Development of photoelectrochemical reactors for solar hydrogen production

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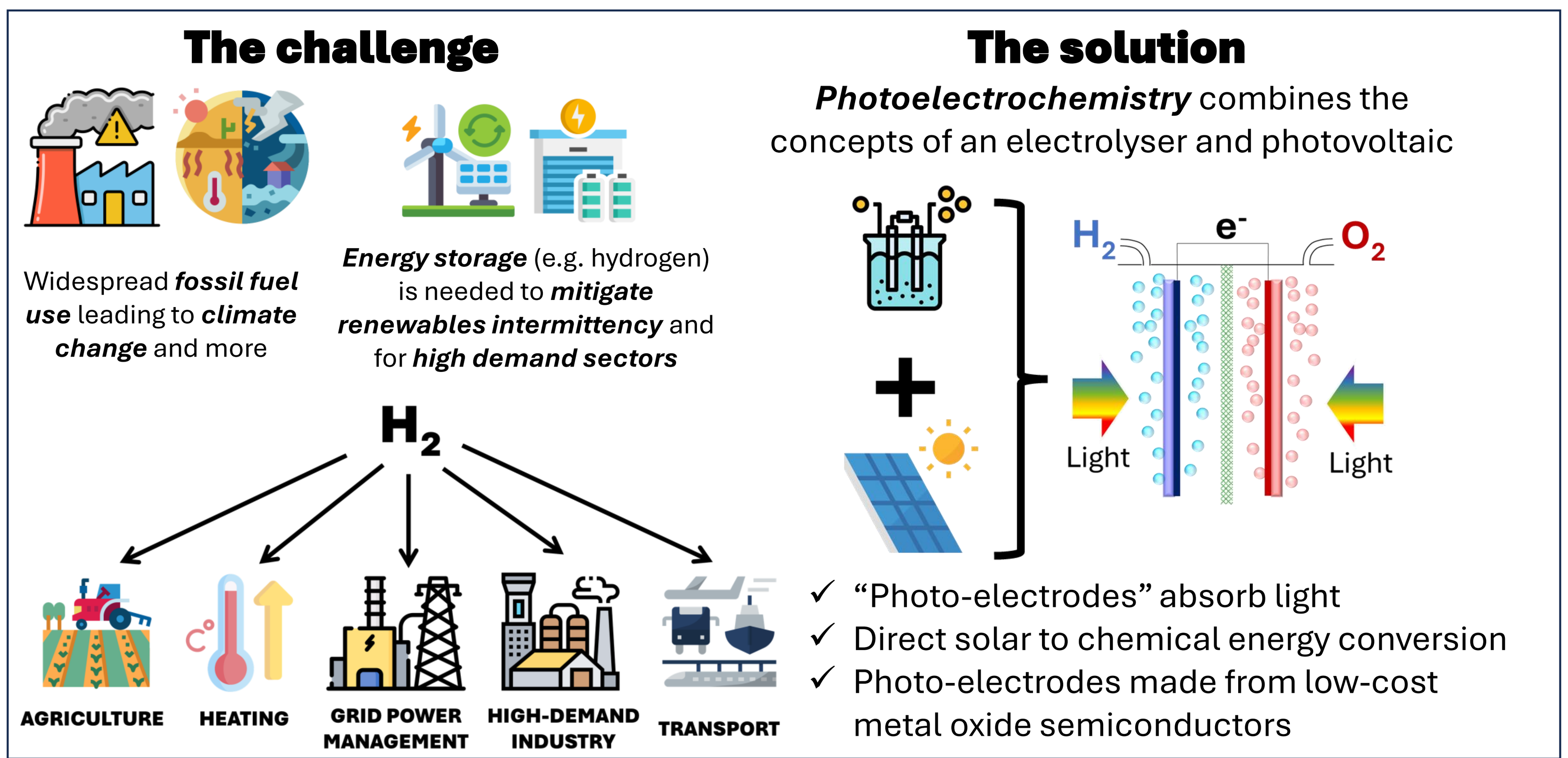
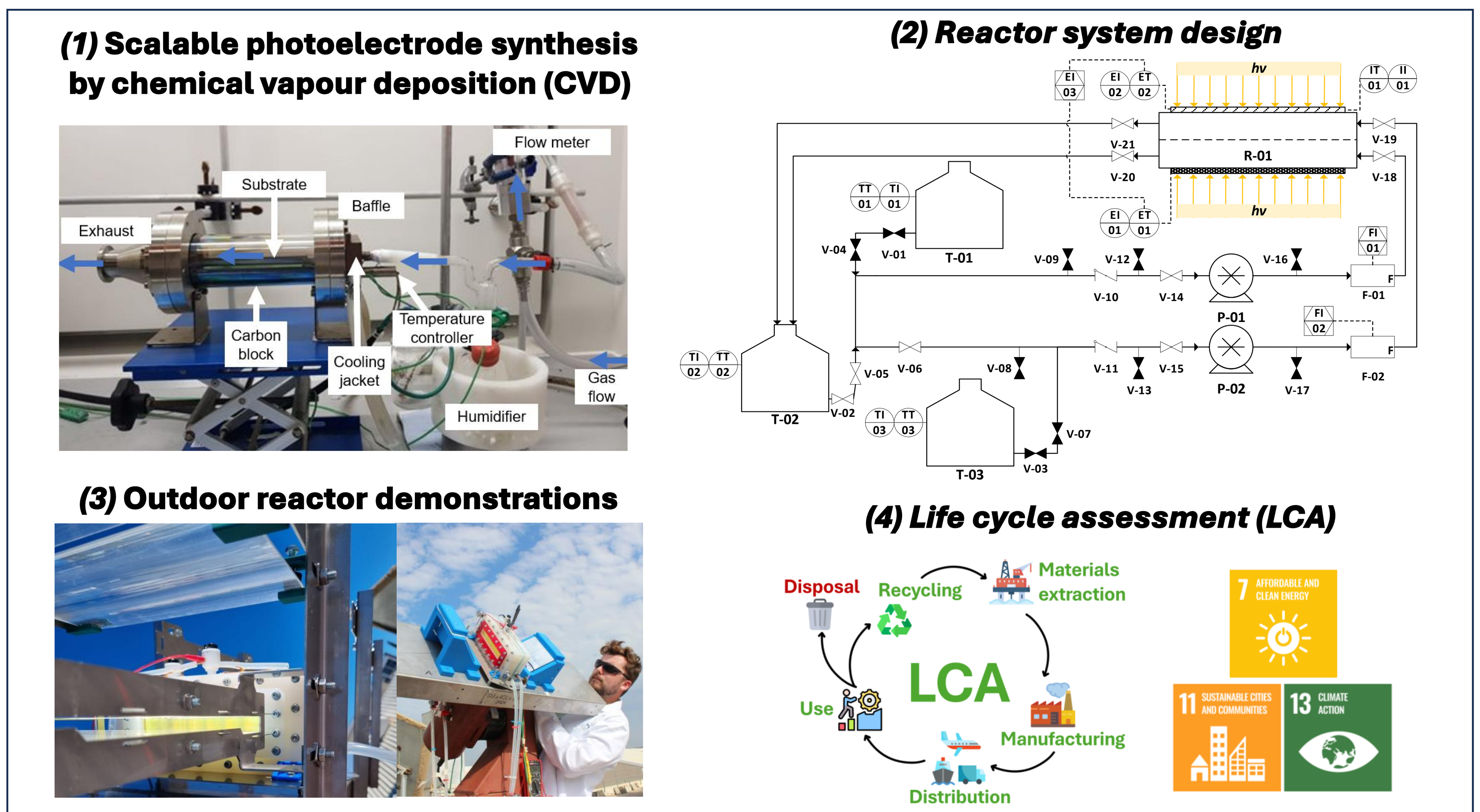
Priority topic area: Energy and Climate Action

1 – INTRODUCTION To address climate change and global warming, we must reduce reliance on fossil fuels. However, renewable technologies, such as solar power can be intermittent, which begs the question: "***how can we store solar energy in a form that can power hard to decarbonise industries like steel, shipping and heavy transport?***"

One answer is photoelectrochemistry (PEC), which can harness solar energy to directly convert water into hydrogen and oxygen. **The central aim of my research** is to develop and demonstrate reactors to take PEC from the lab (***TRL 3-4***) to the field (***TRL 5-6***).

My **key objectives** include: ***(1)*** develop stable photo-absorbing materials using scalable fabrication routes, ***(2)*** design prototype reactor systems ***(3)*** demonstrate viability in real-field conditions and ***(4)*** keep research grounded in real-world impacts via life cycle assessment (LCA).





2 – METHODOLOGY

My research follows a ***scale-up led workflow***, from ***materials fabrication*** to ***field testing*** and ***life cycle assessment***, showing how nanometre-scale morphology drives metre-scale impacts in PEC reactors. My research to date has spanned ***TRL 3*** to ***TRL 5+***, from small-scale materials design to prototype-scale outdoor field testing.

- ***Fabricating WO_3|$BiVO_4$|NiFeOOH photoelectrodes*** via up-scalable chemical vapour deposition (CVD) routes.
- Evaluating ***photoelectrode performance and stability*** under ***deployment-relevant conditions*** (e.g. different temperatures, flowrates and light intensities)
- ***Scaling-up photoelectrodes*** and integrating them with a ***prototype PEC reactor***, characterised outdoors in ***real field conditions***.
- ***Life cycle assessment*** (LCA), informing feasibility and keeping design grounded in real-world environmental impacts.

3 – RESULTS

a) SCALABLE AND DURABLE PHOTOELECTRODE MATERIALS (*SDG 7*)

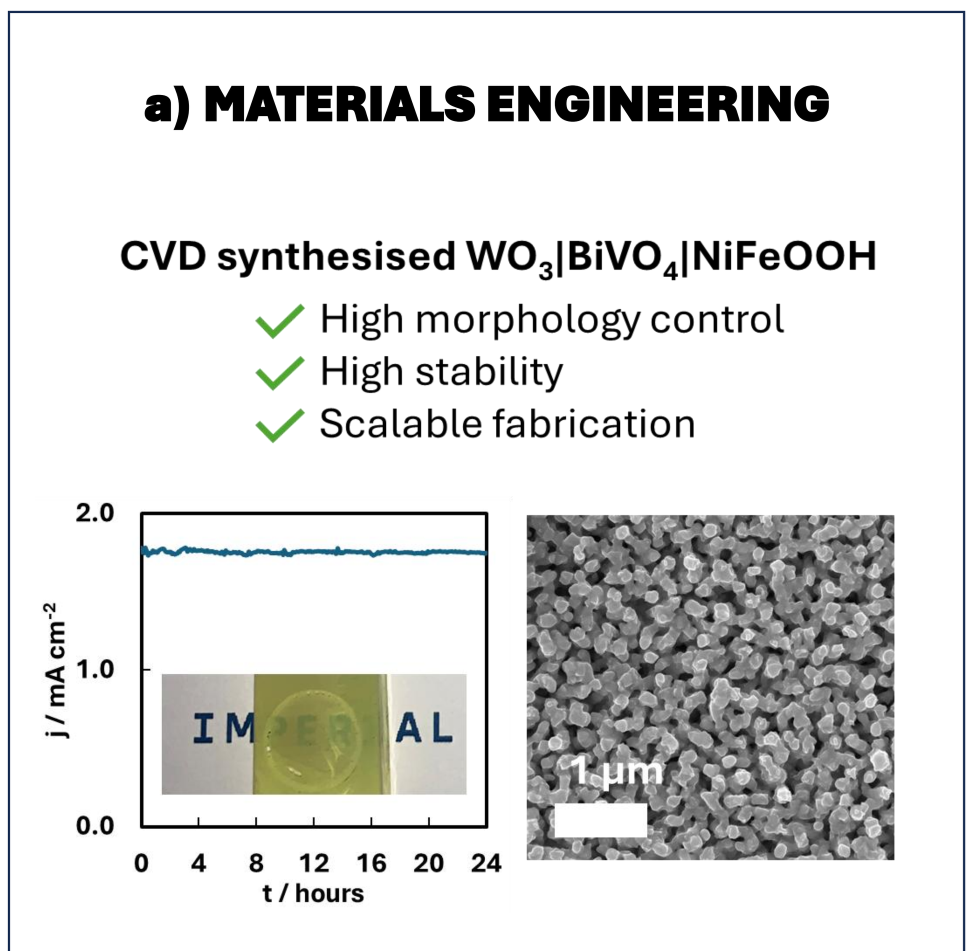
- Fabricated high-performance and scalable ***WO_3|$BiVO_4$|NiFeOOH photoelectrodes*** via CVD – an industrial glass coating technique
- Tuned morphology to achieve ***24 hours operational stability*** under electrolyte flow

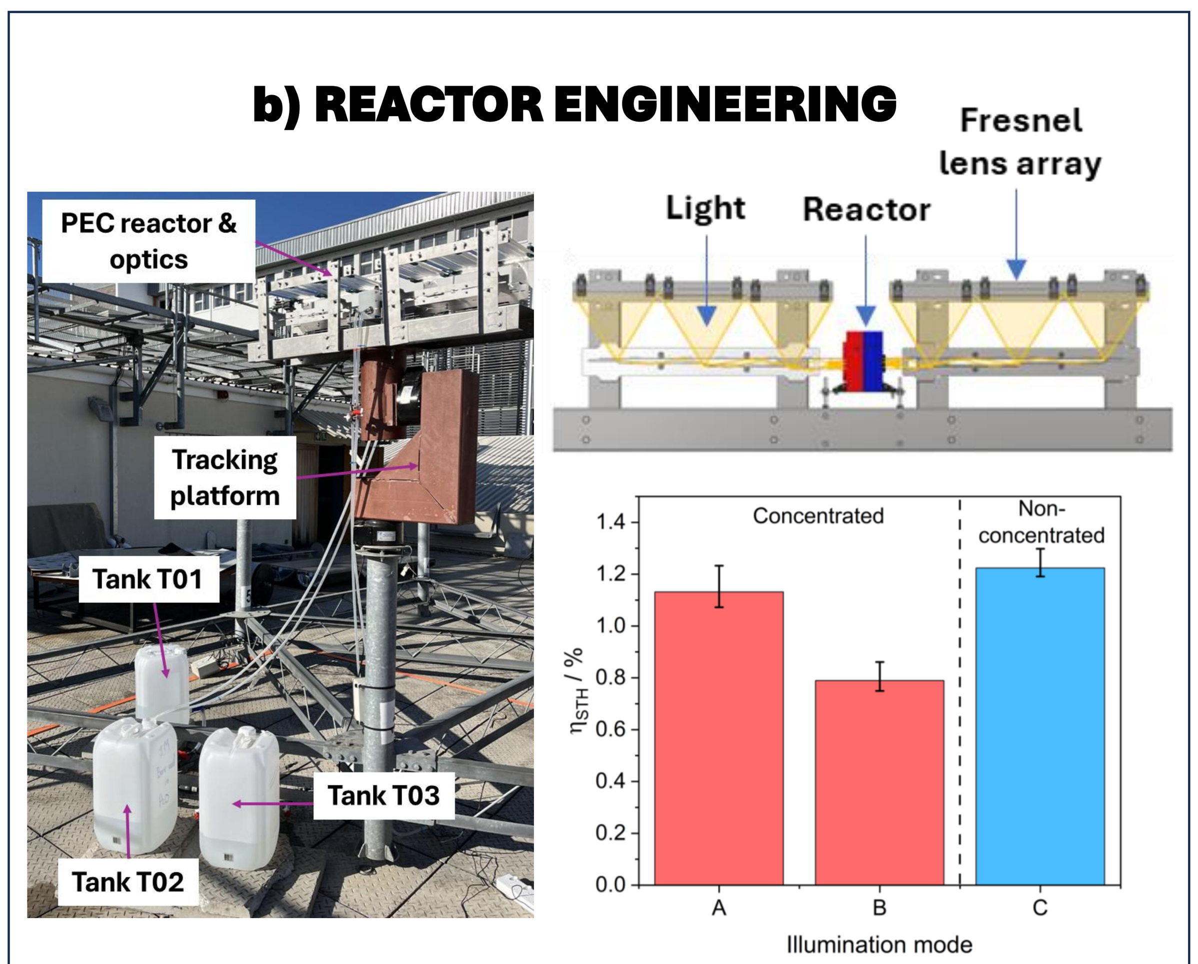
b) REACTOR DEVELOPMENT AND FIELD PERFORMANCE (SDGs 7 & 13)

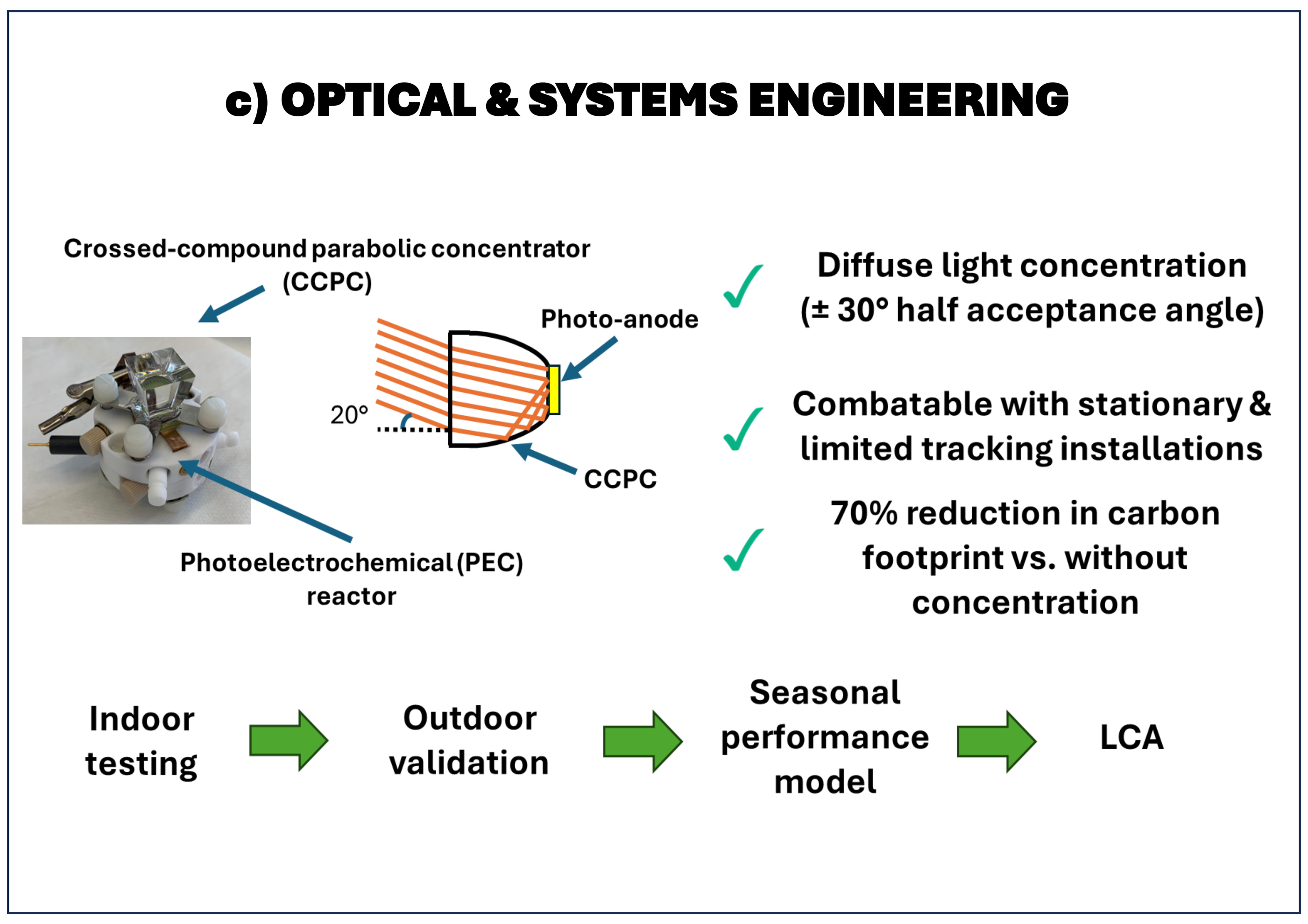
- ***Successfully scaled-up*** from 1 cm^2 laboratory samples to a 30 cm^2 prototype reactor
- Achieved ***>1% solar-to-hydrogen efficiency***, a significant benchmark for up-scaled systems operating in ***real-field conditions***
- ***Proved viability for decentralised energy storage*** through operation without an external power supply or expensive noble metal catalysts

c) REDUCING ENVIRONMENTAL IMPACTS (SDGs 7 & 13)

- Integrated ***diffuse-light concentrating optics*** with a PEC reactor which ***maintain performance in cloudy weather*** and validated outdoors
- LCA predicted a ***70% reduction in carbon footprint*** with diffuse light concentration compared to without concentration
- Removed the need for solar tracking, ***simplifying balance-of-system*** and making PEC ***easier and cheaper to deploy*** in communities.







4 – RESEARCH SIGNIFICANCE AND BENEFITS

My research focuses on ***translating small-scale laboratory successes*** in photo-electrochemistry to ***field-tested prototypes***. This directly aligns with ***SDG 7*** (Affordable & Clean Energy) and ***SDG 13*** (Climate Action) by producing clean hydrogen using only solar energy and water in a single integrated device. By using ***low-cost semiconductor materials*** rather than expensive rare metal electrodes, this technology has a clear path to cost-effective manufacturing. With potential for use in ***decentralised community energy storage***, this also aligns with ***SDG 11*** (Sustainable Cities & Communities).

5 – FUTURE WORK

✓ ***Longer term outdoor prototype demonstration*** (100 cm^2 scale) to evaluate seasonal performance (***TRL 5-6***)

✓ Use ***technoeconomic analysis*** (TEA) and ***life cycle assessment*** (LCA) to rank pilot design options and use cases (e.g. community/domestic H_2 storage)

✓ Develop and demonstrate a ***m^2 scale pilot reactor*** outdoors (***TRL 6-7***)

References & Acknowledgements

1. Moss *et al.*, *Adv. Energy Mater.*, **11** (2021). DOI: 10.1002/aenm.202003286
2. Creasey *et al.*, *J. Mater. Chem. A*, **13** (2025). DOI: 10.1039/D5TA00440C
3. Creasey *et al.*, Research Square (2025). DOI: 10.21203/rs.3.rs-7963830/v1 (Preprint)
4. Creasey *et al.*, ChemRxiv (2026). DOI: 10.26434/chemrxiv.15000253/v1 (Preprint)

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