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OFFICE OF THE PRINCIPAL SCIENTIFIC ADVISER TO THE
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Confederation of Indian Industry

Electrolyser Technologies: Challenges and Opportunities

Theme: Hydrogen Production – Electrolysis & Biopathways

INTERNATIONAL CONFERENCE ON GREEN HYDROGEN 2023

05th - 07th July 2023, Vigyan Bhawan, New Delhi

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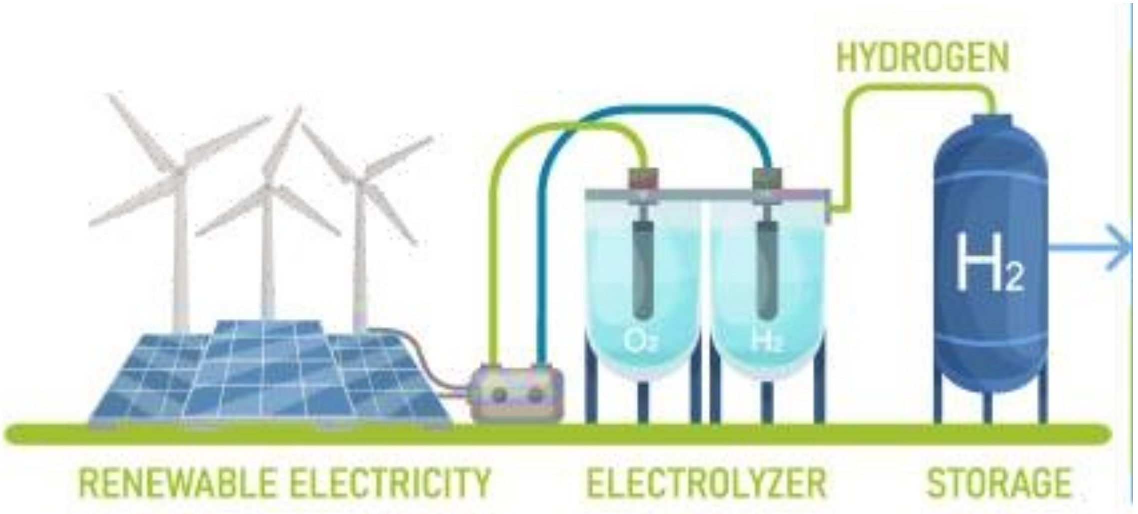
Council of Scientific and Industrial Research
Ministry of Science and Technology

Prelude: Outline & Scenario

Hydrogen Economy
Energy Transition
Affordable Green Hydrogen
World, India & CSIR



Transport
Industry
Energy

- Hydrogen generation pathways
- Electrolysis & Green H_2 generation
- Electrolyser Technologies: state of the art
- AEM Electrolyser technology: a case study
- Challenges and Opportunities
  - @ core level
  - @ system level
- Testing & Infrastructures
- Summary and Future

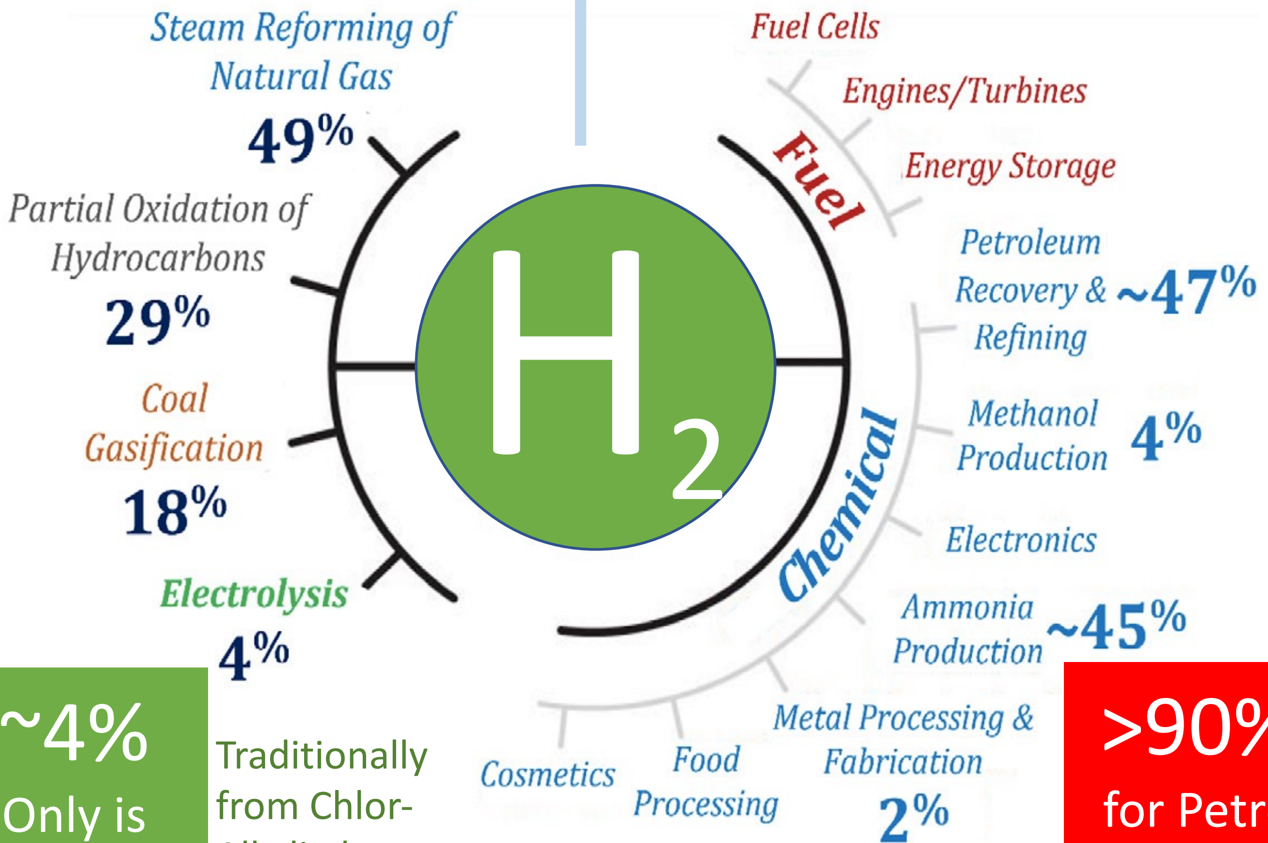
'Implementable Hydrogen Economy': The verticals

- **Phase-out fossil** fuels & Mitigate **climate change**
- **Low-carbon** economy
- Use hydrogen to decarbonize the **hard-to-electrify** sectors. eg., Steel, Cement, Transport
- **Develop** low cost H_2 **technologies**

  (**Electrolysers**, Storage, Fuel cells etc.)
- **Less polluting H_2 generation:** CH_4 pyrolysis or SMR **with CCS**
- **Push** earlier **energy transition**

Production

Consumption

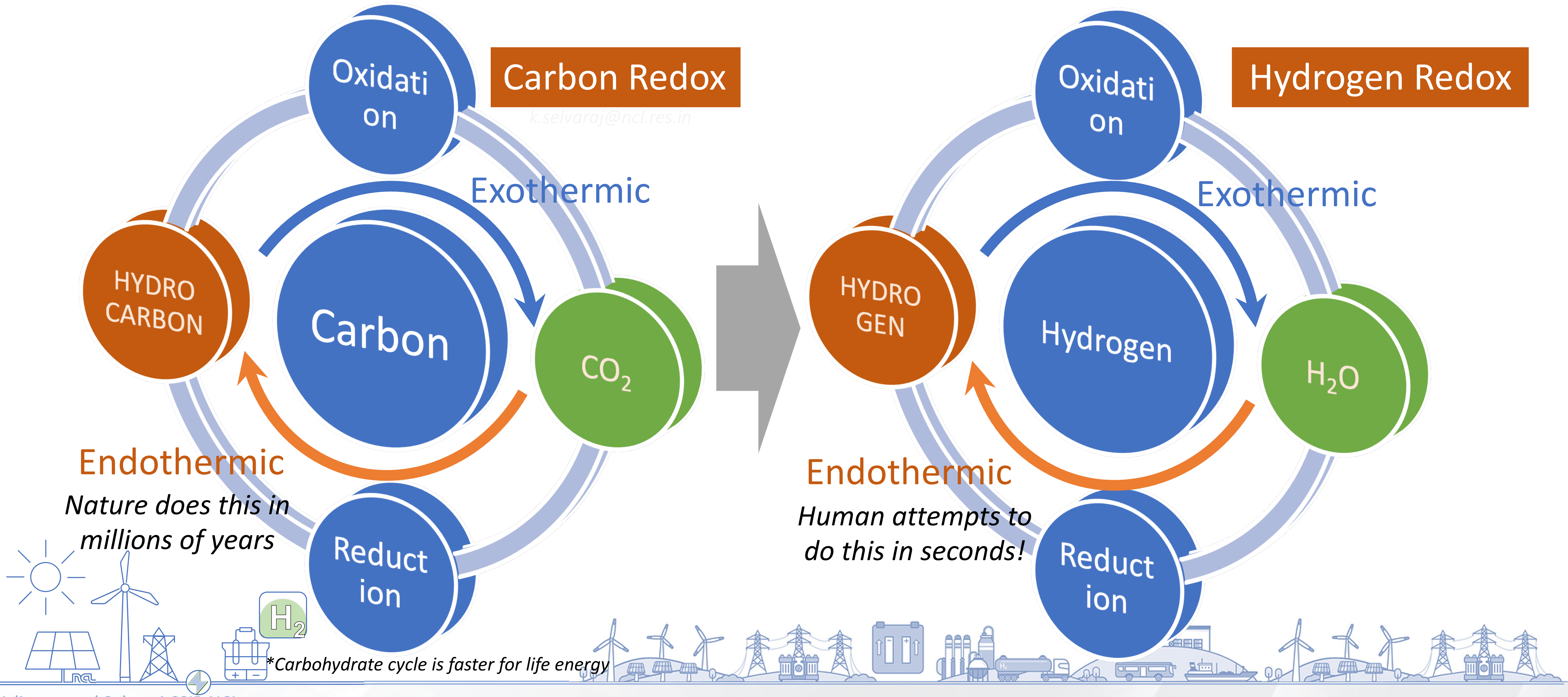


~4% Only is green

Traditionally from Chlor-Alkali plants

>90% for Petro & NH_3

Energy Transition: Simplified



*Carbohydrate cycle is faster for life energy

Hydrogen: Sustainable Generation and Projections

H_2	Generation	Source	Products	Cost $/kg	Emission CO_2
Brown	Gasification	Brown Coal (Lignite)	H_2+CO_2	1.2 – 2.1	High
Black	Gasification	Black Coal (Bituminous)	H_2+CO_2	1.2 – 2.1	High
Grey	Reforming	Natural Gas	H_2+CO_2 released	1.0 – 2.1	Med
Blue	Reform + CC	Natural Gas	H_2+CO_2 85-95% captured	1.5 – 2.9	Low
Green	Electrolysis	Water	H_2+O_2	3.5 – 5.8	Minimal

Level-play future

	2020				2050			
	Alkaline	PEM	AEM	SOEC	Alkaline	PEM	AEM	SOEC
Cell pressure [bara]	< 30	< 70	< 35	< 10	> 70	> 70	> 70	> 20
Efficiency (system) [kWh/KgH_2]	50-78	50-83	57-69	45-55	< 45	< 45	< 45	< 40
Lifetime [thousand hours]	60	50-80	> 5	< 20	100	100-120	100	80
Capital costs estimate for large stacks (stack-only, > 1 MW) [USD/kW_{el}]	270	400	-	> 2 000	< 100	< 100	< 100	< 200
Capital cost range estimate for the entire system, >10 MW [USD/kW_{el}]	500-1000	700-1400	-	-	< 200	< 200	< 200	< 300

IRENA 2020

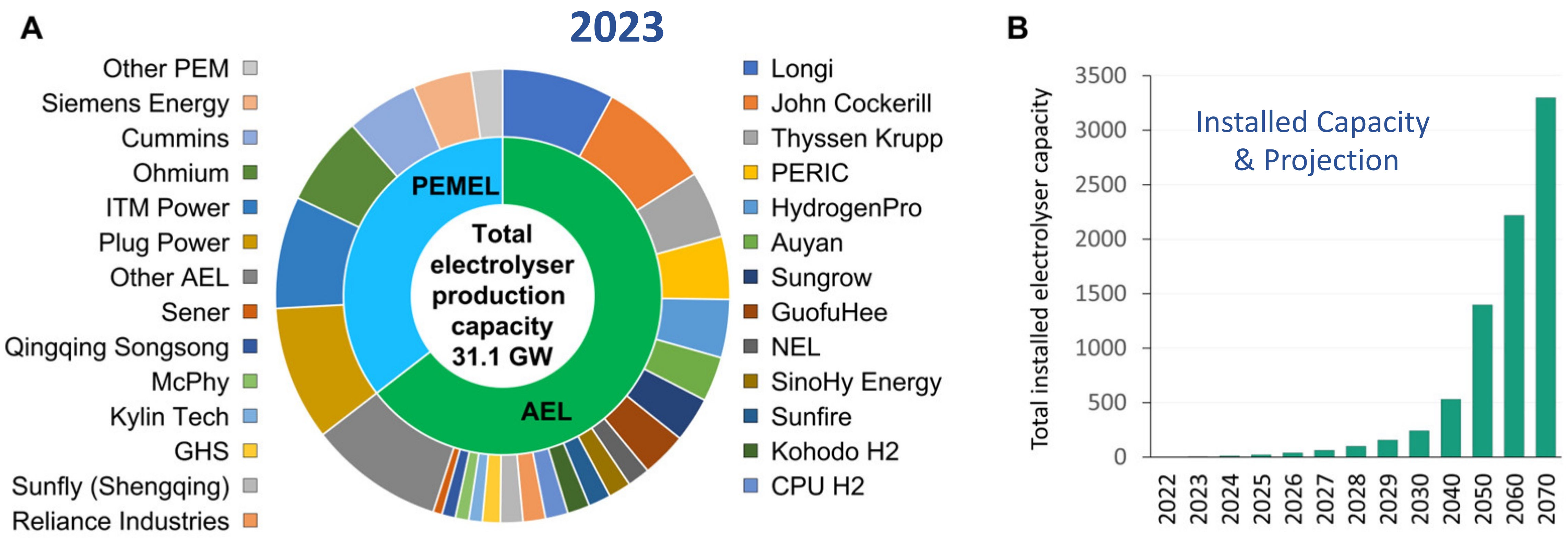
WE technologies

Electrolysis

- ALKALINE (AWE) – OH^-
- PEM (PEMWE) – H^+
- AEM (AEMWE) – OH^-
- SOE (SOEWE) – O^{2-}

Hydrogen Production: Typical Global Scene

Current electrolyser production capacity by type and manufacturers

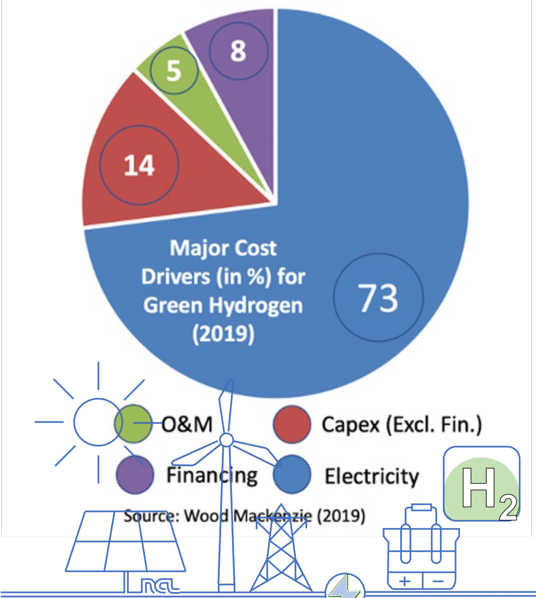


Energies **2023**, *16*(8), 3604

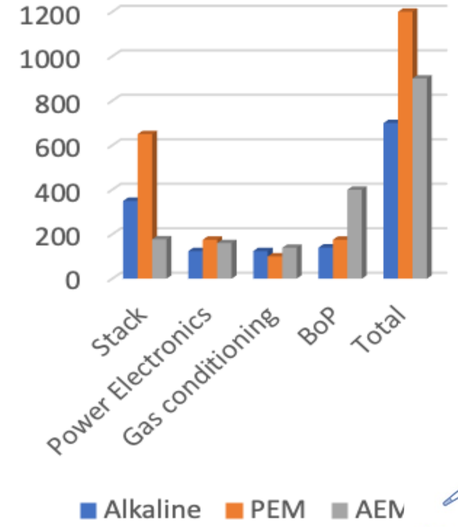
Electrolyser Technologies: State of the art

LT Electrolysis	Alkaline	PEM	AEM
Electrolyte	Aq. KOH (**40%**)	PEM (Nafion) + (**Acidic**)	AEM + **dil.KOH** (**<6%**)
Cathode	Ni, Ni-Mo alloys	**Pt,Pt-Pd**	**Non-precious metals**
Anode	Ni, Ni-Co alloys	**RuO2, IrO2**	**Non-precious metals**
Separator	Diaphram (ZP 500µm)	Nafion 117 (<100µm)	AEM (<50µm)
Cell voltage	1.8 - 2.4 V	1.8 - 2.2 V	1.8 - 2.2 V
Current density	**0.2 – 0.4 A/cm2**	0.6 – 2.0 A/cm2	**0.2 - 1.2 A/cm2**
Gas purity (vol%)	>99.5	>99.999	>99.99
Pressure (bar)	1-30	30-75	1-40

Main cost drivers : green H_2



Rough Cost USD @ 1MW
IRENA 2020b



CSIR's planned activity

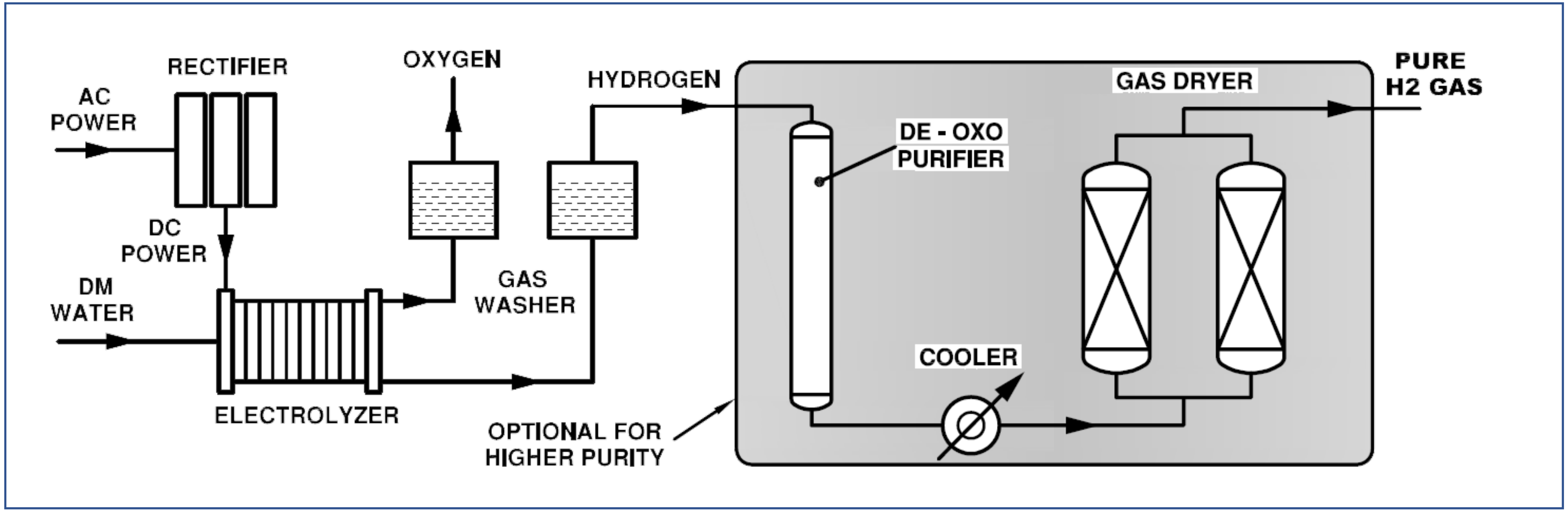
Collaborating with Industrial partners

State-of-the-art and future KPIs for all electrolyser technologies.

IRENA
International Renewable Energy Agency

	2020	Target 2050	R&D focus
	AEM electrolysers		
Nominal current density	0.2-2 A/cm²	> 2 A/cm2	Membrane, reconversion catalysts
Voltage range (limits)	1.4-2.0 V	< 2 V	Catalyst
Operating temperature	40-60°C	80°C	Effect on durability
Cell pressure	< 35 bar	> 70 bar	Membrane
Load range	5%-100%	5%-200%	Membrane
H_2 purity	99.9%-99.999%	> 99.9999%	Membrane
Voltage efficiency (LHV)	52%-67%	> 75%	Catalysts
Electrical efficiency (stack)	51.5-66 kWh/Kg H_2	< 42 kWh/Kg H_2	Catalysts/membrane
Electrical efficiency (system)	57-69 kWh/Kg H_2	< 45 kWh/Kg H_2	Balance of plant
Lifetime (stack)	> 5 000 hours	100 000 hours	Membrane, electrodes
Stack unit size	2.5 kW	2 MW	MEA
Electrode area	< 300 cm²	1 000 cm²	MEA
Cold start (to nominal load)	< 20 minutes	< 5 minutes	Insulation (design)
Capital costs (stack) minimum 1 MW	Unknown	< USD 100/kW	MEA
Capital costs (system) minimum 10 MW	Unknown	< USD 200/kW	Rectifier

Cost: System Technology – Integration & Engineering



AC-DC converters
Efficient rectifiers
Pumps
Heat exchangers

Gas leak detectors
Dryers
HP components
Accelerated tests

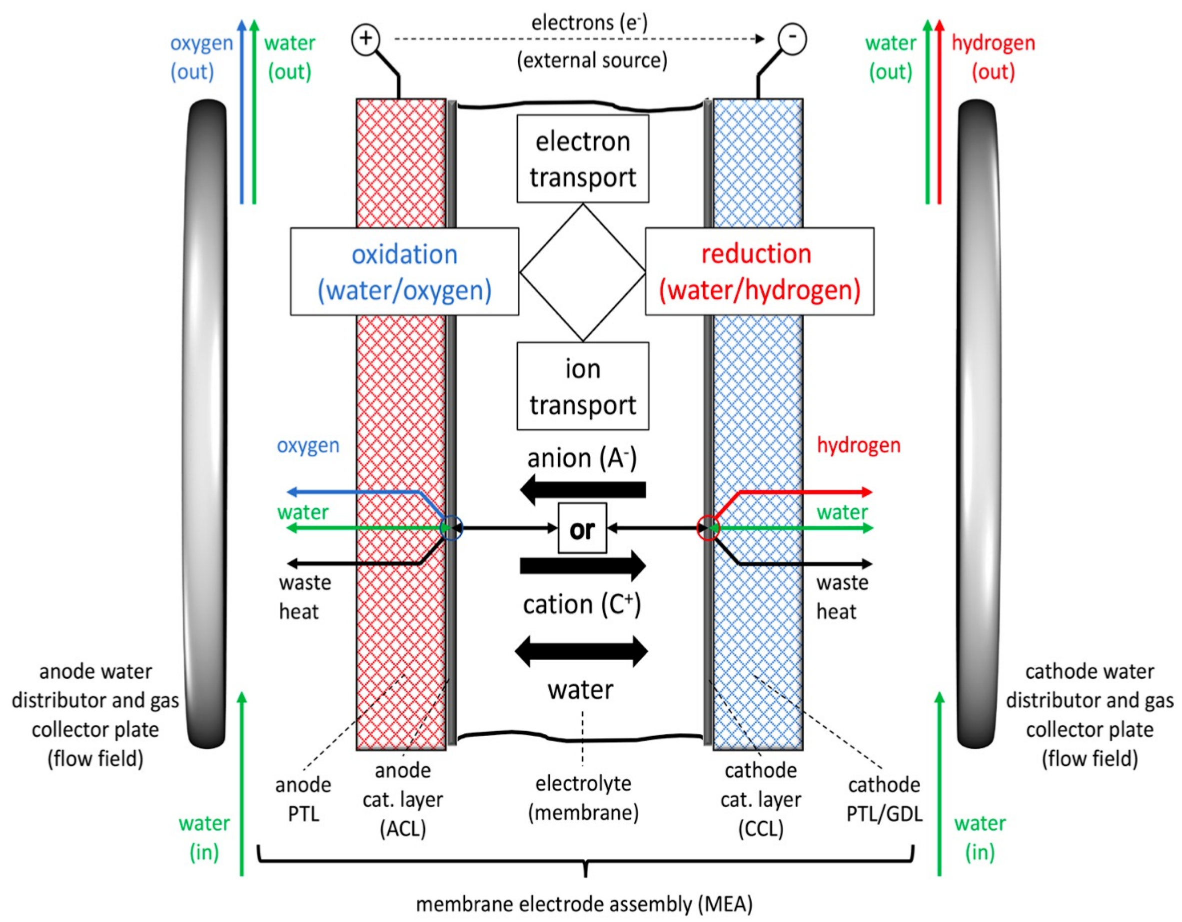
Efficiency influenced by component integration

Durability & Life are influenced by affordable MoC & op. conditions

India is fairly comfortable in BoP, Electronics etc.

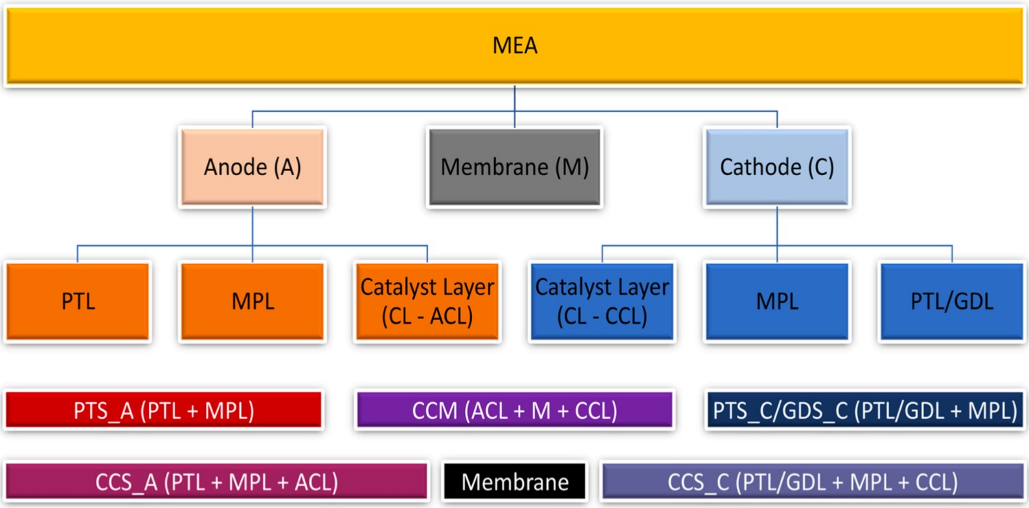
Cost: Core technology: R&D - cheaper & efficient component

Cell Structure



JACS Au 2021, 1, 527–535

Core Technology



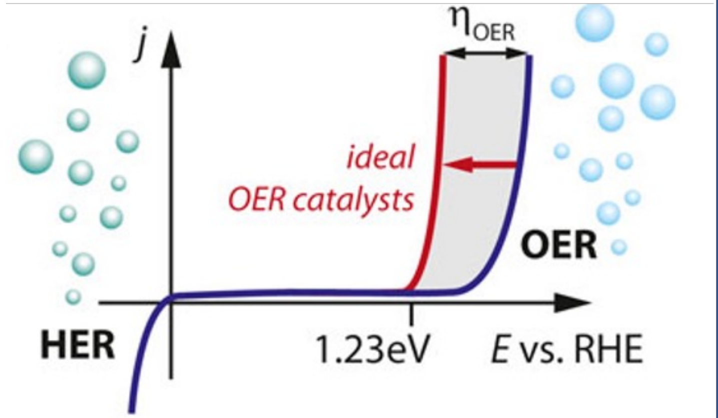
PTL, porous transport layer; **MPL**, microporous transport layer; **GDL**, gas diffusion layer; **PTS**, porous transport system; **GDS**, gas diffusion system; **CCS**, catalyst coated substrate; **CCM**, catalyst coated membrane.

Indigenization of core technology is critical for an Atmanirbhar Bharat

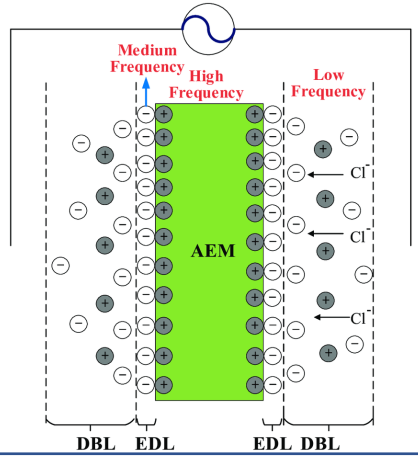
Cost: Stack Technology - Thermodynamics & Kinetics

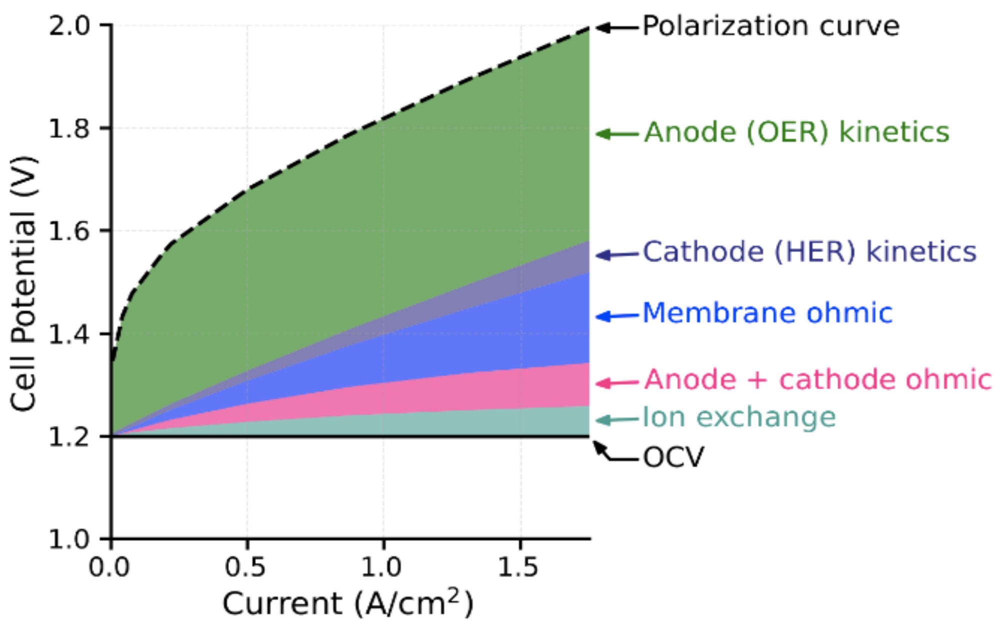
1 H_2O + Electricity (237.2 kJ mol−1) + Heat (48.6 kJ mol−1) → H_2 + ½ O_2 ~ 1.23 V

Overpotential & Electrolysis

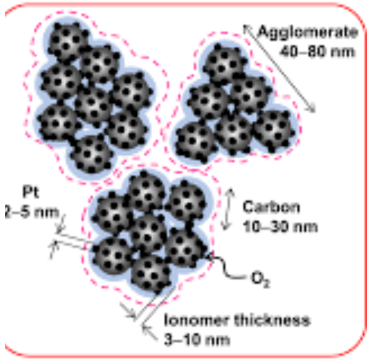


Membrane Conductivity





Triple-phase boundary



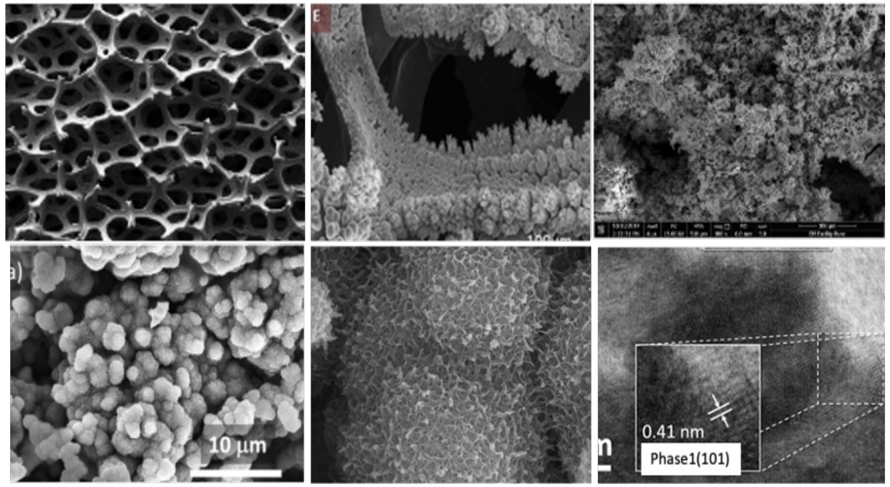
Efficiency influenced by components & their electrochemistry

Durability & Life are influenced by components & their stability

Immense scope for R&D, Game-changing potential

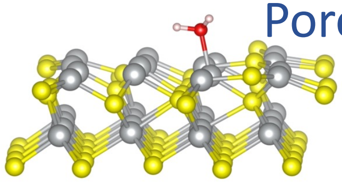
Cost: Stack Technology – Immense R&D opportunity

High performing durable non-PGM Catalysts

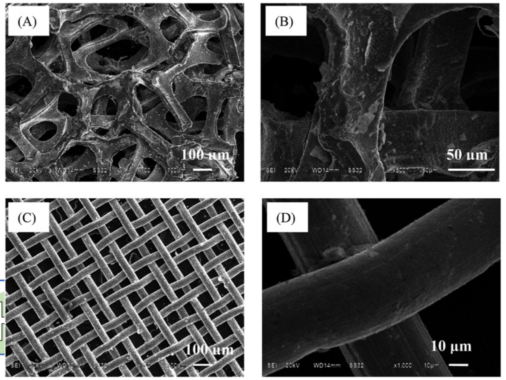


Multilevel hierarchically porous & rough catalysts

Porous metal electrodes/GDLs

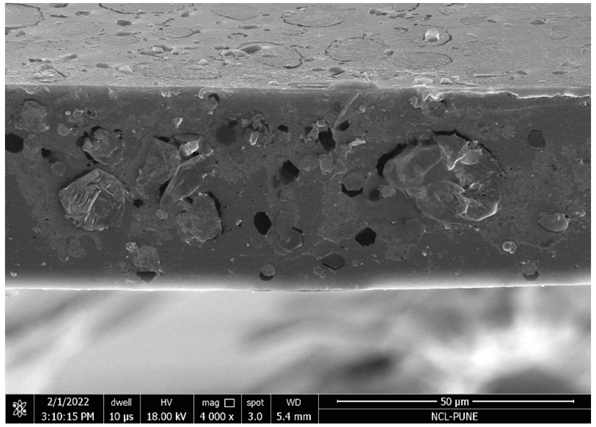


Computational catalyst design

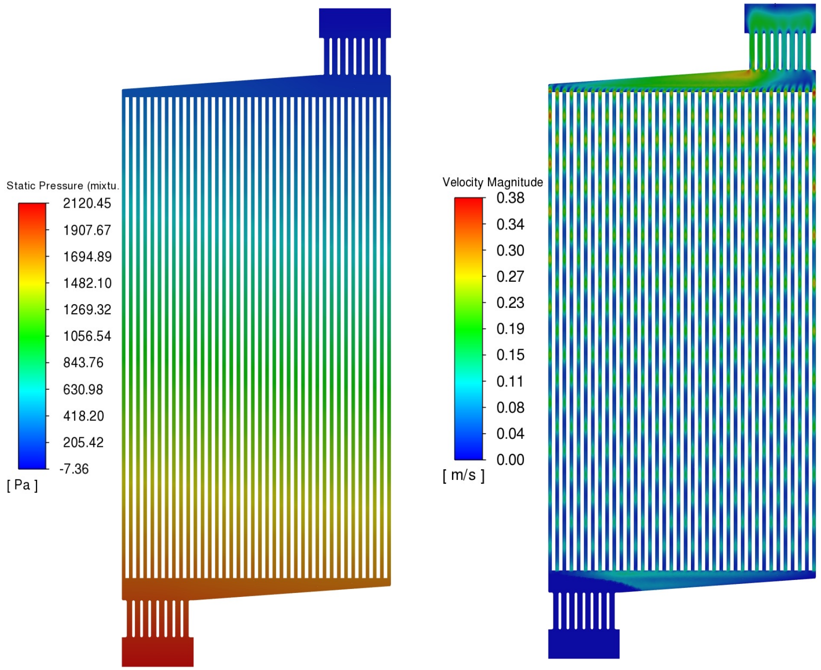


Mass production of membranes

High IEC AE Membranes



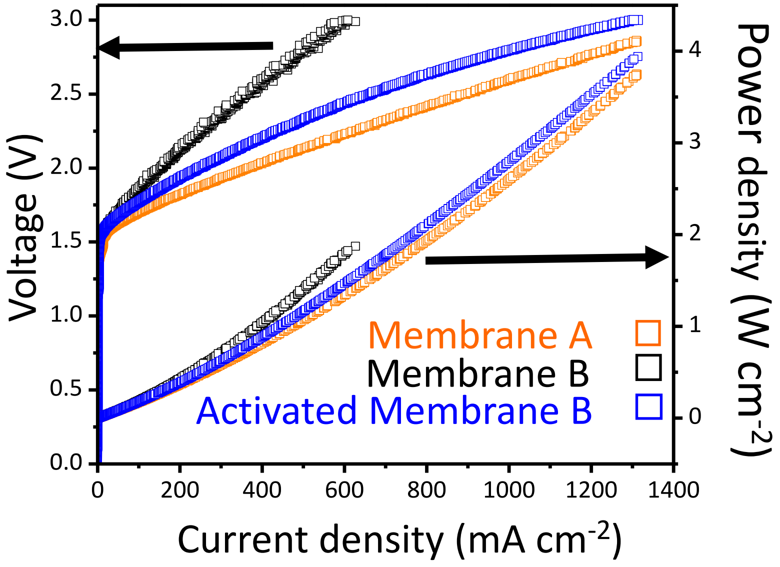
CFD simulation based improved flow fields

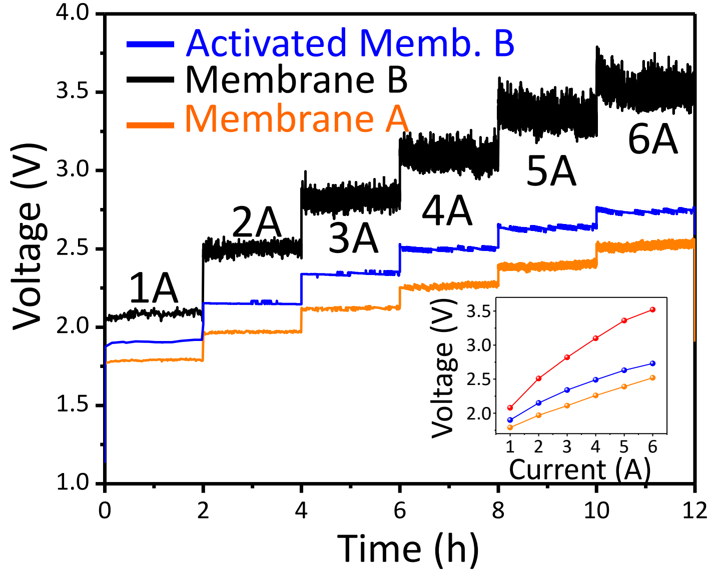


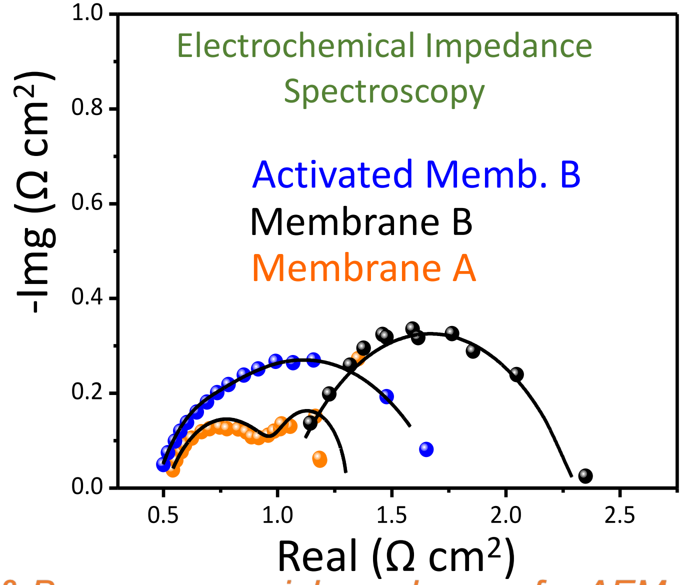
Improved fluid dynamics for better H_2 production

Membrane: Critical component

Catalysts: Ru/C v/s Pt/C @ Room temperature

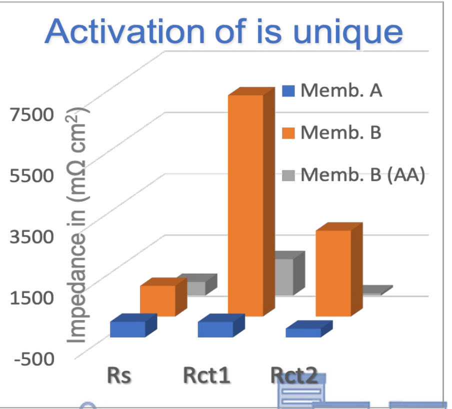


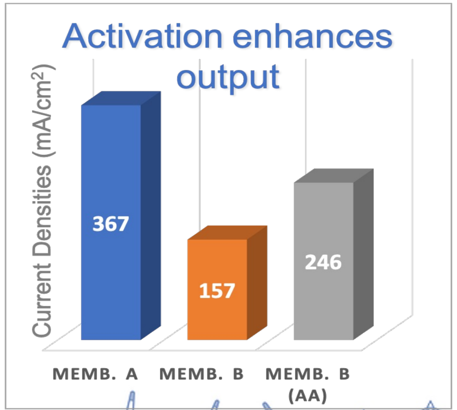




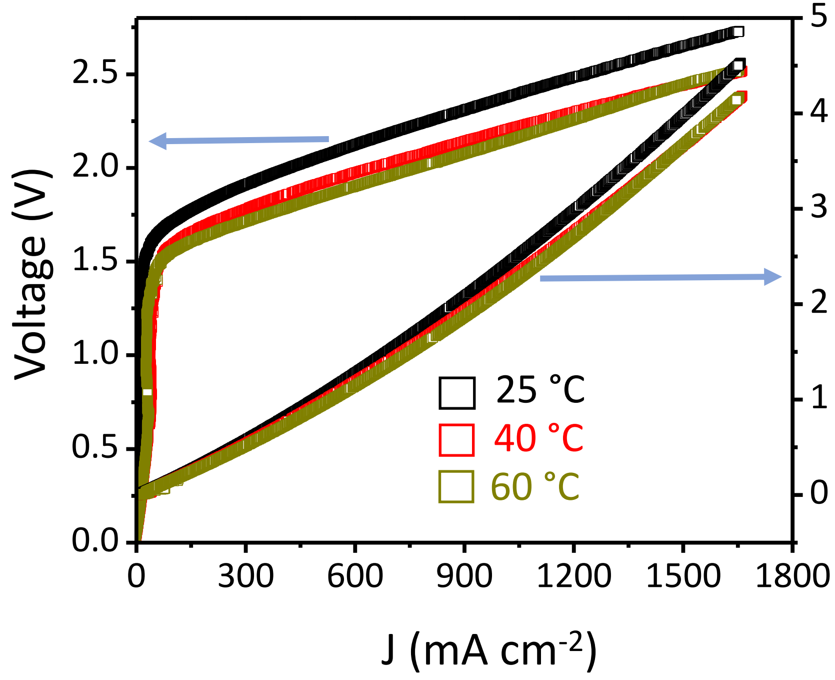
AEM	Typical activation protocol
Membrane A	1. 24h in 1 M KOH (Cl^- ions to ^-OH ions) 2. 5h heat treatment @ 55 °C
Membrane B	1. 24h in 1 M KCL (I^- ions to Cl^- ions) 2. 24h in 1 M KOH (Cl^- ions to ^-OH) (manufacturer's recipe)
Membrane B (After custom activation)	1. 30h in 1 M KCL (I^- ions to Cl^- ions) 2. 48h in 1 M KOH (Cl^- ions to ^-OH) (**CSIR NCL's recipe**)

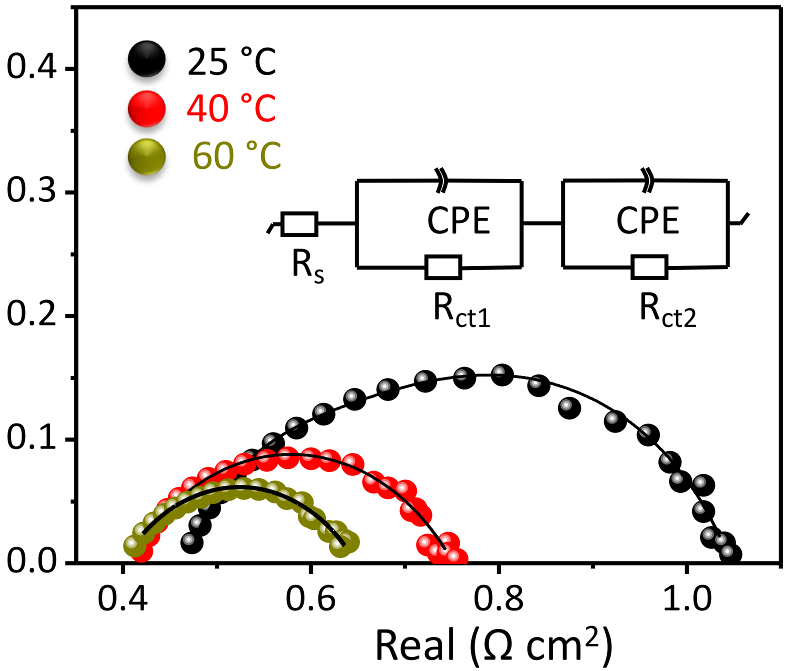
Membrane A & B are commercial membranes for AEM

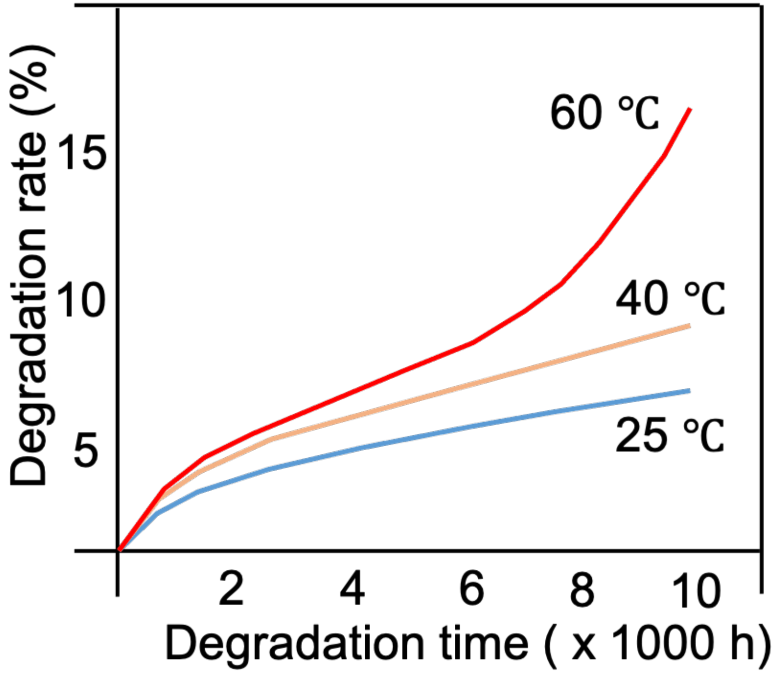




Operating conditions: Performance vs Life - Trade-off







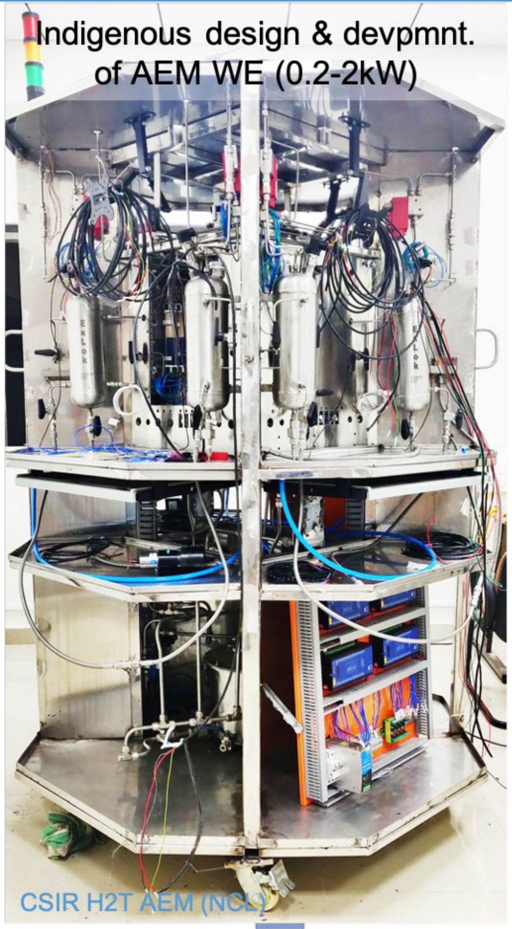
Example case in AEM

- Higher operating temperature enhances the IEC of the membrane and reduces the overpotentials
- Higher potential operation increases the hydrogen production capacity
- Higher operating temperature reduces the life of components and the electrolyser

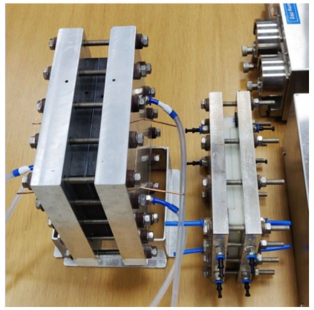
Challenges in testing R&D: Hydrogen Generation Tech.

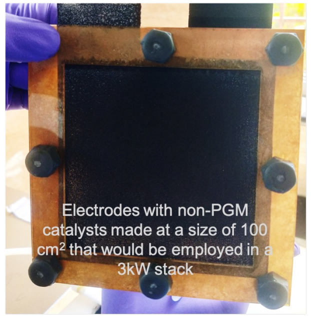
- A handful of international test station manufacturers
- Surging orders, long lead times, long queues
- India: No comm. electrolyser test station manufacturing
- TRL variations (PEM/AEM/SOE): unpredictable test-bench market
- R&D labs are forced to fabricate own test stations (extra load)
- Import dependency: components (EIS) & accessories
- Poor supply chain: components & consumables
- Expensive power supplies: AC-DC or DC-DC converters
- Affordable & reliable H_2 leak detection devices
- Lab Safety: Continuous & larger quantities of H_2 & O_2 generation
- H_2 Vent (demands flash arrestors / N_2 for dilution)

CSIR's first indigenous AEM Water Electrolyser



100 cm²
square cell





Challenges in testing manufacturing: Hydrogen Generation

- Testing hydrogen production at MW level needs new facilities
- Such facilities/protocols are unprecedented
- Key aspects: Electricity, Water, Gas analysis (H_2 & O_2)
- Large-scale utilities: Power supply (@MW scale)
- Low voltage (400V)-high current(2.5kA): needs new excl. safety
- Safety: Large quantities of H_2 & O_2 (H_2 sink)
- Large-scale gas flow: Limiting the range of MFM
- Testing cost: Affordable Electricity & Remunerated H_2 sink
- H_2 sink1: Cold Vent (demands 24X of N_2 for dilution)
- Venting large H2 is eventually not feasible (GWP of H_2 is 5.8)
- H_2 sink2: Flare (to be alive, demands CNG: emissions & soot!)
- H_2 sink3: Captive consumption FC (high CAPEX, H2 purity!)
- H_2 sink4: Chemical industry via pipeline (CAPEX, purity!)

Electrolyser test field at the Hydrogen Lab Leuna. (1) Concrete slab for placing devices under testing (DUT), (2) safety cold vent, (3) connection to Linde H_2 pipeline as H_2 sink, (4) medium-voltage power supply, (5) programmable logic controller and control room interface, (6) individual utility interface (IUI). Insert: Close-up of the IUI. (7) H_2 and O_2 analysis, (8) N_2 supply, (9) compressed air suplly, (10) H_2 product output, (11) process water supply, (12) deionized water supply, (13) low-pressure steam supply. © Fraunhofer IWES.

- Location of test facility: Non-residential (Explosion Safety)
- TRL-based test variations: 'One-size-does-not fit all'
- AWE, PEM, SOEL, PC, PEC, AEM

Summary & Future

- Affordable electrolyser technology development is key to realizing Energy Transition
- Apart from affordable renewables, R&D at core technology is critical to reducing LCOH of H_2
- India should focus on building R&D infrastructure & testing capabilities
- Component development and manufacturing are keys for India to be self-reliant in H_2 generation & export
- AEM seems to be a game changer in electrolyser technology; Focused activity will help to realize it.
- Setting safety & standards will boost the tech. development and market penetration
- Incentivizing PPP mode tech development will help to fill up the 'Valley of Death' in mid-range TRLs
- The global electrolyser industry is set to grow exponentially, and India should not miss the bus.

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THANK YOU

For kind attention

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