HOW TO IMPROVE GREEN H_2 PRODUCTION EFFICIENCY FROM AN ENGINEERING PERSPECTIVE

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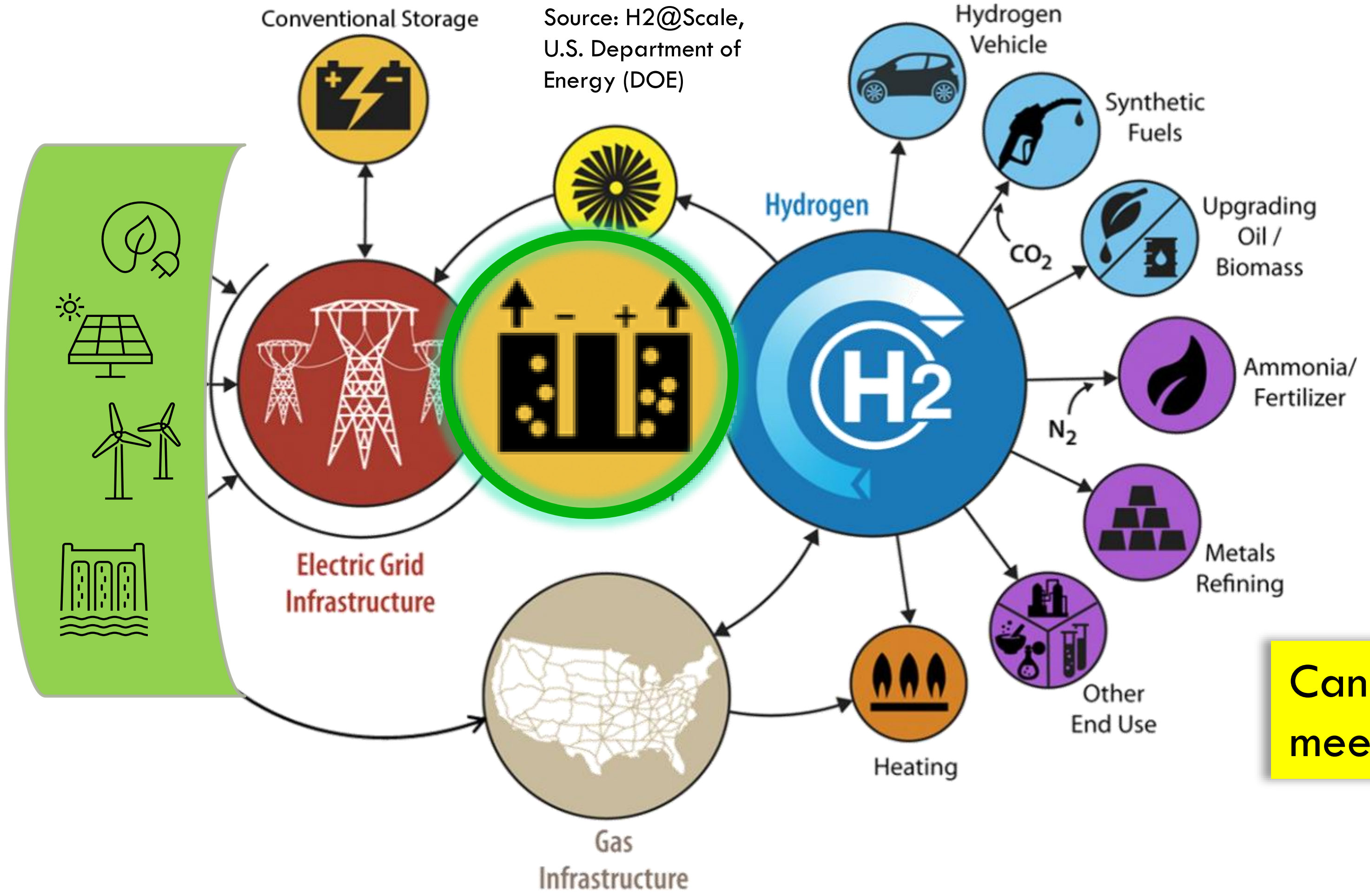
GREEN H2 ECONOMY

H_2, a green energy carrier, is an important contributor to net-zero carbon emission by 2050



- ❑ hard-to-abate sectors such as steel manufacture
- ❑ long-haul transport, shipping and aviation;
- ❑ seasonal storage of renewable electricity
- ❑ a chemical feedstock

Can H_2 generation scale up fast to meet the demand by 2050?

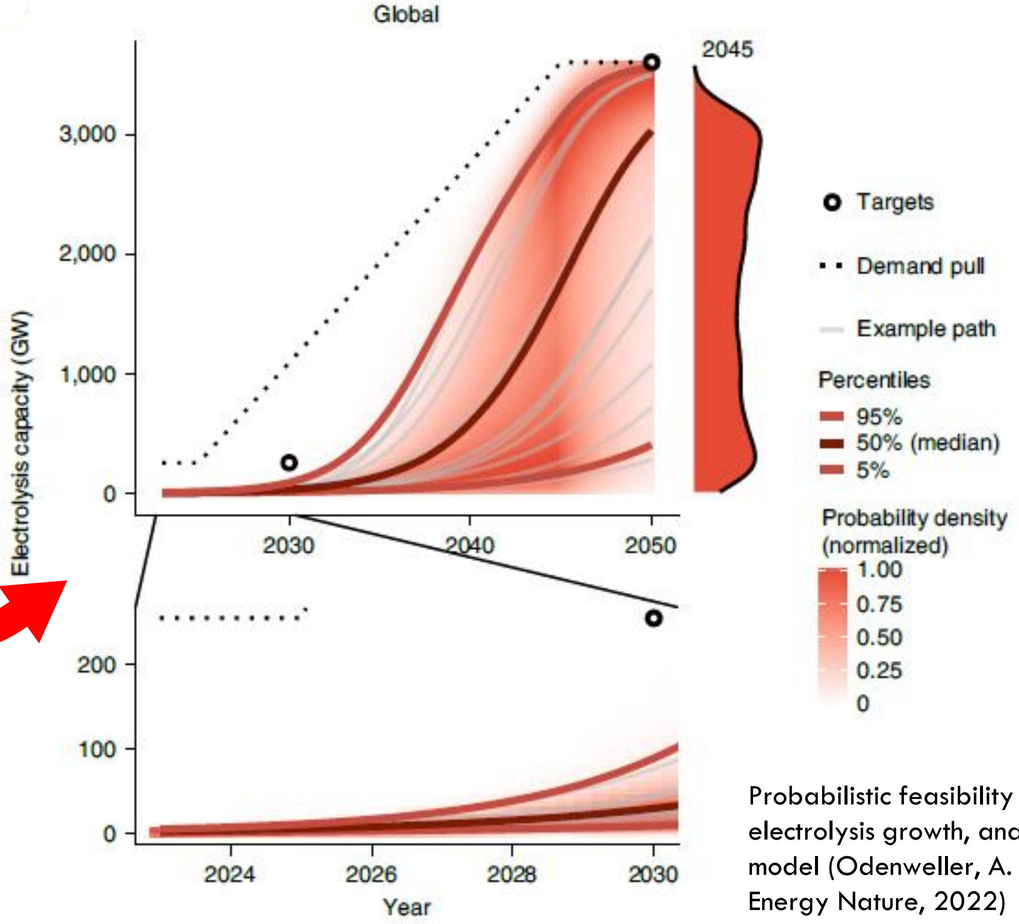
CAN PRODUCTION MEET THE TARGET?

NZ domestic demand for decarbonising 8% energy emission:

180,000 tonnes (1.5 GW) per year by 2035,

560,000 tonnes (4.5 GW) by 2050

	State-of-the-art	Future goal global
Water electrolysis capacity	600 MW (installed by 2021)	150GW (target in 2030)
Energy Consumption	~53 kWh/kg H2	<42 kWh/kg H2 (by 2050)
Energy Efficiency	74 %	~ 93.8 %



Probabilistic feasibility space of electrolysis growth, analysis model (Odenweller, A. et al. Energy Nature, 2022)

 Source: MBIE NZ Interim H2 roadmap 2023 (Source: IRENA report 2020)

CONVENTIONAL WATER ELECTROLYSER (WE)

Alkaline Water Electrolysis

Overall cell:

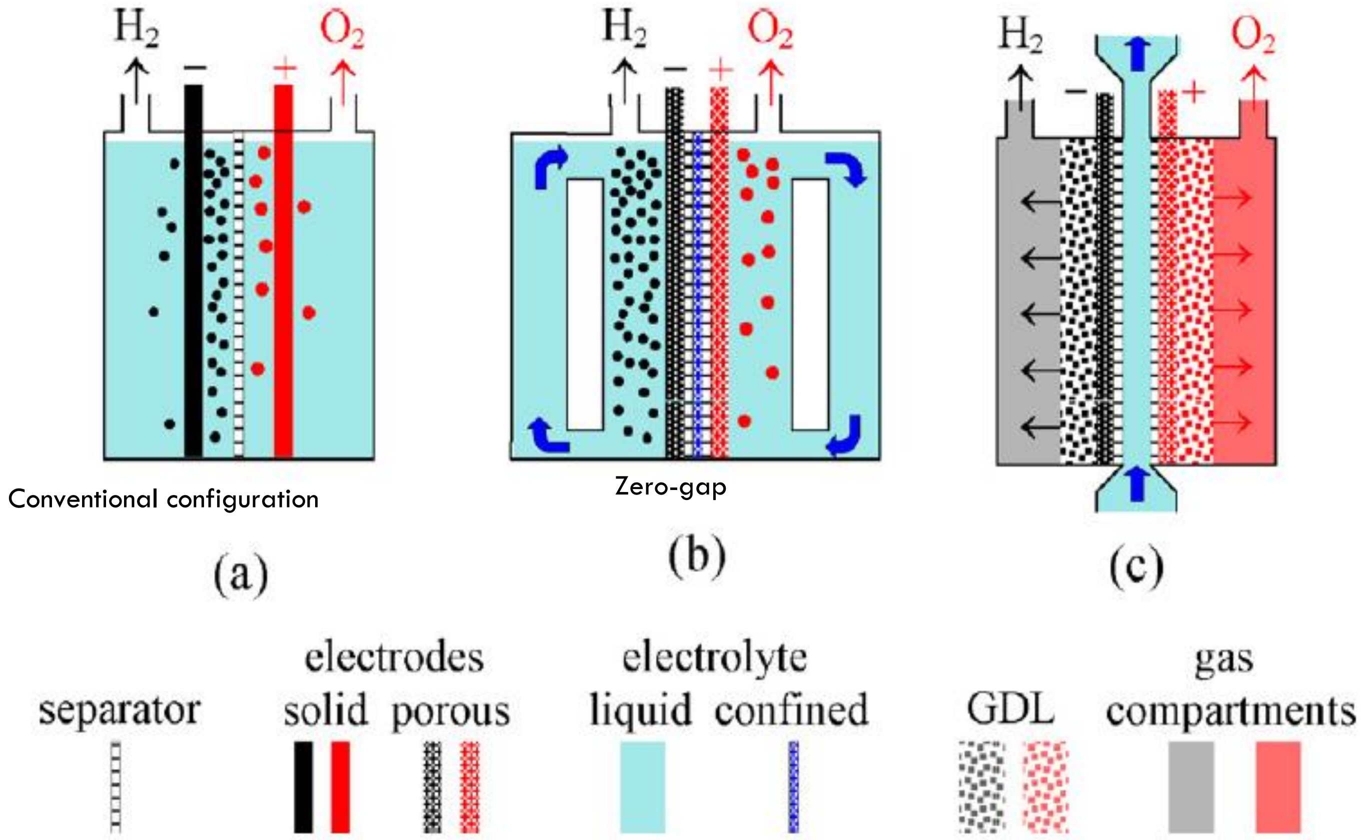
$$\mathbf{H_2O + energy \xrightarrow{\text{electricity}} H_2 + \frac{1}{2}O_2}$$

Cathodic: $2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$,

Anodic: $2OH^- \longrightarrow 1/2O_2 + H_2O + 2e^-$

Gas impermeable membrane or separator:

- Permeable to ions
- Avoids mixing hydrogen and oxygen
- Separate the electrodes
- Introduce resistivity/extra cost/lifespan
- Bubble reduce the active area



S Marini et al: Advanced alkaline water electrolysis. Electrochimica Acta, (2012) 384-391.

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CONVENTIONAL WATER ELECTROLYSER (WE)

PEM Water Electrolysis

Overall cell:

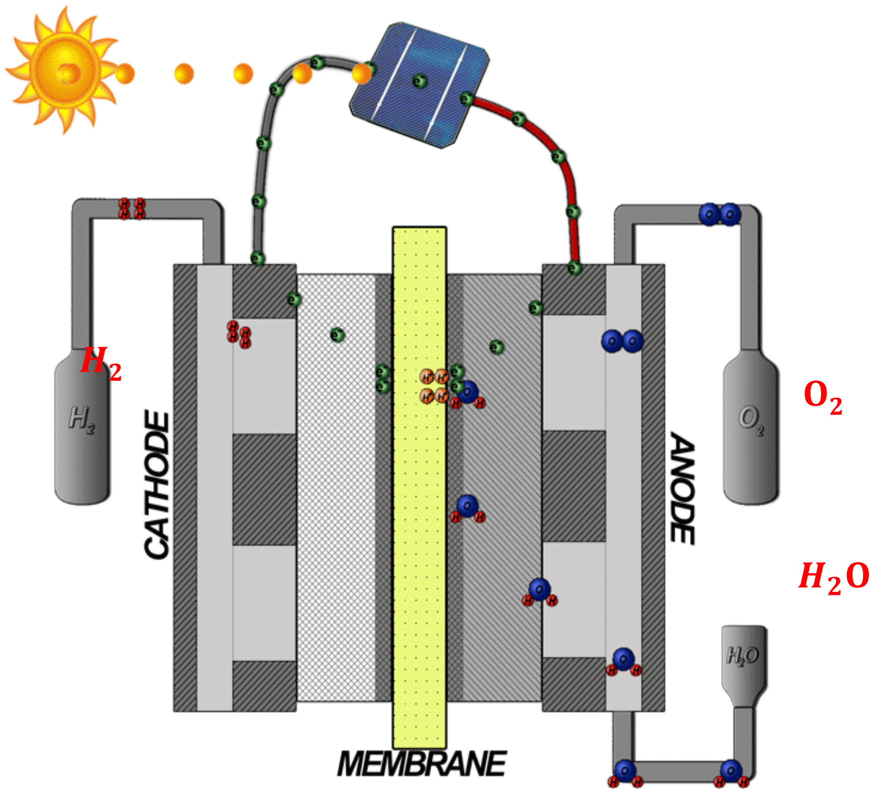
$$H_2O + energy \xrightarrow{\text{electricity}} H_2 + \frac{1}{2}O_2$$

Cathodic: $2H^+ + 2e^- \rightarrow H_2$,

Anodic: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

Gas impermeable membrane or separator:

- Permeable to ions
- Avoids mixing hydrogen and oxygen
- Separate the electrodes
- Introduce resistivity/extra cost/lifespan
- Bubble reduce the active area



Davidlfritz (2013): PEM Elektrolyse 5.gif

Advantage:

- High current density
- High efficiency
- Rapid response

Challenges:

- Younger than other AE
- High cost
- Degradation

S Marini et al: Advanced alkaline water electrolysis. Electrochimica Acta, (2012) 384-391.

HOW TO SCALE UP IN INDUSTRY?

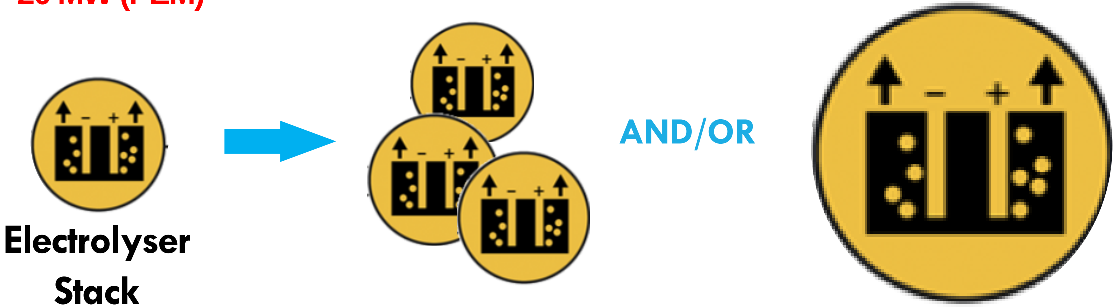
Water electrolyser – an old process but "YOUNG" technology

$$H_2O \xrightarrow{\text{electricity}} H_2 + \frac{1}{2}O_2$$

10 MW (AKL),
20 MW (PEM)

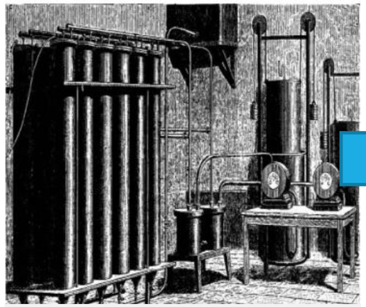
GW production line ?

Larger stack?



Electrolyser Stack

Flexible power supply & high current density?



Scientific American Supplement, Vol. XXXII, no. 819: New York, 1891

~ 1890 (1st WE Unit)

Single Alkaline water electrolyser stack, 10 MW

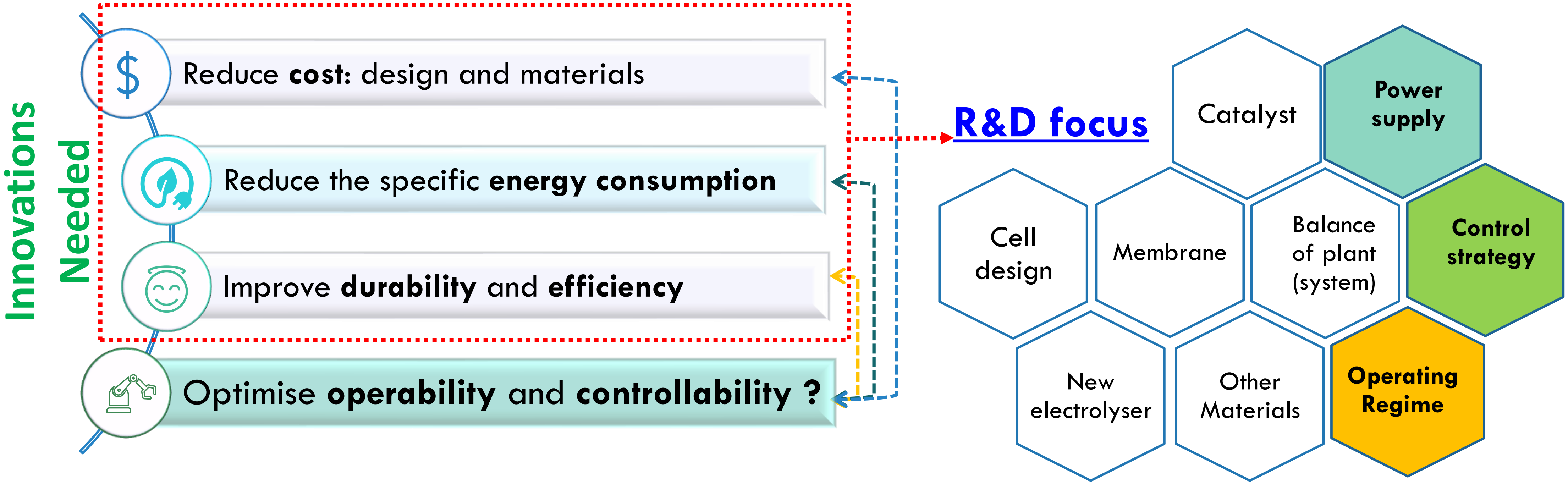
PEM

Cummins largest 20 MW PEM, 2022

Jingjing Liu et al 2022, Challenges in Green Hydrogen Production with Renewable and Varying Electricity Supply: An Electrochemical Engineering Perspective J. Electrochem. Soc. 169 114503

ISSUES IN INDUSTRY SCALE UP ?

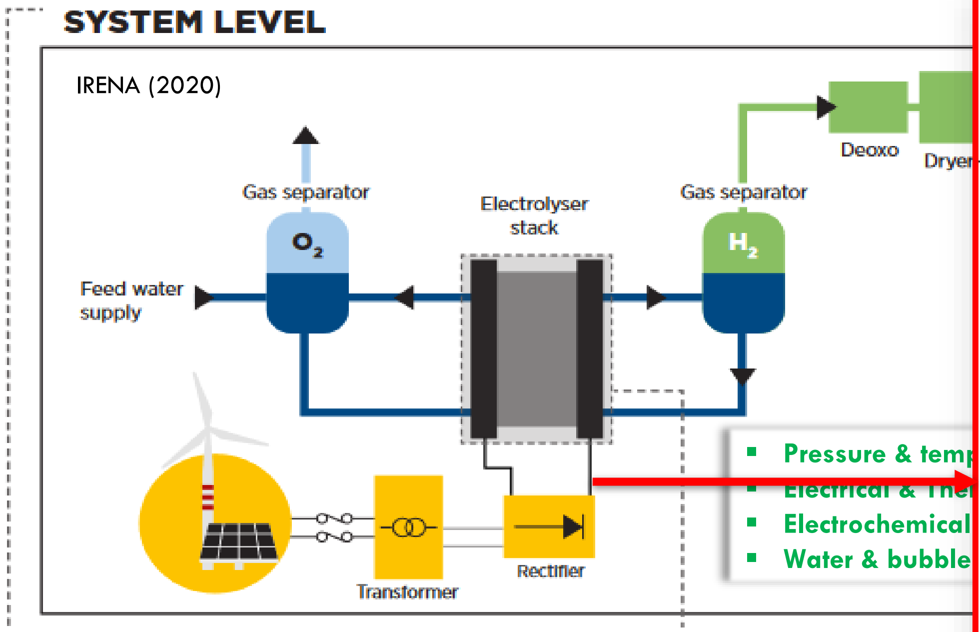
Aim: Store the renewable energy in hydrogen with high efficiency and low cost.



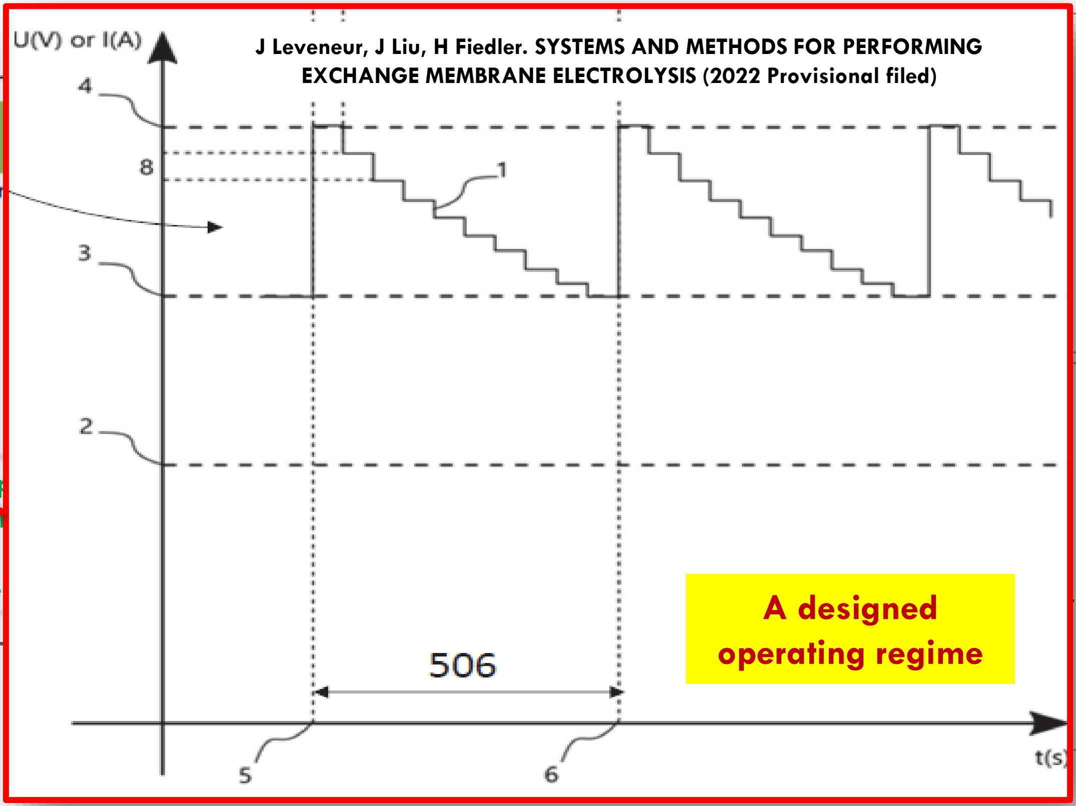
IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5°C Climate Goal, International Renewable Energy Agency, Abu Dhabi.

ON IMPROVING THE EFFICIENCY WHILE OPERATING....

$$\eta_{Energy} = \frac{\eta_{Faradaic} \times HHV_{H_2}}{nF \times U_{cell}} = \frac{1.48}{U_{cell}} \eta_{Faradaic}$$



- Pressure & temp
- Electrical & The
- Electrochemical
- Water & bubble



e impact ?)

Liuyi Huang

Sam Clarke

Thea Larsen
Supervised by
Dr Seho Kim

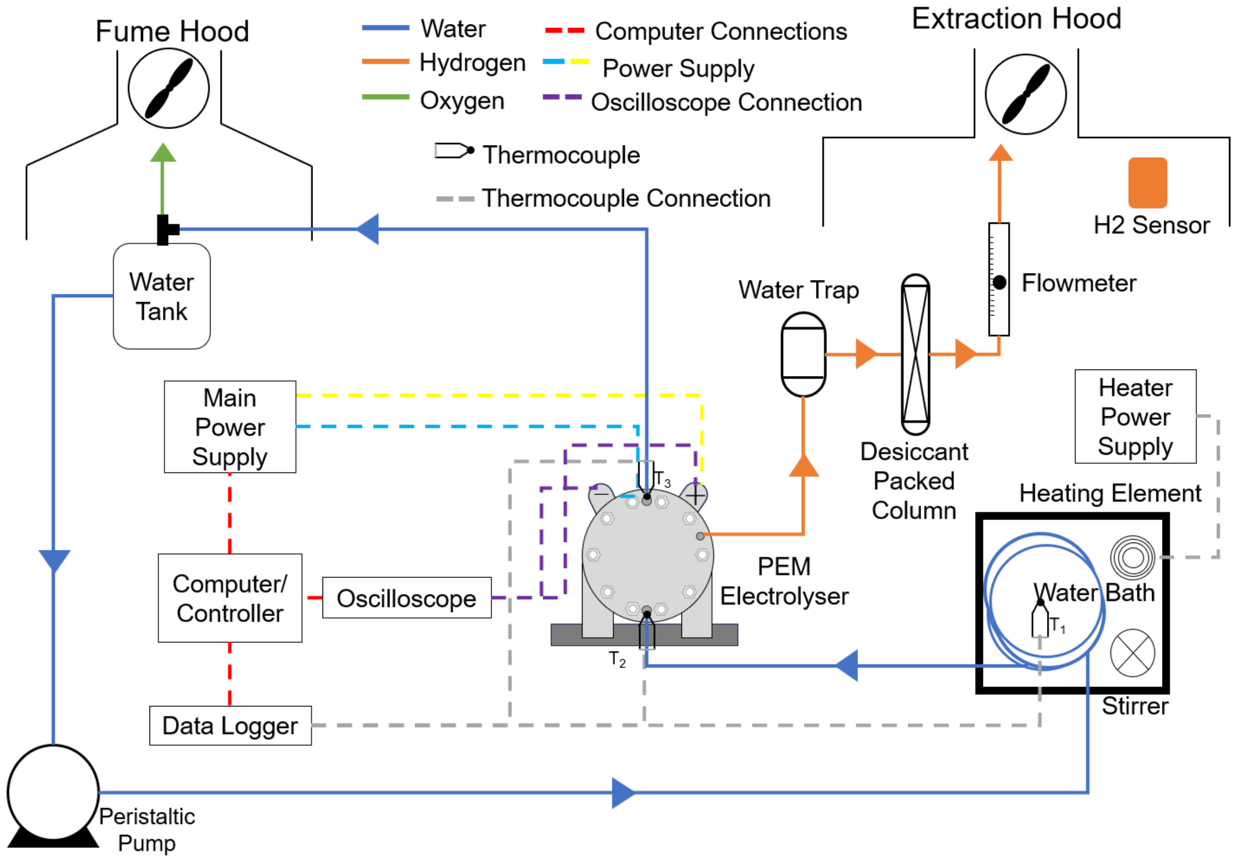
A POWER CONDITIONING SYSTEM

Operating conditions:

- Water temperature control up to 60 °C
- Power modulation paths controlled by a power converter
- Water flowrate
- No pressure regulation
- Two PEM electrolyser stacks
- 2021 – 2023

Table 1 Water electrolyser stack technical data

	QLC-500 Model Stack	60Z series Stack
Active Area	56 cm^2	1.247 cm^2
Stack Size	2	1
Operating Current Range	0 – 36 A	0 - 9A
Max Current Density	0.536A/cm^2	7.217A/cm^2
Voltage Range	2.2 – 5 V	1.45 – 2.2V
Manufacturer	Shandong Saikesaisi Energy Company	Fuel cell store



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J Liu et al. Experimental investigation of PEM water electrolyser stack performance under dynamic operation conditions. Revision resubmitted, J. Electrochem. Soc. 2024.

Sam Clarke Thea Larsen

PEM WATER ELECTROLYSER STACK PERFORMANCE UNDER DYNAMIC OPERATION CONDITIONS

Energy saving of the current regime sustained over 24 months

- H_2 production rate wasn't affected
- Cell voltage decayed over time at low – medium current range (10-20% increase)
- Material degradation

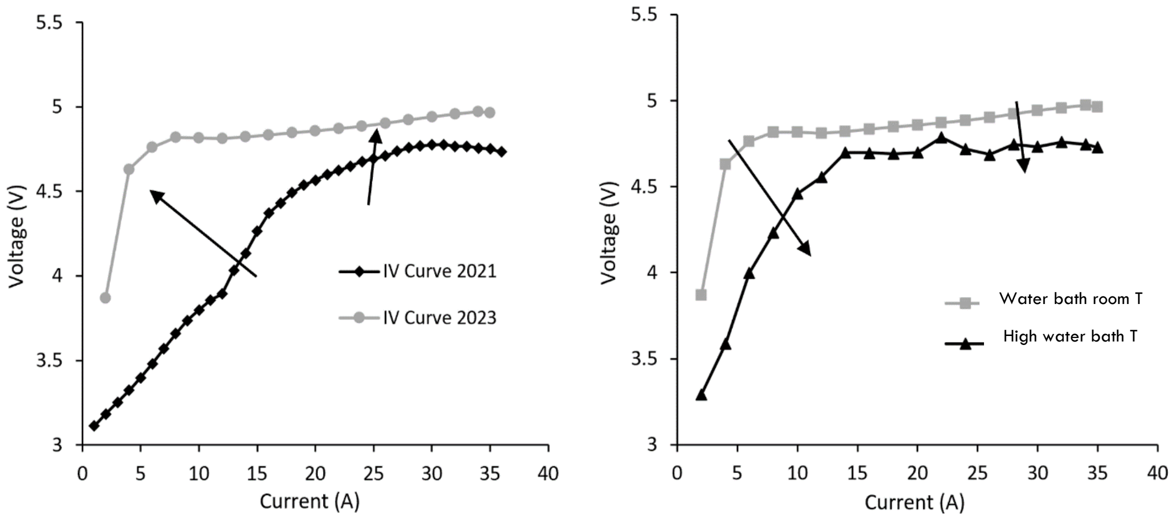

Figure 4 (a) IV curve of new and degraded electrolyser; (b) IV curve of high and low temperature operation.

Temperature and current control→ improve Energy performance, and mitigate voltage decay

Energy saving scenario:

- Optimal current controlled path: **2.16 kWh/kg H_2** was saved from Steady State **57.8 kWh·kg^{-1}H_2**
- Efficiency increase up to +10 %

Materials degradation (undergoing work)

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RELATE OPERATING REGIME TO ELECTRODE SURFACE DYNAMICS

Anie Shejoe (PHD)
Dunbar Sloane
Asmitha Muruganathan
Maggie Li,
Callum Campbell-Ross

Cells have many sources of resistance, generating *Overpotentials*

$$V_{cell} = V_{rev} + (\eta_{act,an} + \eta_{act,cath}) + \eta_{ohm} + (\eta_{conc} + \eta_{diff} + \eta_{bub})$$

Free Energy
1.23 or 1.48 V

Activation Energy

- Kinetics
- Mass transport

Material Design related:

- Catalysis activity
- materials modification
  - Surface area
  - PTL

Influenced by Cell Operations:

- **Bubble behaviour**
- **Current density, thermal management**

Simulation (COMSOL):

- Materials
- Structure (porosity, pore gradient, pore diameter, thickness, etc.)
- Catalyst
- Electrical conductivity

Experiemntal PTL and MEA properties &impact:

- Materials
- Structure (porosity, pore gradient, pore diameter, thickness, etc.)
- Pretreatment
- Catalyst
- Surface wettability
- Electrical conductivity

RELATE OPERATING REGIME TO ELECTRODE SURFACE DYNAMICS

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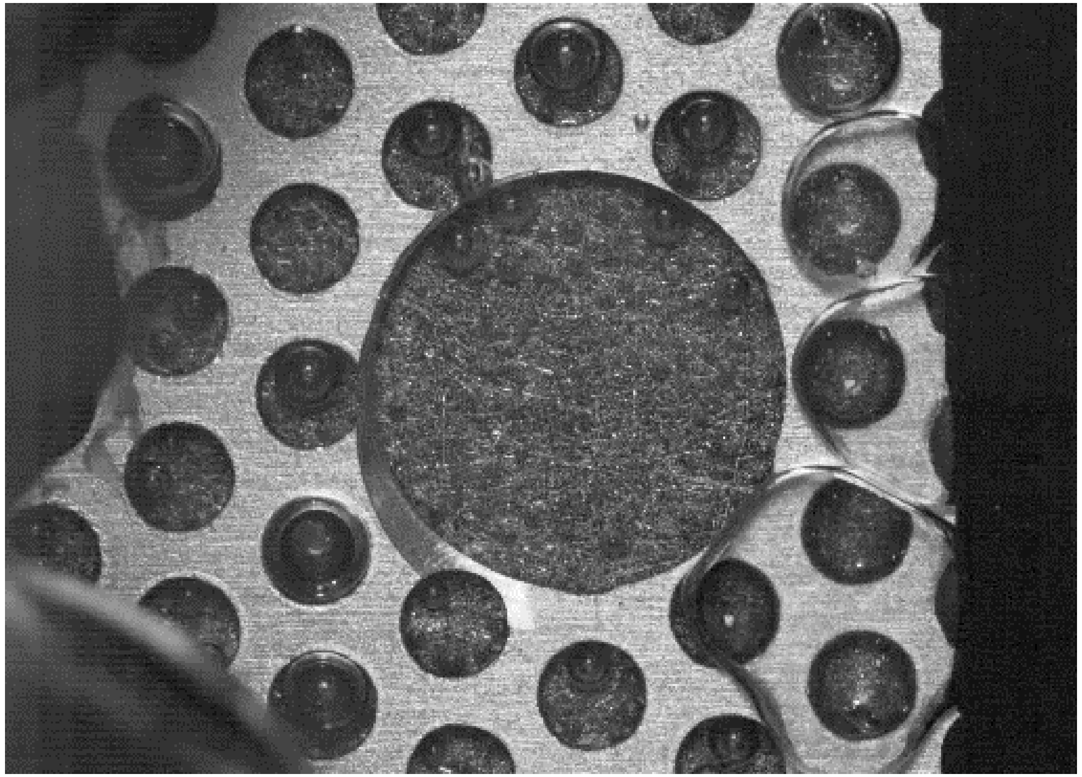
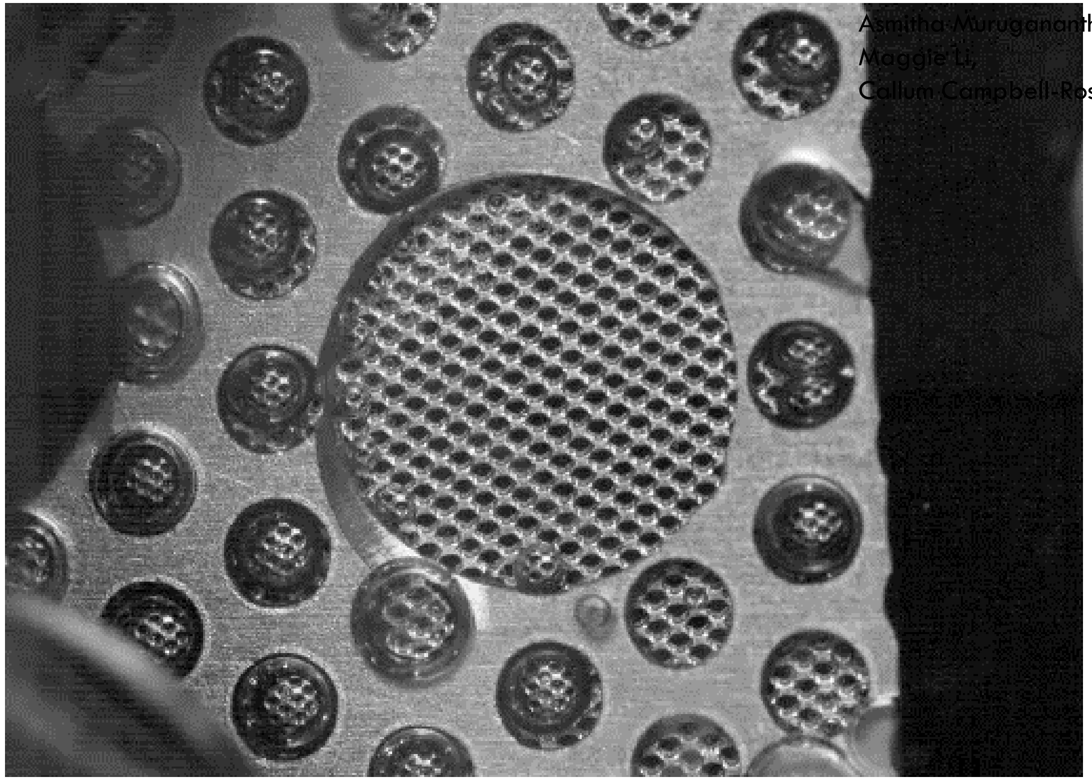


Felt Gas Diffusion Layer at 0.25 A/cm^2, (4 A)

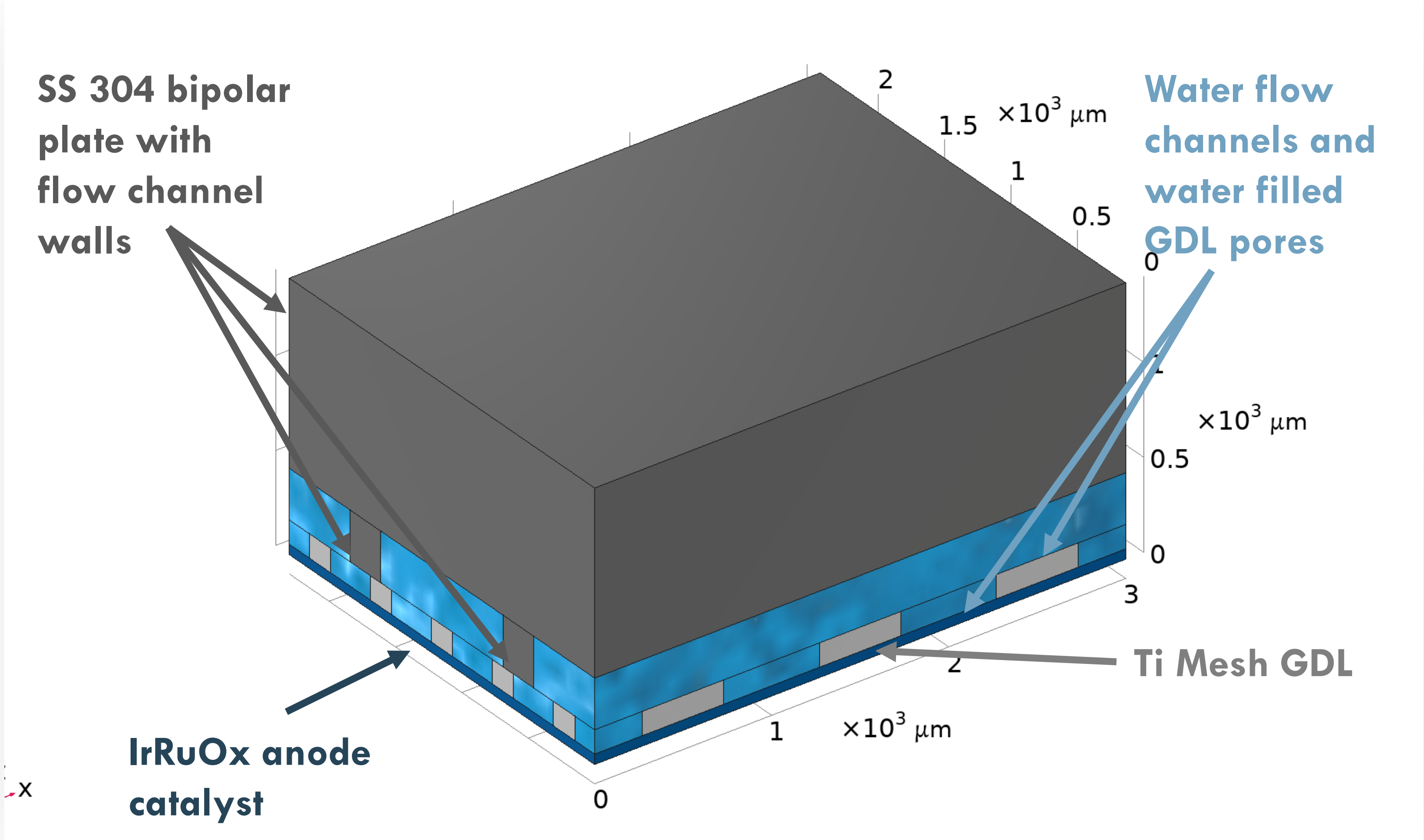


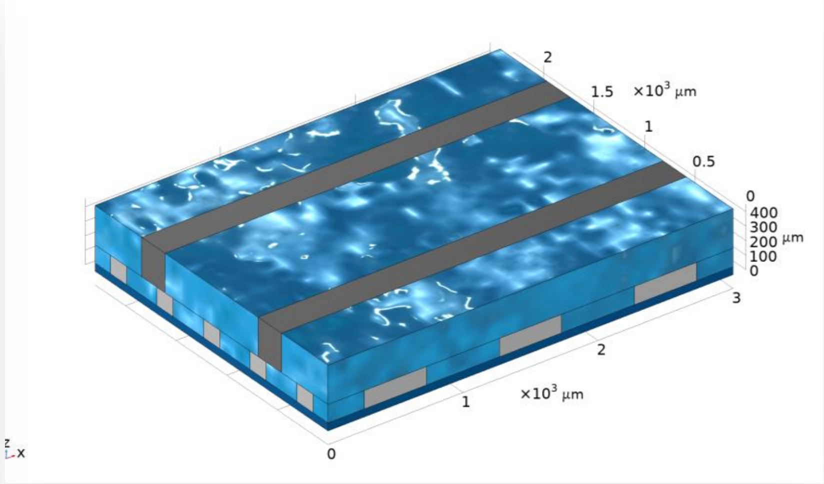
Mesh Gas Diffusion Layer at 0.25 A/cm^2, (4 A)

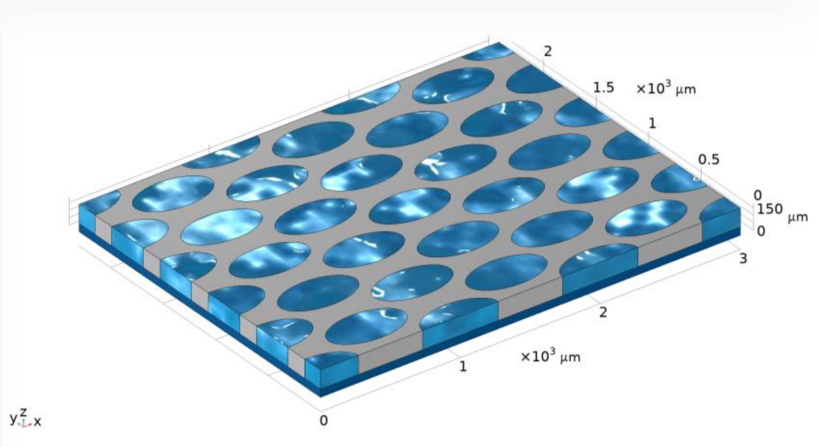
MODEL GEOMETRY

3mm x 2.3mm repeating geometry	COMSOL Multiphysics 6.1	Model does not include membrane or cathode

Sam Williams







FUTURE WORK OF THE SIMULATION

Yuyao Huang (PHD)

2023 Catalyst: Seeding General

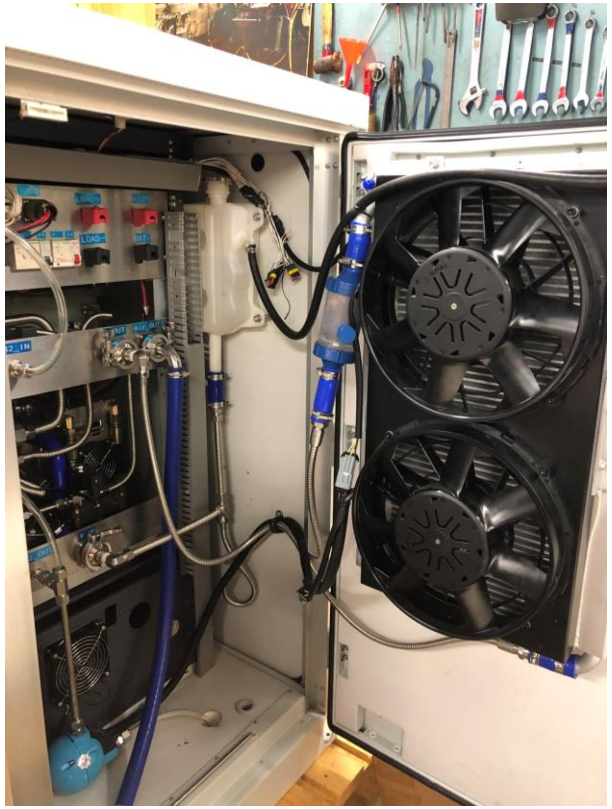
Lawrence Livermore National Laboratory, a Research group led by **Dr Brandon Wood.**

A VALIDATED DIGITAL TOOL FOR NOVEL GREEN H2 PRODUCTION TECHNOLOGY

Product Accelerator

IMPROVEMENTS TO OVERALL ENERGY PERFORMANCE OF PROTON EXCHANGE MEMBRANE FUEL CELLS (PEMFC) VIA VARIOUS HEAT RECOVERY AND UTILISATION ROUTES

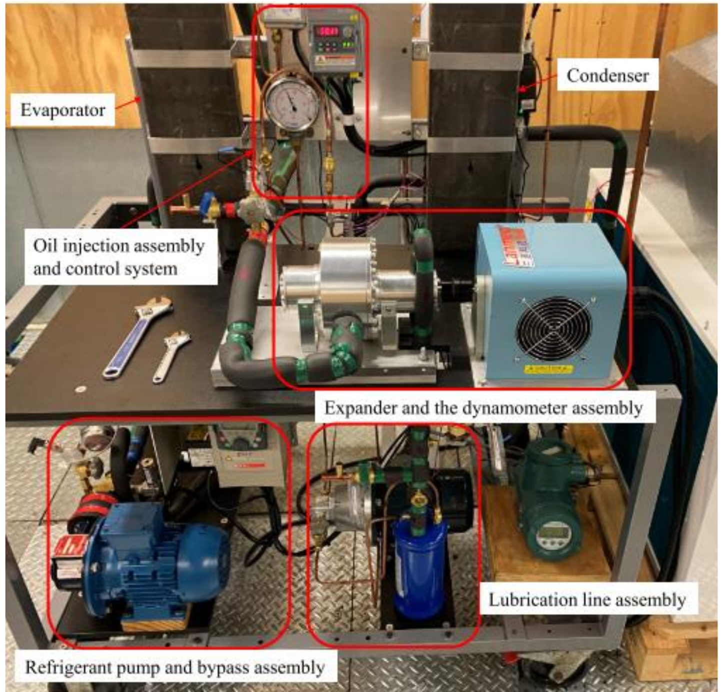
Dr Jenny Hung,
Isaac Severinsen,
Michael Kalpage,
Prof Brent Young



Preliminary results from a PEMFC-ORC model based on:

Commercial 5kW LT-PEMFC

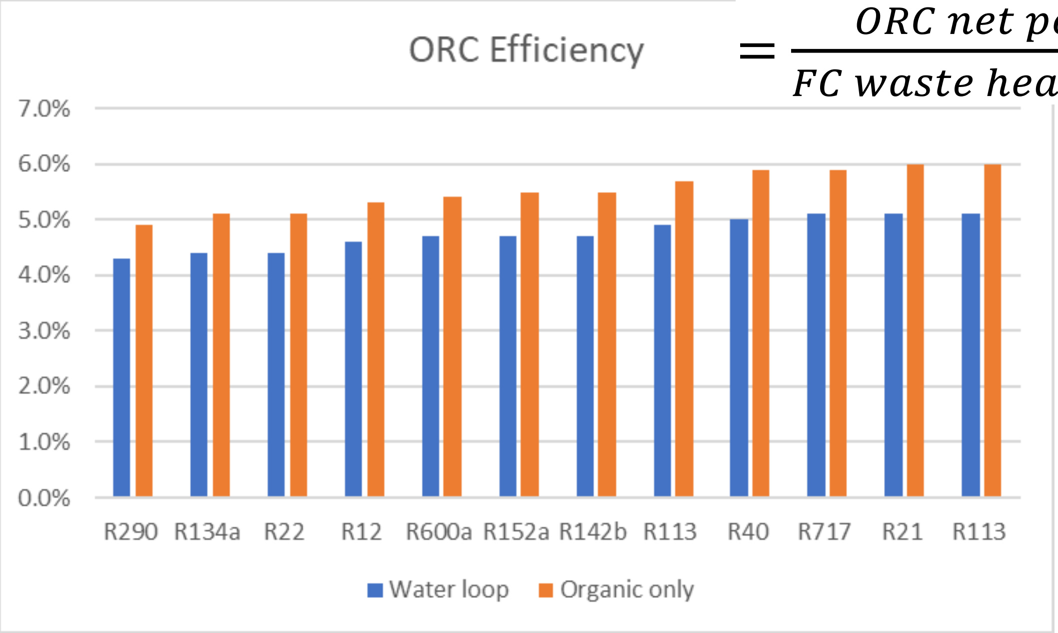
Lab built micro-ORC



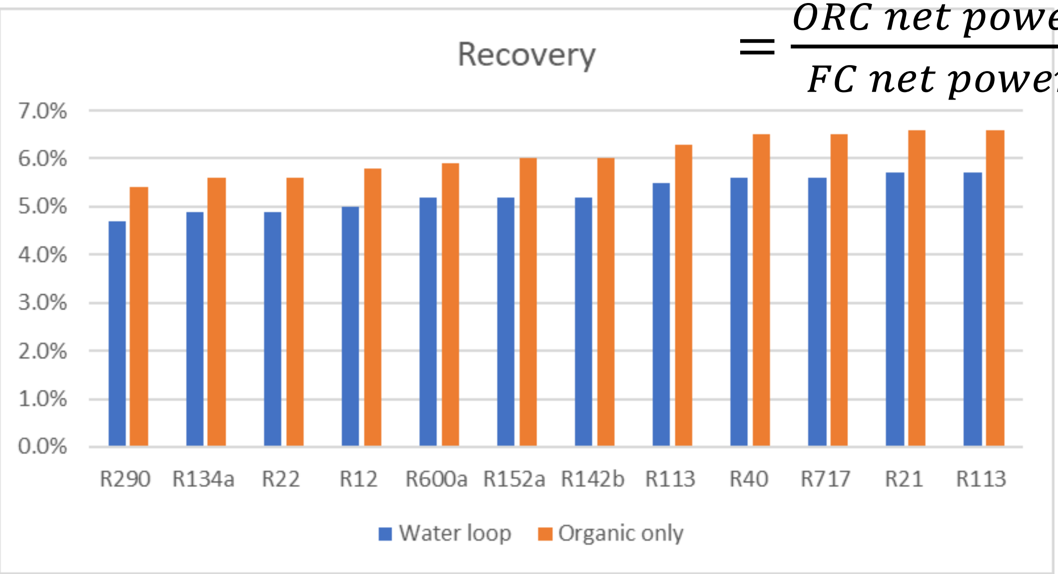
RESULTS

- R134a among worst
- ORC efficiency increase when intermediary water loop is removed
  - Re-design?
  - Material compatibility?
  - Electrical conductivity?
- Recovery:
  - Water loop 4.7 – 5.7%
  - Organic only 5.4 – 6.6%

$$\text{ORC Efficiency} = \frac{ORC\ net\ power}{FC\ waste\ heat\ power}$$



$$\text{Recovery} = \frac{ORC\ net\ power}{FC\ net\ power}$$



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  - Aaron Marshall
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- Technicians (especially David Cotton)