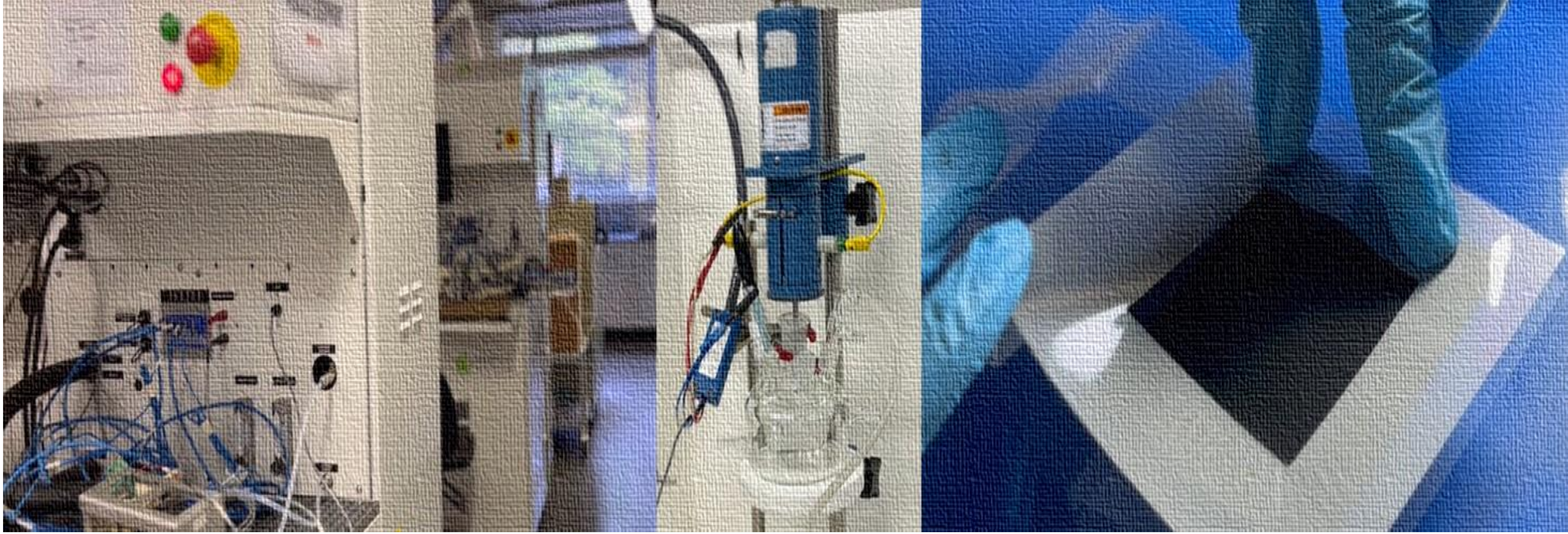


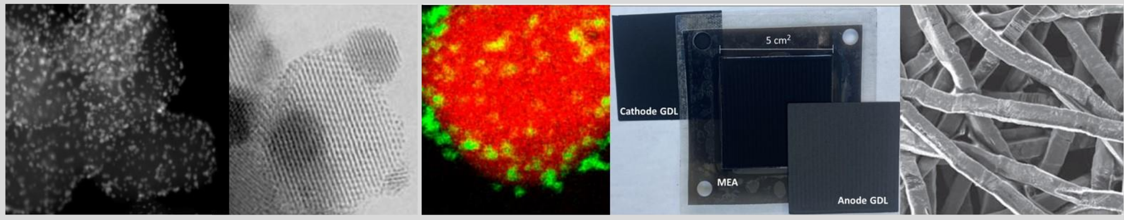
Advanced Electrocatalysis for Green Hydrogen Production

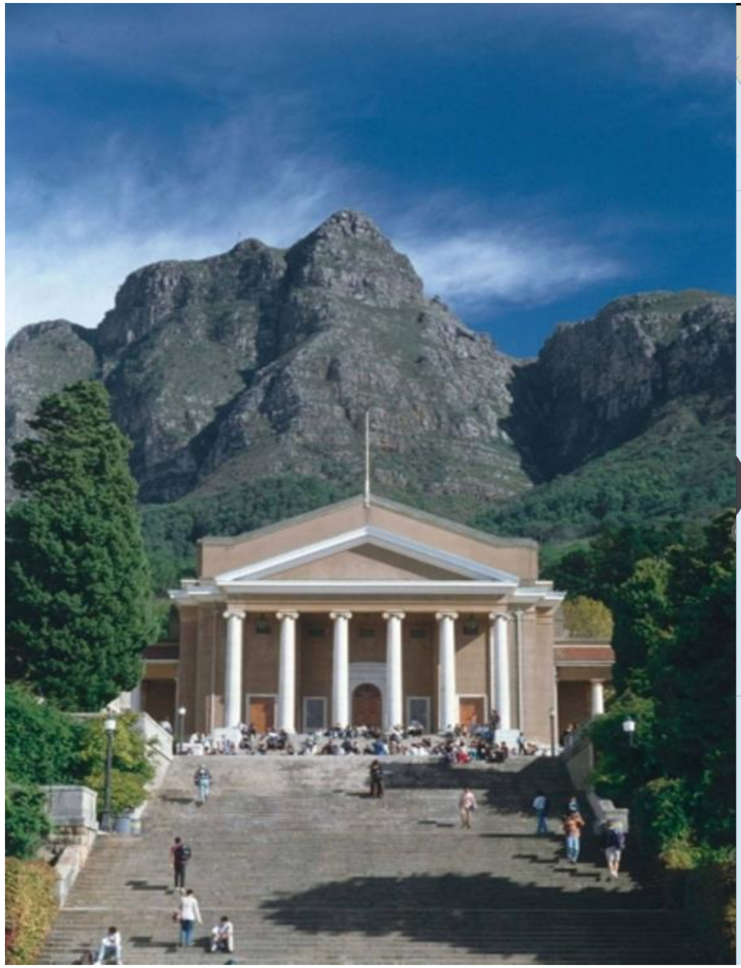
Ziba S.H.S. Rajan, Genevieve C. Moss, Bamato J. Itota, Darija Susac, and Rhiyaad Mohamed

April 7th, 2025

HySA Catalysis
University of Cape Town (UCT)
South Africa

https://ebe.uct.ac.za/catalysis-institute



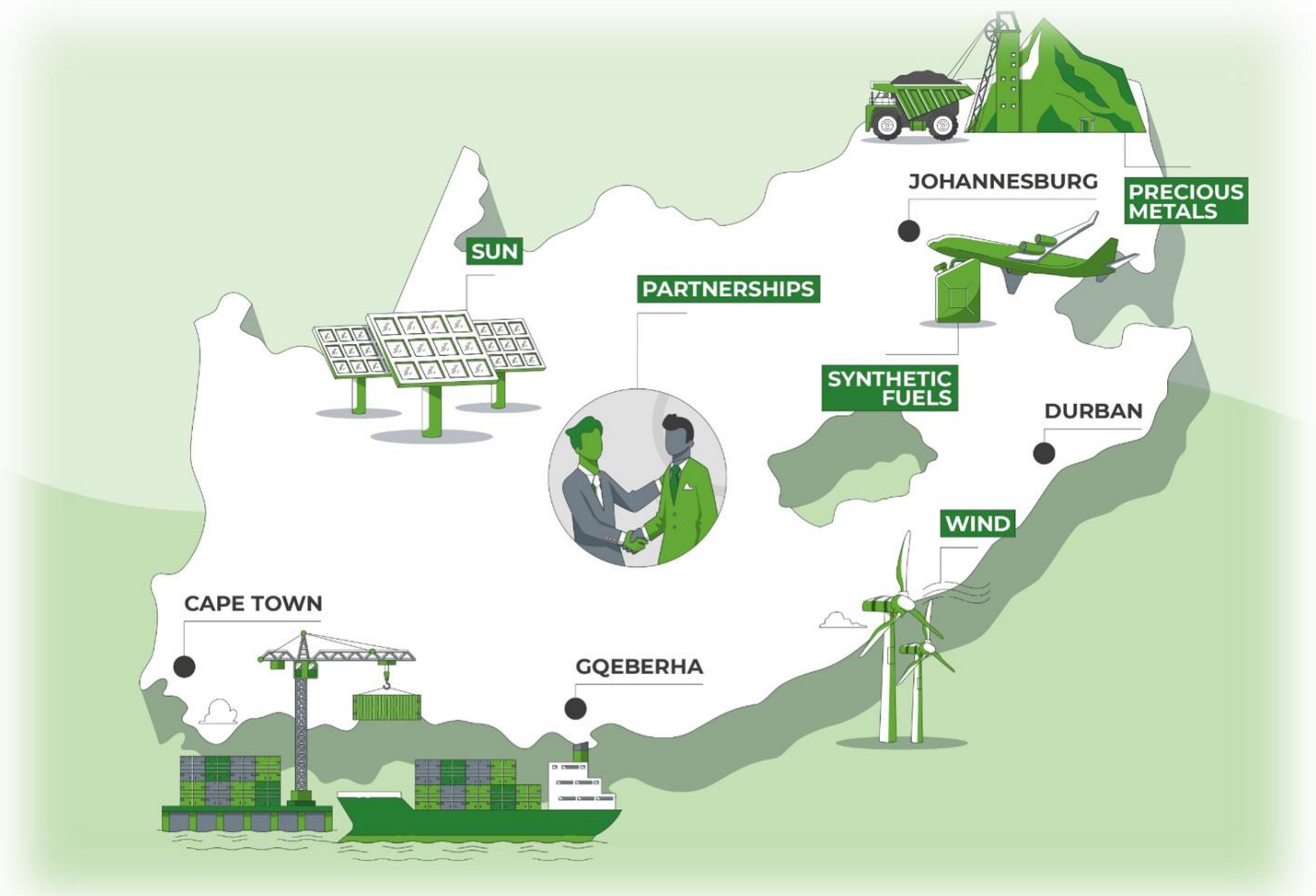


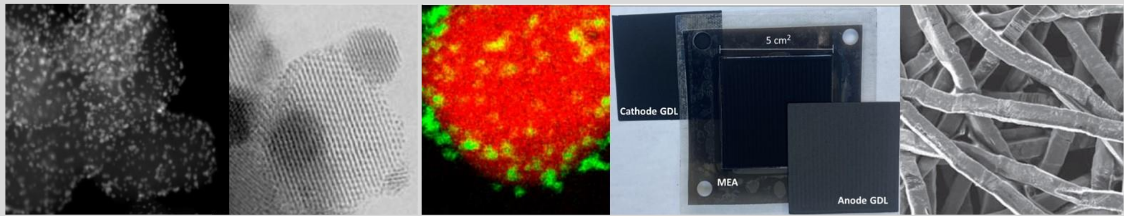
catalysis institute

HySA Catalysis Hydrogen South Africa

Centre of Competence
Co-hosted by UCT and Mintek

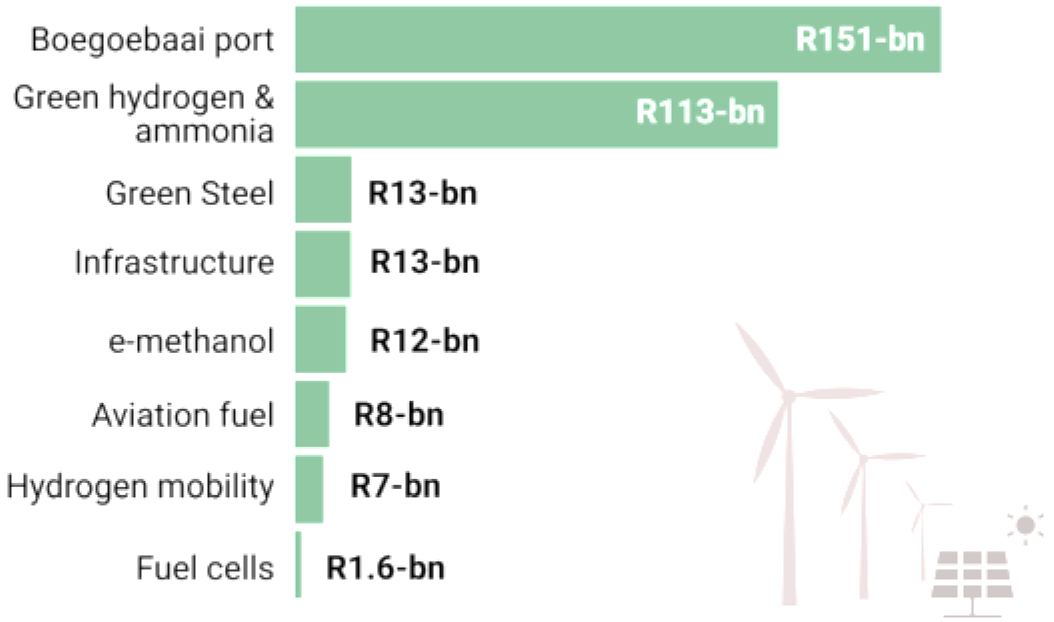
The Big Picture – SA's Potential for Hydrogen





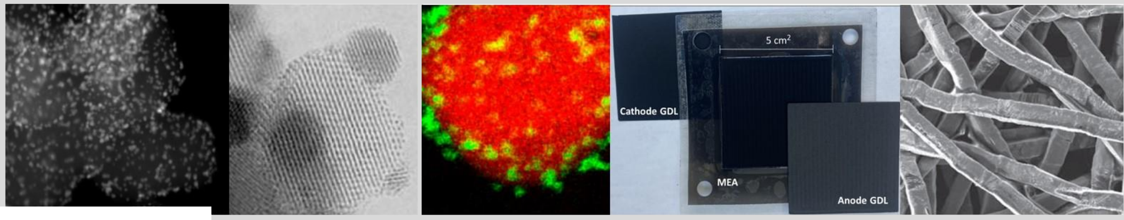
SA's green hydrogen plan

An estimated R319bn is needed to develop the sector, which includes a port and 7 hydrogen projects

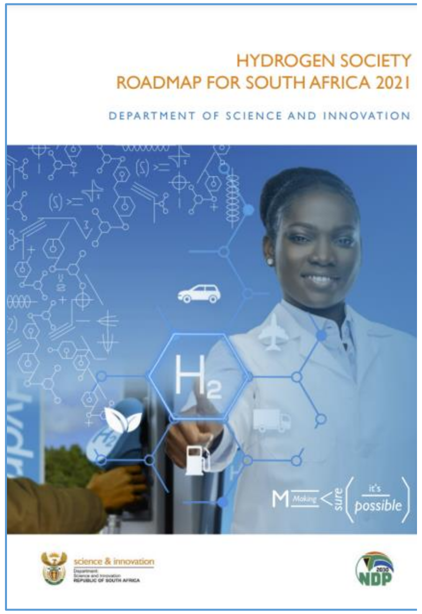


Source: Just Energy Transition Investment Plan 2023-2027

The Hydrogen Society Road Map



science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA



https://www.dst.gov.z/images/South_Africa_Hydrogen_Society_RoadmapV1.pdf

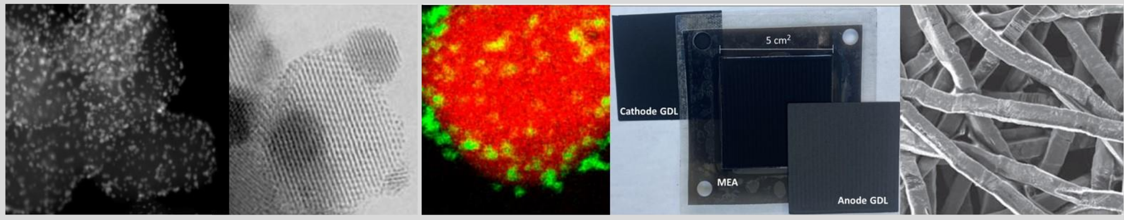
HySA Catalysis Mandate (R&TD):

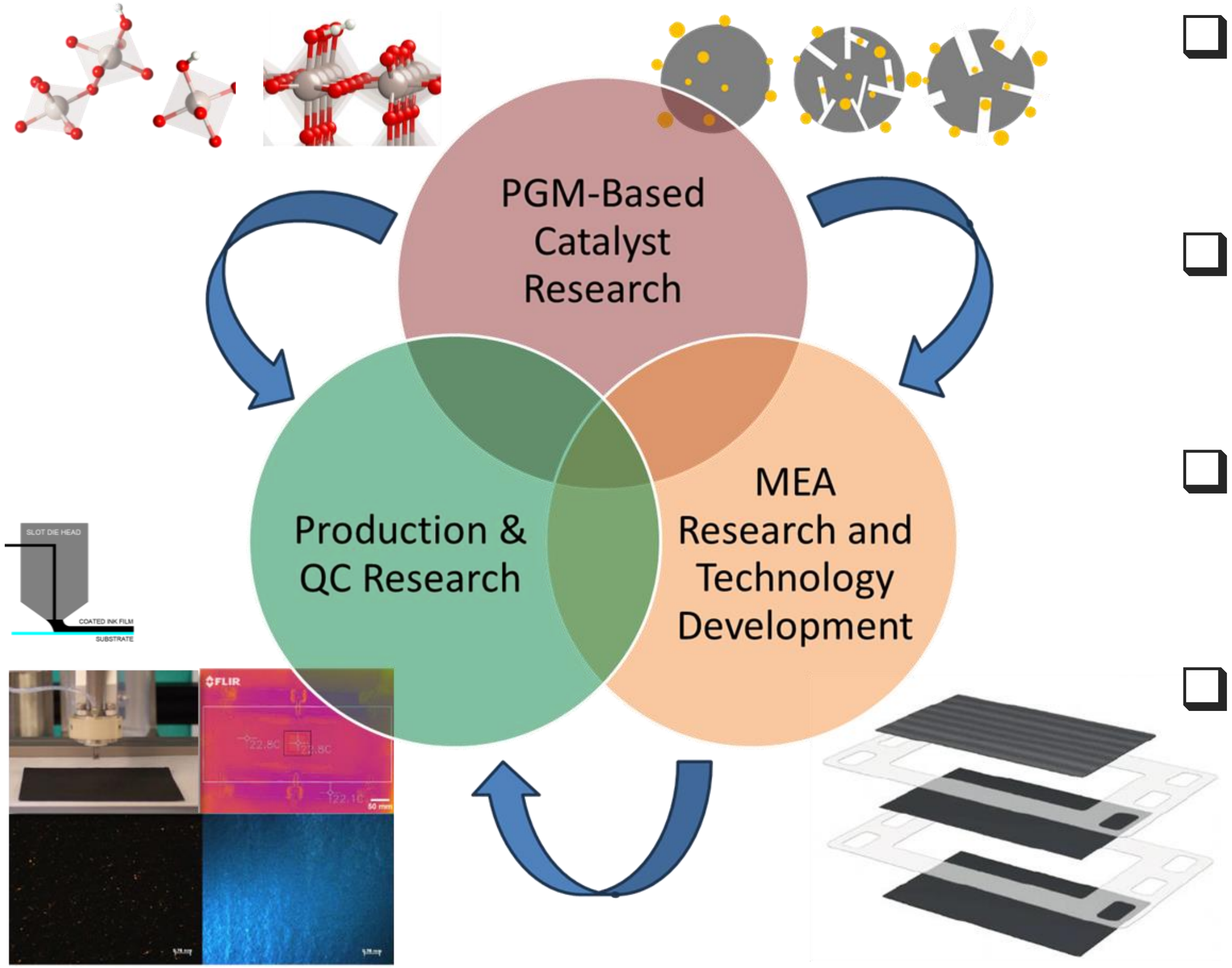
Components: catalysts and MEAs for PEM fuel cells and electrolysers

Electrolysers: H_2 generation

Fuel cells: H_2 utilisation for electricity production

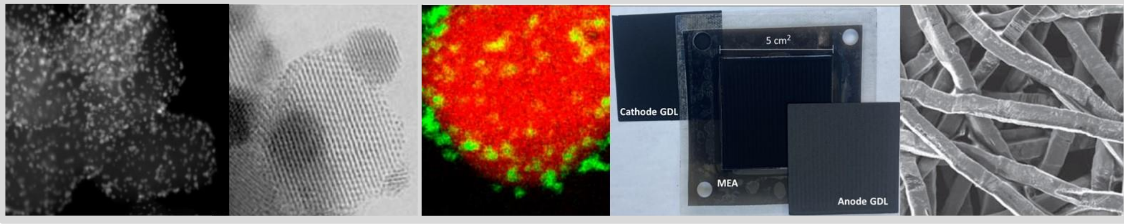
Pem Fuel Cell And Electrolyser Materials: From Catalysts to MEAs (TRL 1 to 6)





- ❑ Optimization of formulations & process technologies
- ❑ Advanced characterisation techniques – *ex-situ* & *in-situ* testing
- ❑ Accelerated stress testing (AST) & durability testing
- ❑ Design lever & transfer function development through structure-property-performance (SPP) correlations

The Research Focus: Electrocatalysis for Energy Applications



- ❑ Water electrolysis to make **green hydrogen**
- ❑ Carbon dioxide reduction to make **valuable chemicals**
- ❑ Hydrogen fuel cells to **generate electricity**

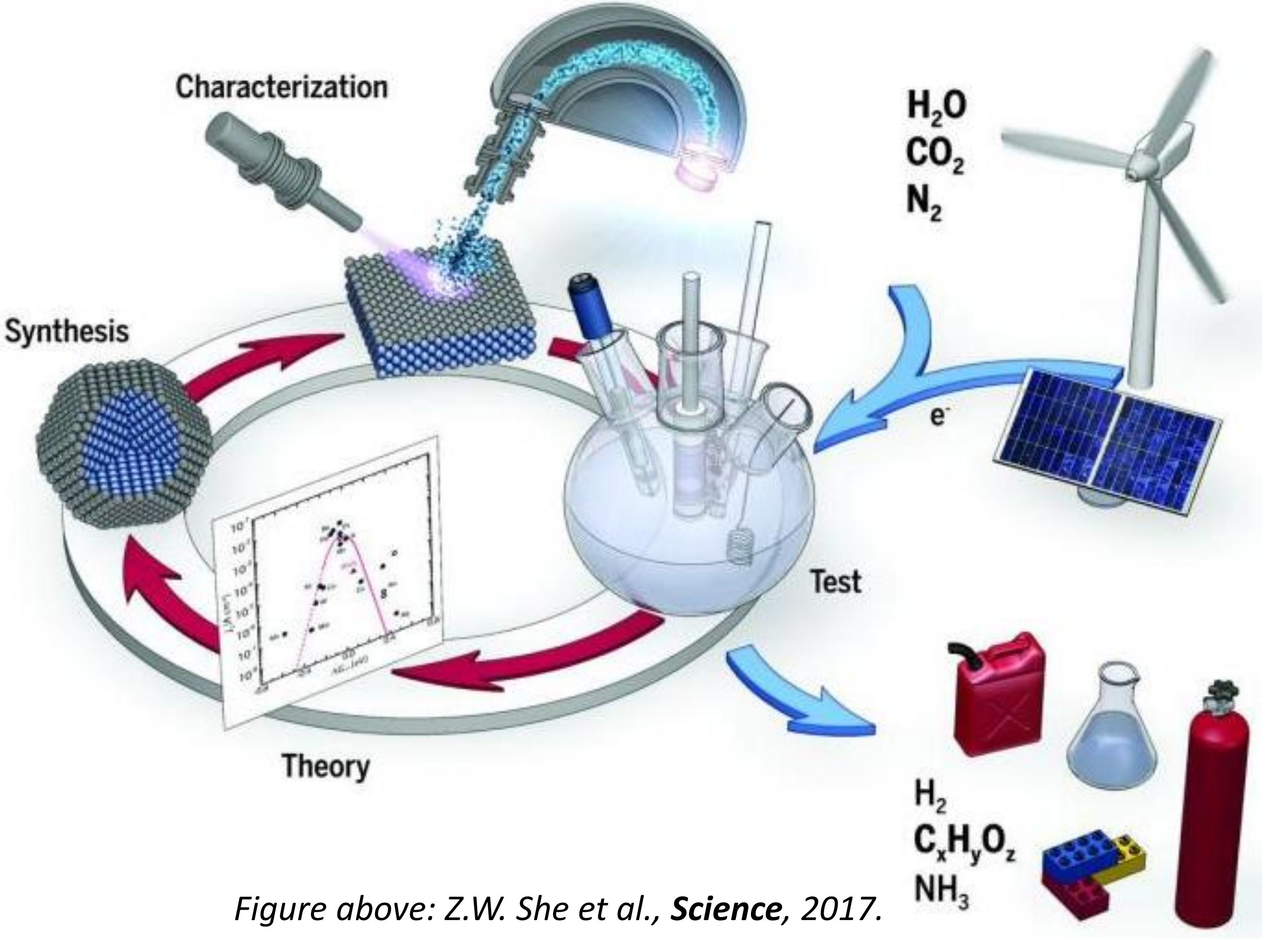
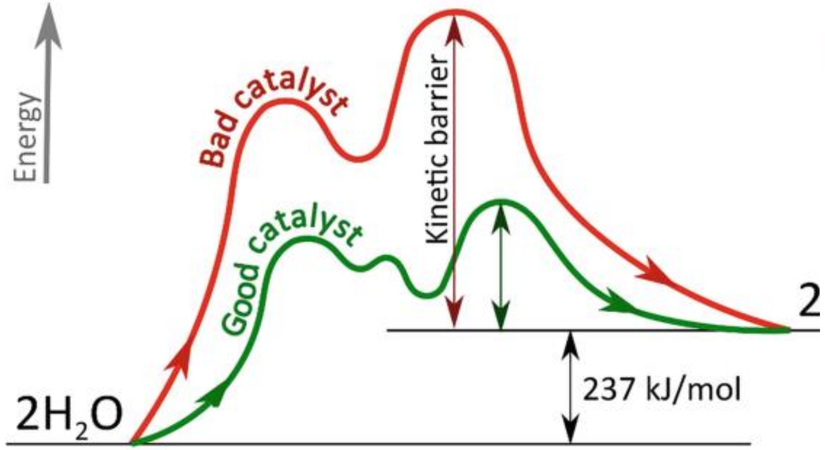
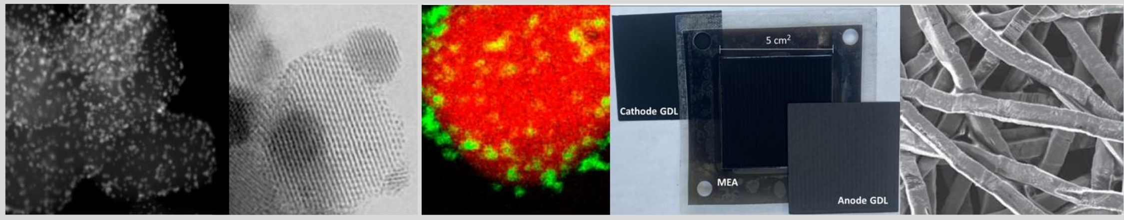


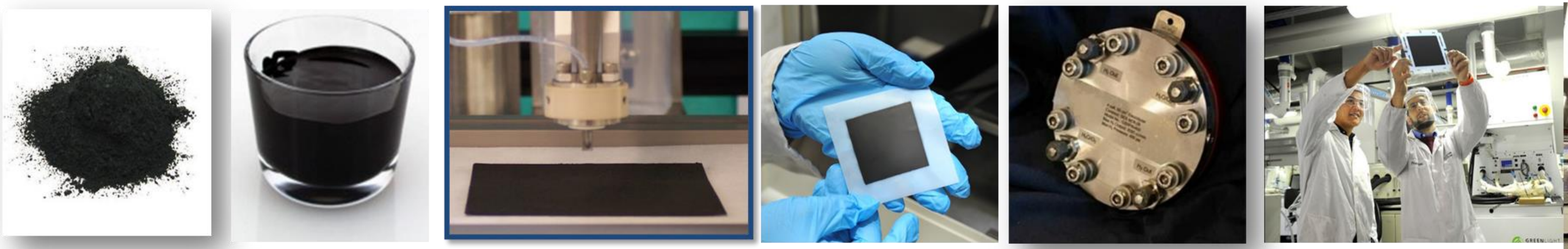
Figure above: Z.W. She et al., ***Science****, 2017.*



Pem Fuel Cell and Electrolyser Materials: From Catalyst Materials to MEAs (TRLs 1 to 6)



To impact the **global PEM fuel cell and electrolyser market** with **locally developed** catalyst and membrane electrode assembly technologies, advancing the **beneficiation of South Africa's PGMs**

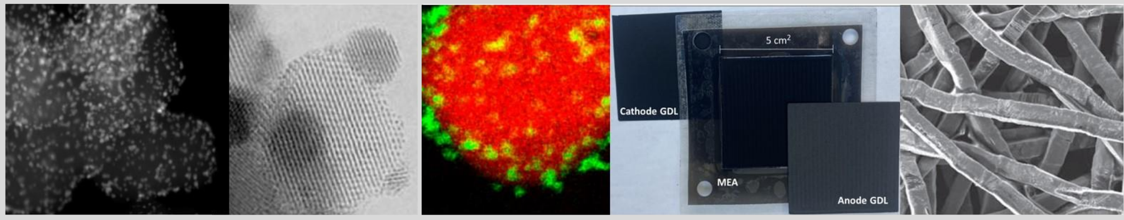


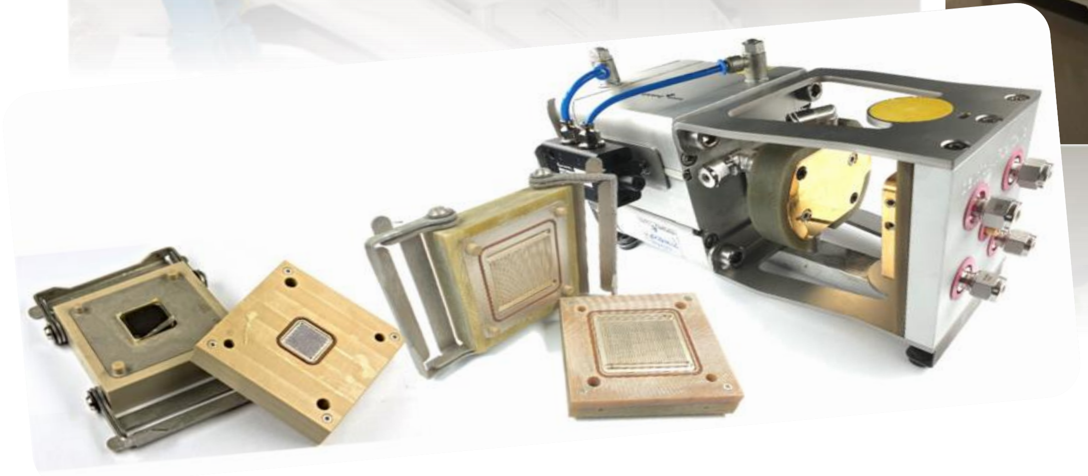
Catalyst synthesis and characterization → Ink Formulations → MEA fabrication → Testing and validation

Knowledge Development → Technology Development → Product Development

TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9

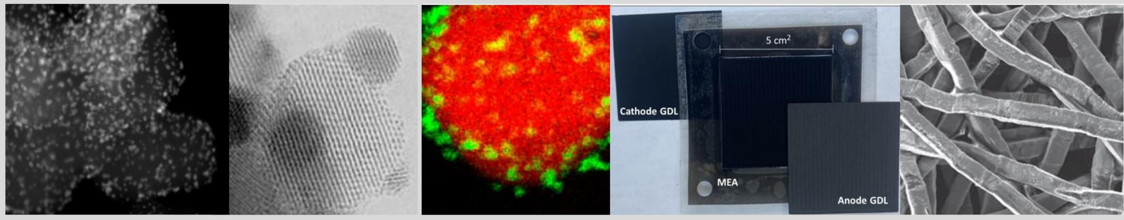
Current Capabilities



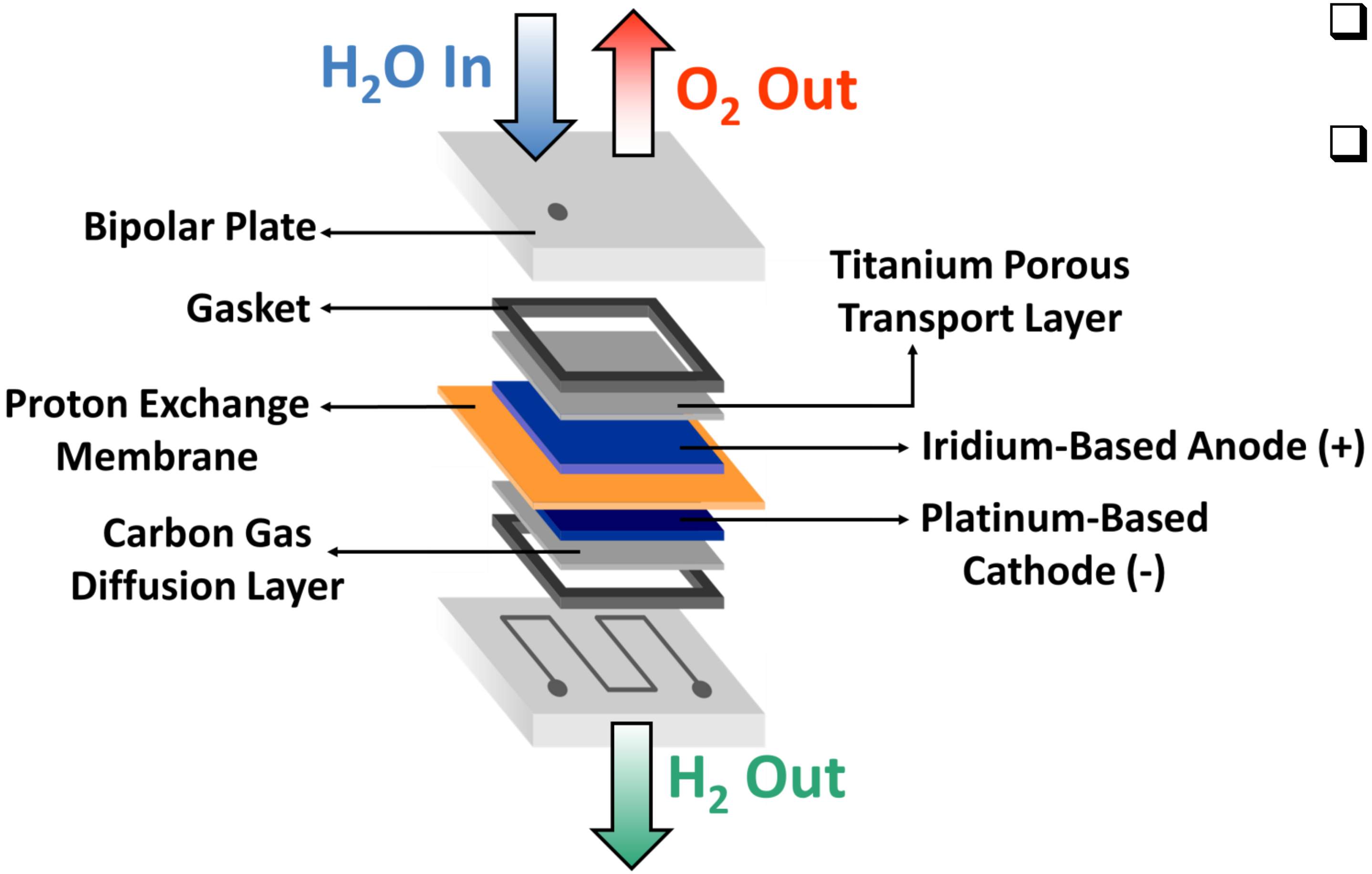


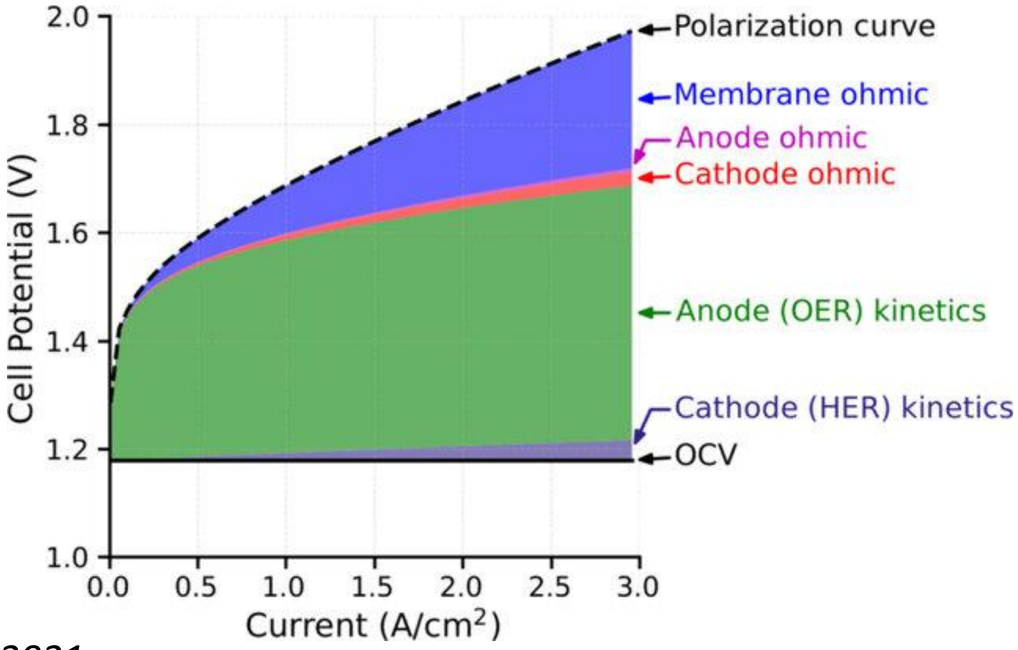
- ❑ Fully equipped for **material synthesis**, characterisation, and screening up to the **25-gram batch size**
- ❑ Electrode **fabrication**, characterisation, and **testing** capabilities

PEM Water Electrolysis



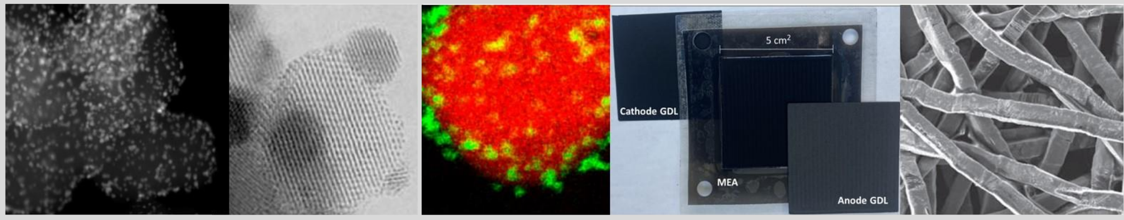
- Iridium is required to catalyse the **sluggish anodic oxygen evolution reaction** *(OER)*
- Platinum is required to catalyse **the cathodic hydrogen evolution reaction** *(HER)*

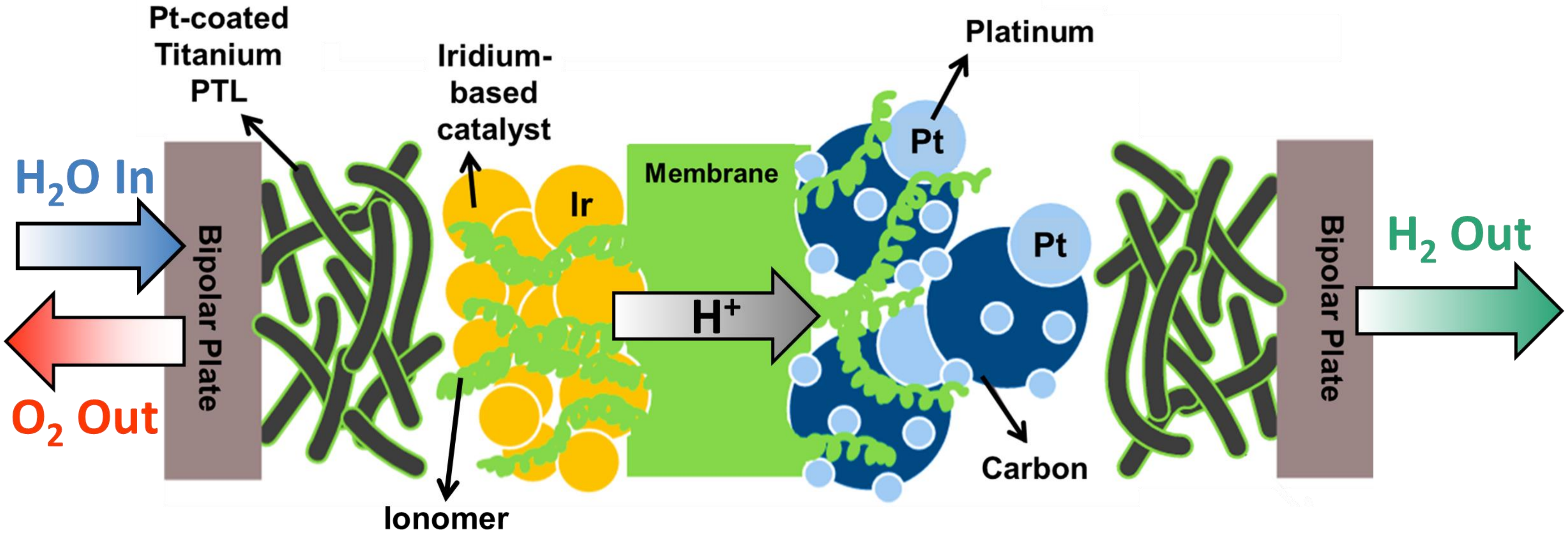




*Loss Breakdown Figure: M.R. Gerhardt et al., **Journal of the Electrochemical Society**, 2021.*

The Membrane Electrode Assembly

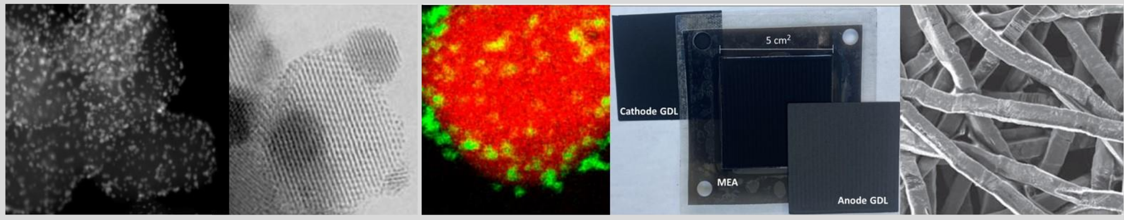


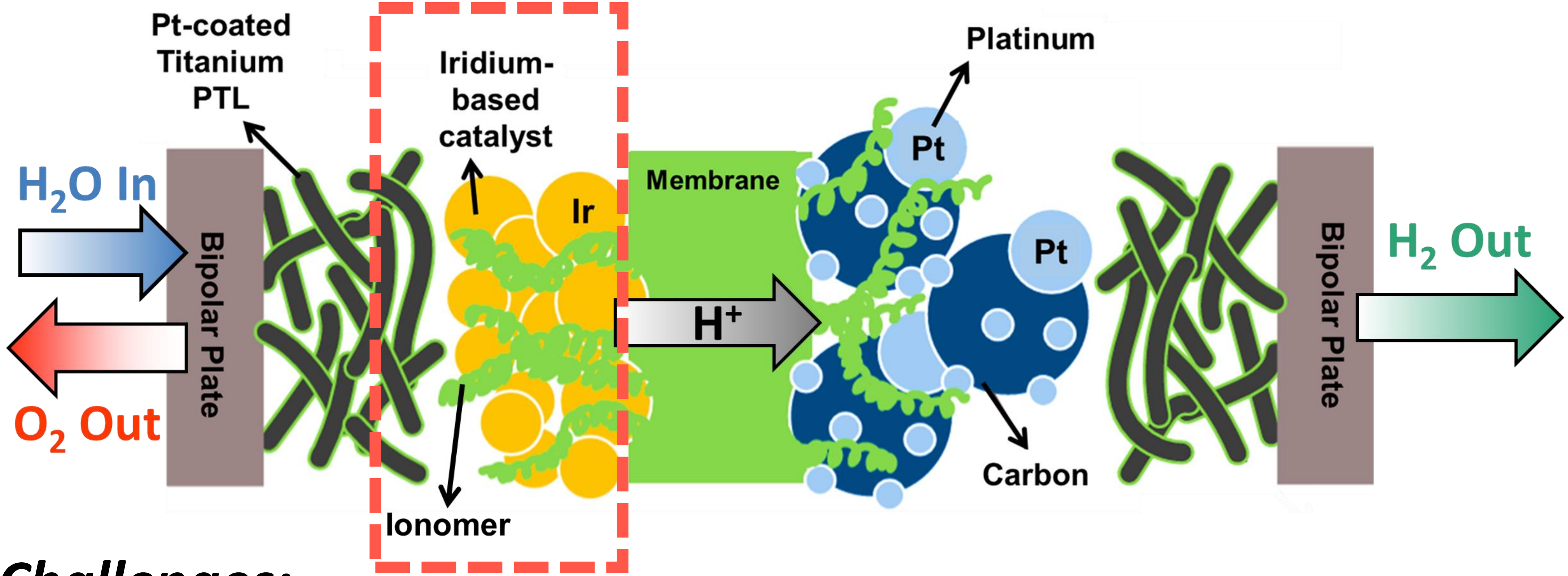


Key Challenges:

- ❑ Electrical conductivity of the components (CL/PTL)
- ❑ H^+ transport resistance
- ❑ Hydrogen gas crossover
- ❑ Electrochemical material degradation
- ❑ Anodic catalyst layer PGM content
- ❑ Anodic catalyst layer porosity

The Membrane Electrode Assembly





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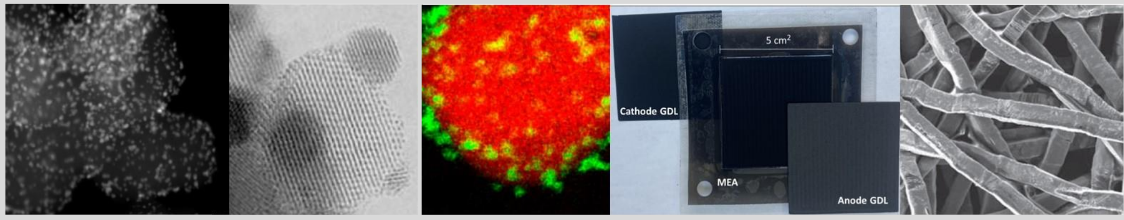
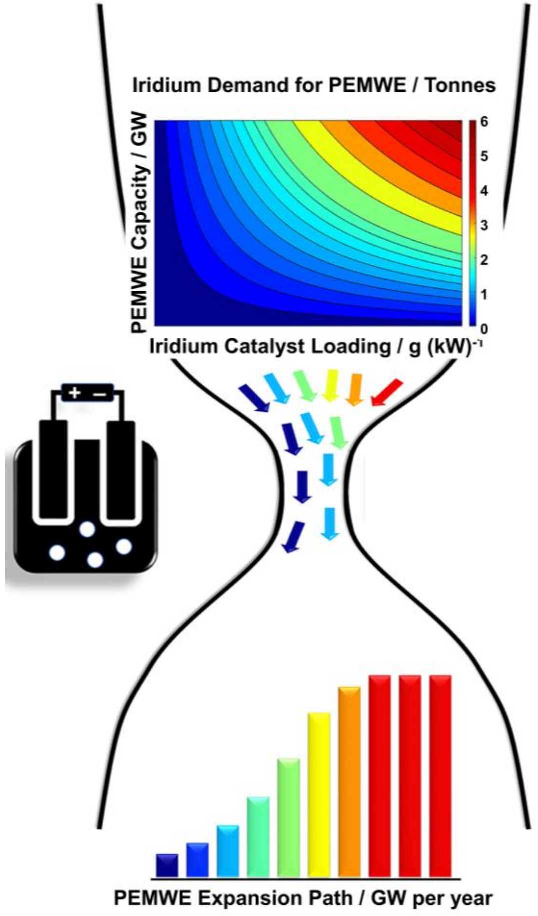
Closing the Iridium Gap

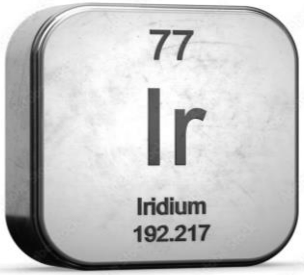




Next-Generation Catalyst Designs:

- ❑ **Alloying**
- ❑ **High-surface-area rutile-type iridium oxides**
- ❑ Core-shell concepts
- ❑ **Supported Ir-based materials**

28 tons
required with traditional OER catalysts

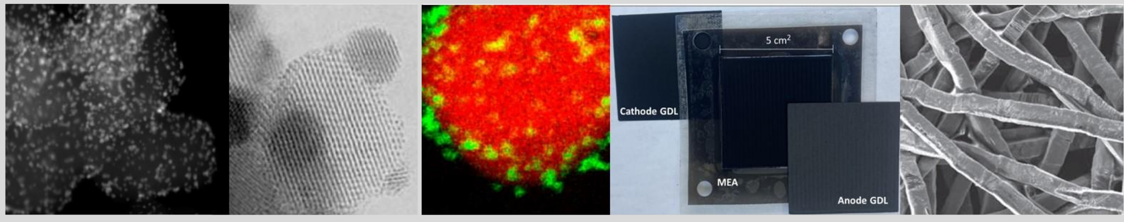


12 tons available on the market, with 75% located in South Africa

7 tons with reduced Ir loading through next-generation catalyst designs

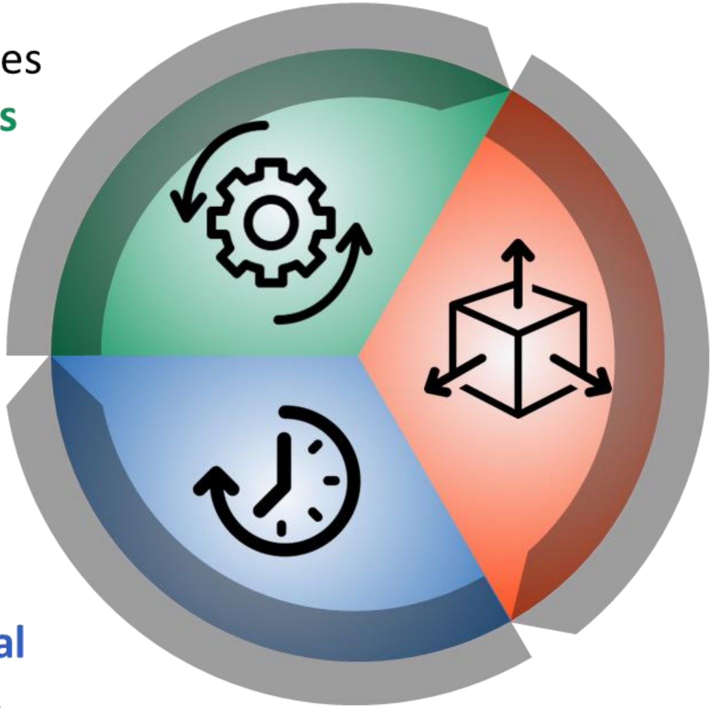
Minke, C. et al., ***International Journal of Hydrogen Energy***, 2021.

Key Research & Development Themes



Material Efficiency

- ❑ Enhancing catalytic efficiency of **OER**/HER reactions
- ❑ High-performance electrodes with **reduced PGM loadings**



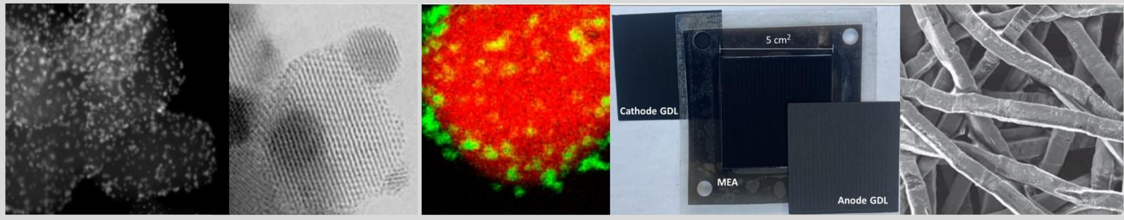
Scalability

- ❑ Cost-effective, scalable **catalyst designs and preparation approaches**
- ❑ Scalable electrode **fabrication processes**

Durability

- ❑ Improving the **electrochemical stability** of OER/HER catalysts
- ❑ Optimised electrode **microstructure**

The OER & the Ir-Oxide Phase Conundrum

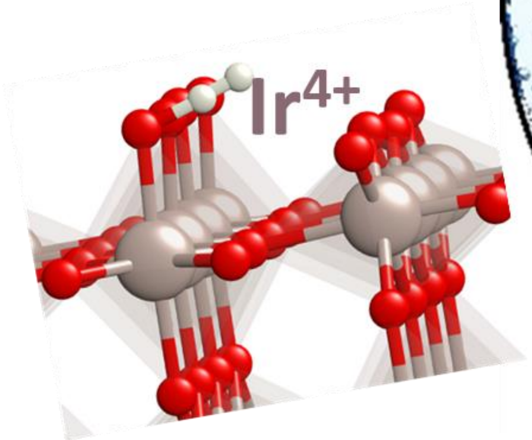


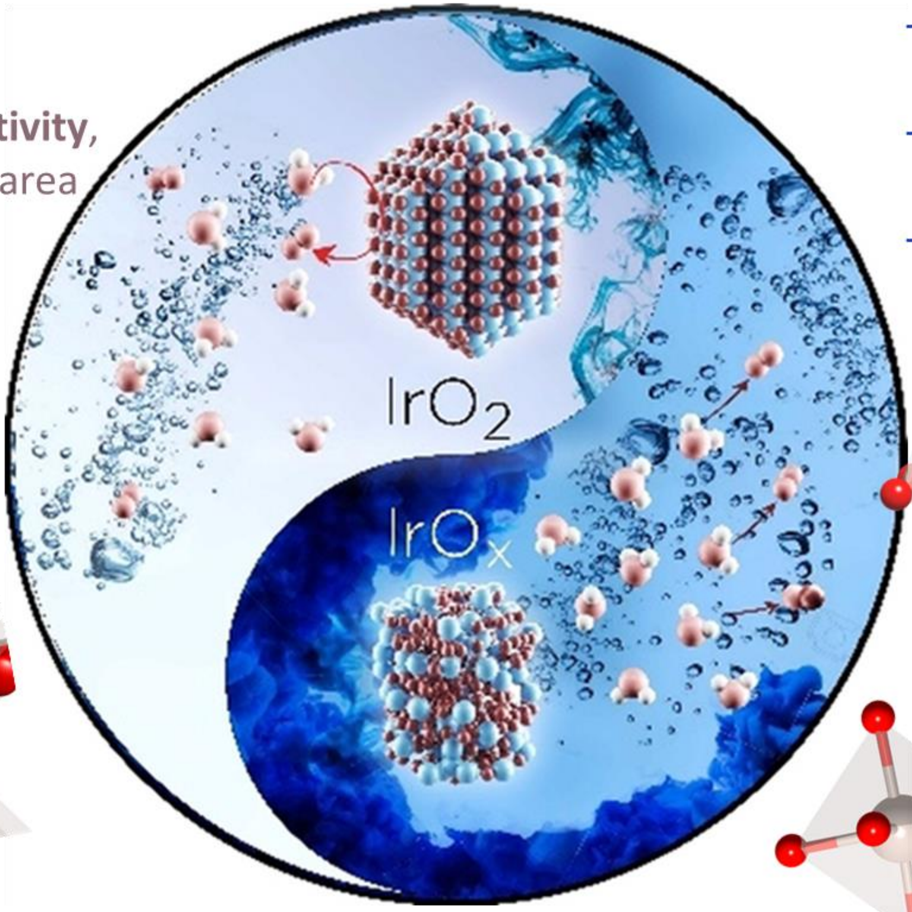
Rutile-type IrO_2

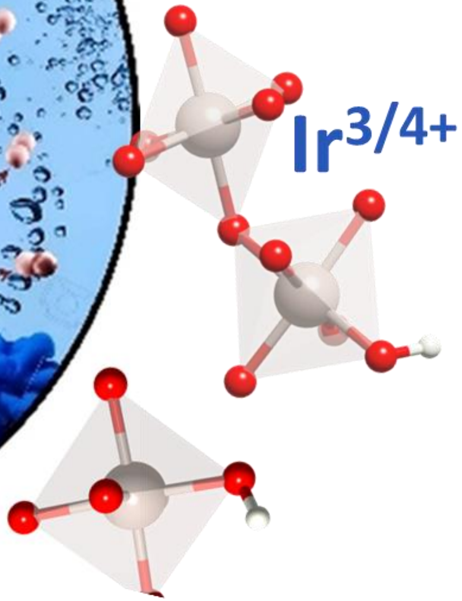
- **High stability**, less dissolution-prone
- **Low intrinsic OER activity**, typically low surface area
- **High electrical conductivity**

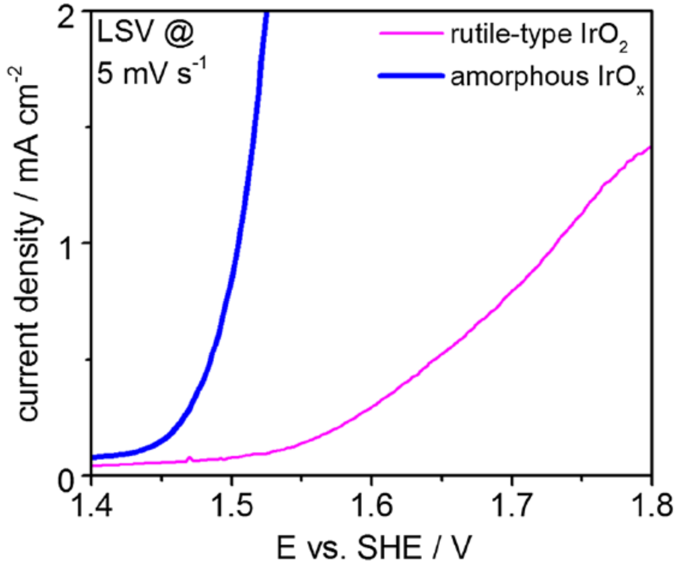
Amorphous IrO_x

- Low stability, **highly dissolution-prone**
- **High intrinsic OER activity**, high surface area
- **Poor electrical conductivity**



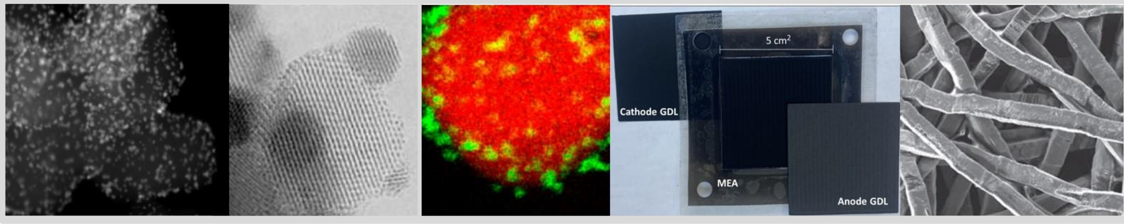






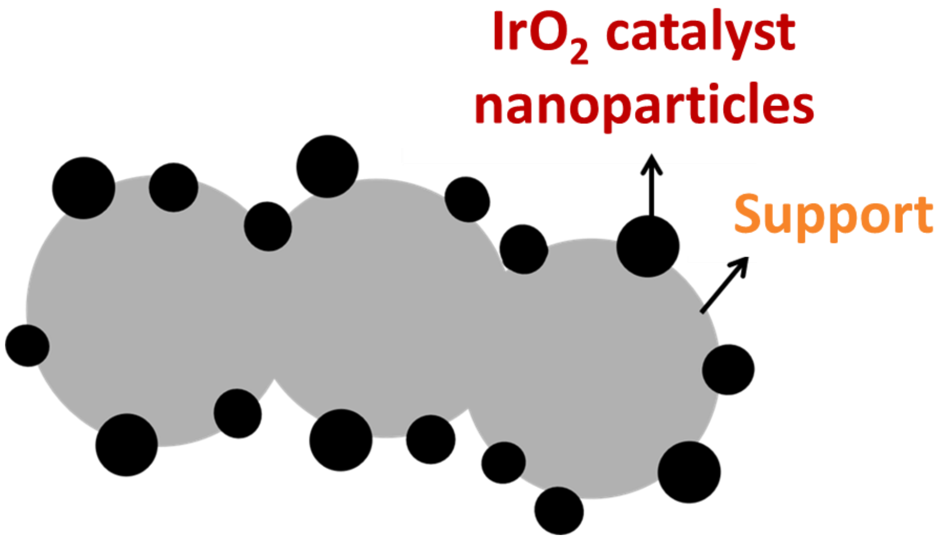
V. Pfeifer et al., ***Surface Science****, 2015.*

Our Catalyst Solutions

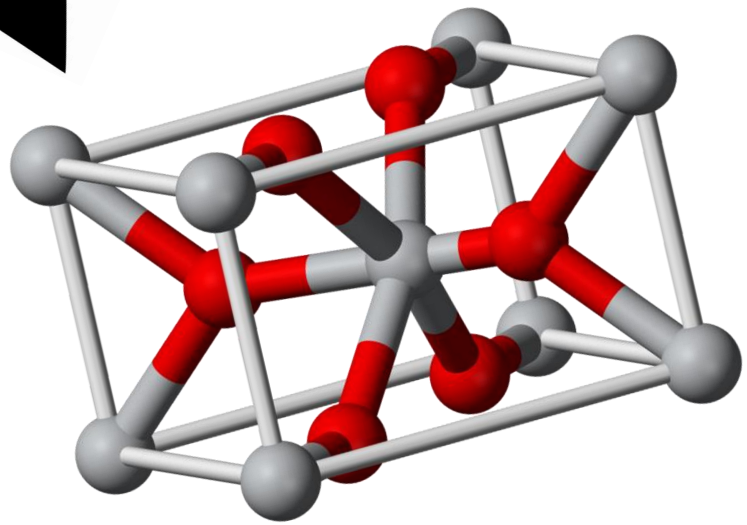


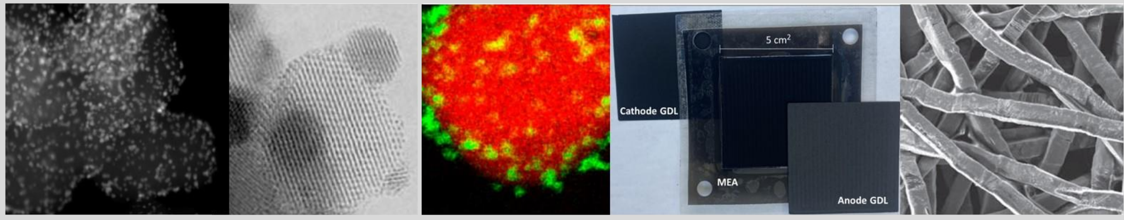
Rutile-type IrO_2 Catalyst Designs

Oxide-Supported Catalysts

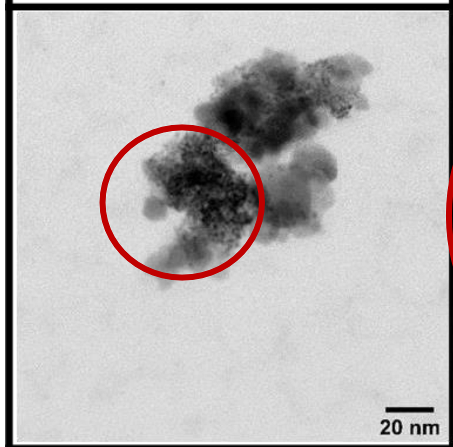
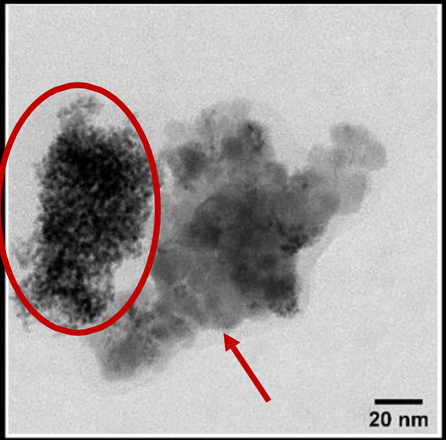
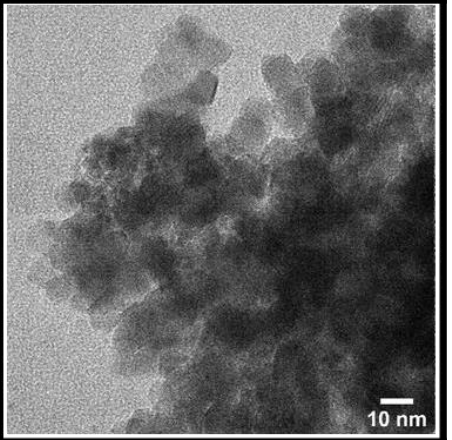


Nanocrystalline IrO_2



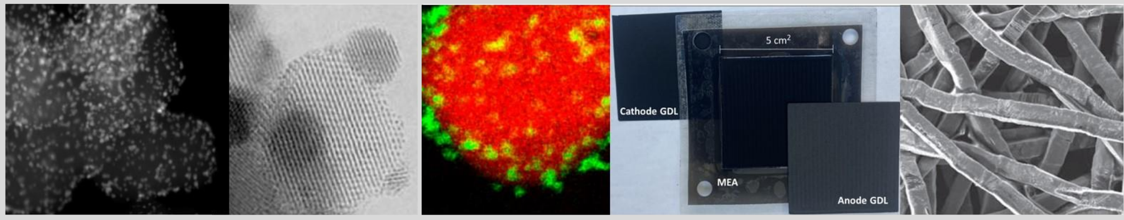


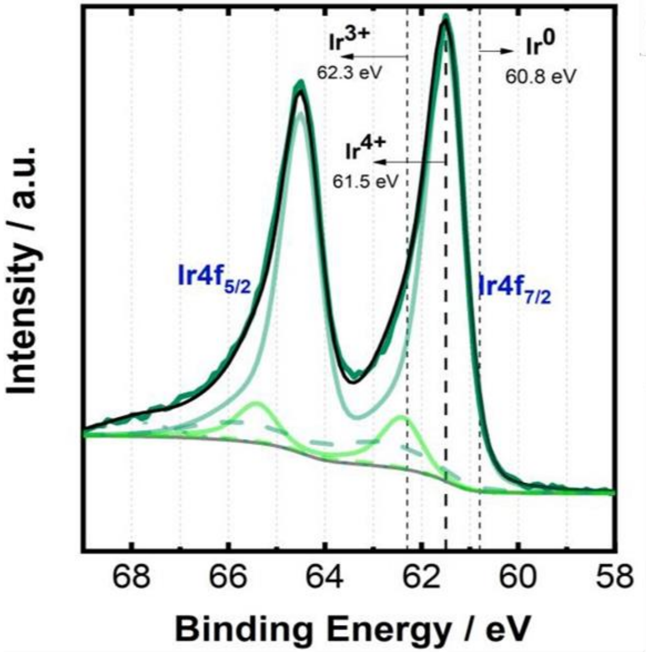
IrO_2 Supported on ATO

Polyol	Chemical Reduction	Adam's Fusion
		
Agglomerated particles that are a **mixture** of metallic Ir and IrO_2, ethylene glycol left behind	**Highly agglomerated** particles that are a **mixture** of metallic Ir and IrO_2	**Large particle sizes** with a dominating presence of **rutile IrO_2**

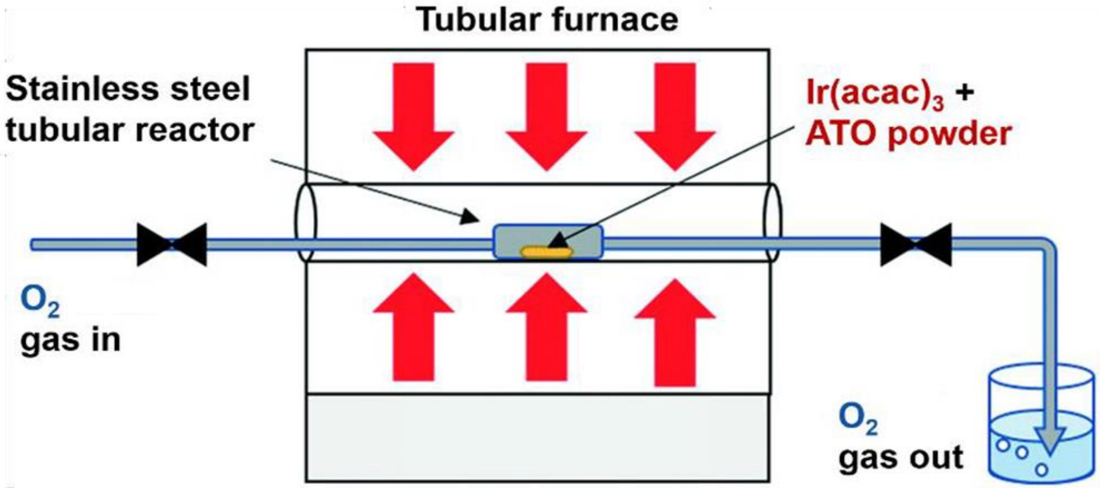
- The development of **rutile iridium dioxide** nanoparticles that are **small** and **highly dispersed** has been a significant challenge in the field

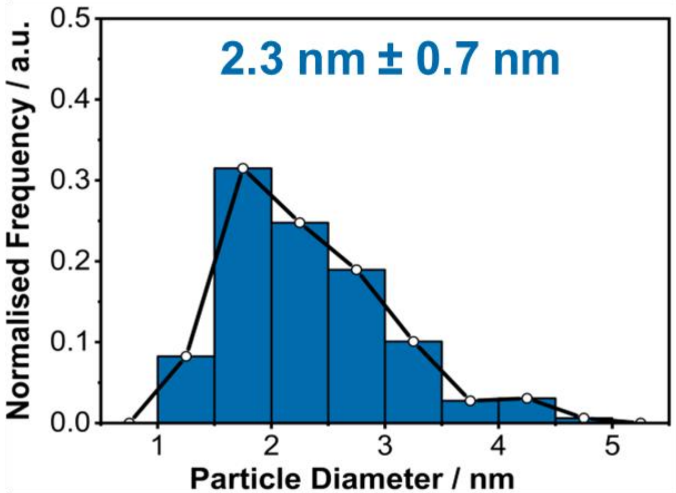
IrO_2 Supported on ATO

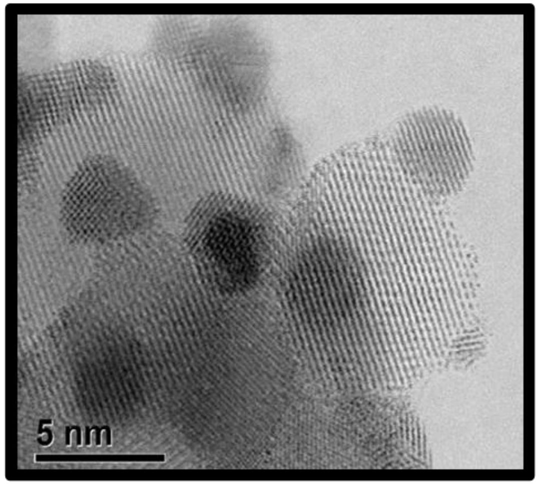




Small, highly dispersed rutile iridium dioxide nanoparticles



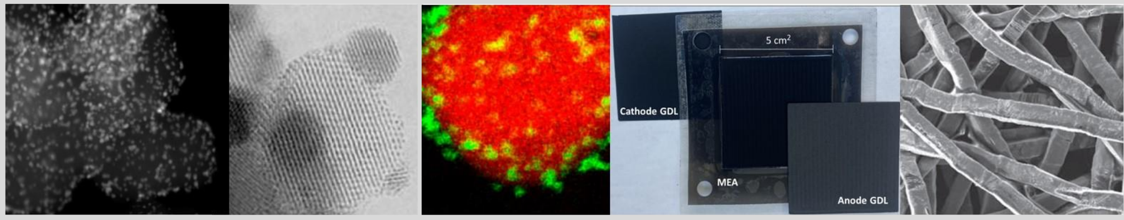




Evidence of a **structural metal-support interaction (SMSI)** in the form of **epitaxial particle anchorage**

Rajan, Z.S.H.S., et al. ***Catalysis Science and Technology***, 2020.

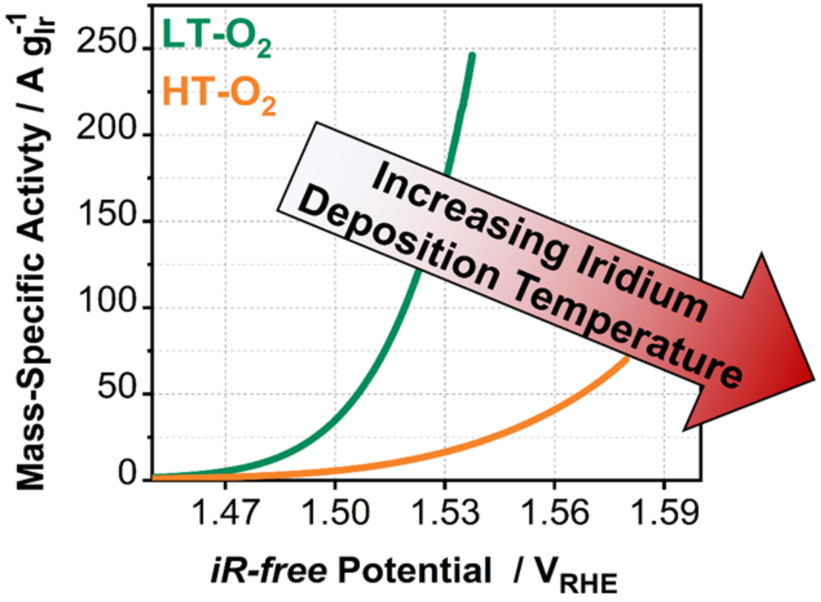
IrO_2 Supported on ATO

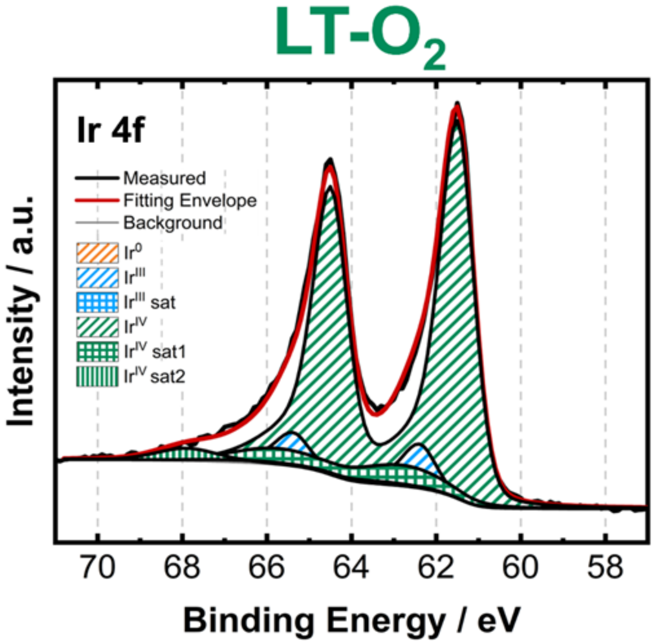


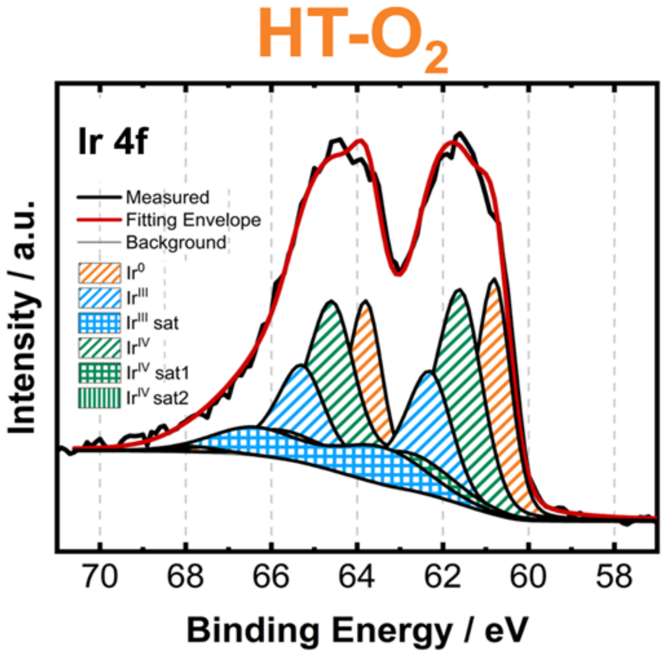
Journal of The Electrochemical Society, 2024 **171** 036505

Reductive Segregation During the Synthesis of Sb–SnO_2-Supported Iridium Electrocatalysts for the Oxygen Evolution Reaction

Ziba S. H. S. Rajan,[1] Tobias Binninger,[2] Patricia J. Kooyman,[3] Darija Susac,[1] and Rhiyaad Mohamed[1,z]







PFHT IrO_2

RESEARCH ARTICLE
NANO · MICRO small
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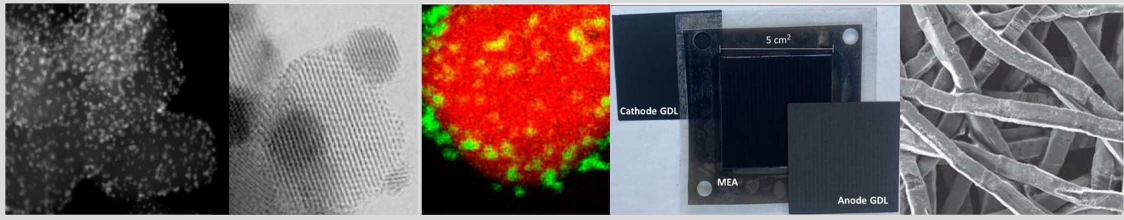
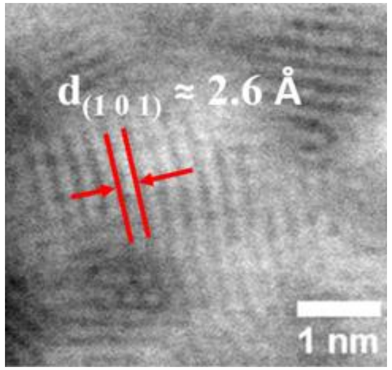
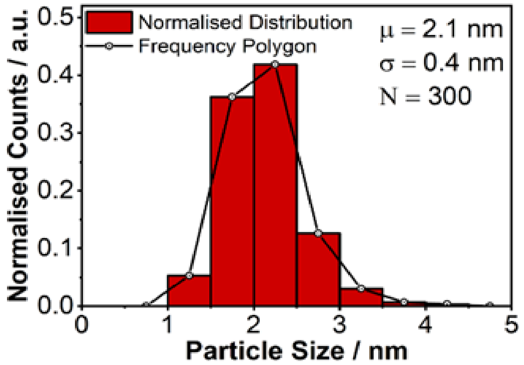
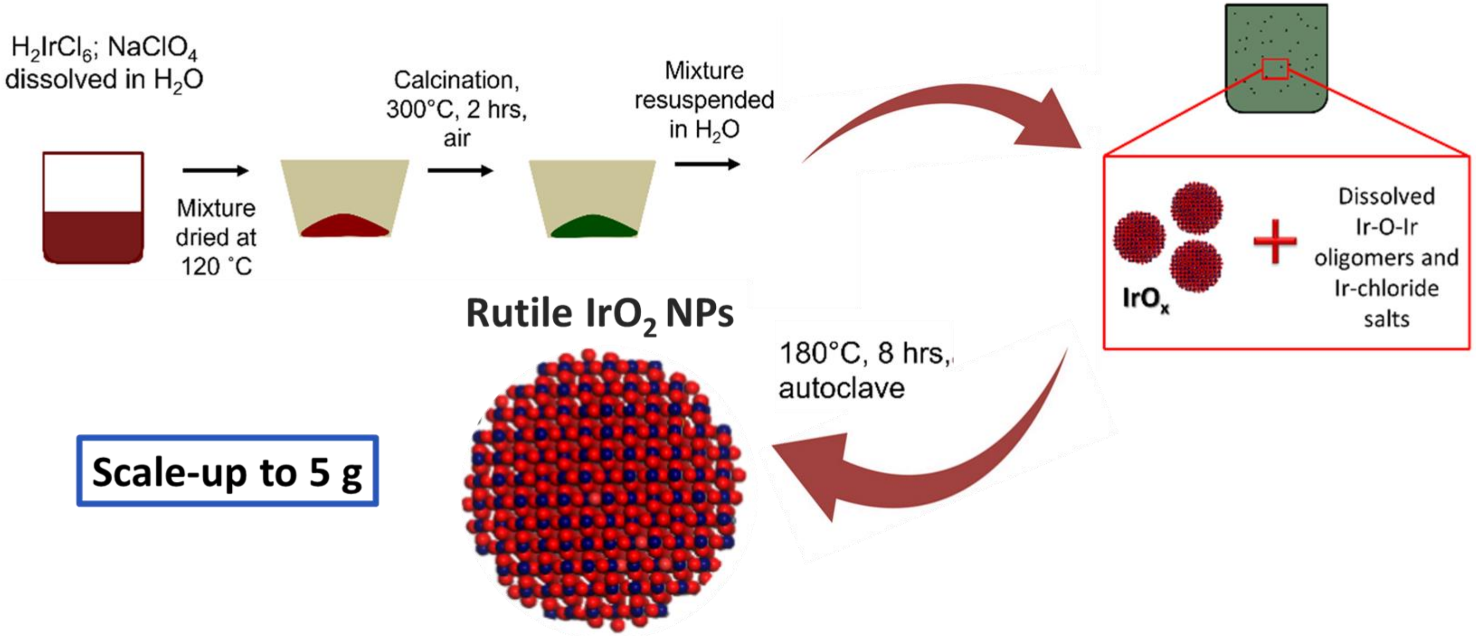
Perchlorate Fusion–Hydrothermal Synthesis of Nano-Crystalline IrO_2: Leveraging Stability and Oxygen Evolution Activity

*Genevieve C. Moss, Tobias Binninger, Ziba S. H. S. Rajan, Bamato J. Itota, Patricia J. Kooyman, Darija Susac, and Rhiyaad Mohamed**

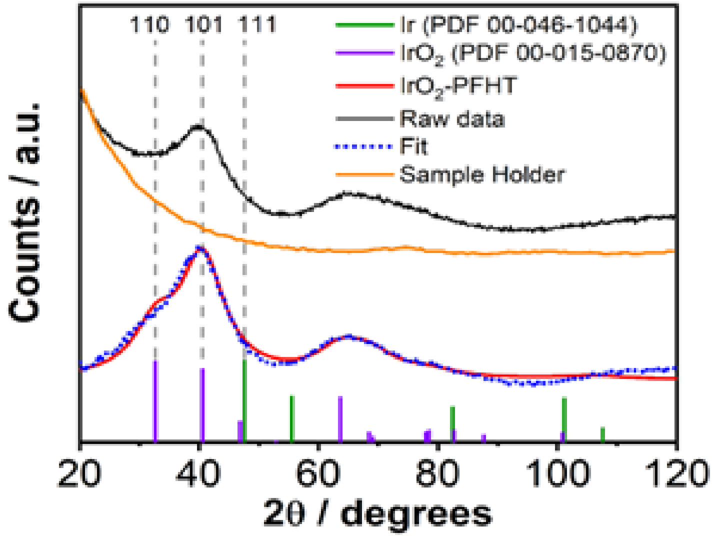




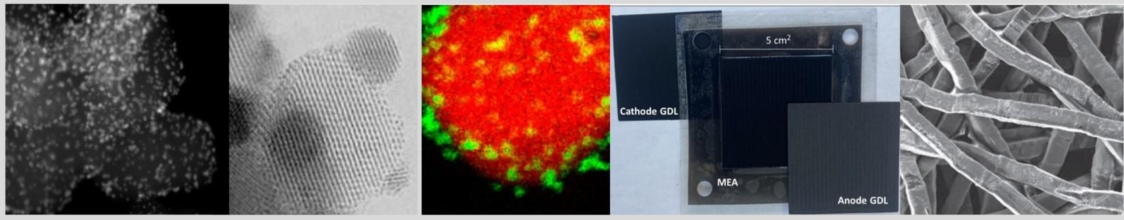


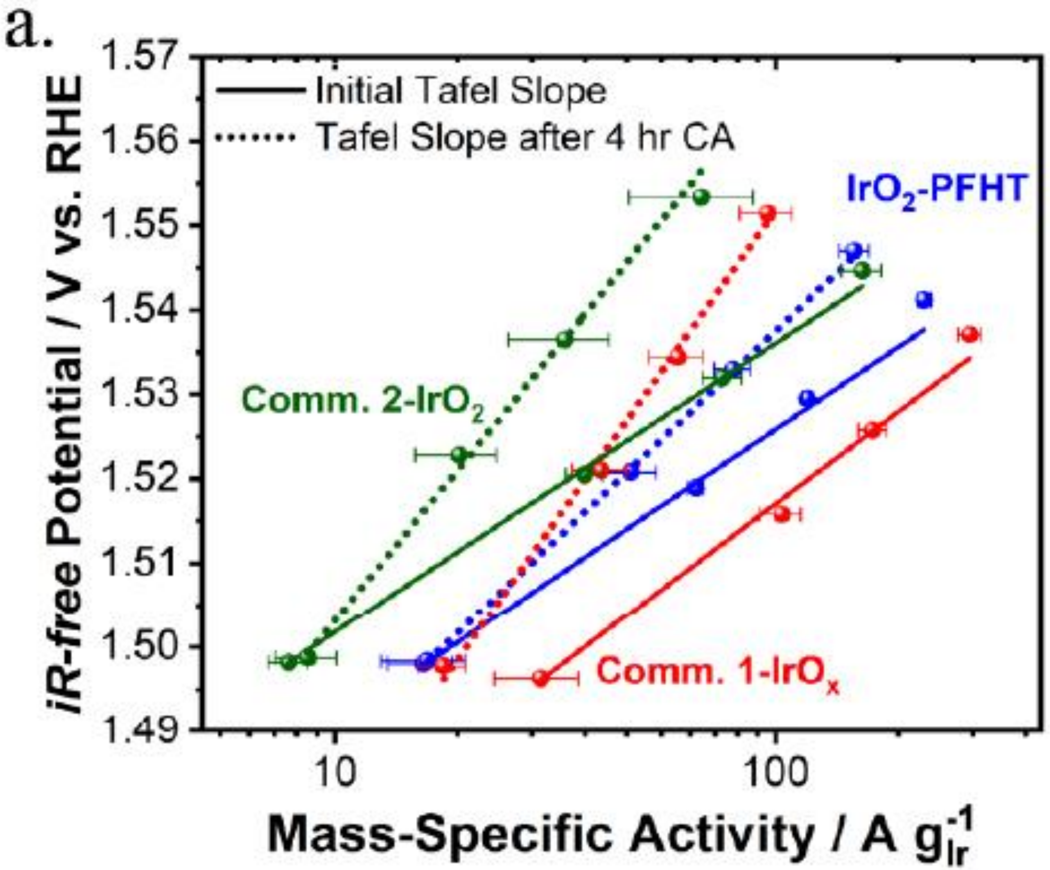


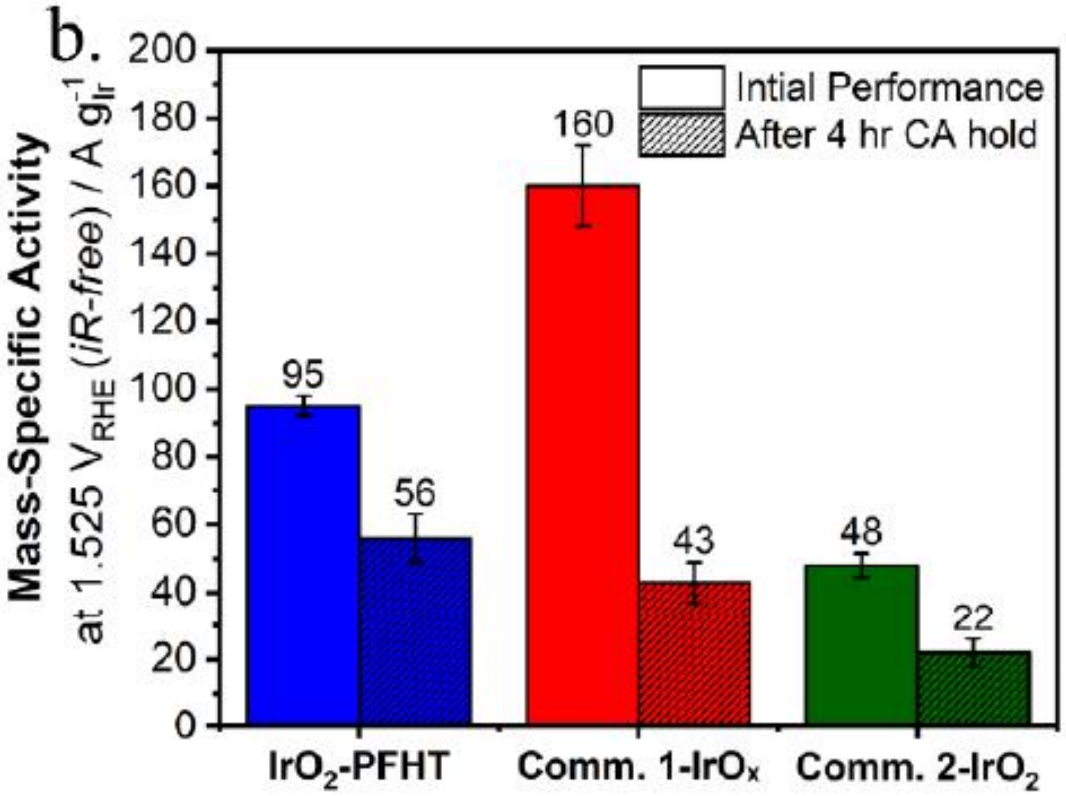
Scale-up to 5 g



PFHT IrO_2 – *Ex-Situ* Performance







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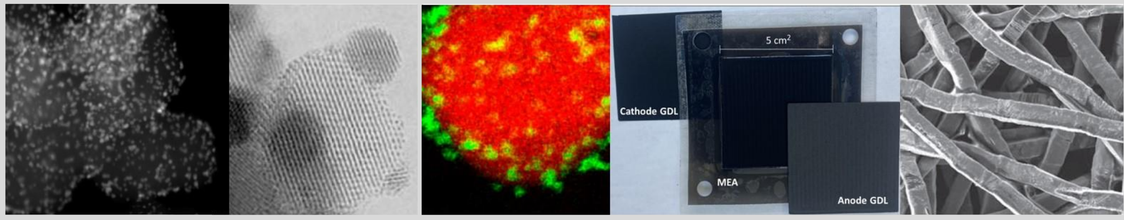
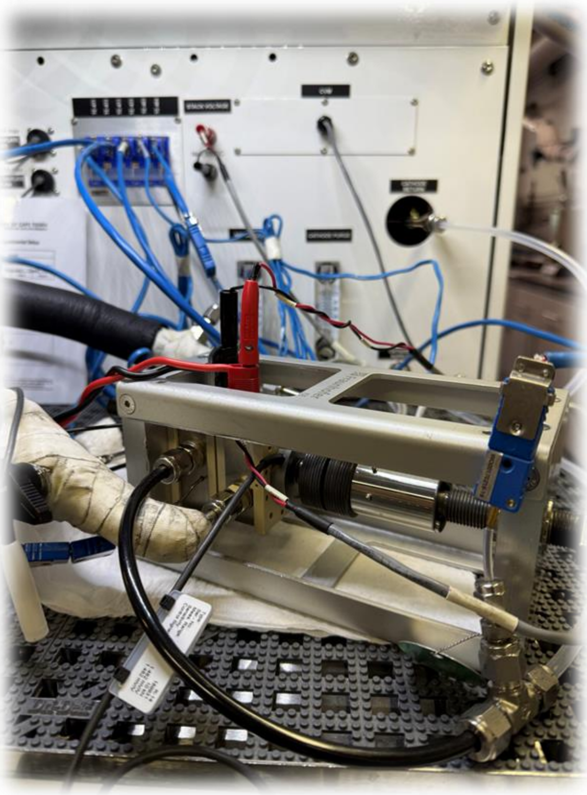
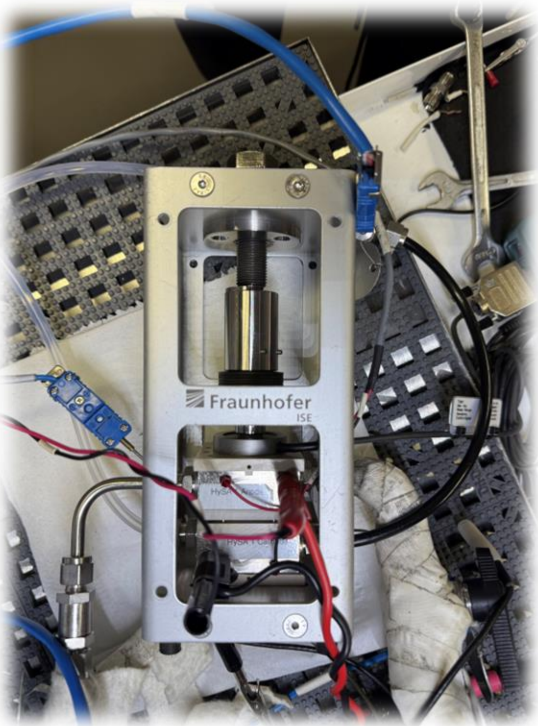
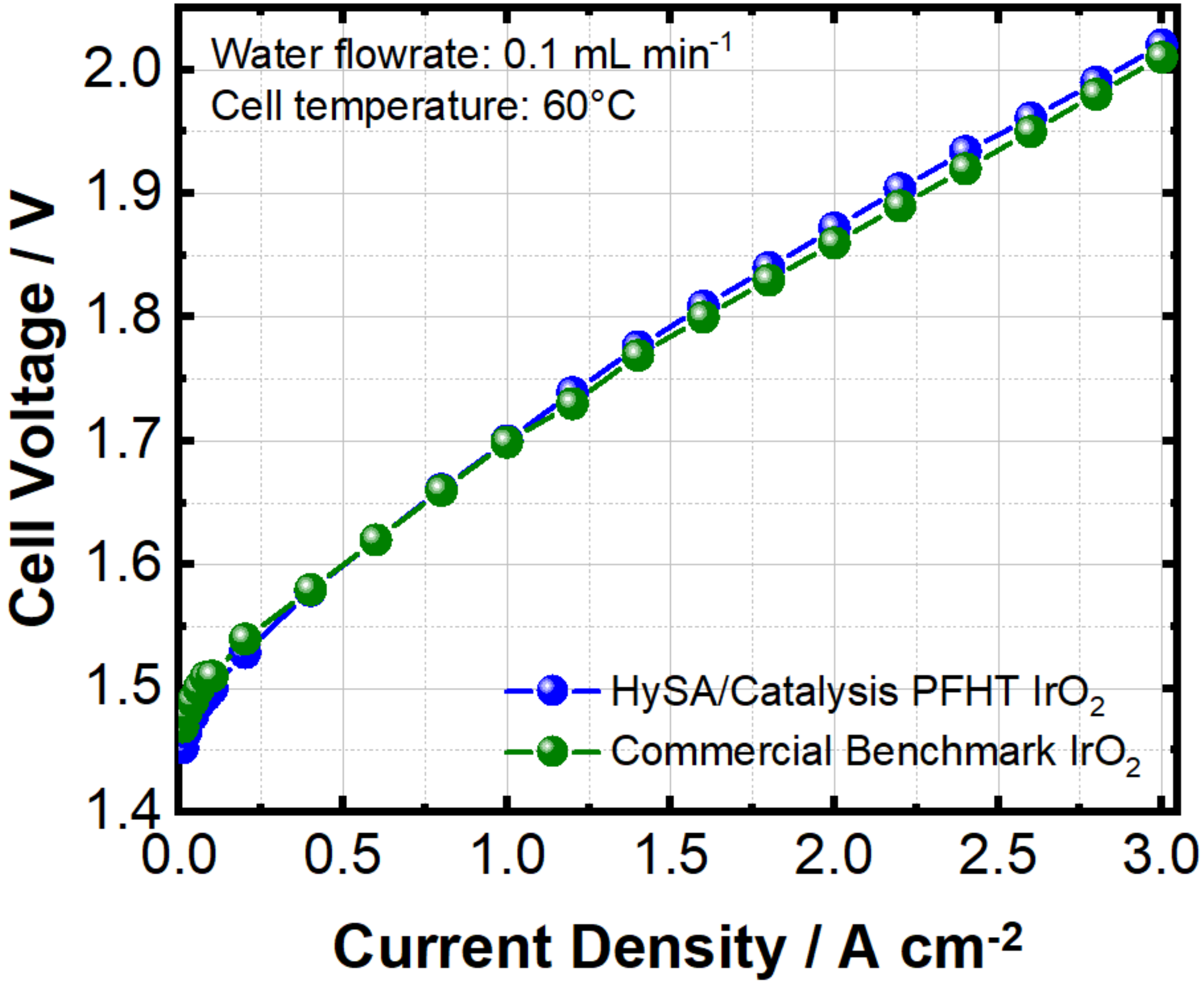
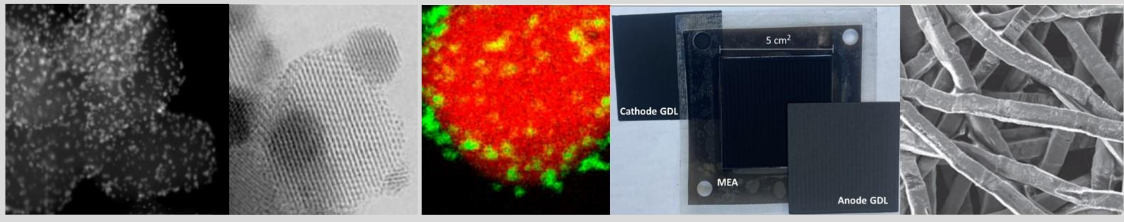






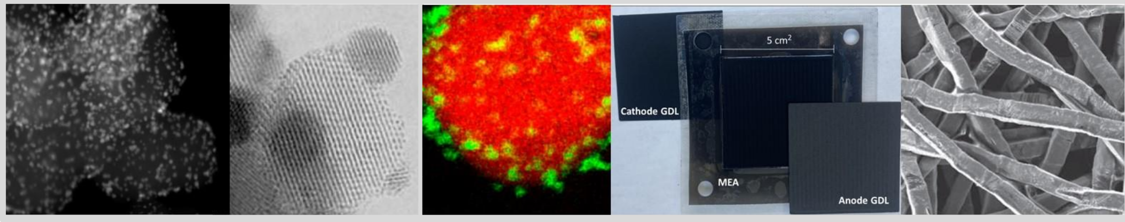


Conclusions and Future Work



- We have successfully prepared and characterised a **range of catalyst designs** consisting of **rutile-type IrO_2**
- **MOCD** has provided the **ideal basis for us to develop a fundamental understanding** towards the **behaviour of oxide-supported iridium oxide catalysts for the OER**
- The **IrO_2-PFHT** catalyst has demonstrated **favourable electrochemical performance in both *ex-situ* and *in-situ* conditions**
- Our future work consists of developing a **robust *in-situ* stability protocol**, composed of the **hundreds of hours online**, as well as the incorporation of our **supported catalyst range in a working electrolyser**

Thank you for your attention









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