Development of Alkaline Water Electrolyzer Technology at BARC for Green Hydrogen Production

Dr. Sandeep K C
Process Development Section
Heavy Water Division
Chemical Engineering Group
BARC, Mumbai
Email: sandipkc@barc.gov.in

24th June, 2022

आज़ादी का अमृत महोत्सव

TECHNOLOGIES FOR NEW INDIA@75

Azadi Ka Amrit Mahotsav

INDIAN INSTITUTE OF CHEMICAL ENGINEERS ESTD. 1947

राष्ट्र की सेवा में परमाणु
भा प अ कें BARC
ATOMS IN THE SERVICE OF THE NATION

Seminar on Production & Use of Green Hydrogen and Green Ammonia in Process Industry

GREEN HYDROGEN

Solar

Wind

Hydel

WATER ELECTROLYSIS

GREEN HYDROGEN

BLACK HYDROGEN

GREY HYDROGEN

BLUE HYDROGEN

INDIA	**H_2:** 6 million MT/yr	**CO_2:** 60 million MT/yr

Natural Gas Import Dependency	**% Import**	**Import Value**
	53 %	9.5 billion USD

Decarbonisation of sectors

Reduce Feedstock Import Bills

Address Climate Change Issue

Promote Energy Security & Self-Reliance

Ref: National Hydrogen Energy Mission (NHEM) Report, International Energy Agency (IEA)

BARC Activities for water splitting

Nuclear Power

Electricity

Electricity + Heat

Heat

Water Electrolysis

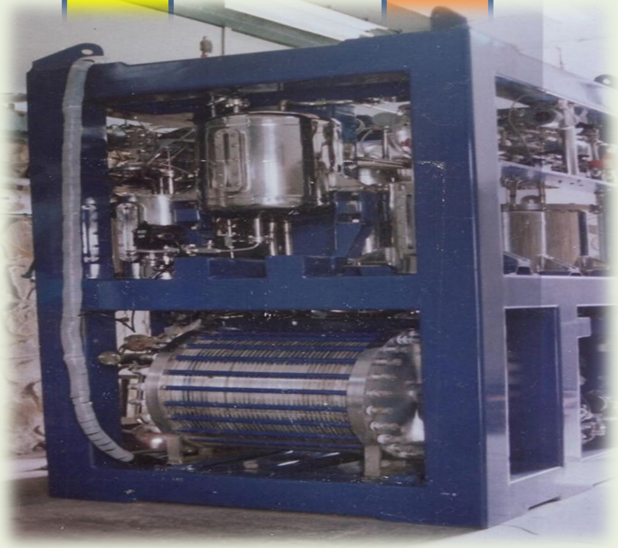
Steam Electrolysis

Thermo Chemical Cycle

LOW TEMPERATURE WATER ELECTROLYSIS

Hydrogen

Oxygen

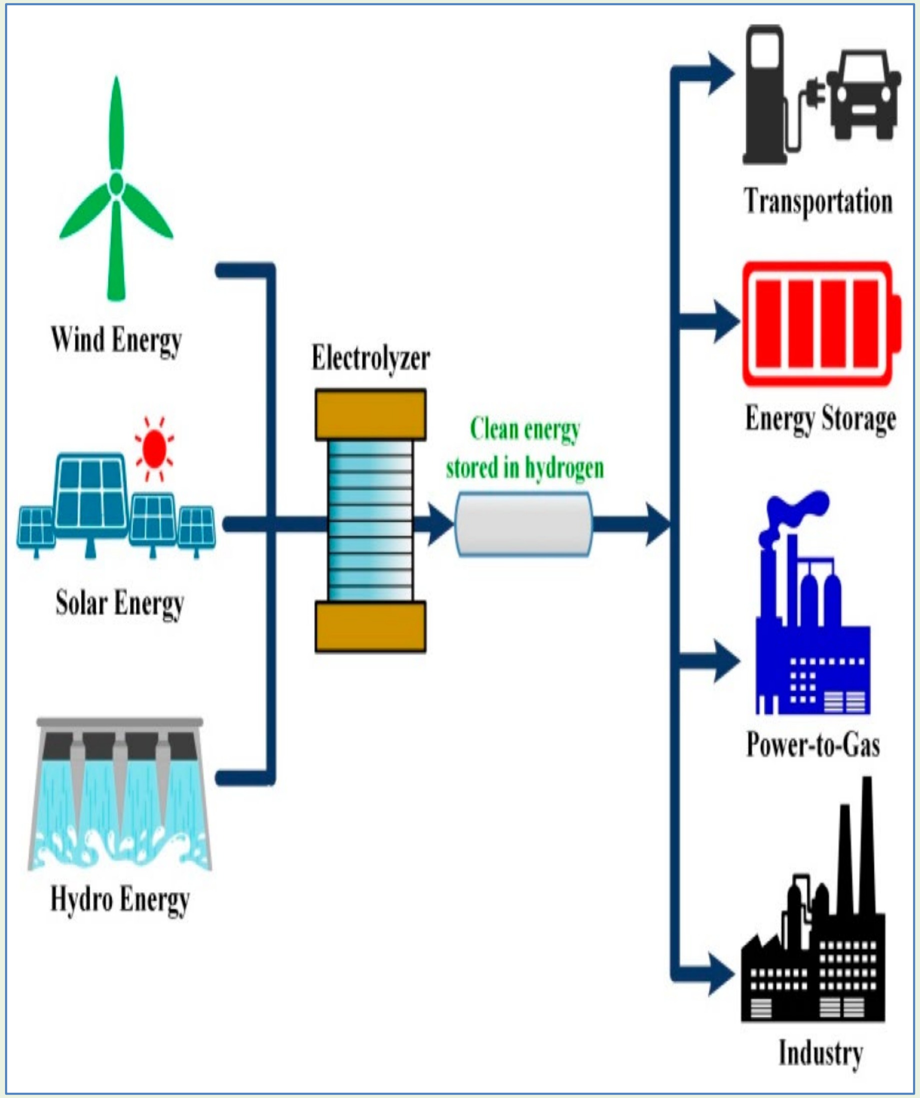


Water

DC Electricity

Ideal Scenario for Low Temperature Water Electrolysis

- ✓ Produces high purity H_2 & valuable O_2 by product in a single step
- ✓ Operates at ambient conditions
- ✓ No CO_2 emission
- ✓ High turn down ratio (20 to 100%)
- ✓ On demand, On site H_2 production
- ✓ Centralized and decentralized source of hydrogen
- ✓ Modular Scalability
- ✓ Commercially matured; but imported.



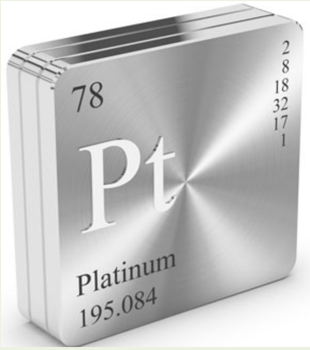
APPROACH

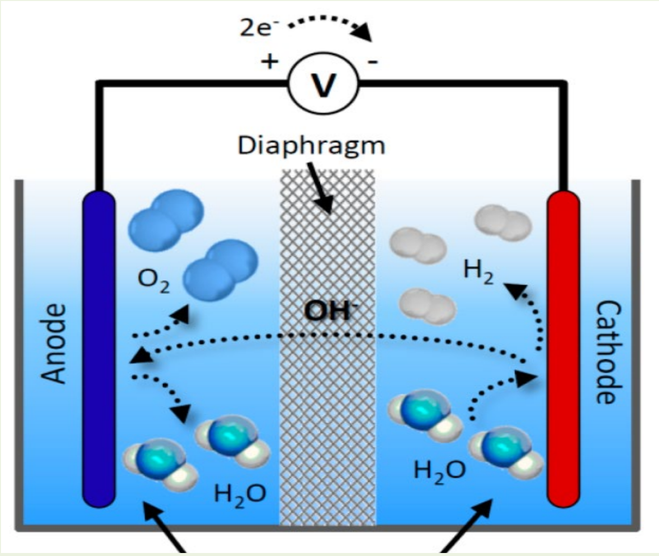
- Current density and cell voltage mainly depends up on the following
- **Electrode material**:-

Steel

Nickel

Platinum



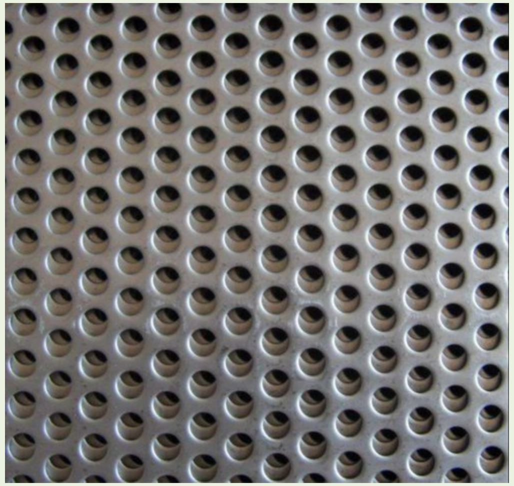


- **Type of electrode configuration**:

Plate Type

Extended surface

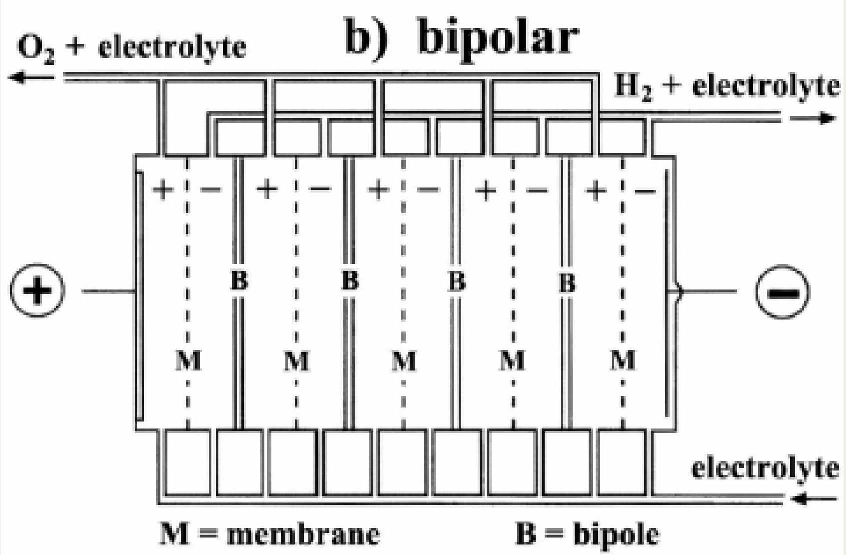
Porous electrodes

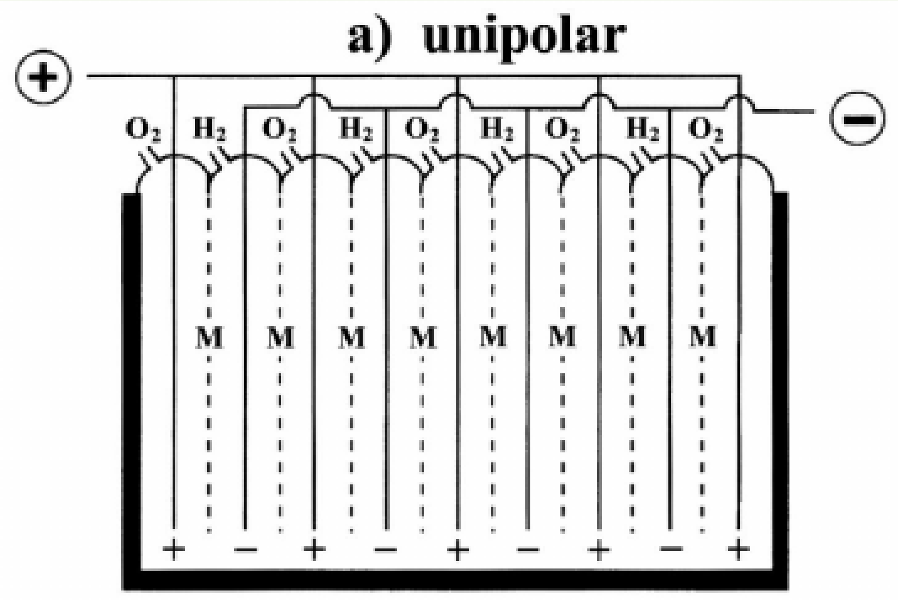


Perforated electrodes

APPROACH

•**Electrolyzer design :** – Bipolar / Unipolar





Ref : https://doi.org/10.1590/S0100-40422013000800017

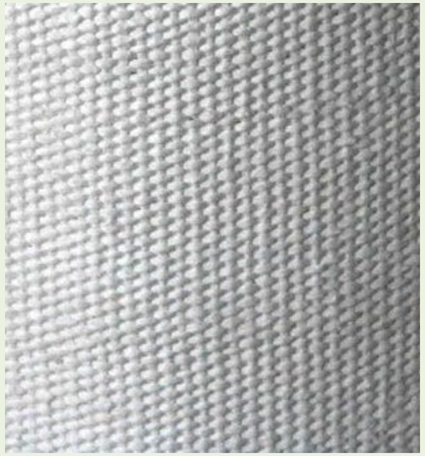
•**Electrolyzer design :** Filter press type

Ref: https://www.mvsengg.com/products/hydrogen/pure-hydrogen/

Tank Type

APPROACH

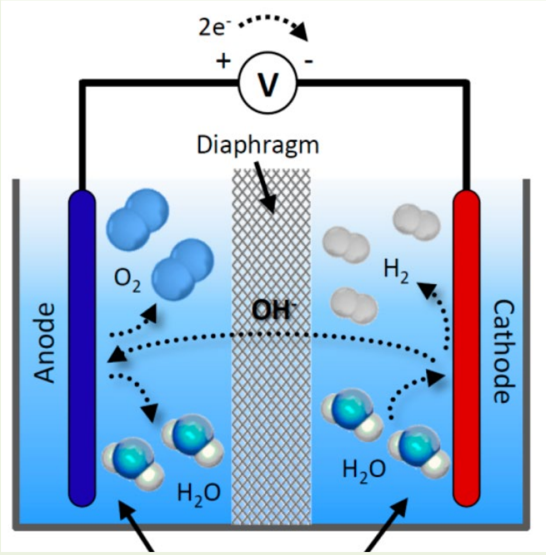
•<u>Diaphragm materials</u>: - Inorganic/ Organic/ Anion exchange



Asbestots

Polysulfones

Anion exchange membrane



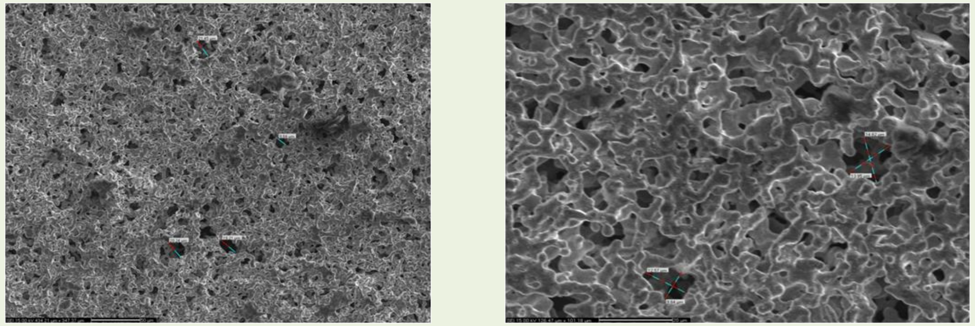
✓Nickel was a cost effective option with favourable kinetic properties and appreciable corrosion resistance towards alkaline medium

✓According to literature use of Porous Ni electrode increased current density to up 10000 ASM, thus making cell module more compact for portable applications

✓Bipolar design was selected to reduce ohmic losses and hence increase efficiency

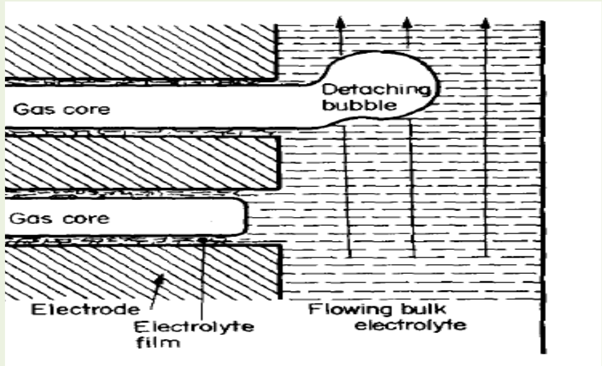
✓Asbestos was used due to its high ionic conductivity leading to lower ohmic drop

POROUS NICKEL ELECTRODE DEVELOPMENT AT BARC



SEM Photograph of electrodes

Finished Porous Ni electrode



Gas flow in porous electrode

•Heavy Water Division, Chemical Engineering Group, BARC is working on the development of porous Nickel electrodes

•Porous electrodes provide a large pore surface area compared to the cross sectional geometric area of the electrode.

•High internal pore surface area enhances overall reaction kinetics resulting in high current density

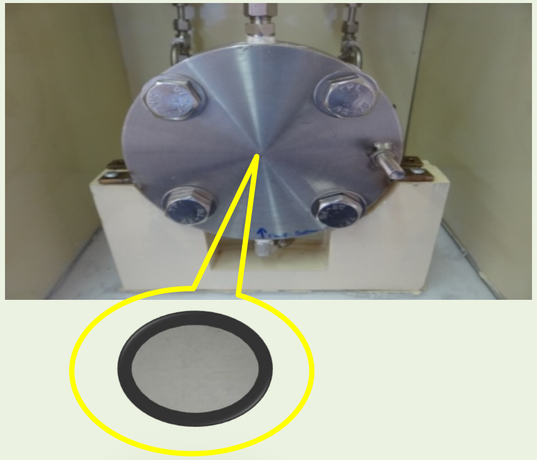
•Being highly porous (>70% porosity), these electrodes can be sandwiched with the diaphragm (with zero gap) leading to a compact cell design.

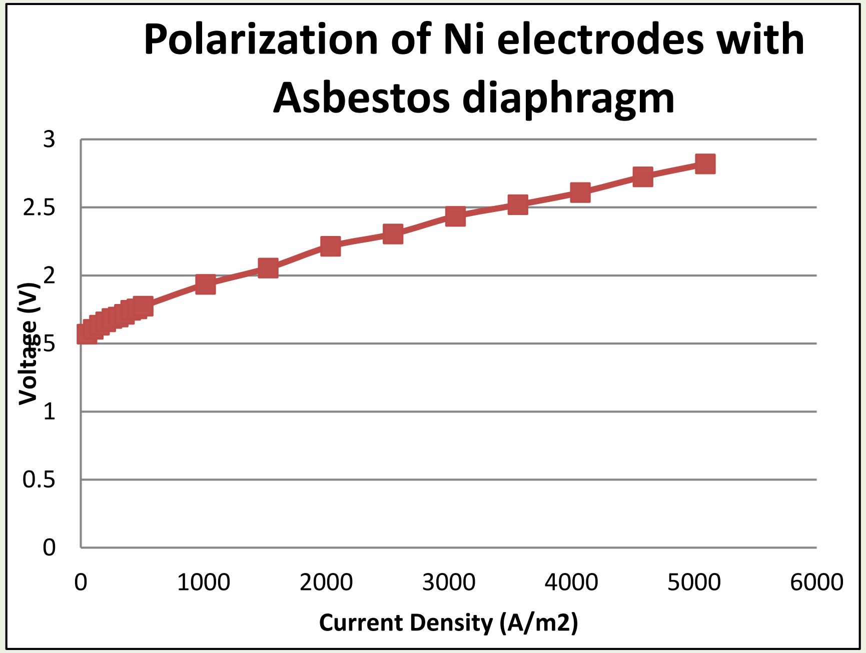
LABS SCALE CELL MODULE DESIGN AND TESTING

- The feasibility is established in a single cell lab scale electrolyzer with porous Nickel electrodes and asbestos diaphragm
- Hydrogen production rate : 4 Nlph

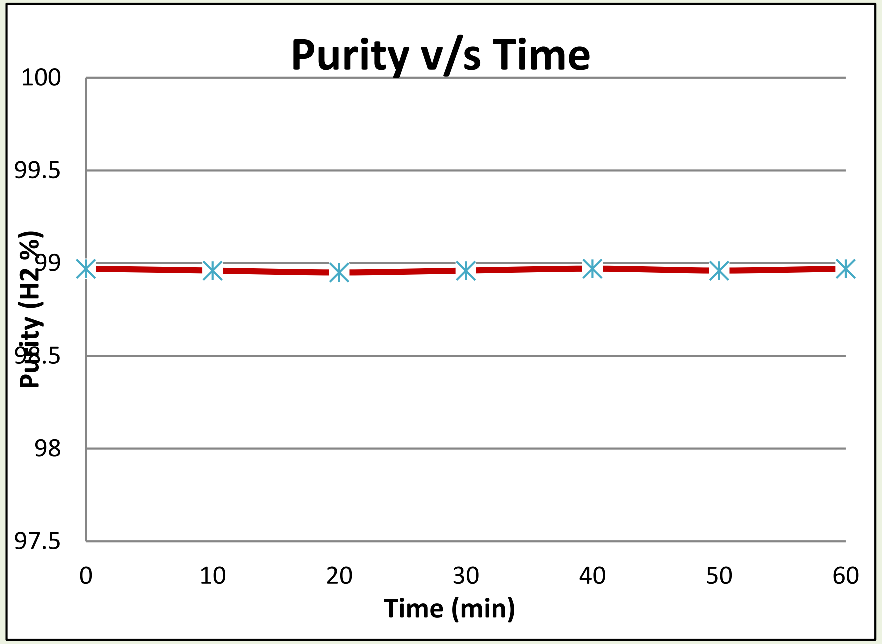
Gas separators

Cell module





Polarization study



Effect of gas purity v/s Time

FURTHER DEVELOPMENT AND SCALE UP

Feature	Lab scale	Lab scale(stack)	Bench Scale	Pilot Scale
Electrode Diameter scale up ratio	1	1	3	9
H_2 production rate	4 Nlph	12 Nlph	80 Nlph	1200 Nlph
Operating Pressure	Atmosphere	Atmosphere	Atmosphere	Up to 1.5 bar(a) maximum
Stacking	No	Yes	Yes	Yes
Electrolyte distributors	No	No	Yes	Yes
Electrolyte Pump	No	Yes	Yes.	Yes

Studies effect of *pump flow rate* & *stacking*

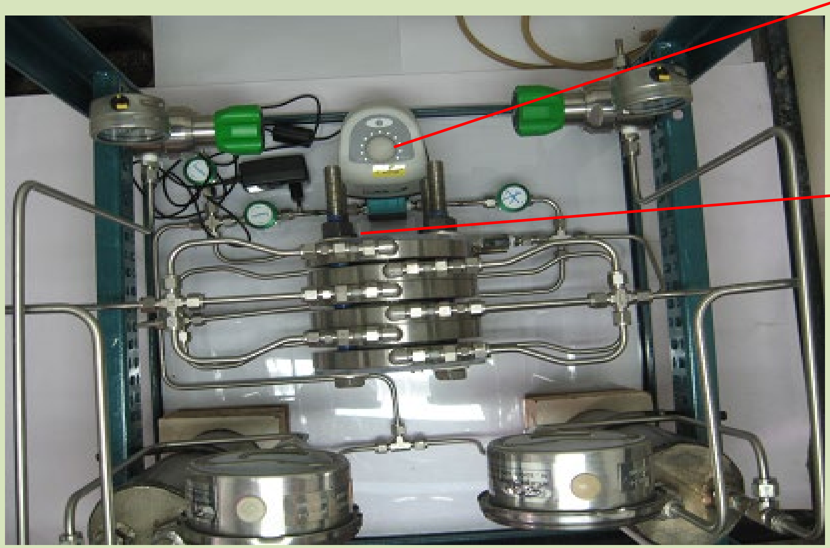
Studies effect of electrode size scale up to *intermediate* scale

Studies effect of electrode size scale up to *actual* scale

SCALE UP TO LAB SCALE STACK (3 CELL MODULE)

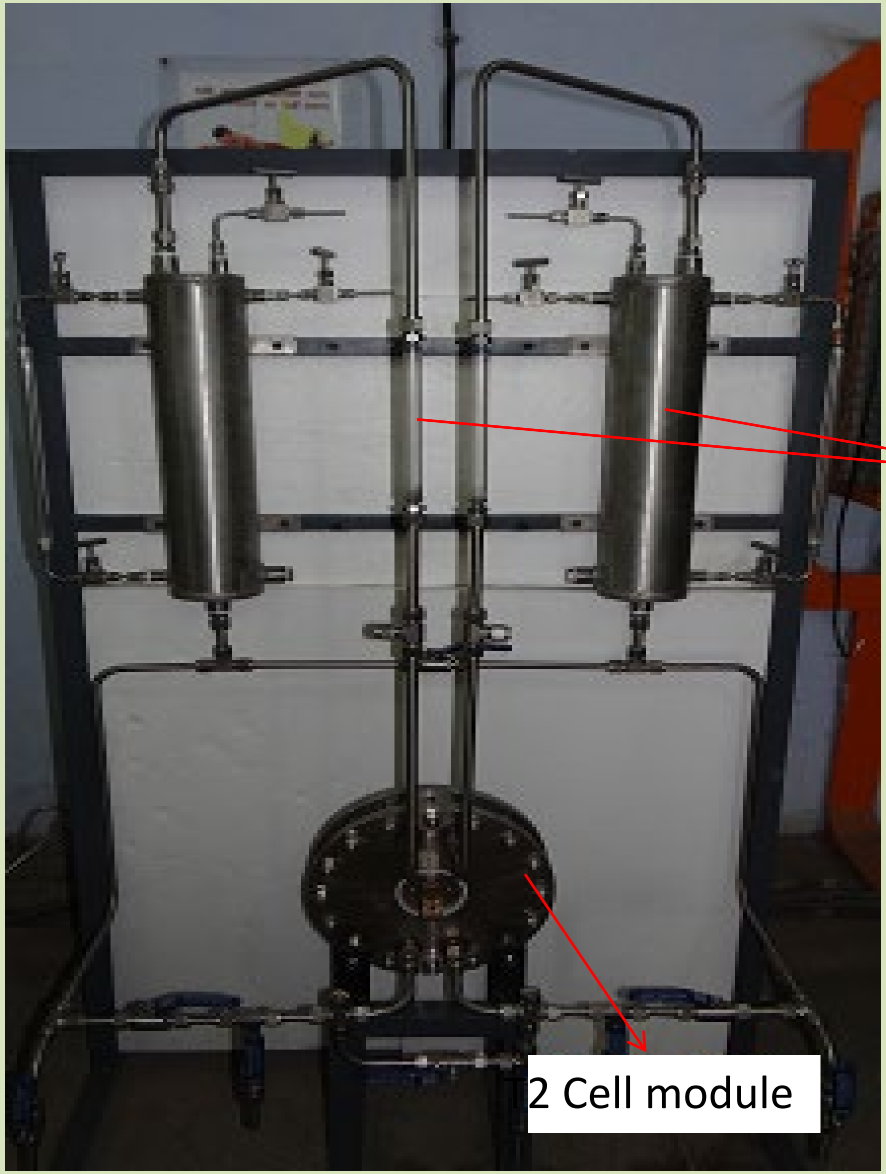
Feature	Lab scale(stack)
Electrode diameter Scale up ratio	1
H_2 production Capacity	12 NLph
Operating Pressure	Atmosphere
Stacking	Yes (3 cell stack)
Electrolyte distributor	No
Electrolyte circulation	Yes

Front view



Top view

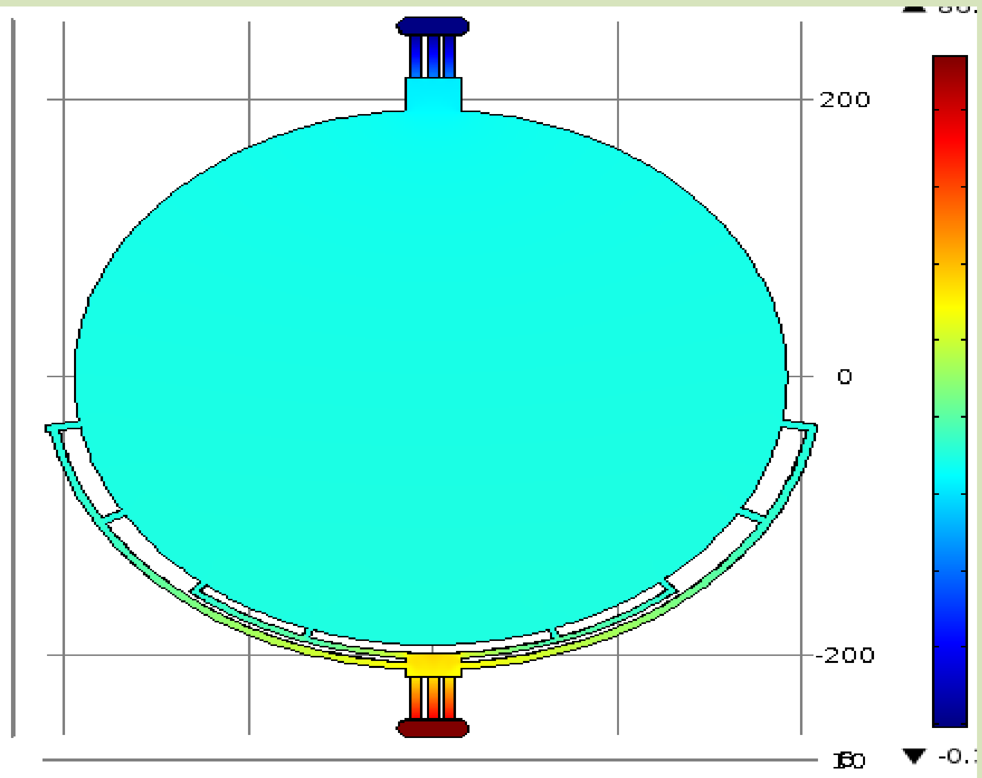
SCALE UP TO BENCH SCALE STACK (2 CELL MODULE)

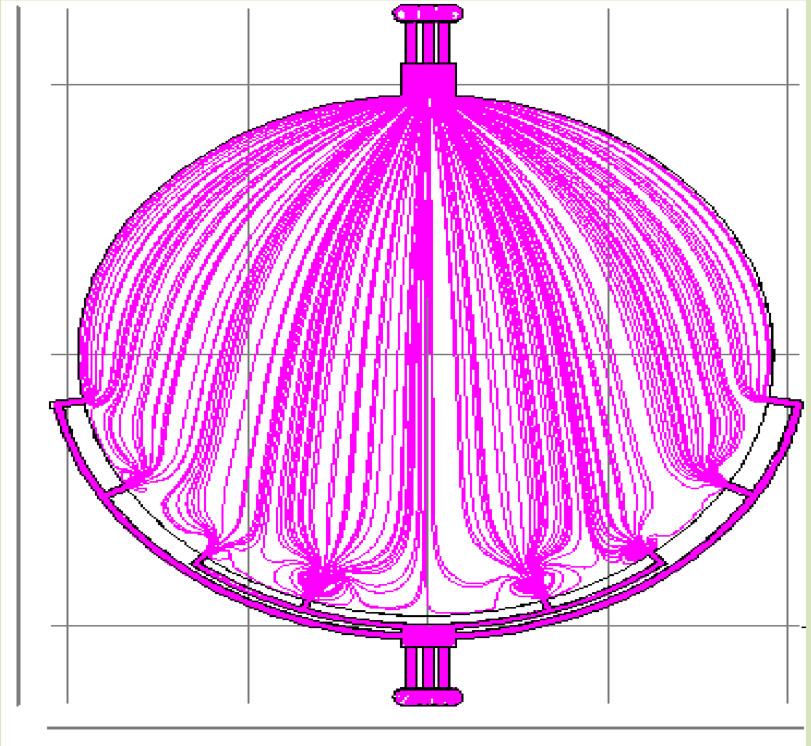


Feature	Bench Scale
Electrode diameter Scale up ratio	3
H_2 production Capacity	80NLph
Operating Pressure	Atmosphere
Stacking	Yes
Electrolyte distributor	Yes
Electrolyte circulation Pump	Yes

Preliminary CFD studies for electrolyte distribution through cell

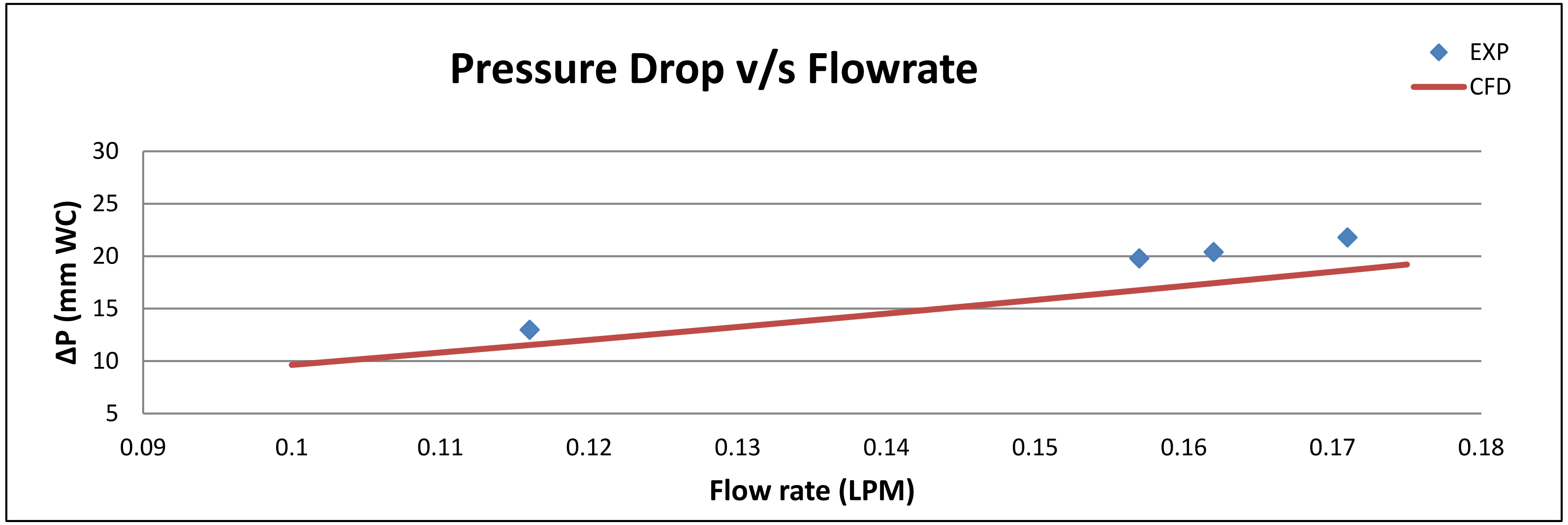
- Aim: To evaluate uniform distribution of electrolyte in the anodic/ cathodic flow channels
- Approach: Laminar Single phase electrolyte flow
- Future Work Plan: Modeling Two phase flow and validation by experiments
- To ensure proper uniform electrolyte distribution at min. ΔP by trying different design modifications

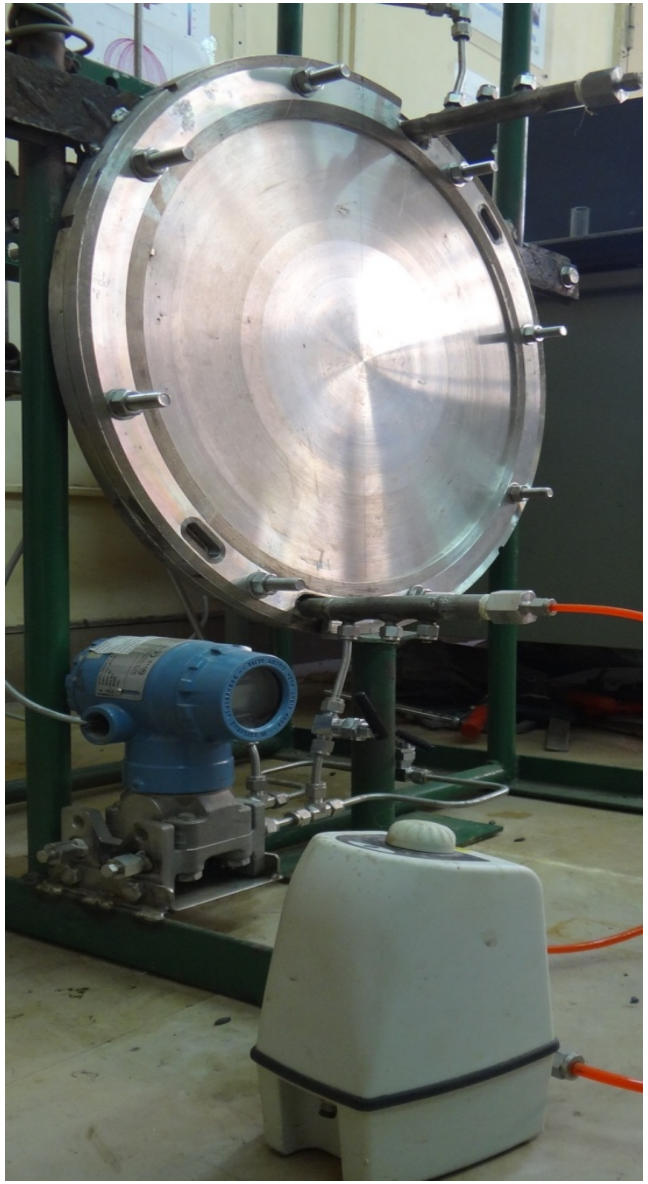




Pressure profile and Velocity streamline

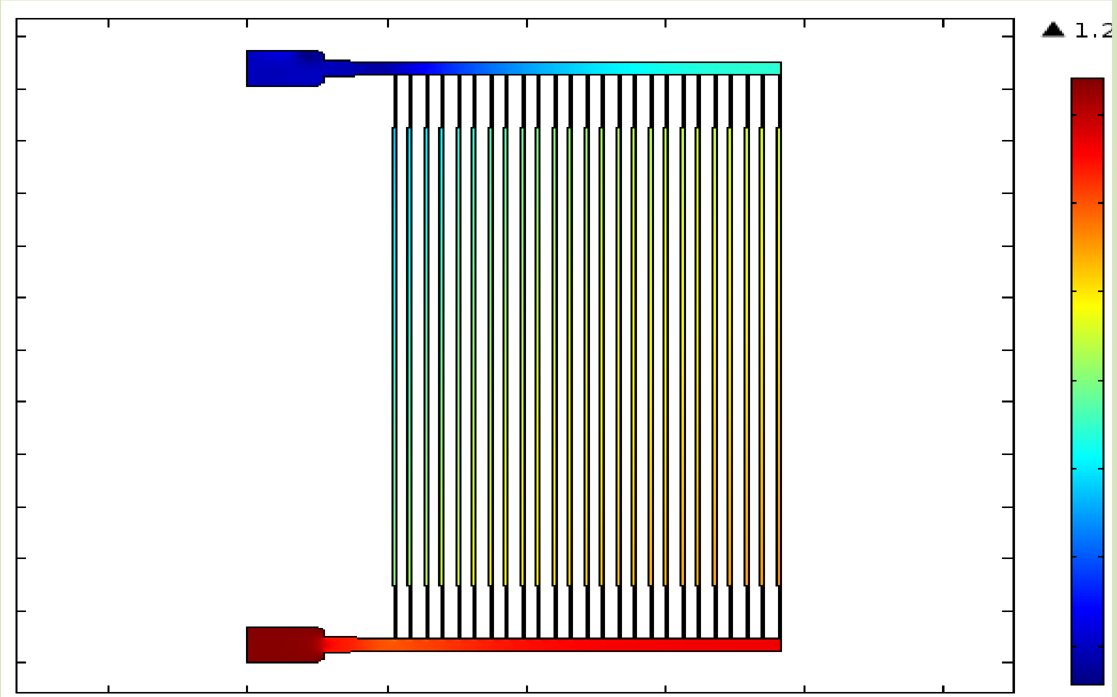
Half Cell Hydro-dynamics Set Up



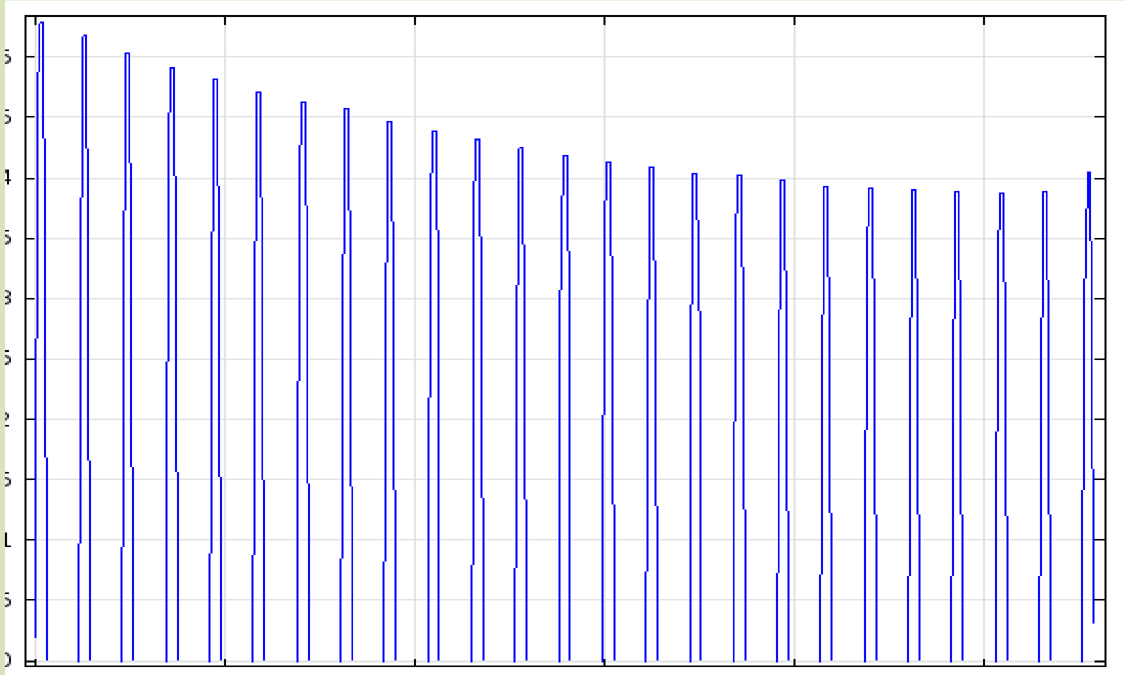


Preliminary CFD studies in 25 cell electrolyser stack

- Aim: To determine ΔP and velocity profile across the cell stack
- Approach: Laminar Single phase electrolyte flow
- Future Work Plan: Modeling Two phase flow and validation by experiments
- To ensure uniform thermal hydraulics in each channel by gradient design approach
- To arrive at min. total ΔP for the cell stack by trying different designs



Pressure Profile



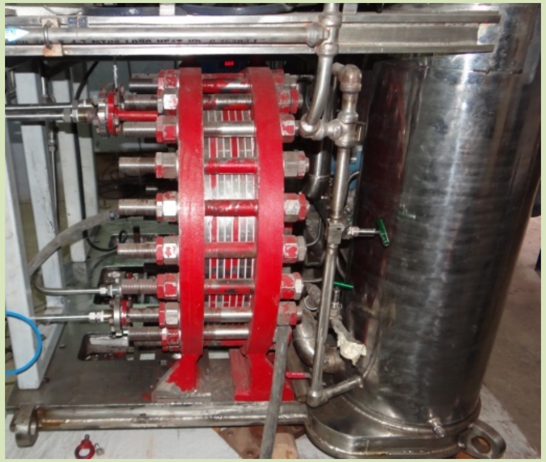
Velocity Profile

PILOT SCALE CELL MODULE (6 CELL MODULE)

Feature	Pilot Scale
Electrode diameter Scale up ratio	9
H_2 production Capacity	1200 Nlph
Operating Pressure	Up to 1.5 bar(a) maximum
Stacking	Yes
Electrolyte distributor	Yes
Electrolyte circulation Pump	15 lpm max.

Process skid

Gas separators



Six Cell module

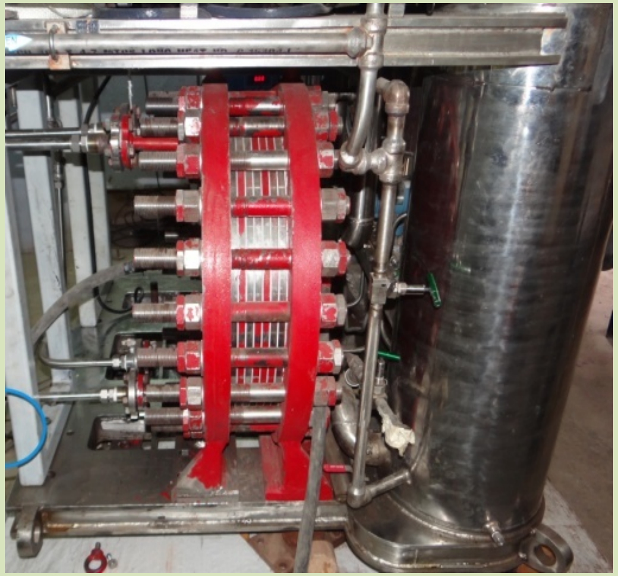
DIFFERENT STAGES OF DEVELOPMENT – "LAB TO LAND"

Single Cell

Three Cell

Two Cell

Six Cell

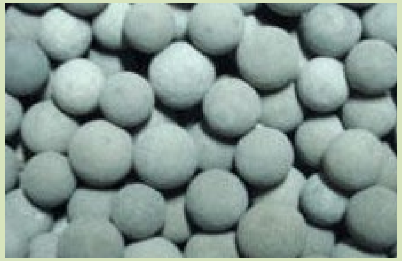


H_2 :4 lph	H_2 : 12lph	H_2 : 80 lph	H_2 :1200 Nlph

H_2 GAS PURIFICATION USING PALLADIUM BASED CATALYST

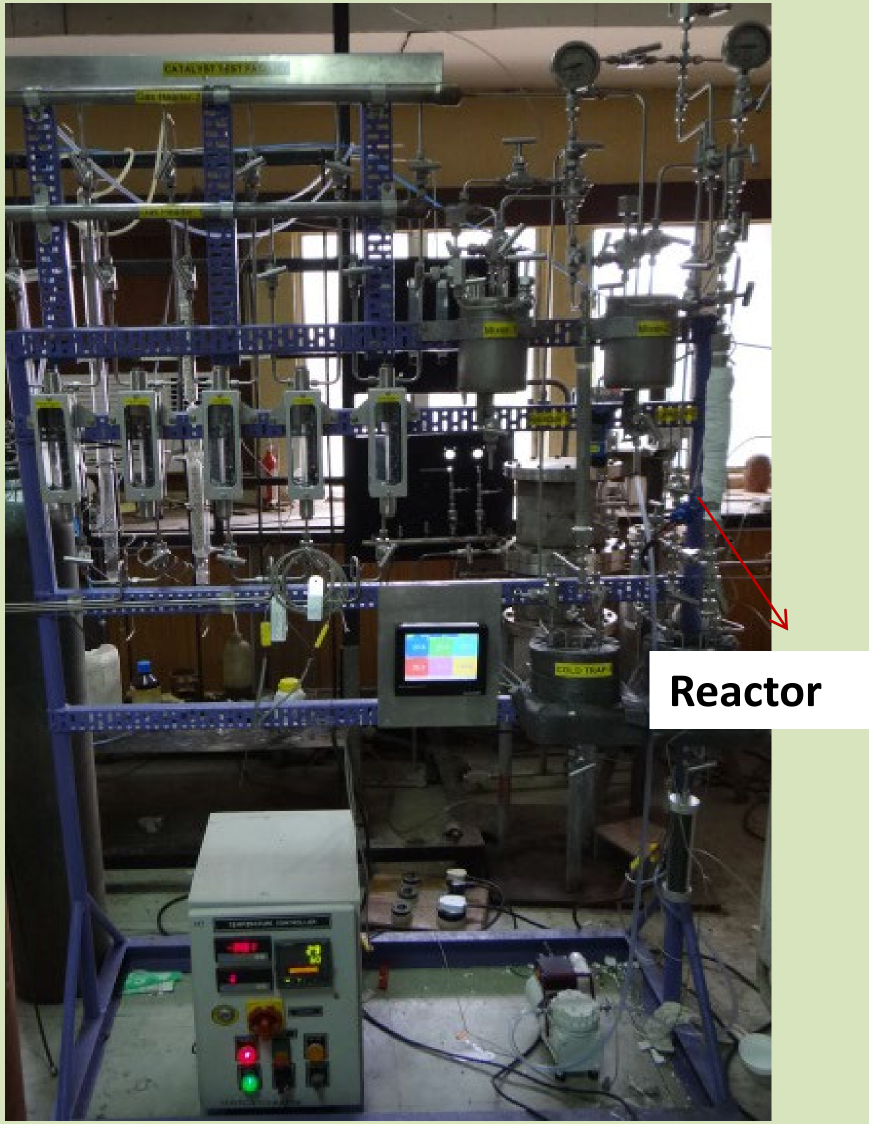
- **The final gas purification of the hydrogen gas is done using palladium based catalyst.**

- $$H_2 \;(\text{Excess}) + \tfrac{1}{2} O_2 \;(\text{Traces}) \xrightarrow{Pd} H_2O$$



Different Catalysts developed with Chemistry Division, BARC

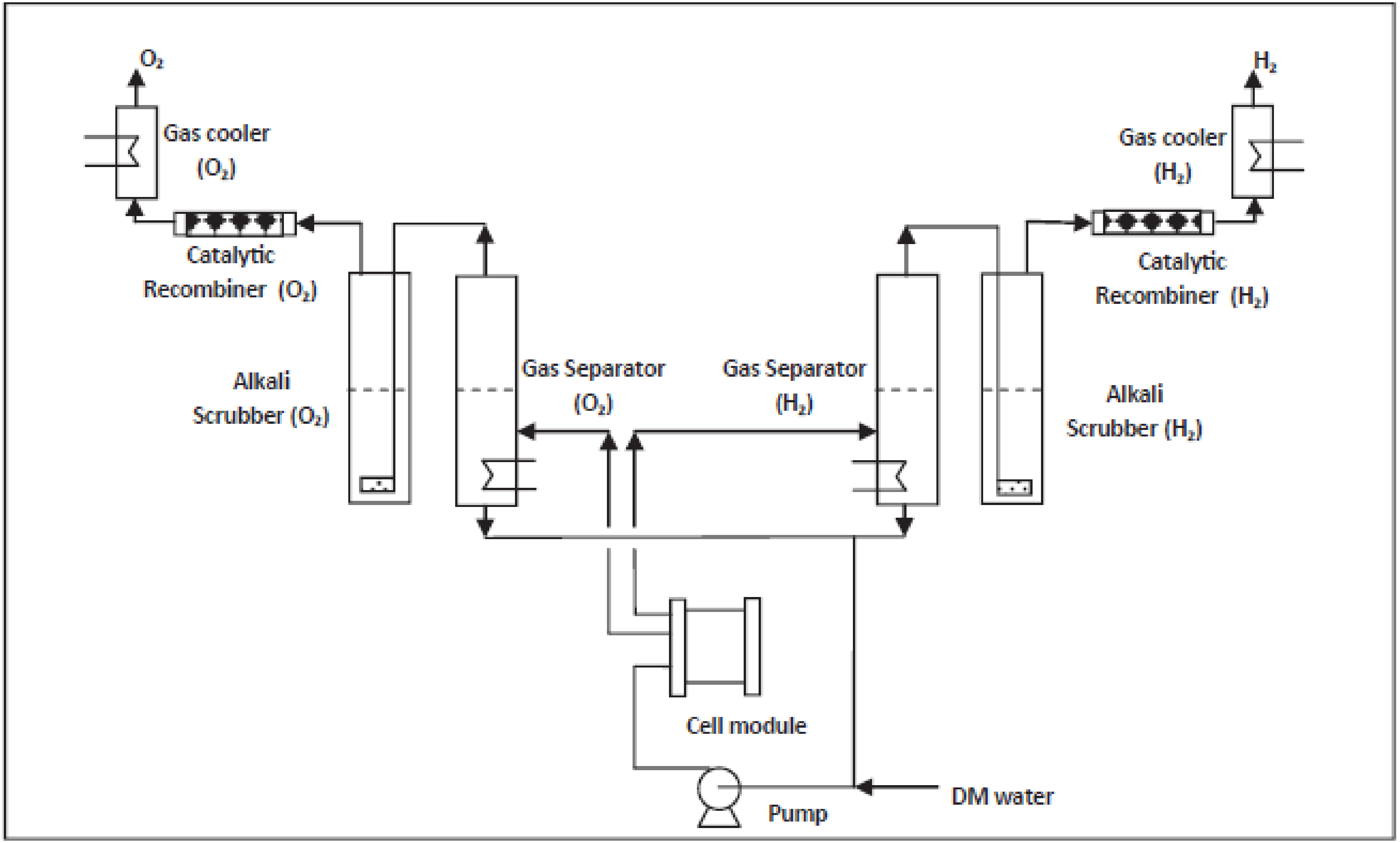
- **In the electrolyzer plant, the final oxygen gas purity of >99.99% is achieved using this catalyst at plant exit.**



Catalyst Test Facility

Ref : K C Sandeep, et al *International Journal of Hydrogen Energy*, 39 (2014) 17906-17912 [2014]

SCHEMATIC OF SCALE UP TO 10 NM^3/HR HYDROGEN PLANT



DIFFERENT STEPS IN POROUS NICKEL ELECTRODE DEVELOPMENT

- **The major steps involved are**

1) Fabrication of the green plaques by spray coating of Carbonyl nickel powder slurry on Ni wire mesh .

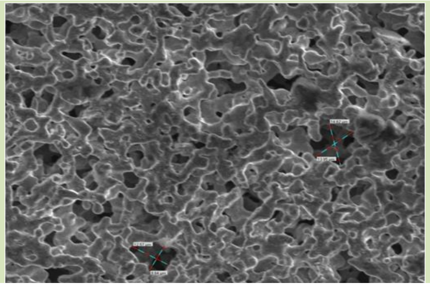
2) Roller compaction to desired thickness.

3) Sintering in hydrogen furnace at high temperature

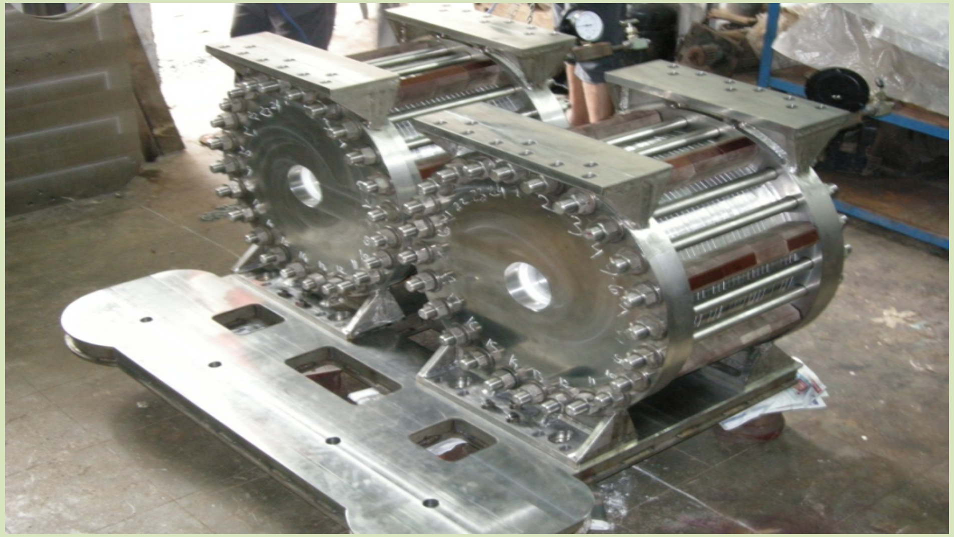
4) EB welding of porous nickel sheet to the electrodes holder Rings

Spray coating

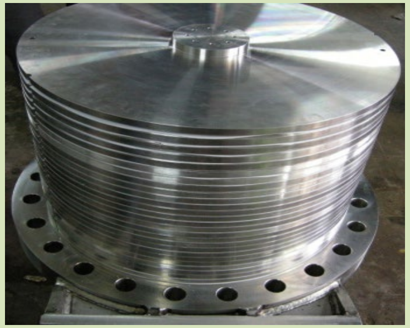
Sintering in H_2 furnace



Porous Ni Electrode

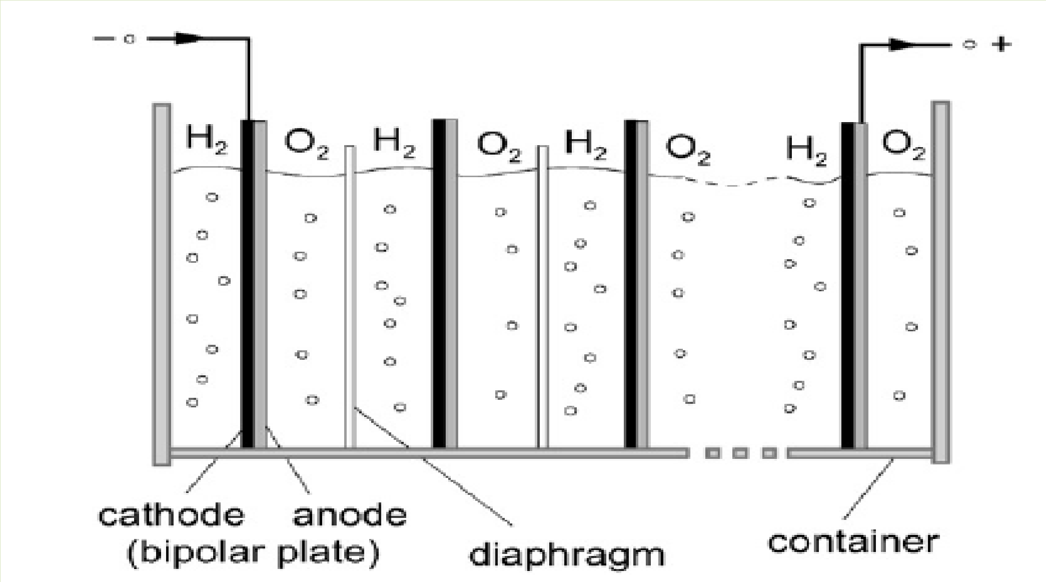


Cell modules after assembly



Cell module assembly

CELL MODULE STACK DESIGN



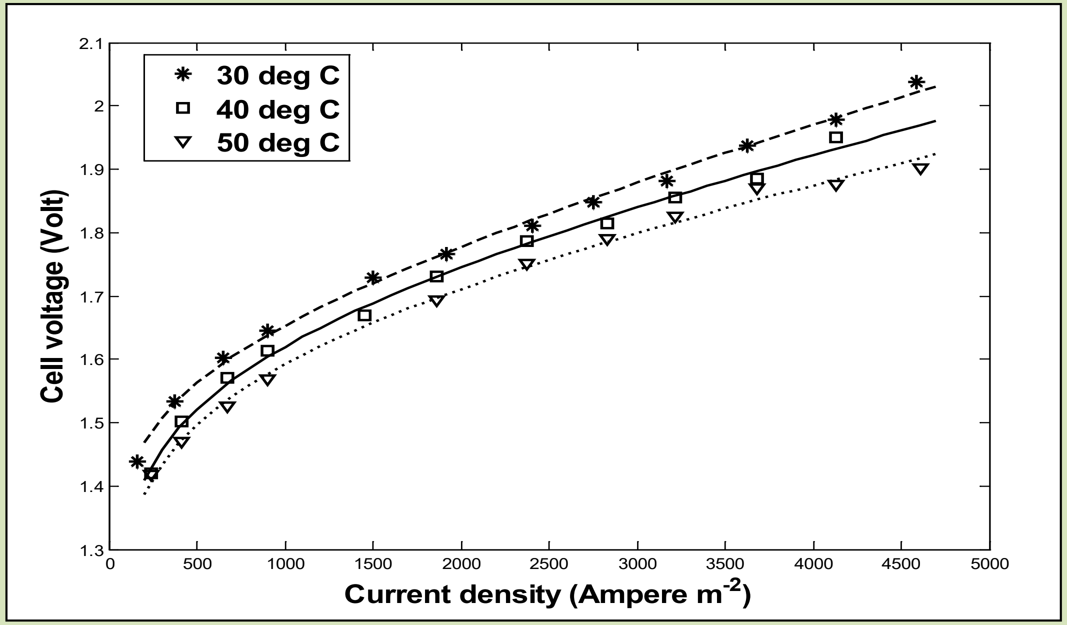
Features:

- ➢Bipolar Compact filter-press type cell module design
- ➢Thin sintered porous nickel electrodes (1mm)
- ➢High current density (5000 ASM) leading to lower cell voltages
- ➢Cell assembly with minimum gap (1 mm)
- ➢High Purity product gases

First Production plant at BARC

- Indigenously developed zero gap, compact alkaline water electrolyser technology
- On demand, On site, High purity Hydrogen & Oxygen produced
- Safe, reliable and robust plant design and automated control philosophy
- Successful operational experience of over 5000 hrs with high availability factor
- Four Nos. of units each capable of producing hydrogen up to 10000 Nlph have been developed and deployed

ELECTROCHEMICAL PERFORMANCE EVALUATION OF ELECTROLYZER PLANT (10000 NLPH H_2)



- **The operational cell voltage versus current density is generated at different operating temperatures (30, 40 & 50 deg C)**

- **The different model parameters accounts for overall cell resistance such as Ohmic & Activation over potentials were estimated.**

Comparison of Ohmic parameter with literature (Kibria et al 2011)

Temperature (°C)	Ohmic parameter (b) (m^2)	
	Reported	BARC
30	7.3×10^{-5}	6.81×10^{-5}
40	7.05×10^{-5}	5.32×10^{-5}
50	6.8×10^{-5}	4.61×10^{-5}

Comparison of exchange current density (Am^{-2}) with literature (Ullsberg et al 2012)

Temperature (°C)	Exchange current density ($A\ m^{-2}$)	
	* Reported for Ni at 30% KOH	BARC
30	6.9540	12.0495
50	18.3251	43.8657

Ref : K C Sandeep, et al *International Journal of Hydrogen Energy*, 2017, 42,12094-12103

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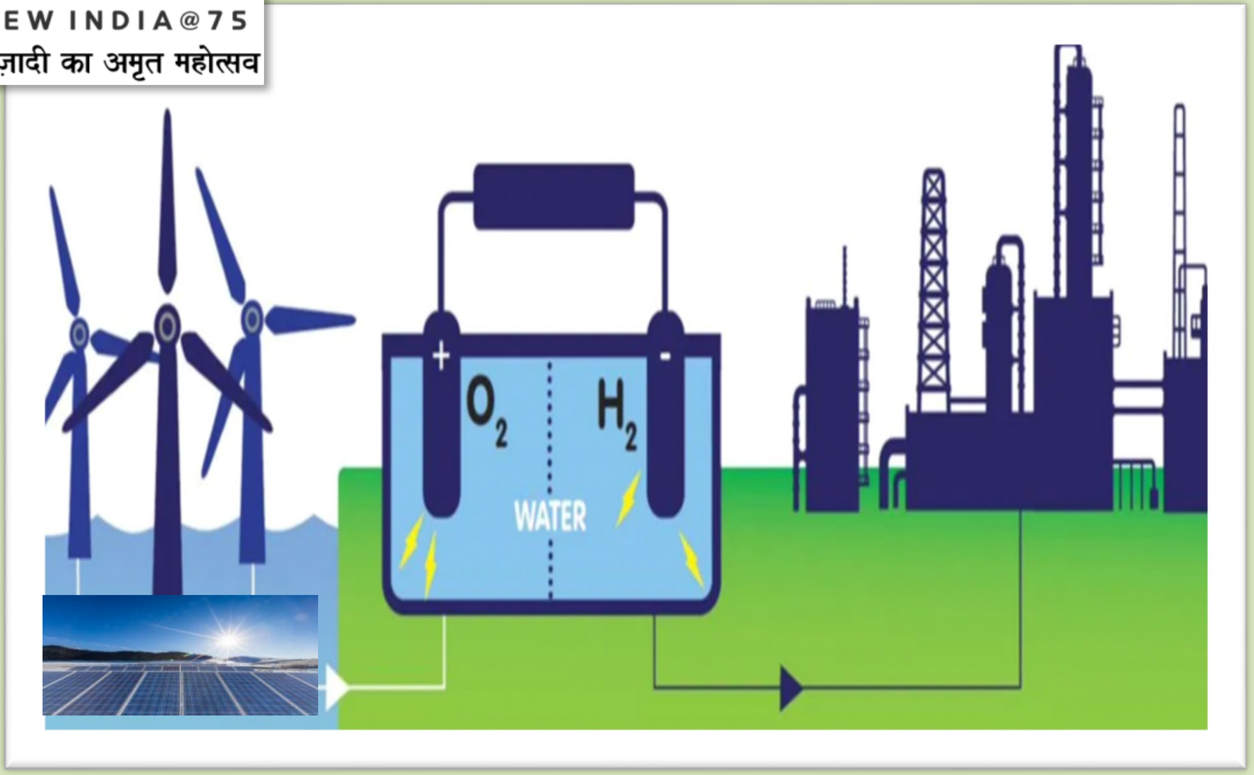
TECHNOLOGY TRANSFER TO INDUSTRY



- Technology transferred to HPCL in 2021

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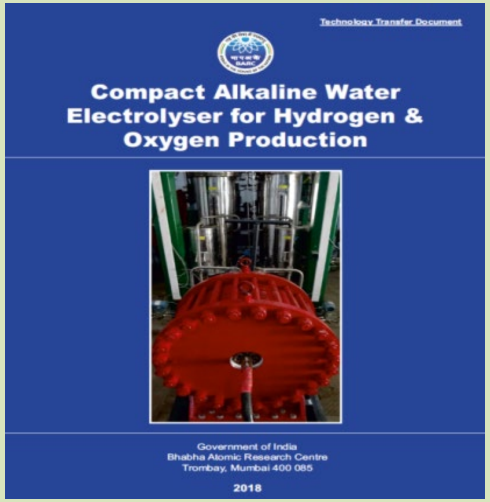
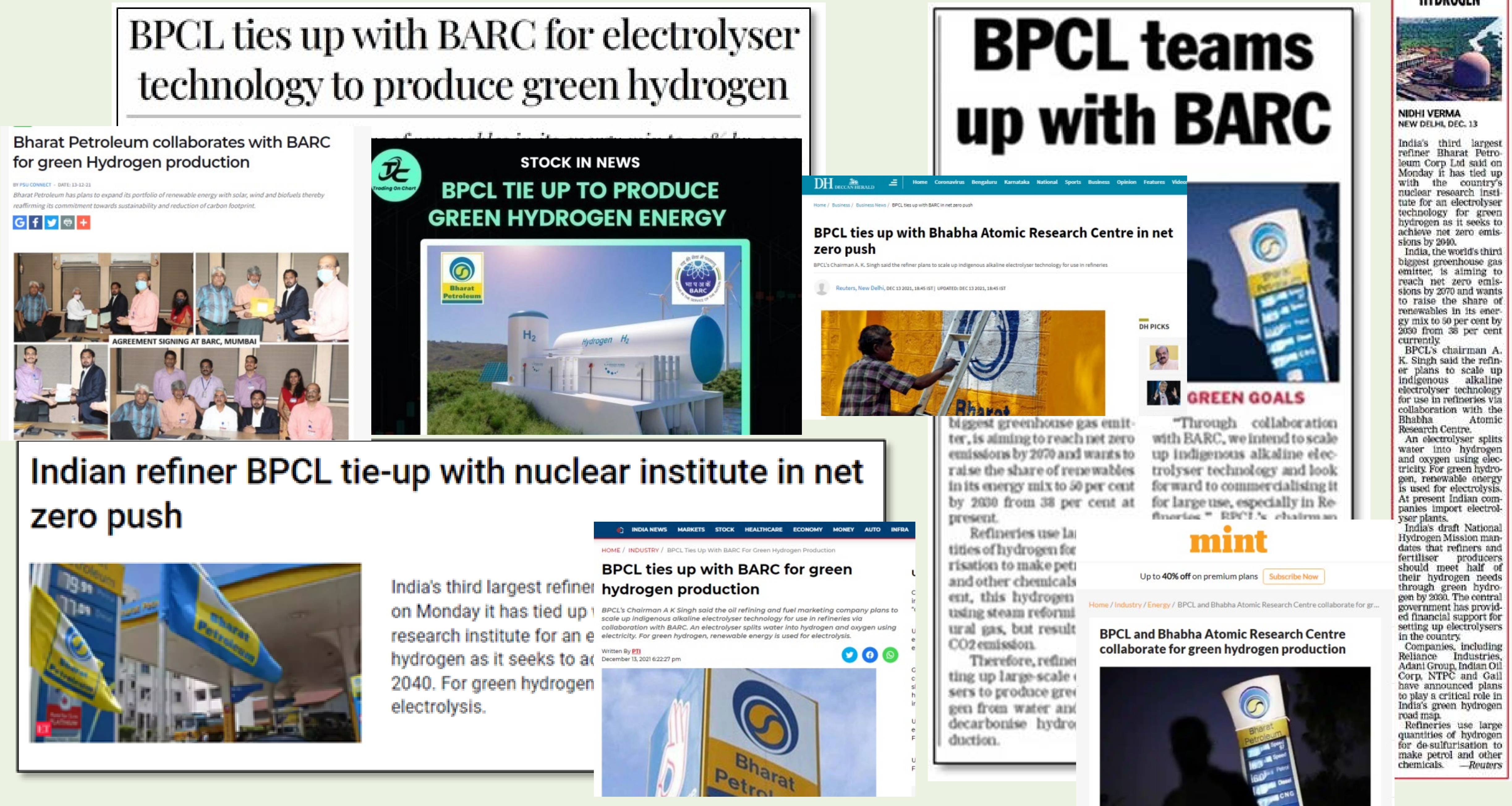
BARC
ATOMS IN THE SERVICE OF THE NATION



हिन्दुस्तान पेट्रोलियम
HP

TECHNOLOGY TRANSFER TO BPCL



BPCL ties up with BARC for electrolyser technology to produce green hydrogen

Bharat Petroleum collaborates with BARC for green Hydrogen production

BY PSU CONNECT - DATE: 13-12-21

Bharat Petroleum has plans to expand its portfolio of renewable energy with solar, wind and biofuels thereby reaffirming its commitment towards sustainability and reduction of carbon footprint.

AGREEMENT SIGNING AT BARC, MUMBAI

BPCL ties up with Bhabha Atomic Research Centre in net zero push

BPCL's Chairman A. K. Singh said the refiner plans to scale up indigenous alkaline electrolyser technology for use in refineries

Reuters, New Delhi, DEC 13 2021, 18:45 IST | UPDATED: DEC 13 2021, 18:45 IST

BPCL teams up with BARC

GREEN GOALS

biggest greenhouse gas emitter, is aiming to reach net zero emissions by 2070 and wants to raise the share of renewables in its energy mix to 50 per cent by 2030 from 38 per cent at present.

Refineries use la... tities of hydrogen for ... risation to make pet... and other chemicals... ent, this hydrogen ... using steam reformi... ural gas, but result... CO2 emission.

Therefore, refine... ting up large-scale ... sers to produce gree... gen from water and ... decarbonise hydro... duction.

"Through collaboration with BARC, we intend to scale up indigenous alkaline electrolyser technology and look forward to commercialising it for large use, especially in Refineries," BPCL's chairman

Indian refiner BPCL tie-up with nuclear institute in net zero push

India's third largest refiner ... on Monday it has tied up ... research institute for an e... hydrogen as it seeks to ac... 2040. For green hydrogen ... electrolysis.

BPCL ties up with BARC for green hydrogen production

BPCL's Chairman A K Singh said the oil refining and fuel marketing company plans to scale up indigenous alkaline electrolyser technology for use in refineries via collaboration with BARC. An electrolyser splits water into hydrogen and oxygen using electricity. For green hydrogen, renewable energy is used for electrolysis.

Written By PTI
December 13, 2021 6:22:27 pm

mint

BPCL and Bhabha Atomic Research Centre collaborate for green hydrogen production

BPCL TIES UP WITH BARC FOR GREEN HYDROGEN

NIDHI VERMA
NEW DELHI, DEC. 13

India's third largest refiner Bharat Petroleum Corp Ltd said on Monday it has tied up with the country's nuclear research institute for an electrolyser technology for green hydrogen as it seeks to achieve net zero emissions by 2040.

India, the world's third biggest greenhouse gas emitter, is aiming to reach net zero emissions by 2070 and wants to raise the share of renewables in its energy mix to 50 per cent by 2030 from 38 per cent currently.

BPCL's chairman A. K. Singh said the refiner plans to scale up indigenous alkaline electrolyser technology for use in refineries via collaboration with the Bhabha Atomic Research Centre.

An electrolyser splits water into hydrogen and oxygen using electricity. For green hydrogen, renewable energy is used for electrolysis. At present Indian companies import electrolyser plants.

India's draft National Hydrogen Mission mandates that refiners and fertiliser producers should meet half of their hydrogen needs through green hydrogen by 2030. The central government has provided financial support for setting up electrolysers in the country.

Companies, including Reliance Industries, Adani Group, Indian Oil Corp, NTPC and Gail have announced plans to play a critical role in India's green hydrogen road map.

Refineries use large quantities of hydrogen for de-sulfurisation to make petrol and other chemicals. —Reuters

Spin off : "Medical Oxygen during pandemic"

- Capable of producing ~5000 Litre O_2 in 1 hr
- No logistic issues

- Capable of storing 6000 N litres O_2
- O_2 stored under high pressure: 120 bar
- O_2 purity >99.9%

BARC joins Covid Fight

All India Radio News
@airnewsalerts

Bhabha Atomic Energy Research Centre sets up a special #oxygen plant to supply medical oxygen to Mumbai.

7:38 PM · 06/05/21 · TweetDeck

Rahul Shewale - राहुल शेवाळे

BARC scientists were appealed on my behalf to solve the problem of oxygen deficiency in Mumbai. Giving a positive response to it, a water-producing oxygen plant has been implemented by BARC. In the first phase from this plant, about 10 oxygen cylinders will be supplied each of 50 liters. This can solve the problem of oxygen in government hospitals, Covid centers in south-central Mumbai. Along with the supply of oxygen, BARC has developed a special mask and remote body temperature machine for the citizens. I #thank the scientists and officers of #BARC who are rushing to help Mumbai during the Corona crisis! #FightAgainstCovid #FightAgaintstCoronavirusTogether Bhabha Atomic Research Centre Bhabha Atomic Research Centre Bhabha Atomic Research Centre India Bhabha Atomic Research Centre,Mumbai CMOMaharashtra ShivSena Shivsena MyBmc

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Mumbai Oxygen Supply: BARC to supply oxygen to Mumbai

The second wave of corona caused a major shortage of oxygen as the infection progressed. MP Rahul Shewale had demanded the Bhabha Atomic Energy Research Center to produce oxygen, which has received a positive response. So now Mumbai will get oxygen from BARC.

By: Manashree Pathak, ABP Mazha, Mumbai | 06 May 2021 05:04 PM (IST)

COVID-19 Pandemic: BARC To Supply Oxygen Cylinders To Mumbai

According to sources, the cylinders will be supplied to government hospitals and COVID-19 care centres in south-central Mumbai.

BY MUMBAI LIVE TEAM • 7 DAYS AGO • HEALTH • MUMBAI

BARC Provides Oxygen Supply To Mumbai: BARC to supply oxygen to Mumbai; Information of MP Rahul ShewaleBARC Provides Oxygen Supply To Mumbai: BARC to supply oxygen to Mumbai; Information of MP Rahul ShewaleBARC Provides Oxygen Supply To Mumbai: BARC to supply oxygen to Mumbai; Information of MP Rahul Shewale

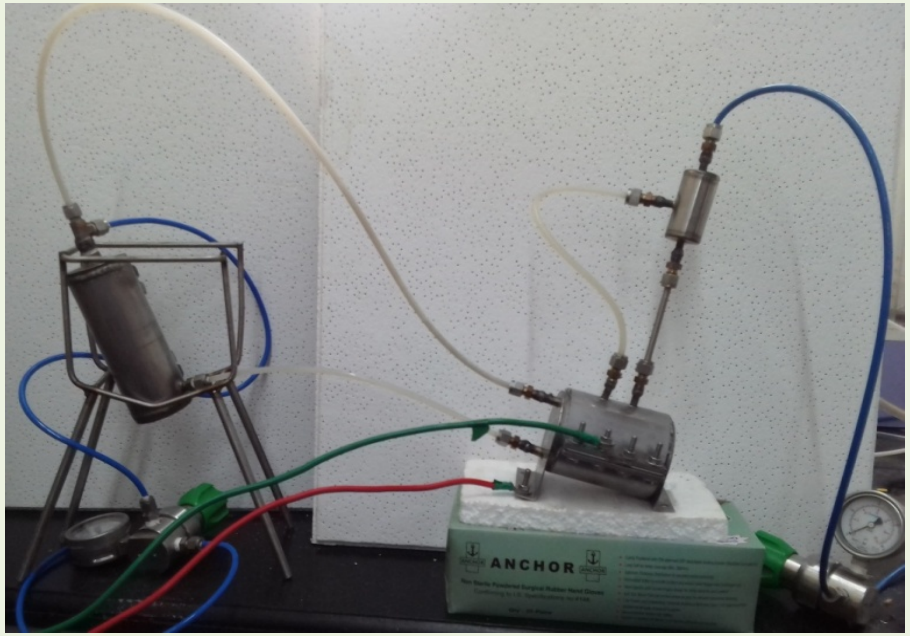
Proposed Scale Up Strategy

2 x 50 cells → **Increase Stack Length** → **Increase Stack Diameter**

H_2: 30 Nm^3/hr	120 Nm^3/hr	500 Nm^3/hr
BARC	Bharat Petroleum, HP	

Development of Lab Electrolyser

- Compact, lab scale unit capable of delivering 4 NLPH High Purity H_2 & O_2
- Both H_2 & O_2 are delivered at pressure up to 8 bar
- Ideal for small lab scale high purity Carbon free applications
- Easy control & plug on system
- Target to increase production up to 18 NLPH
- Product aesthetics



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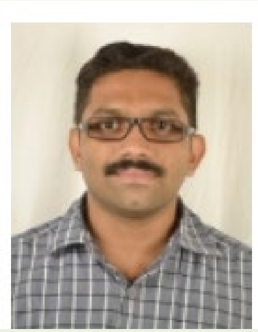
- Fire Service Section, BARC
- Safety Review Committee & BSC (SF), BARC
- Chemistry Division, BARC
- Chemical Technology Division, BARC
- Alkali Materials & Metals Division, BARC

Team







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