Current Challenges & Opportunities in Sea Water Electrolysis

delivered at

Japan-India Pilot Symposium towards De-carbonisation of Global South

by

Professor A. S. K. Sinha, *Director*
Rajiv Gandhi Institute of Petroleum Technology
Jais, Amethi
&
Umaprasana Ojha, Professor
Indian Institute of Technology Bhubaneswar

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Abstract

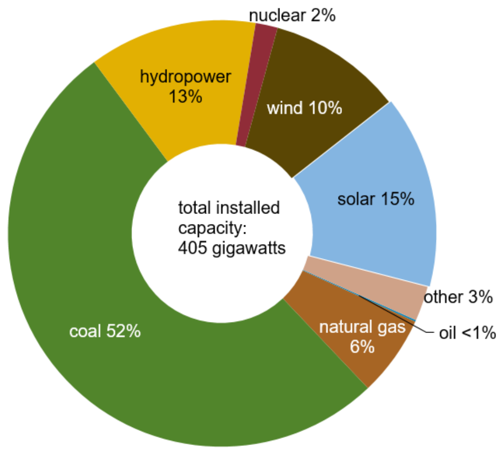
Alternative avenues to supplement the energy needs of the society and at the same time ensuring zero carbon emission is essential to realise the global decarbonization drive.

Among the various green sources of energy given due consideration, green H2 is gradually emerging as the most promising owing to its high energy density and availability of multiple processes such as electrochemical, photochemical, and thermal procedures of generating the same.

This presentation emphasizes the affordable and viable production of green H2 from sea and low grade water sources to facilitate the decarbonization drive.

Importance of H_2 Energy in Context of Decarbonisation

Current principal energy sources in India



Data source: India Ministry of Power

Statistics

Source	Energy Generated	CO_2 Evolved
Coal	1.14 kWh/lb	2.4 lb/lb*
H_2	14.97 kWh/lb	Nil

*500 MW coal plant will produce 10 billion lb/year

Energy Information Administration, Quarterly Coal Report, January-April 1994, DOE/EIA-0121(94/Q1

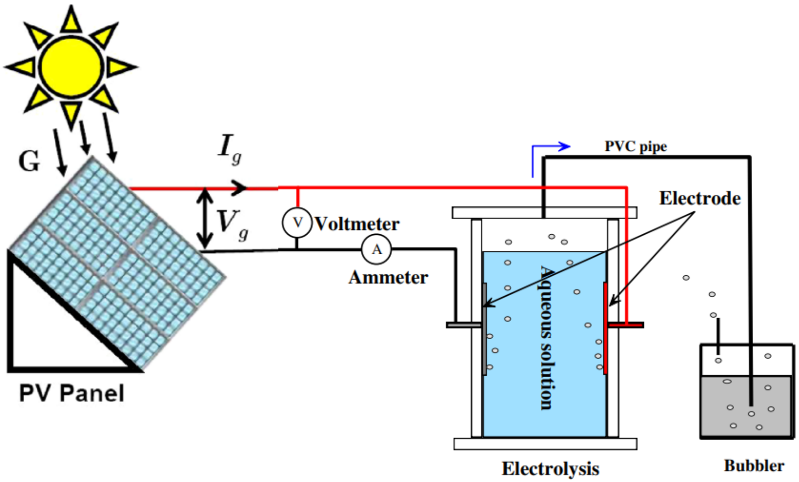
Hydrogen by Electrolysis of Water

$$H_2O + \text{Electric Energy} \rightarrow H_2 + \tfrac{1}{2} O_2$$

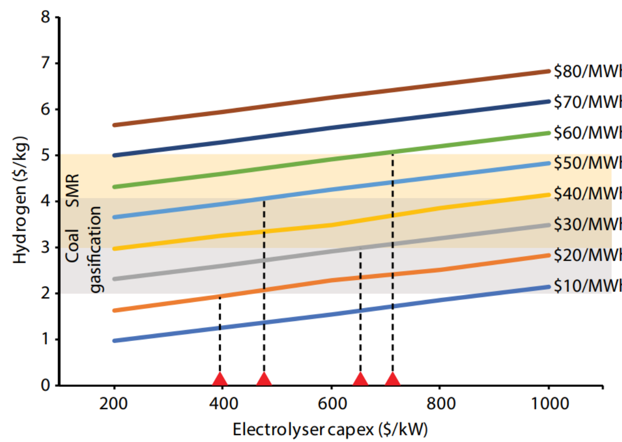
- Most large commercial electrolysers are based on alkaline electrolysis and operate with aqueous electrolytes containing 30% KOH which gives the maximum ionic conductivity, at operating temperatures between 70 – 90 deg C and approximately 30 bar.
- In recent years commercial development has actively focused on an acid electrolyte, typically using a solid polymer electrolyte and not an aqueous electrolyte. This enables a compact and higher efficiency system.
- In more recent years, two other very promising electrolyser technologies have been under investigation for hydrogen production: the alkaline polymer membrane and the high temperature solid oxide or similar ceramic based cells.

Green H_2 by Definition & Economic Viability

The feedstock and utilized energy sources to be green
The whole process to be carbon neutral

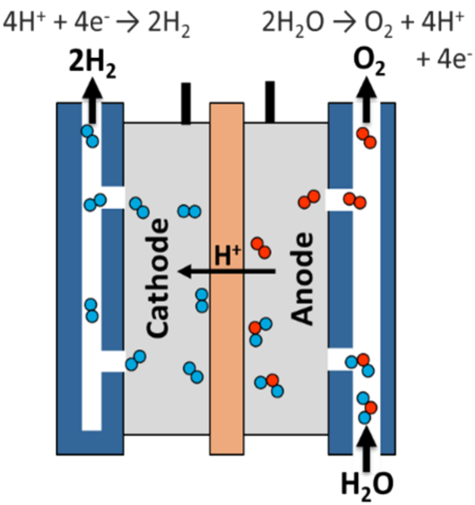


Balabel et al 10.1007/s13369-014-1050-6

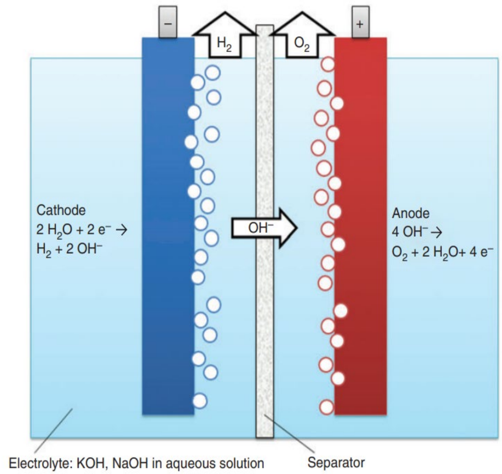


Commercial Electrolyzer Technology

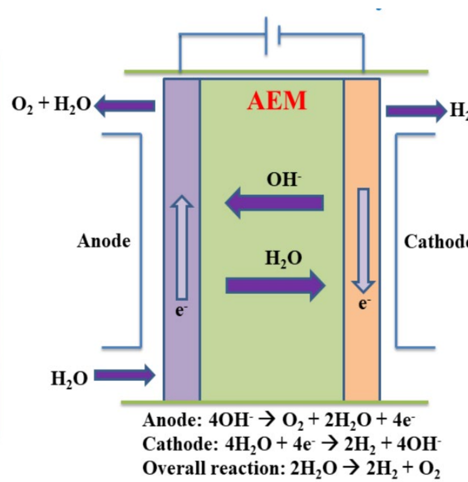
Polymer Electrolyte Membrane (PEM) Electrolyzer



Alkaline Electrolyzer

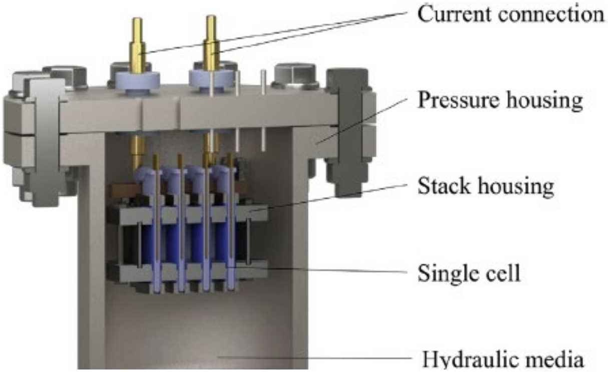


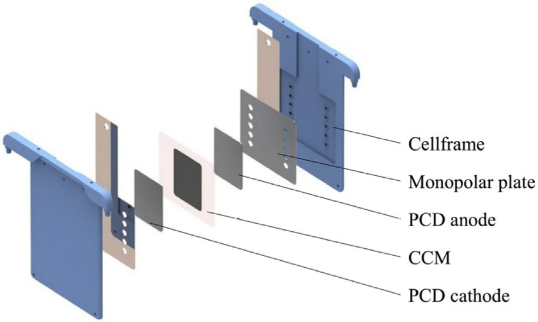
AEM Electrolyzer



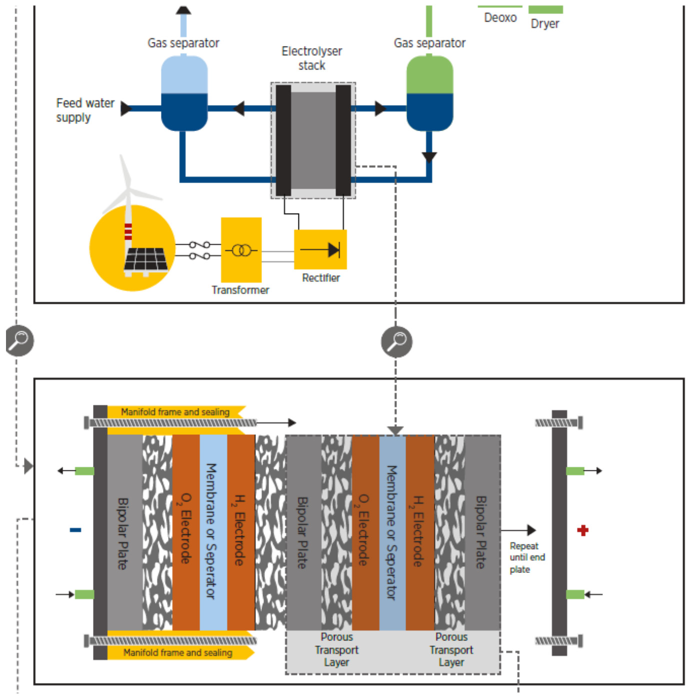
Modular Arrangement in Commercial Electrolyzers

PEM





Alkaline



Challenges in Green H_2 Commercialization

- Feedstock

Potable water is not affordable: Consumption (India): ~7.9 x 10^8 L/day

Sea water is realistic feedstock for sustainable production

Electrode material: Ni is scarce, SS or Fe based systems are preferable

Cost of H_2: 1-2 $/kg H_2

Electricity: Solar

- System (Alkaline Electrolyzer)

Membrane disadvantageous: Fouling in sea water and clogging with hard salts

Electrode degradation in saline water: Halide resistant electrodes desirable

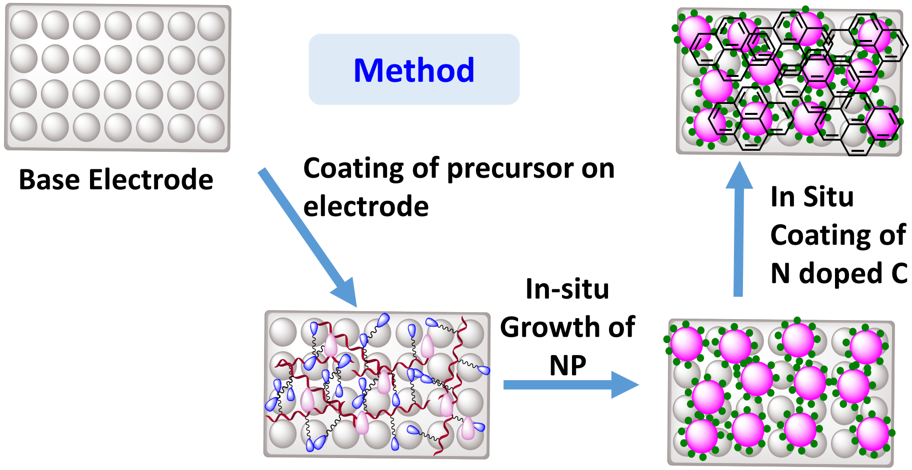
Stagnant electrolyte: Accumulation of particulates and ions

Flow system desirable: To regulate the pH, concentration of ions and facilitate output purity

Solution:

Membrane less flow through modular electrolyzer system with Cl- resistant electrodes

Design & Fabrication of Catalyst Coated Electrode: Innovation



Characteristics

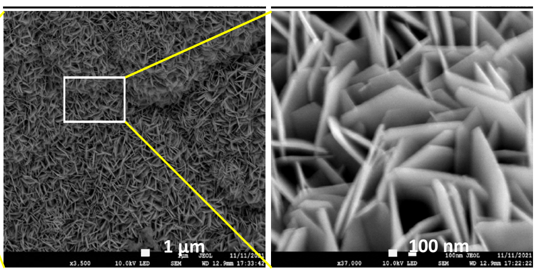
- Nitridation/phosphidation induces porosity
- Conductive N@C aids conductivity & selectivity of OER over CER
- In-Situ growth aids bonding between support and catalyst
- Ni-3d and N-2p orbitals overlapping aids conductivity
- The non-metals formed the corresponding oxide anion (NO_3^-, PO_4^{2-}, SO_4^{2-}) and repelled the corrosive ClO- ion

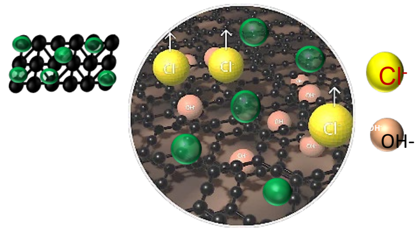
Electrode Development for Sea Water Electrolysis

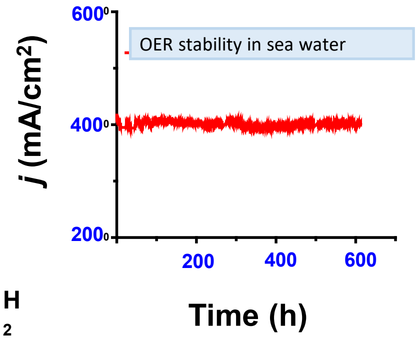
Feedstock: Sea water

Cl^- resistant Electrodes

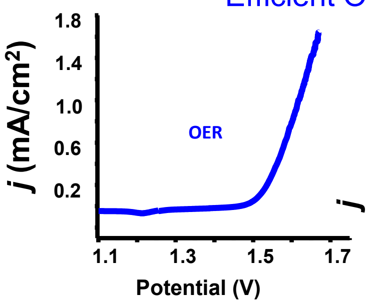
Nano Arrays: High surface area

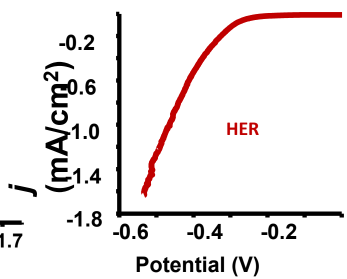


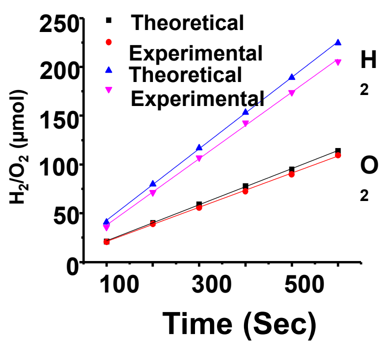


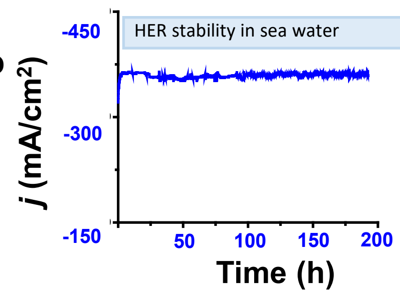


Efficient OER/HER activity









Indian Patents Filed

Current State of the Art: Electrode Development at RGIPT

Electrodes for sea water electrolysis

Catalyst Systems	OER (A/cm²) (Overpotential, V)	HER (A/cm²) (Overpotential, V)	Project
$Ni(OOH)_2$-NiNx@CN NF	0.6/0.35	-0.4/0.55	NTPC
CoNi-$Fe(OOH)_2P_x$ NF	0.4/0.37	-0.4/0.30	NTPC
(Zn-Fe)Nx@CN NF	1.0/0.67	-1.2/0.65	DST
(Co-Ni)N_xCN NF	1.5/0.27	-0.6/-0.50	DST
$Fe(ON)_y$-NiN_x@NC NF	1.5/0.20	-1.5/0.13	DST
(Fe-Co)S_x-NF*	1.0/0.22	1.0/0.45	DST

The electrodes are bi-functional in nature, Electrolyte: 2 M KOH in simulated Sea water

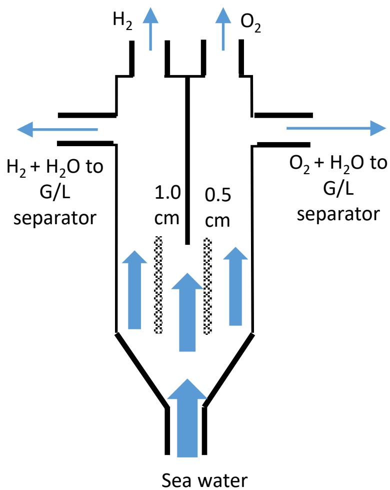
*Catalyst synthesized at 50 °C under hydrothermal condition

Membraneless Flow Through Electrolyzer

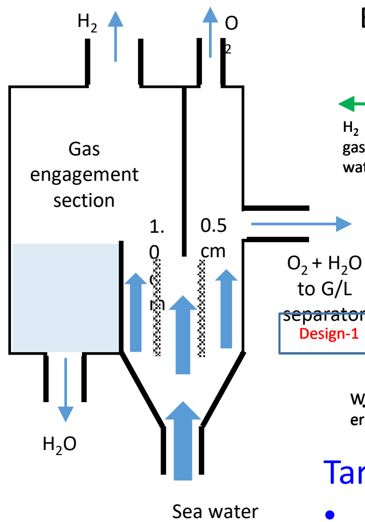
Operating parameters:
Concentration of alkaline water: 4M KOH
T = 60°C, P = 1 atm
Electrode area = 5 x 4 cm^2
H_2 prod. Rate = 2 L/hr
Electrolyte flow rate = 0.5 L/min

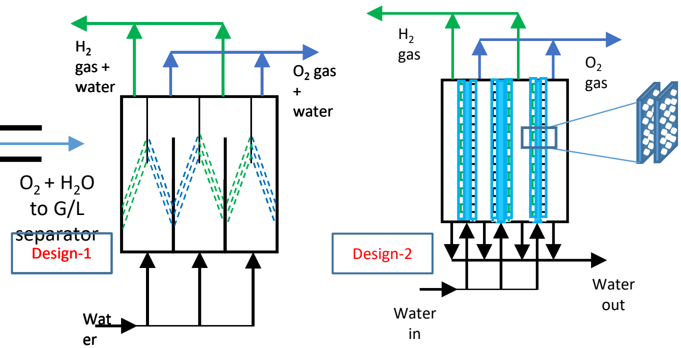
Schematics of Core Set up

Model – 1



Model - 2



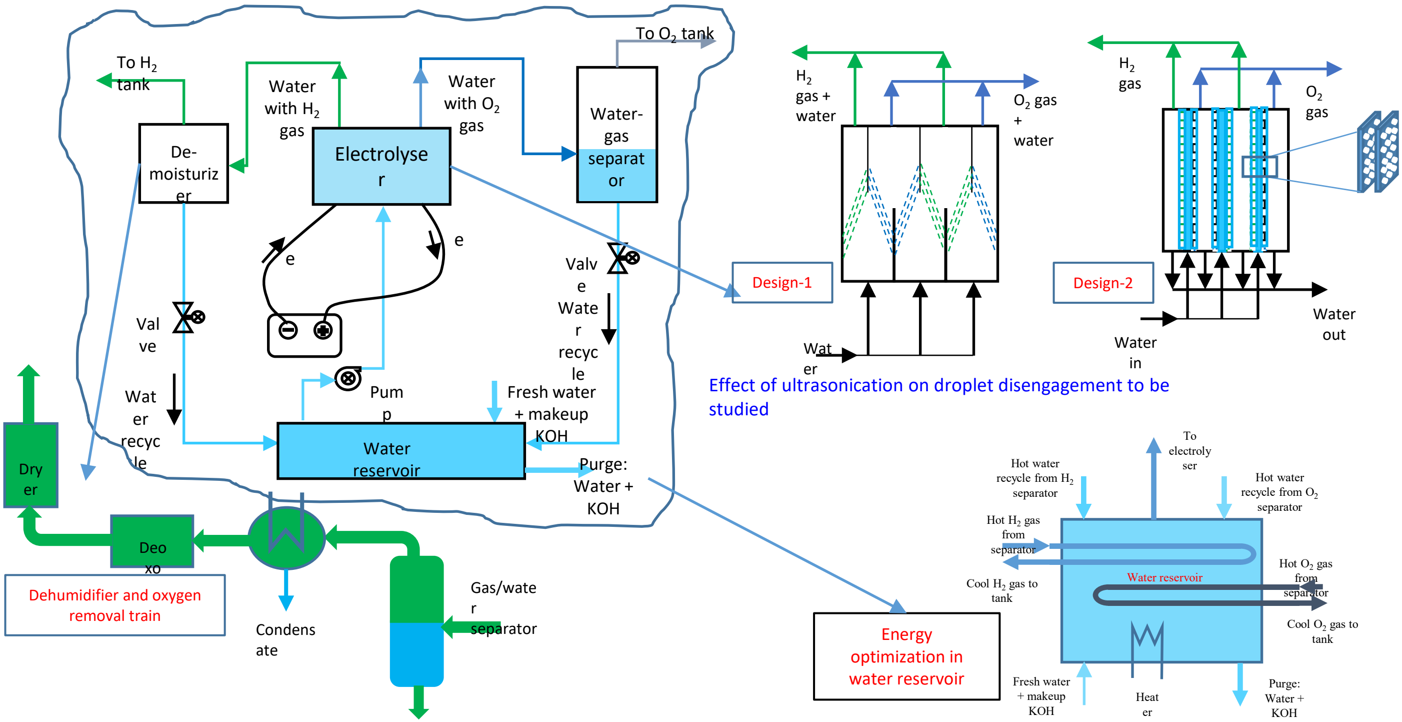


Results:
H_2 purity > 99.9%
%H_2 in O_2 gas = <2%

Target (Complete Set up)

- 200 sL/day : 5 months
- 3200 sL/day: 10 months (0.3 kg/day H_2)

Our Membrane less Design



Key Performance Indicators

Parameter	PEM	AEM	Alkaline	SOE	Our Design
Current Density	1-2 A/cm^2	0.2-2.0 A/cm^2	0.2-0.8 A/cm^2	0.3-1.0 A/cm^2	0.4-1.0 A/cm^2
Pressure	<30 Bar	<35 Bar	<30 Bar	1 Bar	1 Bar
Temperature	50– 80°C	40-60°C	70-90°C	700-850°C	40-60 °C
Potential	1.4-2.5 V	1.4 – 2.0 V	1.4–3.0 V	1.0 – 1.5 V	1.5-2.5 V
Electrode Area	1500 cm^2	< 300 cm^2	1 – 3 m^2	200 cm^2	150-900 cm^2
Voltage Efficiency	50 – 68%	52 – 67%	50 – 68%	75 - 85%	65-75%
Electrical Efficiency (Stack)	47-66 kWh/kg H_2	51.5-60 kWh/kg H_2	47–80 kWh/kg H_2	35-40* kWh/kg H_2	40-67 kWh/kg H_2
Capital Cost	1182 $/kW	Unknown	1268 $/kW	> 2200 $/kW	900 $/kW

* Electrical efficiency only, thermal energy consumption is high

Thank You