in service and demonstrated at MW+ scale

March 2023

A feasibility study to validate the concept

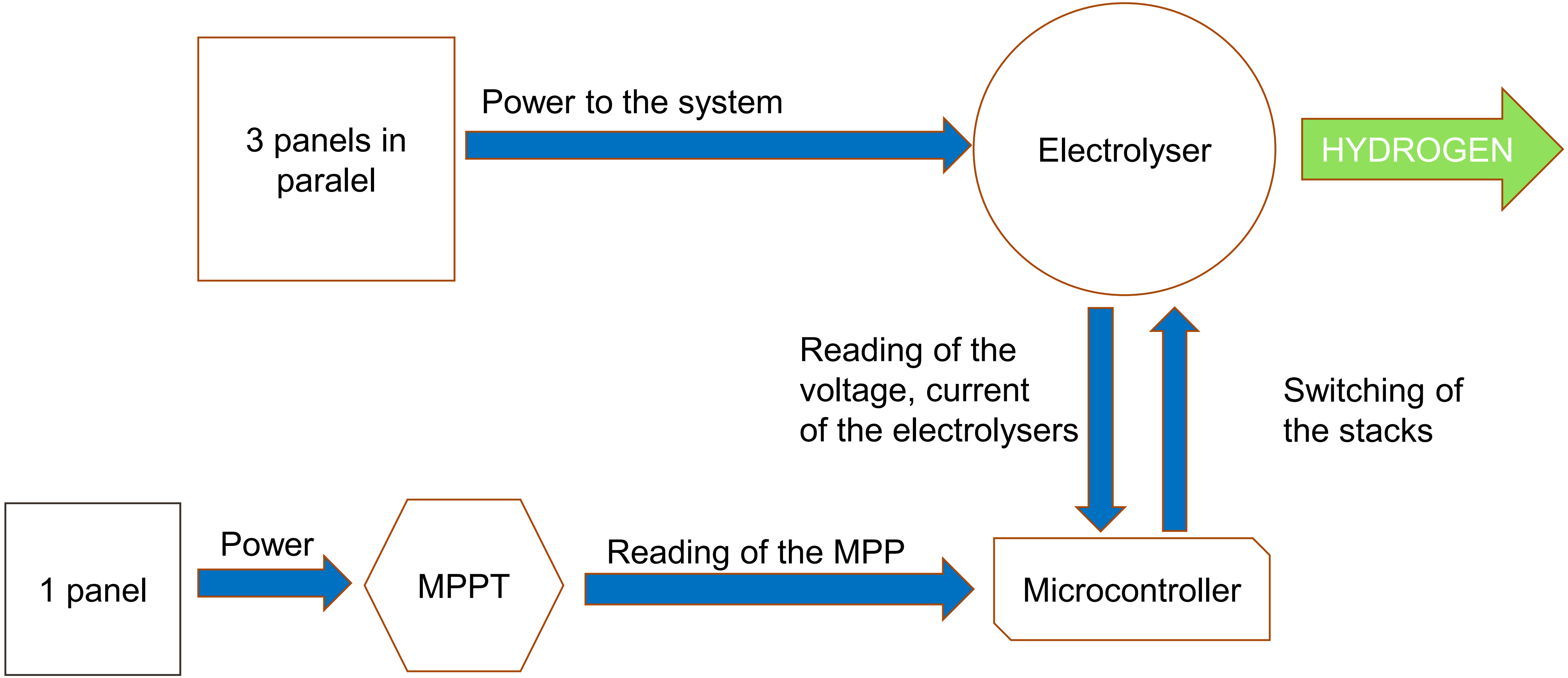
Aim and Objectives

Aim: Develop a quasi-lossless **automated** control system prototype for a **direct-coupled** 1.2 kW PEM electrolyser to **maximise** hydrogen production

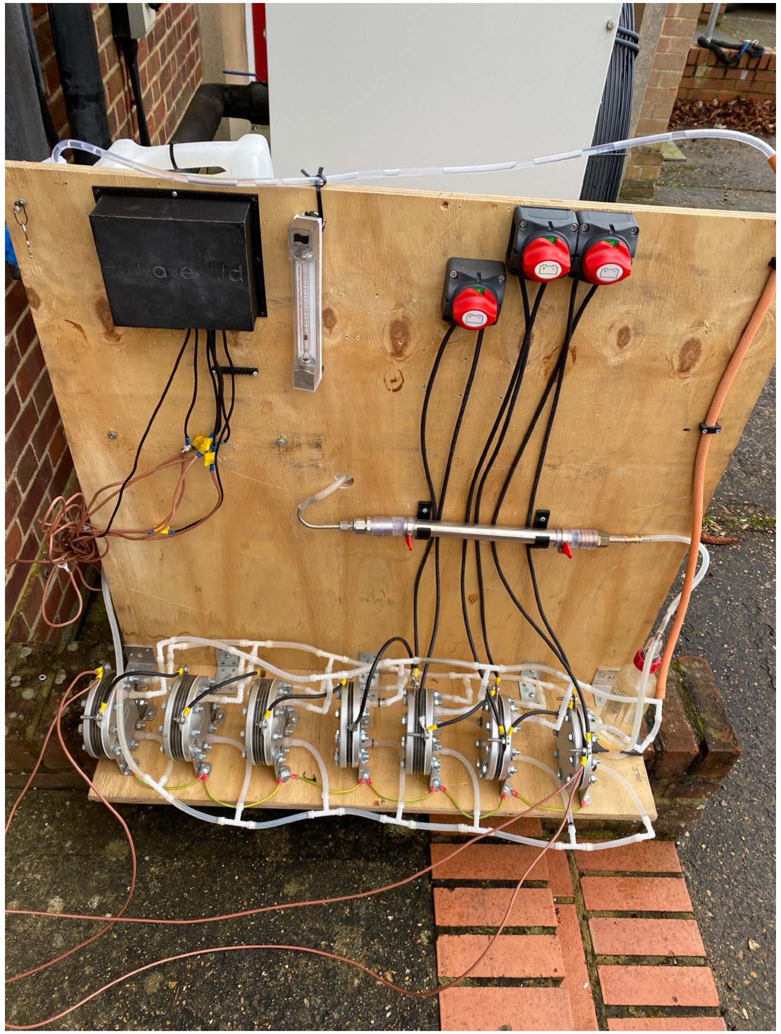
Objectives:

1. Develop an accurate model of the system, to include a theoretical response in the control.
2. Integrate in the control system an MPPT device, making the prototype work close to the MPP of the solar array.
3. Assemble a low-cost electronic circuit to automatically modify the configuration of the electrolyser.
4. Manufacture an easily scalable prototype, for subsequent scale up.
5. Demonstrate the correct performance of the prototype.
6. Feasibility of implementation of this design in a 50 kW PV plant.

Sketch of the system



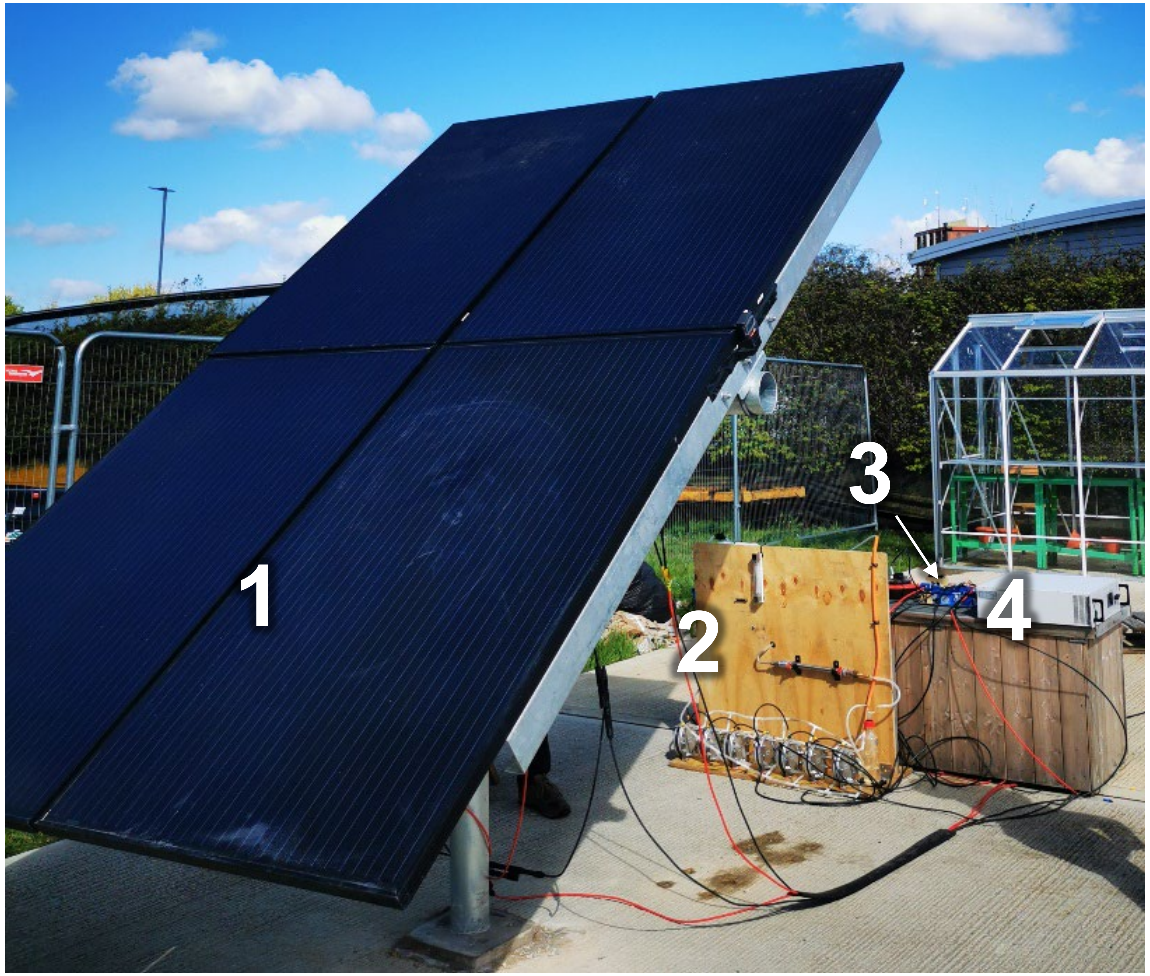
Electrolyser setup



Electrolyser's image

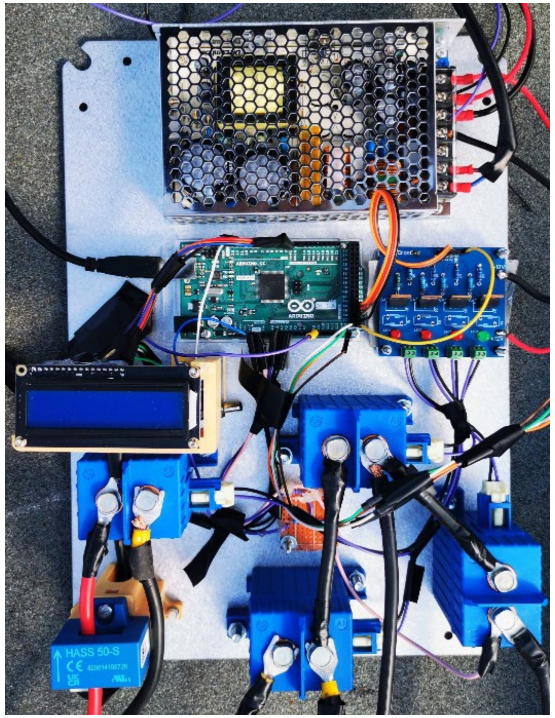
- Proton Exchange Membrane (PEM) type electrolyser
- 7 stacks of 4,2 and 1 cell
- 21 cells
  - 14 cells always operational: fixed stack
  - 7 cells for regulation divided in 3 stacks
- Manually switched
- Maximum current 40A

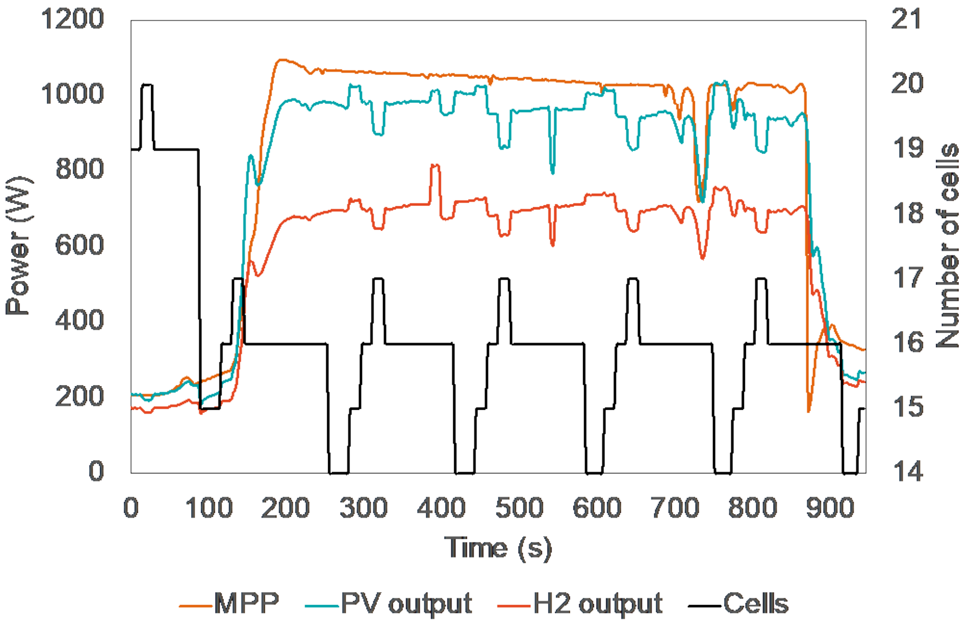
Field test: experimental set up



Testing site's equipment

1. Solar array
2. Electrolyser
3. Control system prototype
4. Electronic load





Conclusions

1. Cells **characterisation** was **not accurate** enough, introducing a significant error in cells prediction algorithm.
2. The **electronic load** introduces errors in MPPT that are **independent** of the control system
3. Electrolyser's **control system** has been successfully automated and MPP is correctly followed
4. **Direct-coupling** concept is successfully implemented with **automated maximum power** point tracking
5. Efficiency of **95%** in every loop under stable conditions

The Team

Q3 and Q4 2023 – journey continues to set plan

A project ‘Design optimisation for solar to green hydrogen plants’, funded by Innovate UK Design Foundation

The concept further optimised for large scale and explore its market potentials

Innovate UK: Design Foundations

Key Objectives:

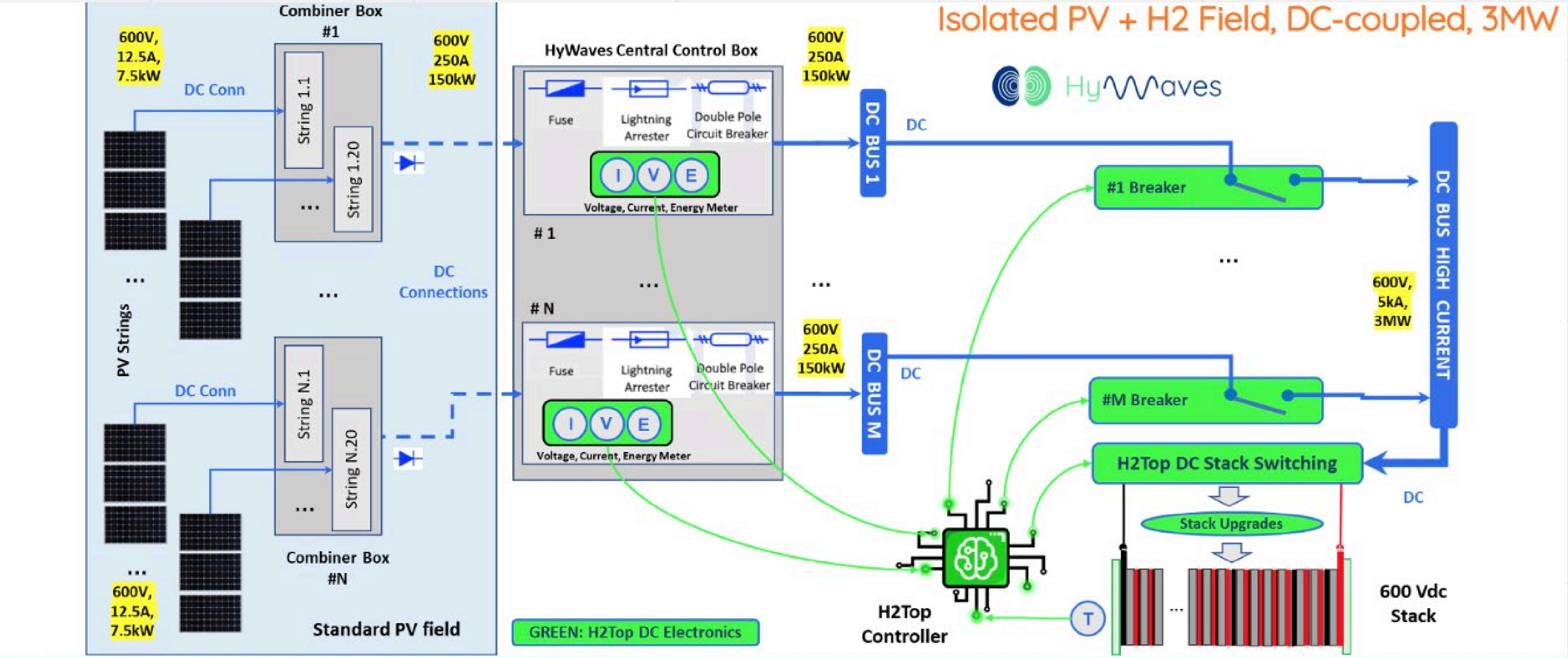
O1. To better understand the drivers of end-users to retrofit PV plants into solar-to-hydrogen plants and define the main user environmental, social, economic targets.

O2. To verify user interest and acceptance of a hybrid PV plant, based on DCH2 concept, producing both hydrogen and electricity, and including short term storage in batteries and medium-long term in hydrogen.

O3. To design an optimised H2Top system architecture that can be easily retrofitted to a wide range of commercially available electrolyser systems.

O4. To refine previous objectives, with ideas, designs and features that improve end-user evaluation in terms of viability, feasibility and desirability, as well as deliver positive impact aligned with Sustainable Development Goals 7,9,12,13.

WP2. T2.3 Analyse: Idea OO.1



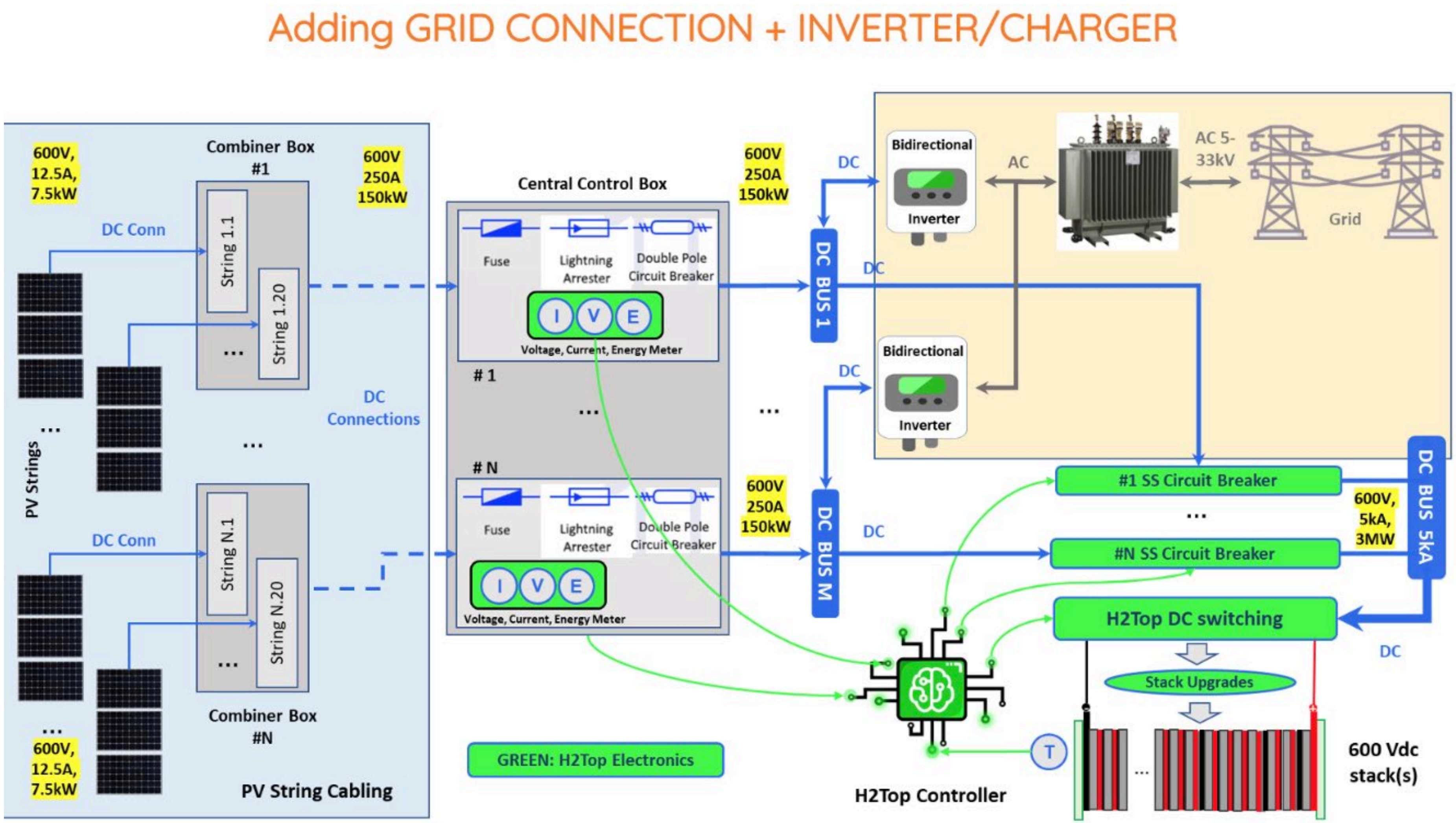
The PV plant is traditional at PV Combiner Box level.

- We add a Central Control Box with energy metering for each DC sub-field
- A set of Solid-State Circuit Breaker, designed by HyWaves, can interrupt the DC sub-field current and dissipate Surge energy
- Each PV sub-field has indicative current of 250A, voltage of 600 Vdc, power of 150kW
- H2Top switching electronics can manage a single or multiple (modular) stack

The architecture is scalable to up to 50+MW, with a “soft” limit posed by the accepted level of cabling costs and losses.

Summary: For the persona ‘the off-grid outlier’ (e.g. Ethical Power and Tower Group) we have created the idea OO1, since this cluster is looking for off-grid solar-to-H2 plant layouts that can maximise production of H2.

WP2. Idea PPAC.1



Summary: For the persona 'the PPA Champion' (e.g. Octopus Hydrogen, IB Vogt) we have created the idea PPAC.1, since this cluster is looking for hybrid solar-to-H2 plant layouts that can maximise production of electricity to export to grid and produce H2 with curtailed energy.

Summary: we have started shared the digital prototypes after ideating several green hydrogen plant layouts based on different user needs. In terms of costing, batteries doesn't seem a viable option at the moment, whilst use of bi-directional inverters should be limited to a minimum. Utilities are interested in using hydrogen as long-term storage, whilst reversible electrolyser (fuel-cell) and small battery storage can help stabilise the power grid. The preferred route-to-market for many electrolyser manufacturers and energy companies seem to be a plug & play solution.

Prototype OO.1

Prototype PPAC.1

ethical power

"Bi-directional inverters and batteries only viable in the future"

POWER to HYDROGEN

"Reversible electrolyser as fuel cell to produce electricity and stabilise hydrogen hub"

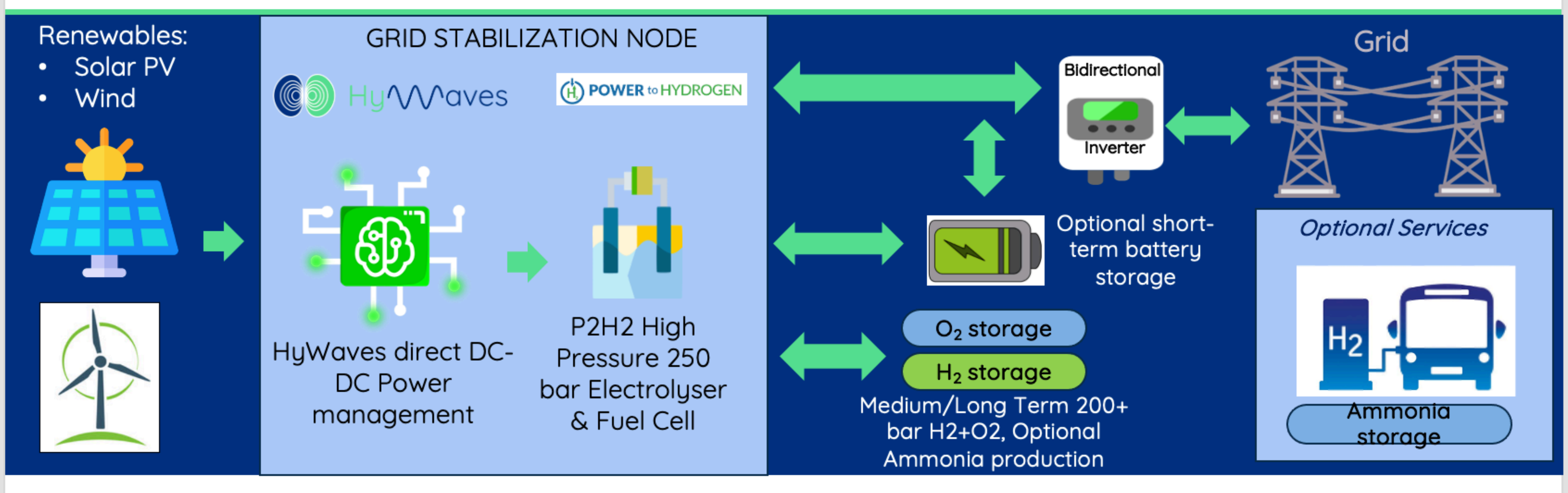
VERSO energy

"Plug & play solution to retrofit electrolyser"

ITM POWER

"Bolt-on for bespokeness, not interfering with mass production and automation"

WP3. Refine: Grid stabilisation node



- Direct DC-DC coupling: lower CAPEX, high efficiency
- P2H2 Reversible Electrolyser / Fuel Cell: half CAPEX, 250 bar pressure for low-cost local storage
- **Curtailment Mode**: Excess energy goes into H2+O2 stored locally at 200+ bar
- **Backup Mode**: inverter feeds the GRID taking energy from the battery, the Fuel Cell, the local renewable plant
- Optional Services: H2 refueling station services. Ammonia storage. Collaboration with other operators

IUK Design Foundations: Final Summary

Outcomes

- Automated electrolyser's control system successfully designed and direct coupling successfully implemented achieving **95% efficiency**

- **Optimal design with grid connection as back-up, reversible electrolyser to maximise production of hydrogen as long-term storage, ammonia or H2 refuelling, option for grid stabilisation** with no or minimum use of batteries.

- **Very competitive cost of technology**. Preferred route-to-market is **bolt-on solution to integrate in electrolyser manufacturing** process or **plug & play in green hydrogen plants**

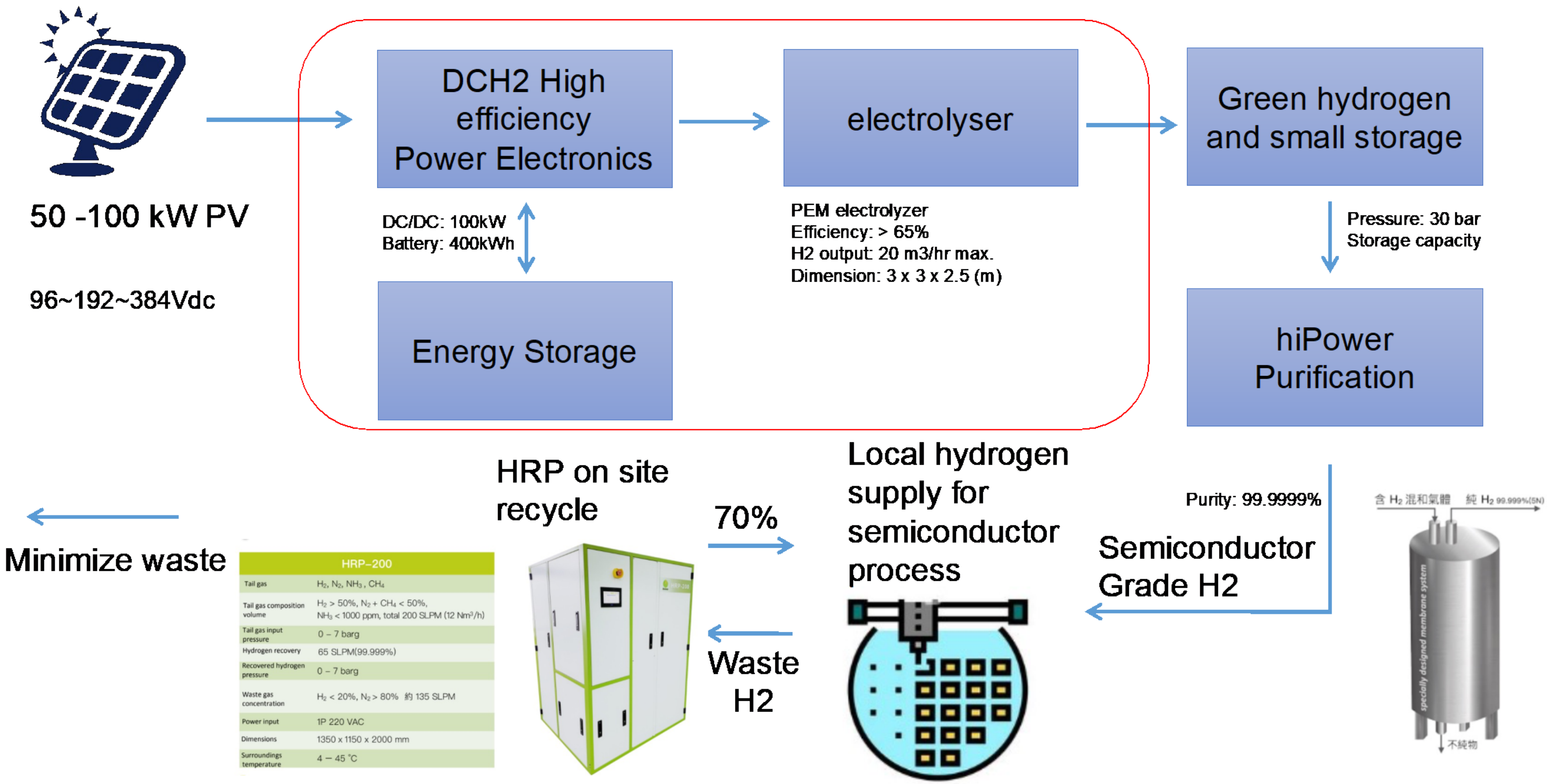
- **Very successful interaction with stakeholders** establishing the foundations for **collaboration in pilot projects** and **commercialisation routes**

Q1 2024 – further journey started for optimisation and prototyping/demonstrations

Two projects to develop the technology to higher TRLs

Project 1: HySEM – Green Hydrogen to decarbonise Semiconductor Industry (PI: Jerry Luo)

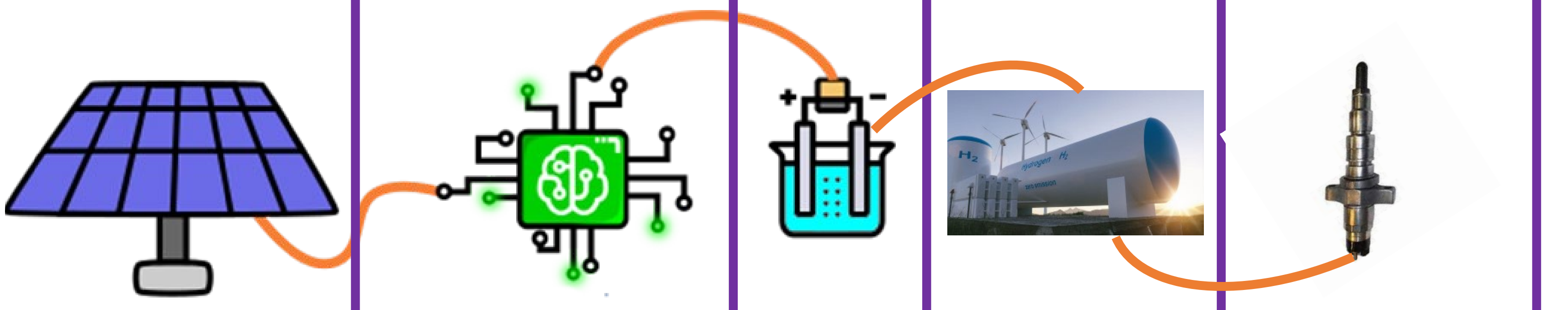
This project is to develop a modularised renewable-to-hydrogen system to produce high purity green hydrogen for use in semiconductor manufacturing process (e.g., plasma cleaning, etching, doping etc.). A typical medium-size seminconductor manufacturer consumes 400 to 500 kg of high purity hydrogen per day.



HRP–200	
Tail gas	H_2, N_2, NH_3 , CH_4
Tail gas composition volume	$H_2 > 50\%$, $N_2 + CH_4 < 50\%$, $NH_3 < 1000$ ppm, total 200 SLPM (12 Nm^3/h)
Tail gas input pressure	0 – 7 barg
Hydrogen recovery	65 SLPM(99.999%)
Recovered hydrogen pressure	0 – 7 barg
Waste gas concentration	$H_2 < 20\%$, $N_2 > 80\%$ 約 135 SLPM
Power input	1P 220 VAC
Dimensions	1350 x 1150 x 2000 mm
Surroundings temperature	4 – 45 °C

Project 2: CMDC (Clean Maritime Demonstration) (PI: Jerry Luo)

This project is to develop & run a zero-carbon, single-cylinder 50 kW Carnot engine operating on hydrogen produced and stored at optimal efficiency and minimal carbon intensity for cold ironing a vessel in harbour. Optimised lifecycle and ideal system architecture for hydrogen use in maritime.



~10kW solar PV system

DC-DC & Power electronics

~5kW Electrolyser (~1 kg/day)

2 stage H2 storage:

- Low pressure bulk
- Higher pressure MOF
- Compressor

HPDI H2 injector

25kW Hydrogen Engine with 7C rated battery

EMS – Holistic system optimisation (with Brunel)

End-user engagement – ports & port authorities

End-user engagement – ports & port authorities and perspective of the vehicle/fleet owner

Q3 and Q4 2024 – current journey

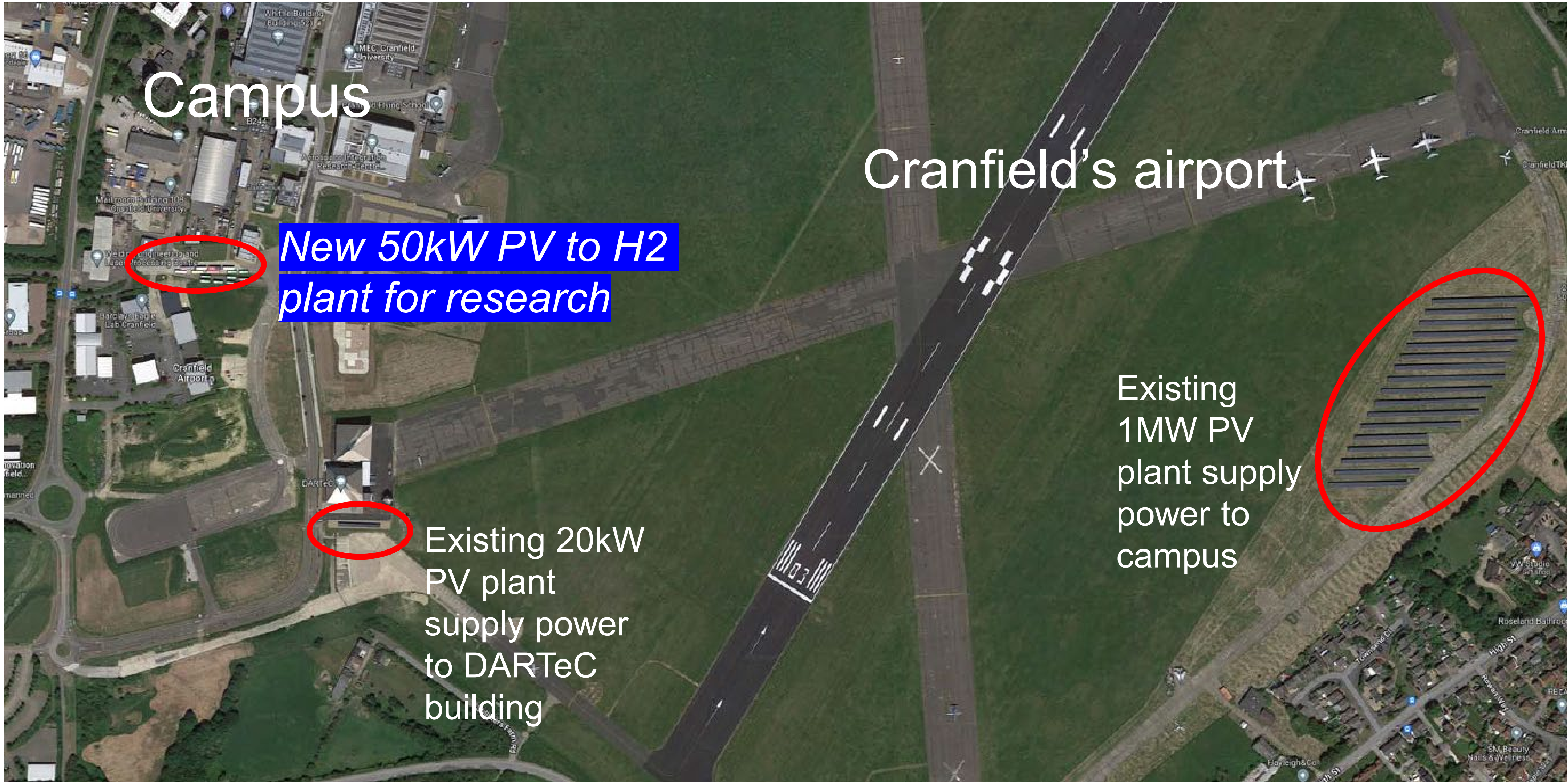
- Deployment of 50kW 5B solar panels and electrolysers (20kW PEM, 20kW alkaline)

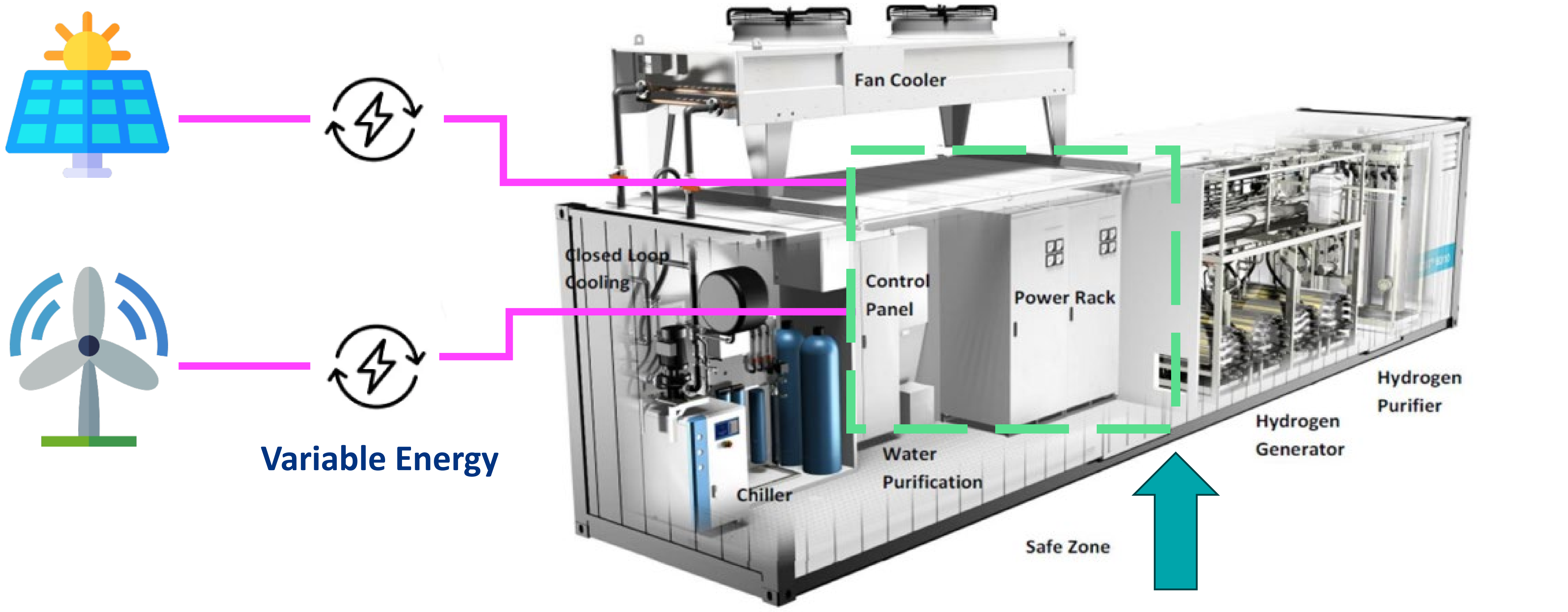
- Experimental testing and demonstrating the DCH2 control system

- Explore other research opportunities on the technology, e.g., offshore hydrogen

New 50kW PV to H2 plant for the research projects

Existing PV plants and the newPV-to-H2 plant





Power system not optimized for hydrogen production (25% of electrolyser cost)


HyWaves

Demonstration site of my research projects

Previous demonstration site showcasing the prototypes from past projects

Current demonstration site housing the 50kW solar-to-hydrogen system (in development)

New 50kW PV to H2 plant

Cranfield University

lightsource bp

bp

5B

HyWaves

hipower

Collaboration and Award

UK Universities' Award for Excellence in Hydrogen Research and Innovation

Gold winner

Cranfield University

Dr Jerry Lou and colleagues at for the direct-coupling control system for green hydrogen production (DCH2)

Producing hydrogen by electrolysis has traditionally required multiple stages of electric power conversion, resulting in significant efficiency losses and high CAPEX. The DCH2 project is developing a novel direct coupling and control power management and architecture for green hydrogen production. The technology is highly efficient, theoretically achieving 99.5% or more of the renewable energy transferred to H2 production, comparing with <90% for the current systems. The judging panel were also impressed with the team's good engagement with industry and a clear development pathway for the technology.