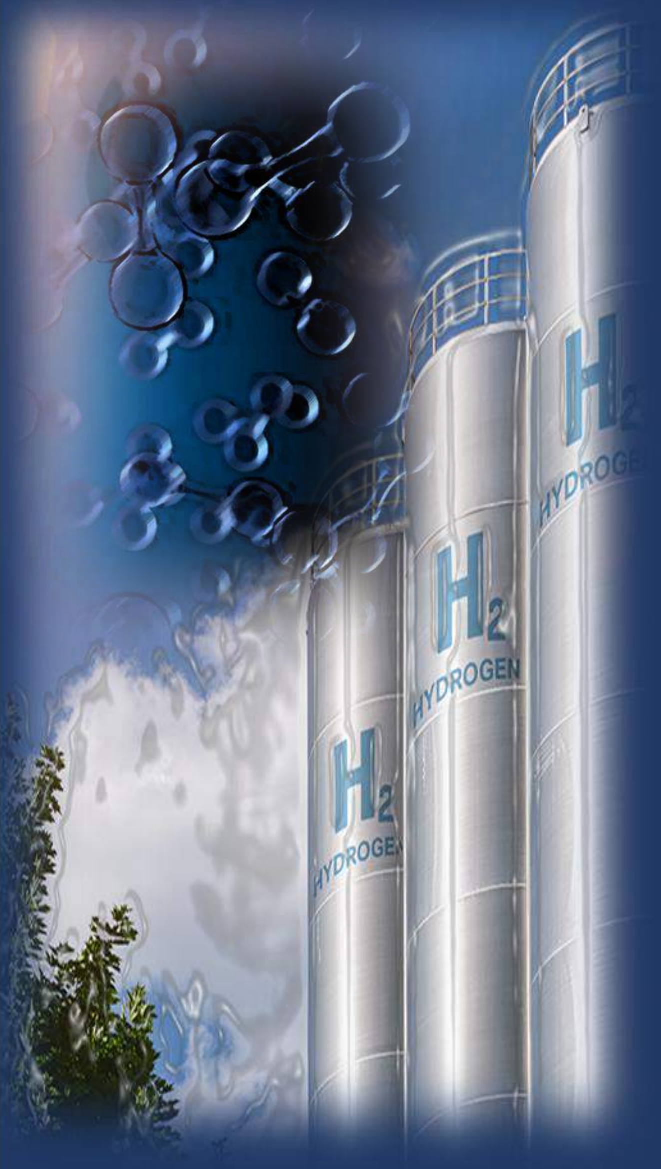



# Indigenization and Self-Reliance in Hydrogen Energy: Connecting Deep Science to Technology Demonstrations


**Sreekumar Kurungot**

Physical & Materials Chemistry Division

CSIR-National Chemical Laboratory

Pune 411008, Maharashtra, India


International Conference on Green Hydrogen 2023, 5-7 July 2023, Vigyan Bhawan, New Delhi

# CSIR's Efforts towards Building Sustainable Hydrogen Economy

$H_2$

## Generation

- Bio-Mass Gasification
- Coal-bed Methane Gasification
- Underground Coal Gasification
- PEM/AEM Electrolysers
- High Temperature Steam Electrolyzer
- Photochemical
- Electrochemical
- Photo-Electrochemical
- Photo-catalytic
- CO-PROX Converter
- Open Loop Thermochemical S-I Cycle

## Storage

- Storage Materials
- Type IV Storage Tank
- Safety Valves
- Sensors & Detectors

## Utilization

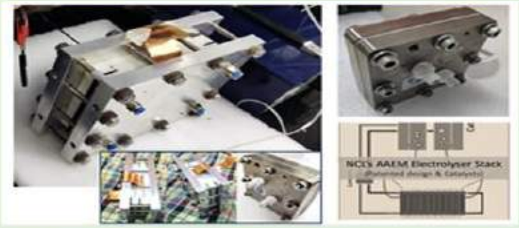
- PEMFC stacks (HT, LT & Open Cathode)
- DMFC stacks
- SOFC stacks (MT & LT)
- FC components (MEA, Electrode, Catalyst, GDL, Membrane, Bipolar Plate, Fixtures, Humidifier/Dehumidifer etc.)
- Solar $H_2$ to Chemical
- Solar Hydrogen Chullah

| Hydrogen Generation | | | | | Hydrogen Storage | | Hydrogen Utilization | |
|---|---|---|---|---|---|---|---|---|
| Gasification | Electrolyzers | Photo/ Electrtochemical | CO-PROX | Open Loop SI Cycle | Materials | Tanks/Valves/ Sensors | Fuel Cells | Solar Hydrogen Chullah |
| CSIR-CIMFR | CSIR-CECRI<br>**CSIR-NCL**<br>CSIR-IMMT<br>CSIR-AMPRI<br>CSIR-CGCRI | **CSIR-NCL**<br>CSIR-CECRI<br>CSIR-IMMT<br>CSIR-CSIO<br>CSIR-CMERI | CSIR-NEERI | CSIR-IIP<br>CSIR-CSMCRI | CSIR-CSMCRI<br>CSIR-CMERI<br>CSIR-AMPRI<br>CSIR-CECRI<br>**CSIR-NCL** | CSIR-CMERI<br>CSIR-NIIST | **CSIR-NCL**<br>CSIR-CECRI<br>CSIR-NPL<br>CSIR-CGCRI | CSIR-CSIO |

# Key CSIR Technologies on Hydrogen Generation & Storage

PEM Water Electrolyser Unit (1 $Nm^3/h$)

Solar Powered Hydrogen Generator (500 L/h)



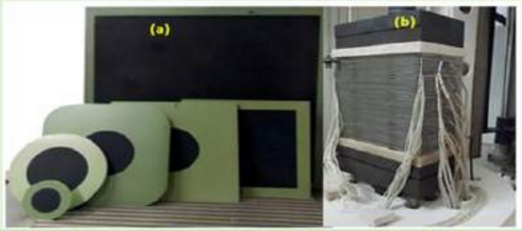
AEM Electrolyser (Non-precious catalysis)

SHADE $H_2$ Electrolyser (10-1000 $cm^2$ stack)

Artificial Leaf for Solar to Chemical Conversion


Photoelectrochemical Hydrogen Production

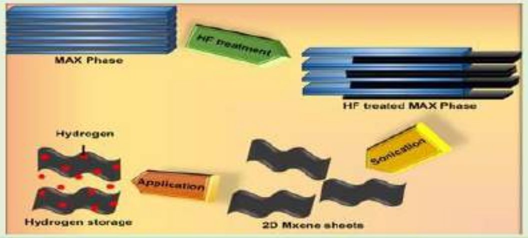

Photocatalytic Hydrogen Production



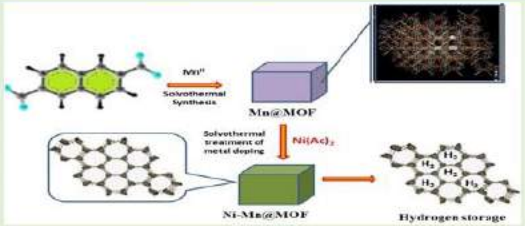

SOFC for High Temp. Steam Electrolyser

Fluidized Bed Gasification Pilot Plant

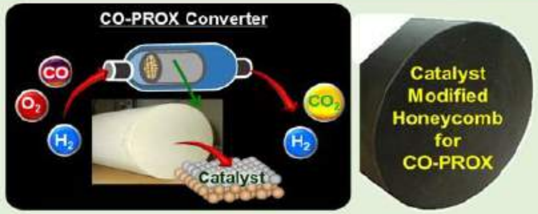
Type IV Hydrogen Storage Tank (CAD Model)



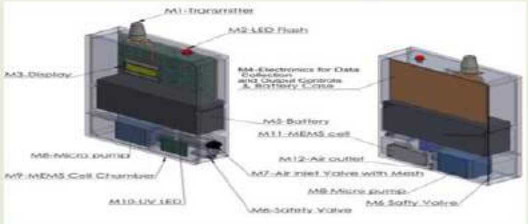

2D MXene based Hydrogen Storage Materials




MOF based Hydrogen Storage Materials

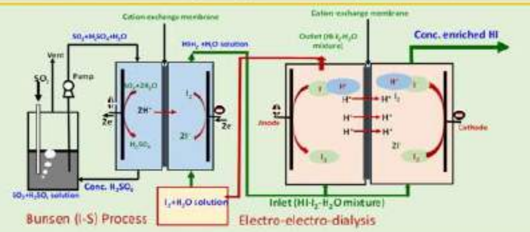



CO-PROX Converter & Catalyst



Hydrogen Detector

I-S Bunsen Cycle




I-S & EED Hybrid Process for HI Production

# Key PEMFC Demonstrations by Team-CSIR

**Demonstration of 3 kWe LT-PEMFC System for telecom tower applications**
**(Industry Partner: RIL)**

- Development of the 3 kWe PEMFC system for the immediate requirement of clean energy based back-up power supply for telecom towers.
- RIL to take lead in test bed development at an appropriate site where fuel grade $H_2$ is available
- CSIR to take lead in stack development based on its knowledge base.

**Demonstration of Fuel Cell Electric Vehicle (FCEV) on 07 Oct 2020**
**(Industry Partner: KPIT)**

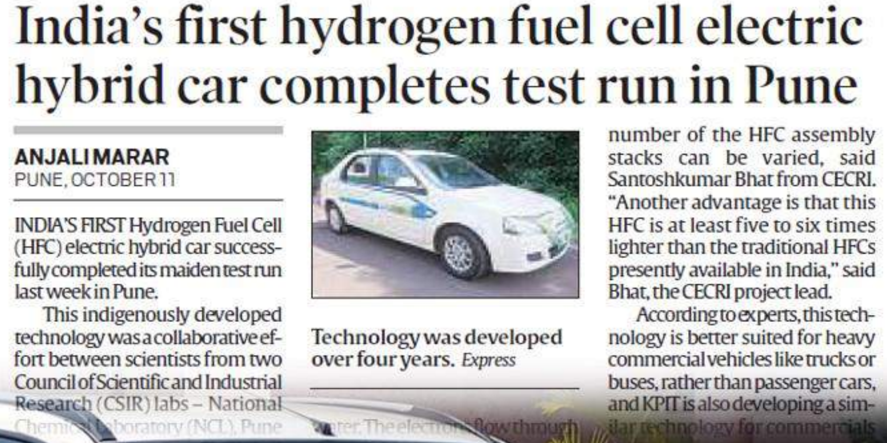

- FC stack has been indigenously developed based on CSIR's knowhow in crucial membrane electrode assembly (MEA) and catalyst technology.
- The FCEV has an onboard Type III $H_2$ storage tank storing about 1.75 Kgs of $H_2$ gas at a pressure of 350 bar giving the FCEV a range of about 250 km at typical Indian road conditions at moderate speed of 60-65 Kmph.

**Demonstration of High Temperature PEMFC based Combined Cooling & Power System**
**(Industry Partner: Thermax Ltd)**


- Country's first indigenous HT-PEMFC system was unveiled by Honourable President of India on the occasion of CSIR Foundation Day at Vigyan Bhawan, New Delhi, on 26 September 2019.
- As per project deliverable, suitable Vapor Absorption Machine (VAM) system was designed, developed and also operated utilizing reject heat from the stack.

# PEMFC Car by CSIR-KPIT Joint Effort

**Power**: 10 kWe PEMFC
**Mode**: Battery-Fuel Cell
**Tank**: Type III Hydrogen
**Tank Capacity**: 1.75 kg $H_2$
**Pressure**: 350 Bar
**Approximate Range**: 250 km
**Optimum Speed**: 60-65 km/h
**Vehicle Used**: Mahindra e-Verito
retro fitted with CSIR-KPIT Stack



## India's first hydrogen fuel cell electric hybrid car completes test run in Pune

**ANJALI MARAR**
PUNE, OCTOBER 11

INDIA'S FIRST Hydrogen Fuel Cell (HFC) electric hybrid car successfully completed its maiden test run last week in Pune.

This indigenously developed technology was a collaborative effort between scientists from two Council of Scientific and Industrial Research (CSIR) labs – National

Technology was developed over four years. *Express*

number of the HFC assembly stacks can be varied, said Santoshkumar Bhat from CECRI. "Another advantage is that this HFC is at least five to six times lighter than the traditional HFCs presently available in India," said Bhat, the CECRI project lead.

According to experts, this technology is better suited for heavy commercial vehicles like trucks or buses, rather than passenger cars, and KPIT is also developing a sim-

# Launch of India's 1st Indigenously Developed Hydrogen FC Bus (KPIT-CSIR Joint Effort)

Wednesday, Oct 12, 2022
EPAPER | TODAY'S PAPER

**The Indian EXPRESS**
JOURNALISM OF COURAGE

Home Explained Political Pulse India Cities Opinion Entertainment Lifestyle Technology Videos Sports Audio Education Premium Investigations

TRENDING Subscribe Now Crossword & Sudoku UPSC Key Health Specials Follow Authors Cricket

Home / Technology / Science / India's first hydrogen fuel cell bus: What is hydrogen fuel cell technology, how will work?

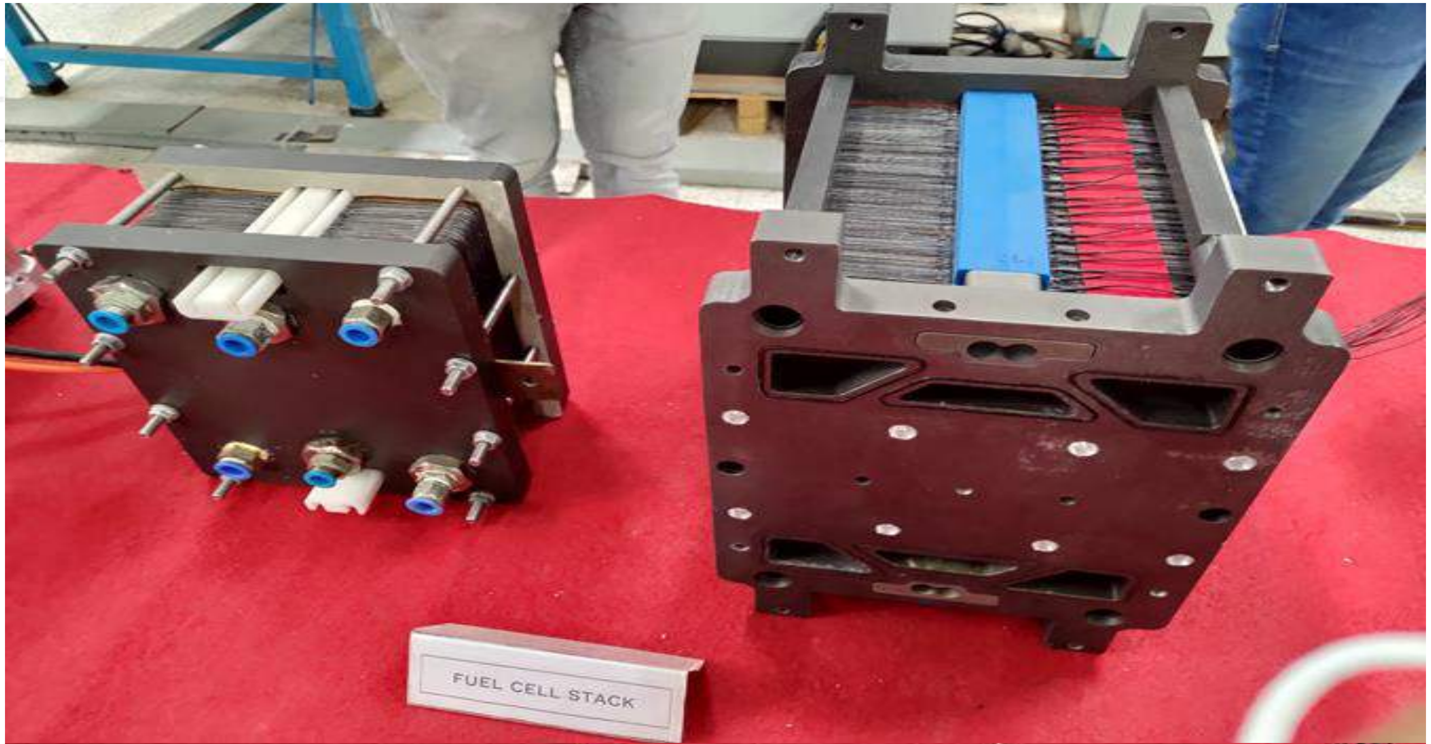
## India's first hydrogen fuel cell bus: What is hydrogen fuel cell technology, how will work?

By: Tech Desk
Thalassery | Updated: August 25, 2022 5:52:07 pm

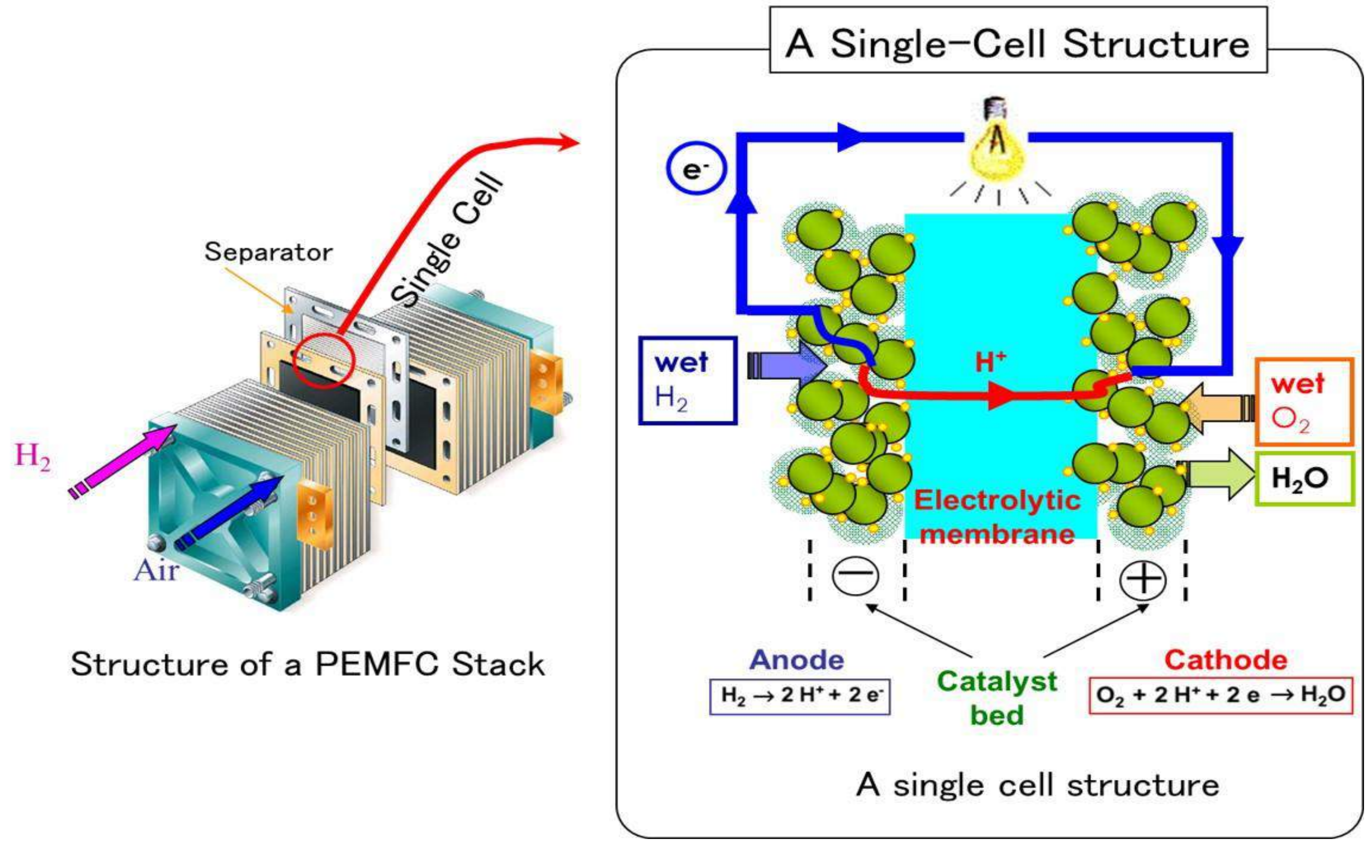
NewsGuard

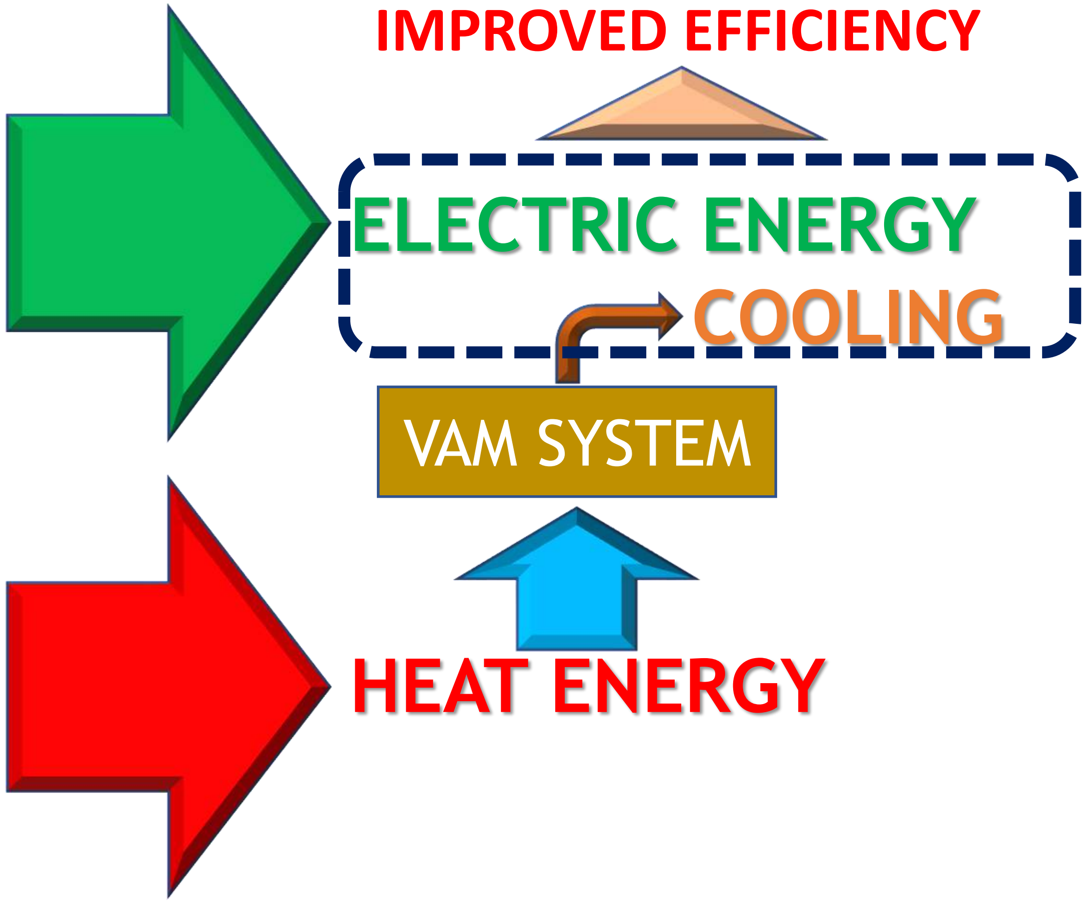
Union minister Jitendra Singh unveiling a hydrogen fuel cell bus in Pune. (Image credit: PIB)

A hydrogen fuel cell bus developed by KPIT-CSIR in Pune was unveiled by Jitendra Singh, Union minister of state for Science and Technology, yesterday. The hydrogen fuel cell uses hydrogen and air to generate electricity, producing only heat and water in the process



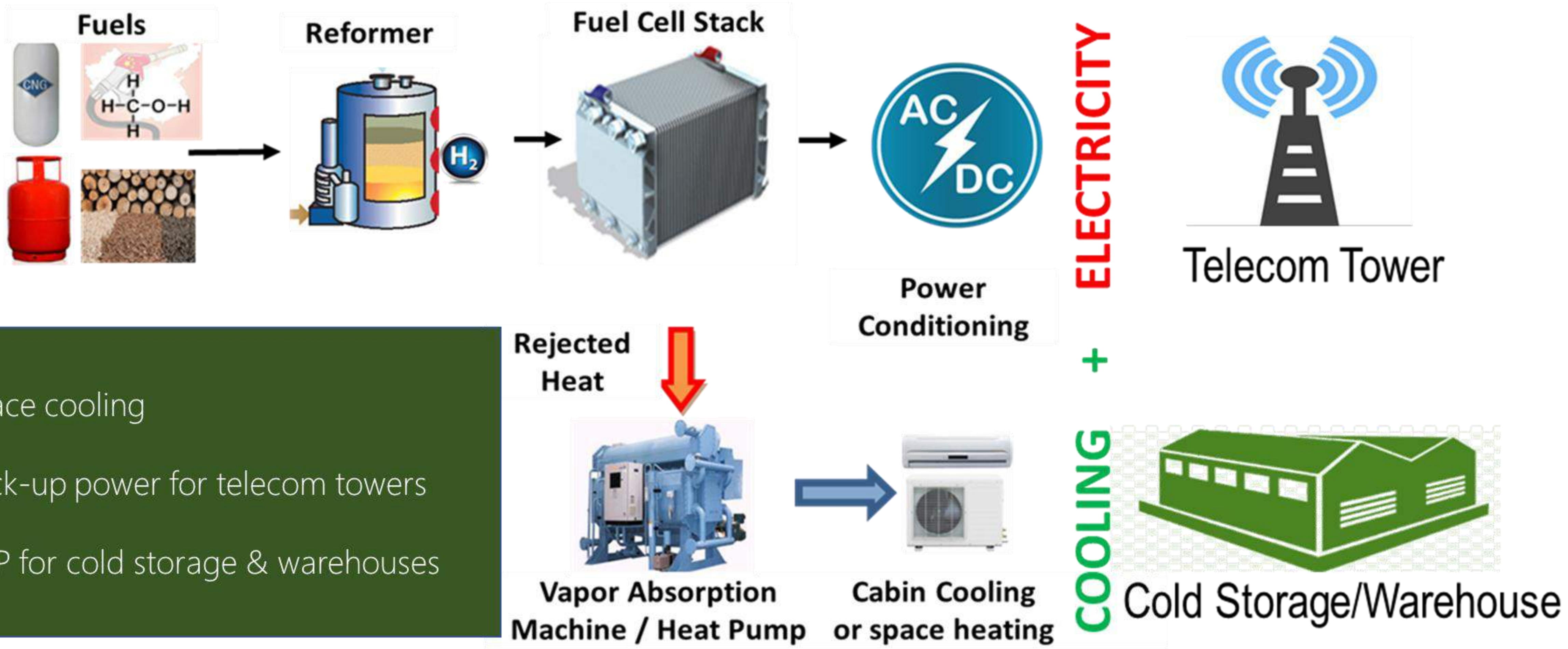

# HT-PEMFC – CSIR's Ambitious Research Program



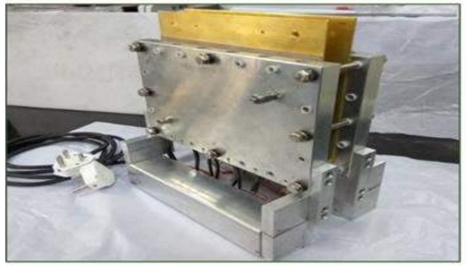

| | |
|---|---|
| LT-PEMFC | Nafion based; humidification needed; low reject heat (<80°C) |
| HT-PEMFC | PBI based; no humidification; high reject heat (150-170°C) |

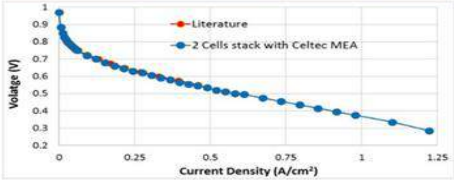
# HT-PEMFC Based Combined Cooling & Power



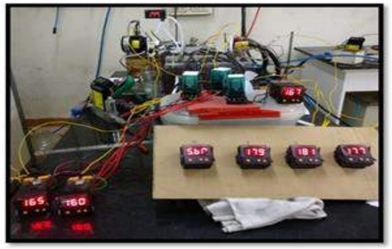

- Space cooling
- Back-up power for telecom towers
- CCP for cold storage & warehouses

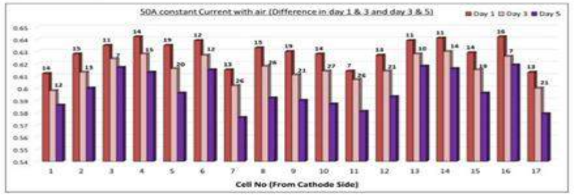
# HT-PEMFC: Status of the Development



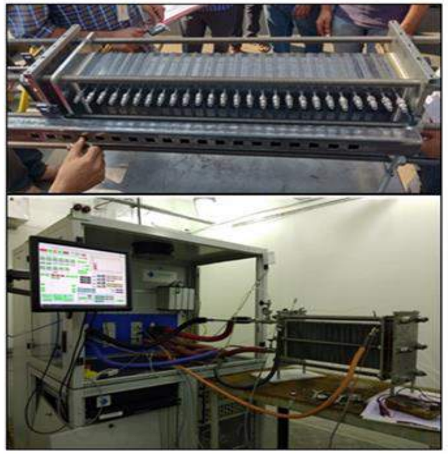



Single Cell study made using imported components

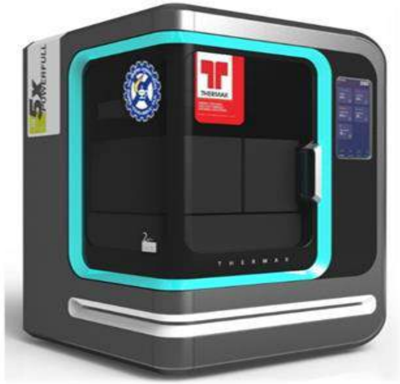





Short Stack assembly and testing

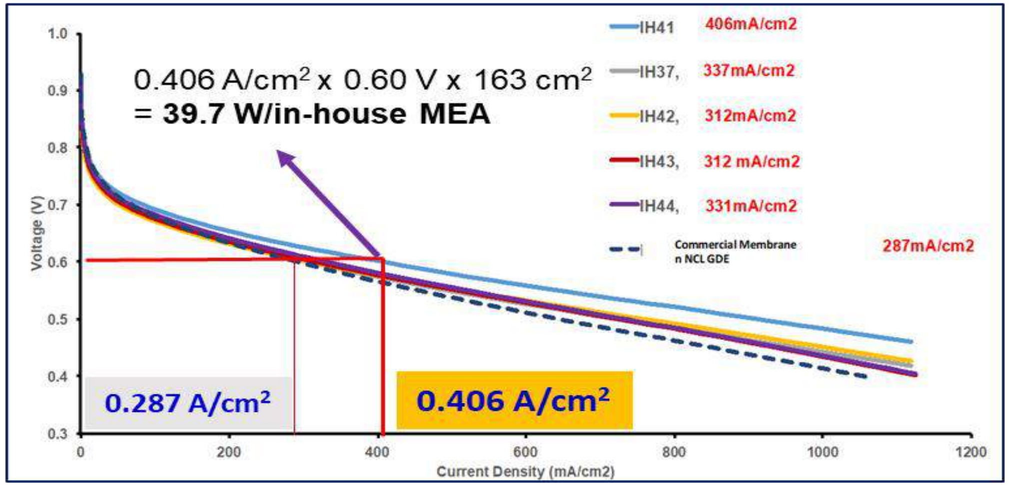


2.5 kW Stacks under testing



5 kW HT-PEMFC System Prototype

Continuous casting of PA-doped PBI Membrane




**Comparison of the stack-sized (163 cm²) MEAs made from CSIR's PBI membrane with the MEA made from commercial membrane**

- A 5 kW HT-PEMFC based CCP demonstration prototype was successfully developed.
- This system comprising of a mix of indigenous and imported components reached a **TRL of 7** implying the readiness of the system prototype in an operational environment.

US Patent Number: 10361446

US Patent Number: 9490488

US Patent Number: 9663624

US Patent Number: 10501317

# Realization of CSIR's HT-PEMFC

Printed from
THE TIMES OF INDIA

## President Ram Nath Kovind unveils green tech fuel system which can replace air polluting DG sets

TNN | Sep 26, 2019, 10.33 PM IST

NEW DELHI: President Ram Nath Kovind on Thursday unveiled India's first indigenous high temperature fuel cell system which will meet the requirement of efficient, clean and reliable backup power generator for telecom towers, remote locations and strategic applications.

This 5.0 kW fuel cell system, generating power in a green manner using methanol/bio-methane, has the potential to replace diesel generating (DG) sets and help in reducing air pollution.

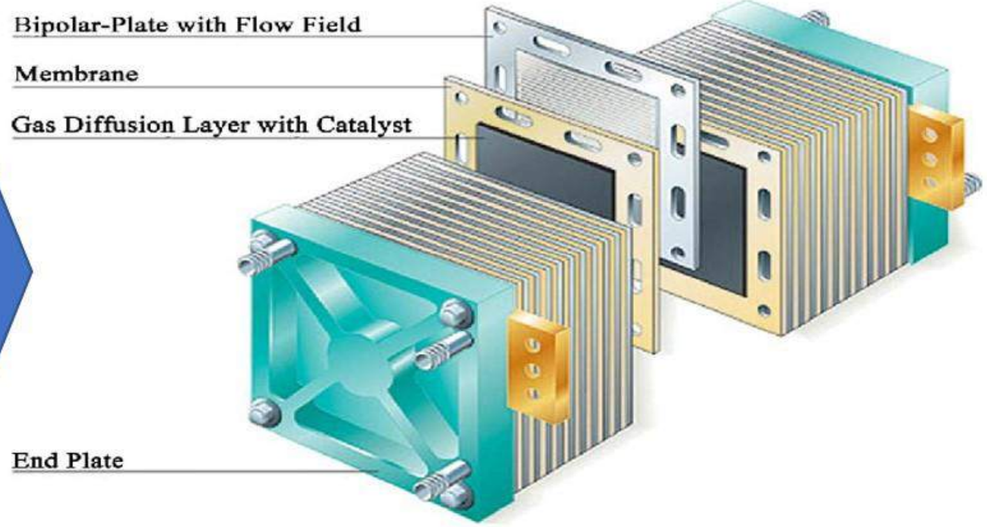
It is developed by council of scientific and industrial research (CSIR) in partnership with Indian industries under the country's flagship program named 'New Millennium Indian Technology Leadership Initiative (NMITLI)'.

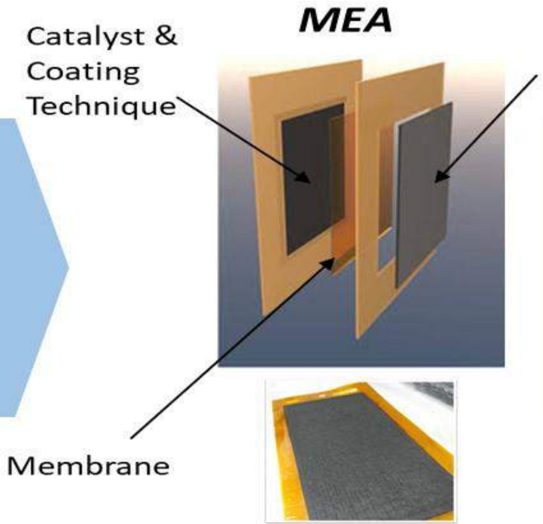
The President unveiled this system on the occasion of the CSIR foundation day at Vigyan Bhawan.The ministry of science and technology, on the occasion, also announced the Shanti Swarup Bhatnagar award for science and technology for the year 2019, selecting 12 scientists from different institutions for this most coveted award in multidisciplinary science in India.

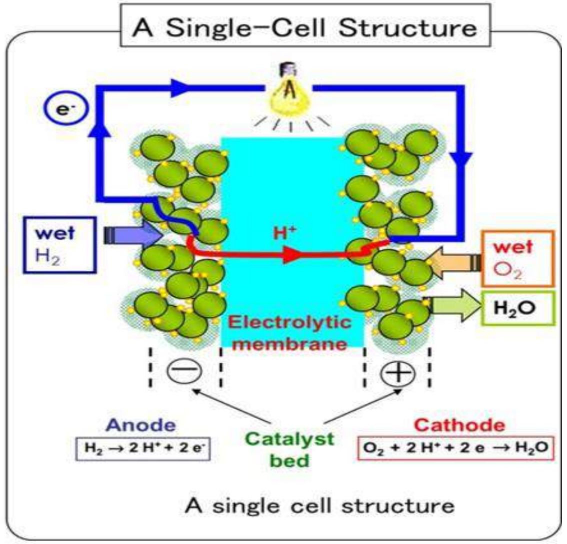
"The development of the High Temperature Fuel Cell system is most suitable for distributed stationary power applications at places such as small offices, commercial units and data centers where highly reliable power is essential with simultaneous requirement for air-conditioning," said a CSIR scientist.

# PEMFC: A Technology Driven through Deep Science

Technology Component

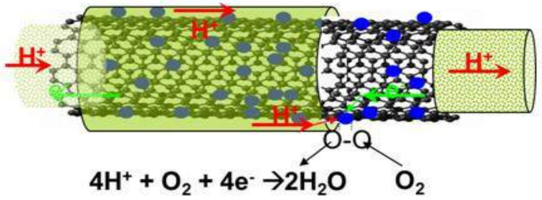


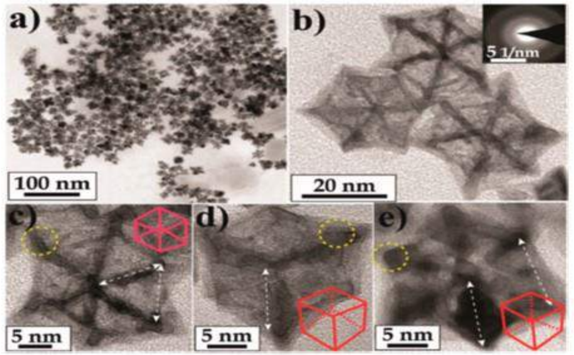





- Proton Conducting
- Electrically Conductive
- Electrochemically Active




Anode side reaction:

$$2H_2 \rightarrow 4H^+ + 4e^-$$

Cathode side reaction:

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

Net reaction:

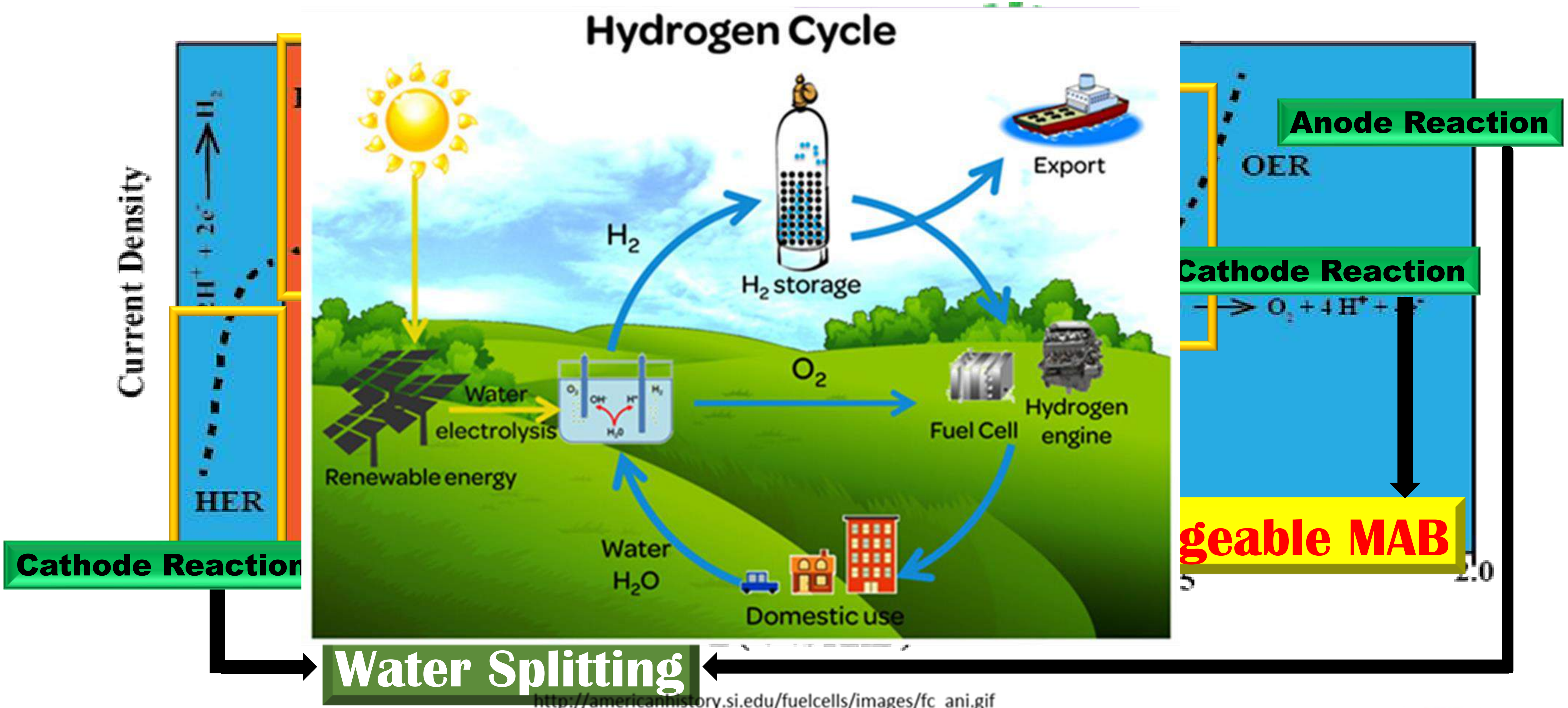
$$2H_2 + O_2 \rightarrow 2H_2O$$

Research Component

**Polymer Materials** | **Hybrid Materials** | **Nanomaterials** | **Electrochemistry**

# Oxygen Electrochemistry for Sustainable Energy Conversion

## Sluggish Process – Requires Better Cost-Effective Catalysts



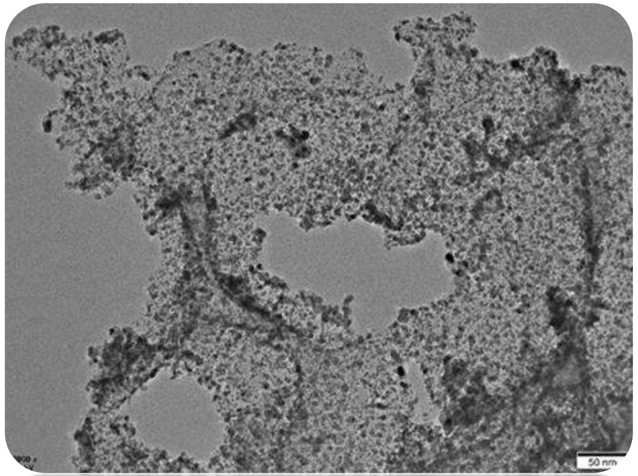

http://americanhistory.si.edu/fuelcells/images/fc_ani.gif

# PEMFC: Innovations through Deep Science

## Electrocatalysts, Electrodes and MEAs

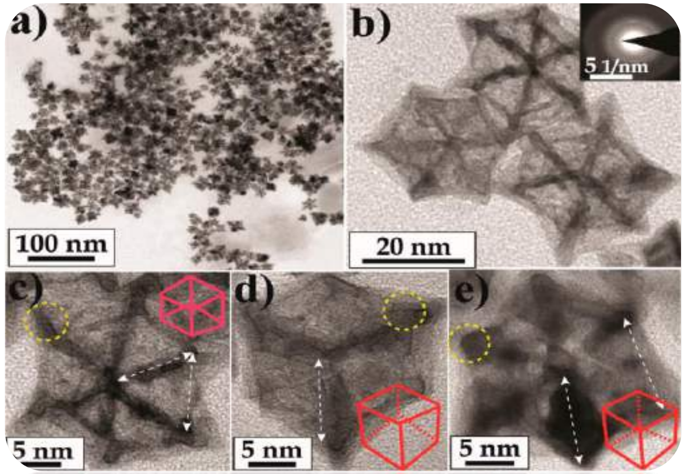
**Cost**

### Pt-Based Electrocatalysts



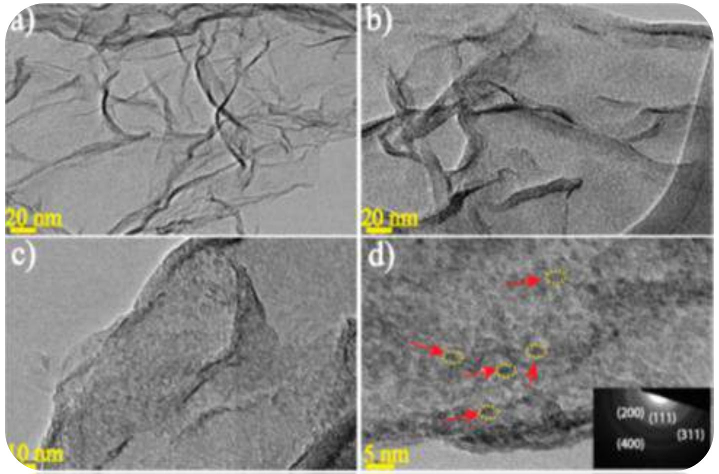
Adv. Sustain. Syst.., 5(1), 2021, 2000125.
J. Mater. Chem. A., 1, 2013, 4265 - 4276.
J. Phys. Chem. C., 113, 2010, 11572.

### Low-Pt Electrocatalysts




ACS Catal., 5 (3), 2015, 1445 – 1452.
J. Phys. Chem. C., 114, 2012, 14754 – 14763.
J. Phys. Chem. C., 116, 2012, 7318.

### Pt-Free Electrocatalysts



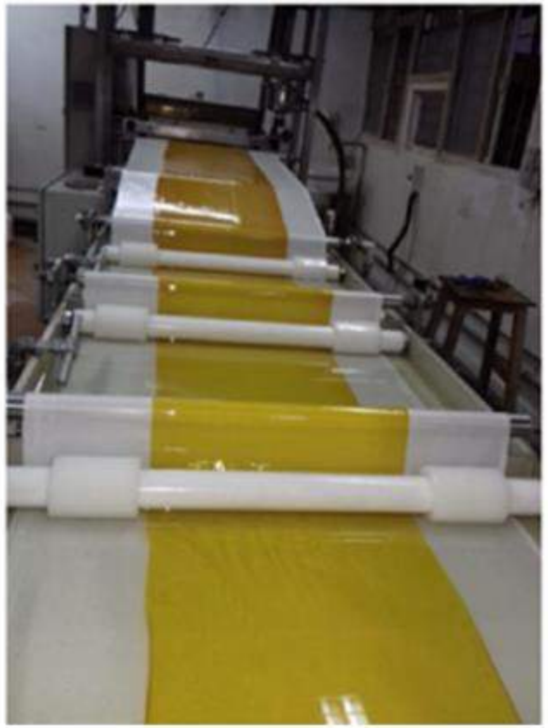

ACS Catal., 7 (10),2017, 6700 – 6710.
Adv. Funct. Mater., 13, 2016, 2150 – 2162.
Energy Environ. Sci. 7(3), 2014, 1059 – 1067.

- Indigenous Technologies
- Scalability
- Performance
- Durability

# PEMFC: Innovations through Deep Science

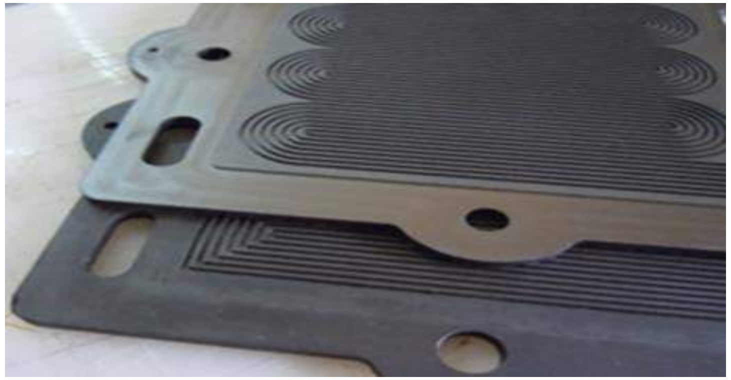
## Electrocatalysts, Electrodes and MEAs

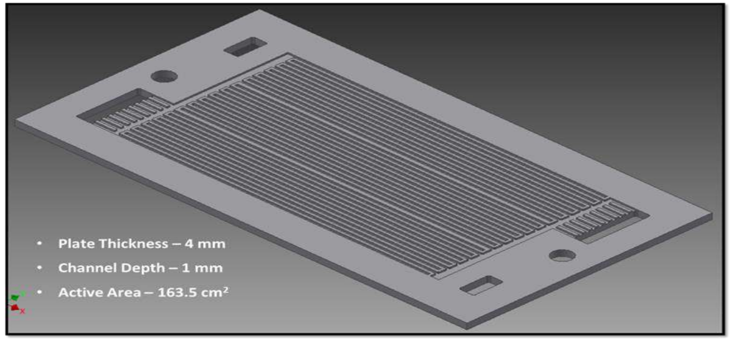
### Membrane



- Indigenous technology
- Continuous casting
- IP-protected processes

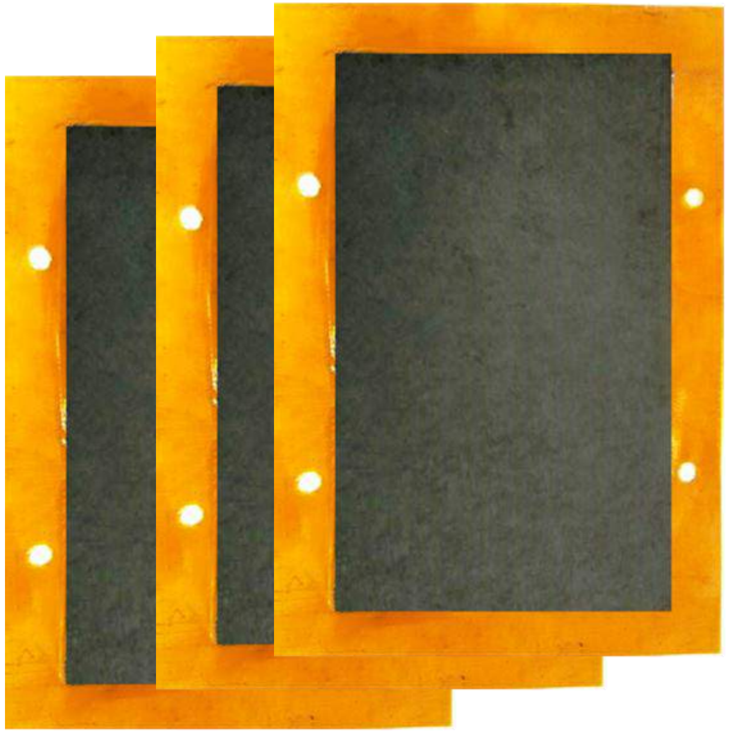
### Bipolar Plate






- IP-protected processes
- High corrosion resistance
- High temperature operability

### MEA

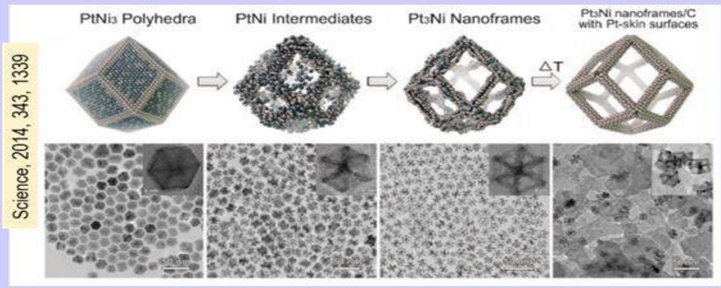


- For LT and HT PEMFCs
- High performance & durability
- High level of indigenization

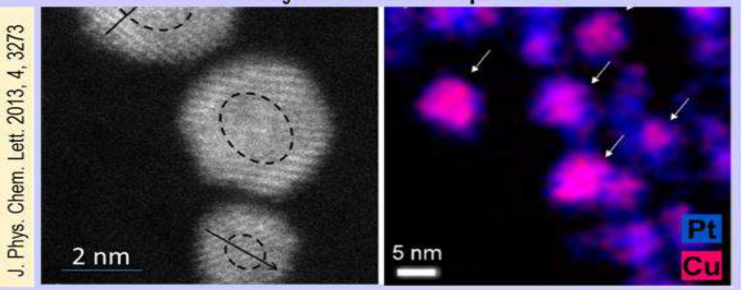
# Catalysts to Electrodes – Need of Complimentary Process Protocols

## Active fancy catalyst morphologies; still fail to perform as electrodes

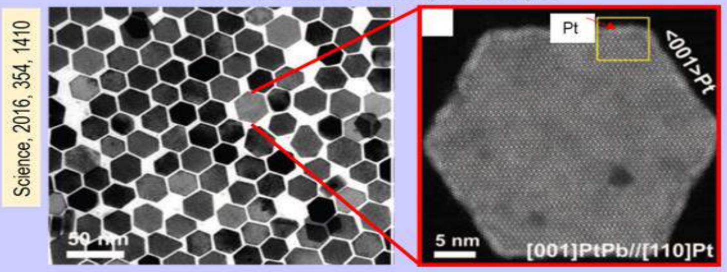
- There are fascinating catalyst morphologies which can bring revolutionary changes in the design and performance aspects of many energy generation/ storage systems.
- Creation of multifunctional requirements for specific purposes involves sequential processes and tedious post-synthesis treatments.
- Such processes significantly spoil the structural and property advantages of many nanomaterial morphologies.



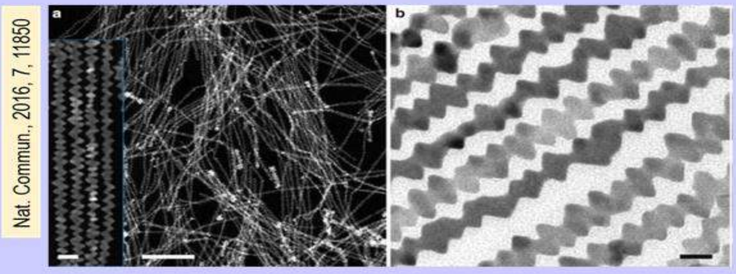

$PtCu_3$ core-shell nanoparticles



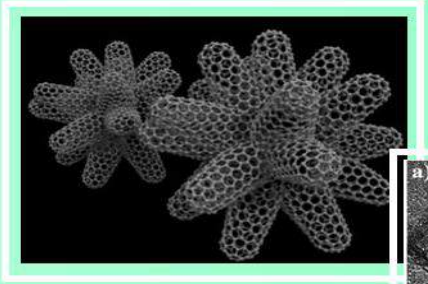

PtPb based Pt thin layer catalyst



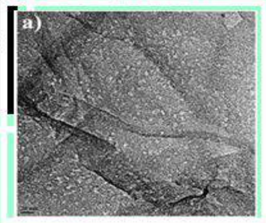

Hierarchical Pt-Co nanowires

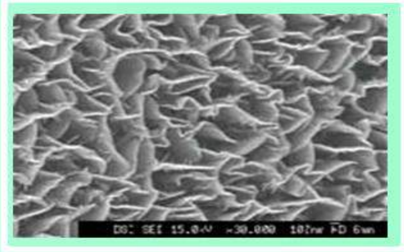



CNH



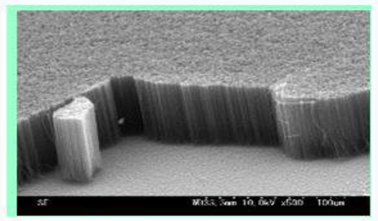
Holey Graphene

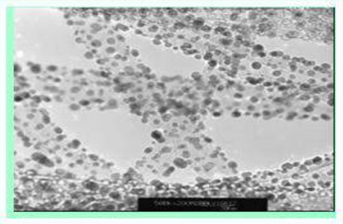


CNW

Vertically Grown CNTs





Pt/CNT

Energy & Environmental Science
ROYAL SOCIETY OF CHEMISTRY
PAPER
View Article Online
View Journal | View Issue
Cite this: *Energy Environ. Sci.*, 2014, 7, 1059

## Nanoporous graphene by quantum dots removal from graphene and its conversion to a potential oxygen reduction electrocatalyst *via* nitrogen doping†

Thangavelu Palaniselvam, Manila Ozhukil Valappil, Rajith Illathvalappil and Sreekumar Kurungot*

ADVANCED FUNCTIONAL MATERIALS
www.afm-journal.de
Materials Views
www.MaterialsViews.com

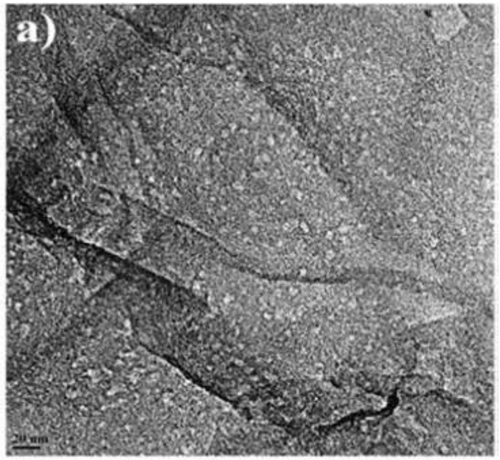
## Nanoporous Graphene Enriched with Fe/Co-N Active Sites as a Promising Oxygen Reduction Electrocatalyst for Anion Exchange Membrane Fuel Cells

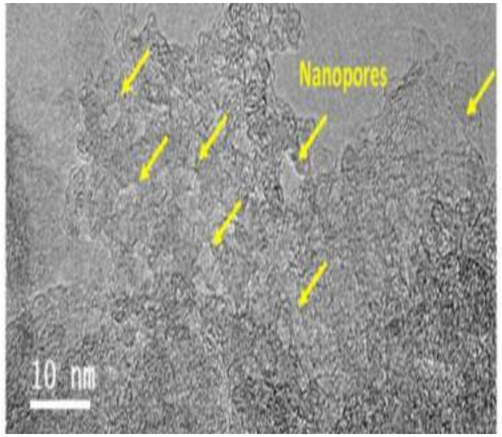
*Thangavelu Palaniselvam, Varchaswal Kashyap, Siddeswar N. Bhange, Jong-Beom Baek,* and Sreekumar Kurungot**

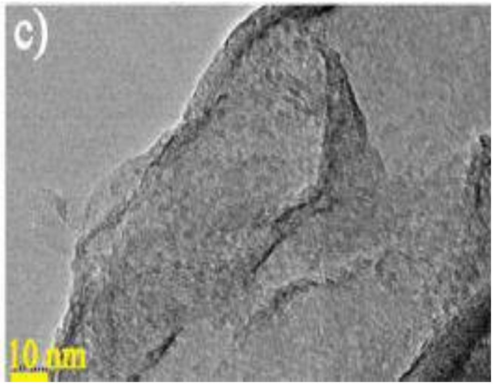
ACS Catalysis
Research Article
pubs.acs.org/acscatalysis

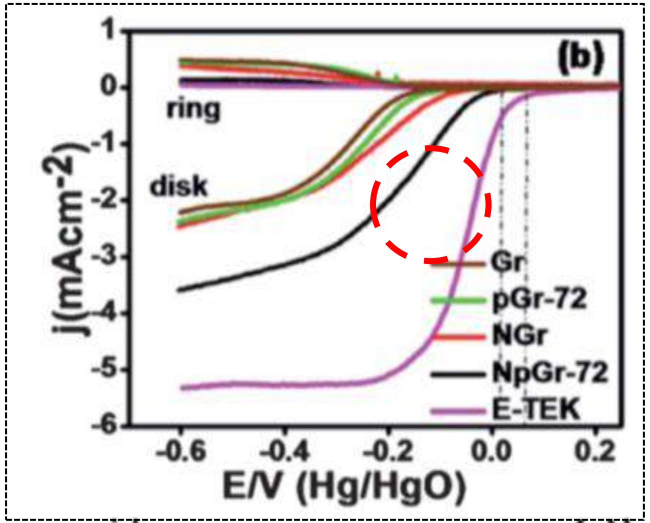
## Efficient and Durable Oxygen Reduction Electrocatalyst Based on CoMn Alloy Oxide Nanoparticles Supported Over N-Doped Porous Graphene

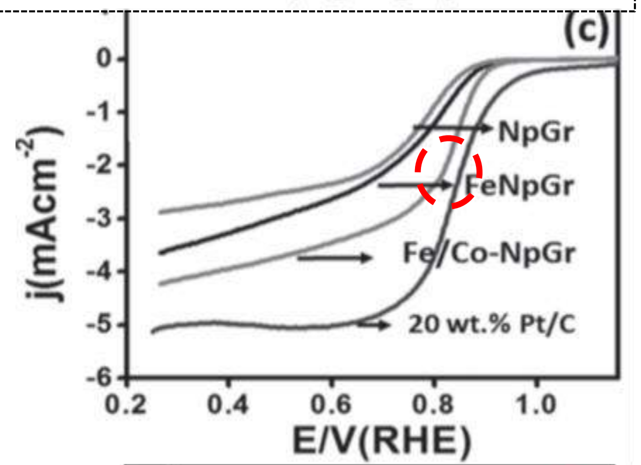
Santosh K. Singh,[†,‡] Varchaswal Kashyap,[†,‡] Narugopal Manna,[†,‡] Siddheshwar N. Bhange,[†,‡] Roby Soni,[†,‡] Rabah Boukherroub,[§] Sabine Szunerits,[§] and Sreekumar Kurungot*[,†,‡]

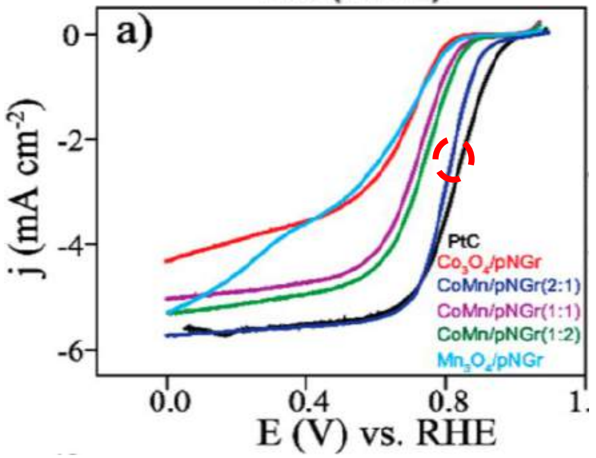


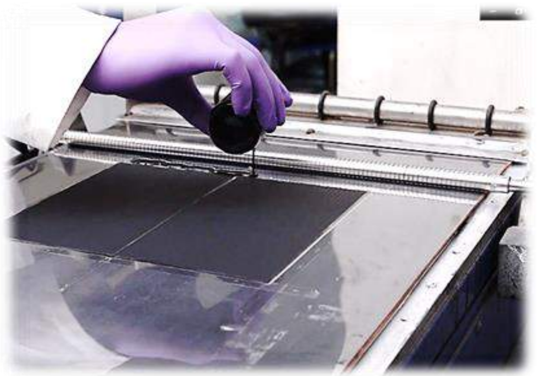



# Process-Friendly Electrodes: Need of Bottom-Up Design Strategies

Catalyst Designing

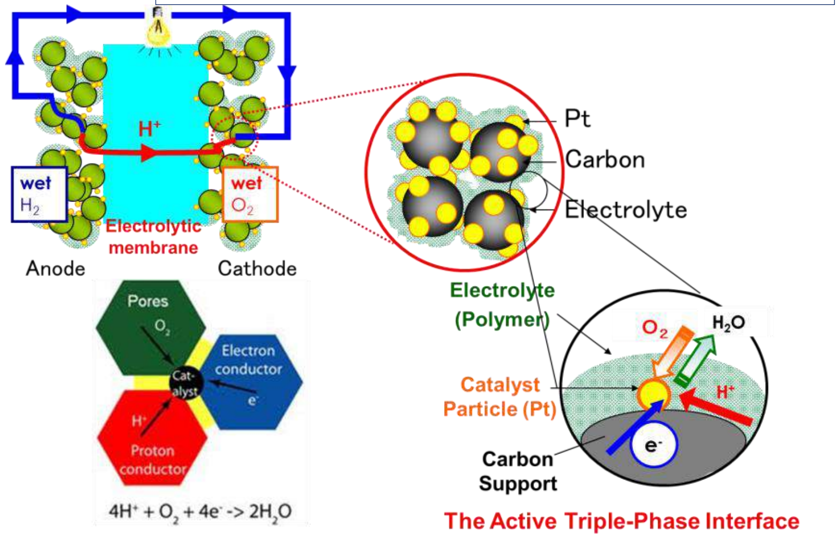
Catalyst Ink Formulation

Electrode Fabrication



MEA Assembling

**Actual Scenario in a PEMFC Electrode**




- Catalyst aggregation
- Under-utilization
- Poor accessibility
- Poor mass-transfer
- Internal flooding
- Oxygen starvation
- Cell reversal
- Local hot-spots
- Catalyst corrosion

To solve the existing issues, designing of a "process-friendly electrodes" with 3D textural architecture derived through a suitable "bottom-up approach" would be promising.

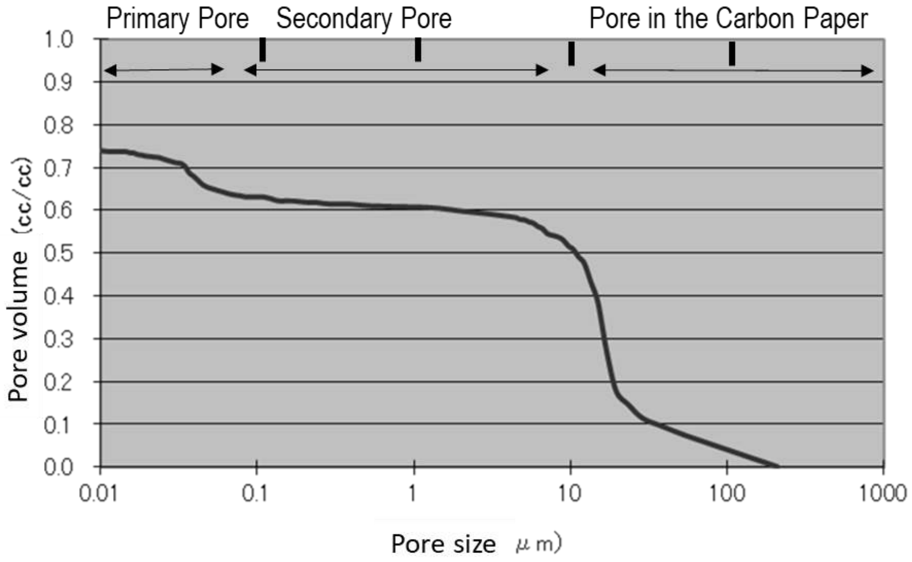

ACS Appl. Mater. Interfaces 2021, 13, 8147−8158.

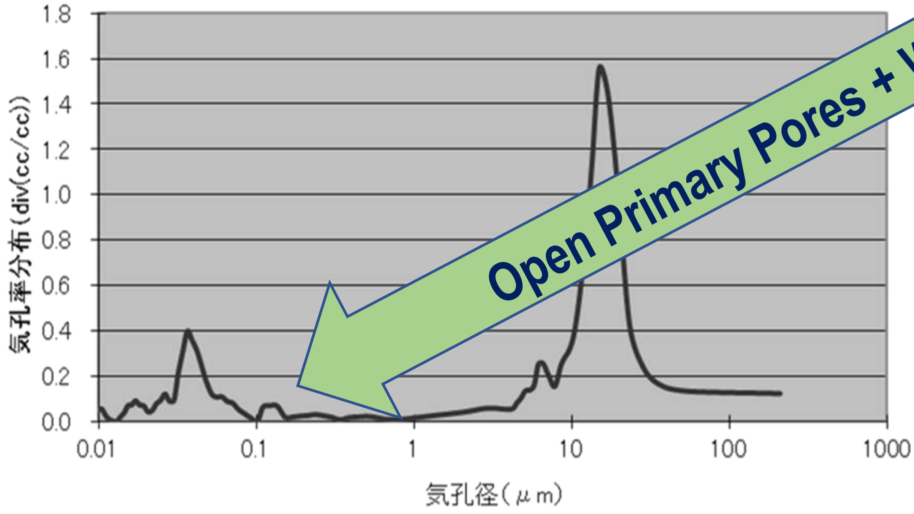
Sustainable Energy & Fuels, 2021, 5 (18), 4758 - 4770.

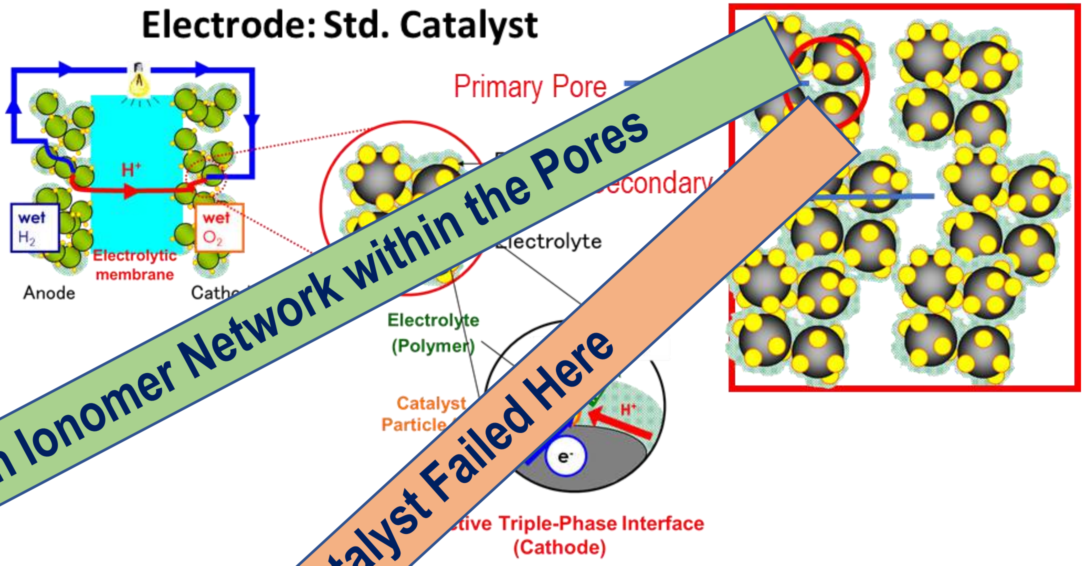
Advanced Sustainable Systems., 2021, 5(1), 2000125.

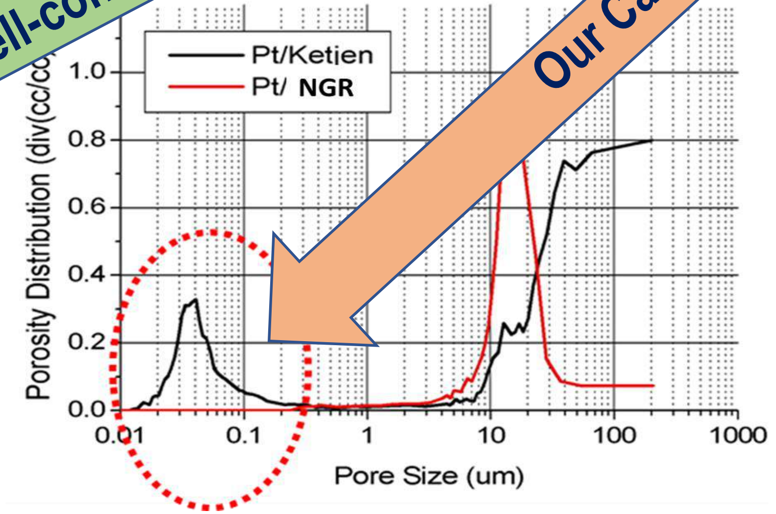
ACS Appl. Energy Mater., 2020, 3(2), 1908 - 1921.

# Process-Friendly Electrodes
## Porosity Plays a Critical Role



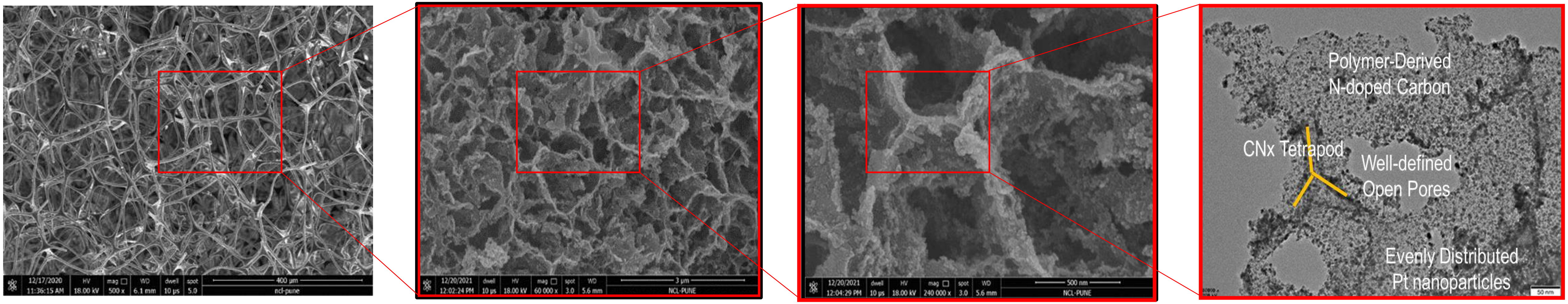




It is important for the electrode to have more available primary pores since they serve as reactant (oxygen and hydrogen) reservoirs and thus play a critical role in deciding the catalyst utilization.

# Electrodes based on 3D-Structured Catalyst (Pt/3DPDC)

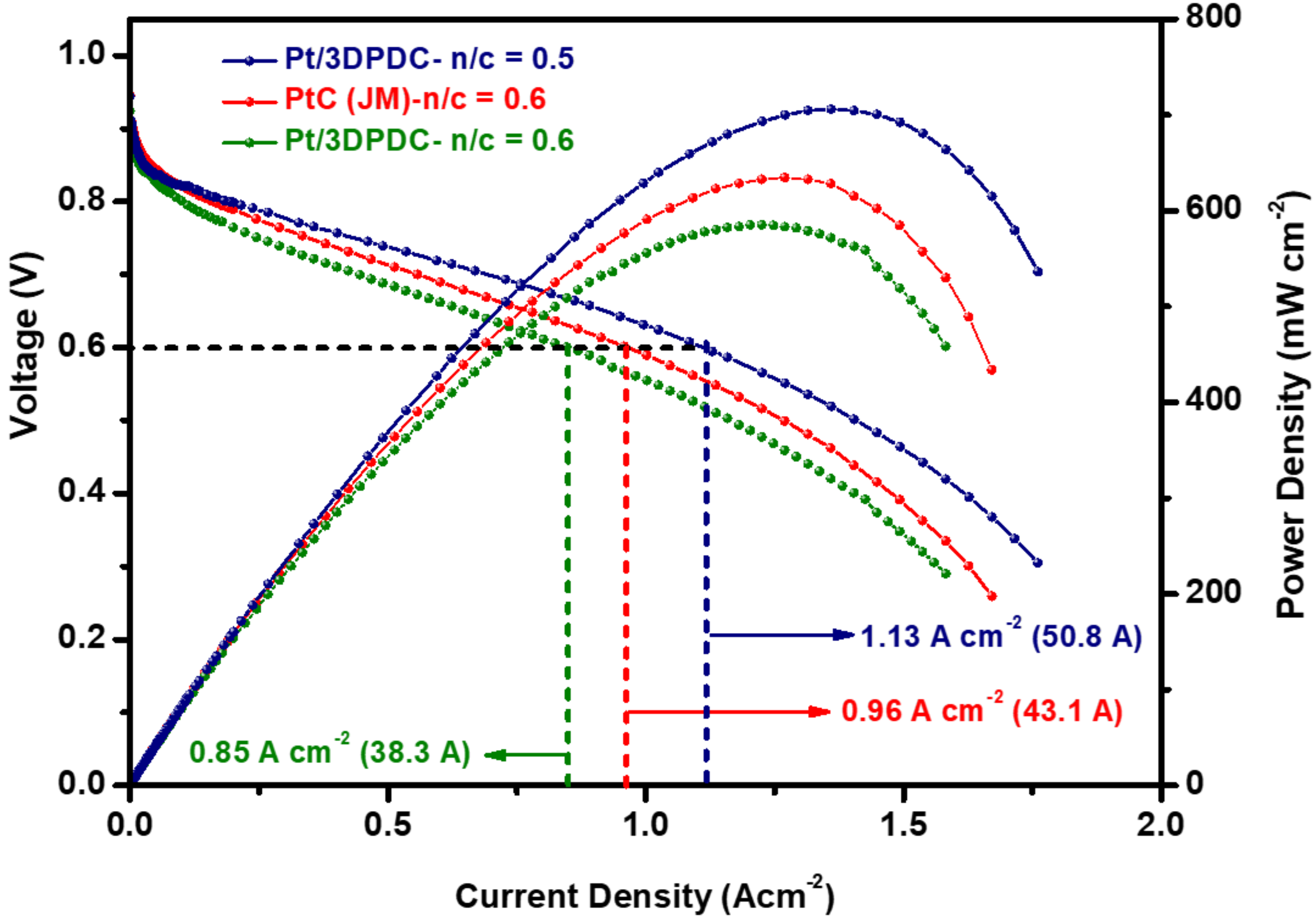
- Rigid Framework
- Open Pores
- Exposed Active Sites




- Pt/3DPDC has well-extended 3D framework structure maintained through the stable backbone of CNx tetrapods.
- The porous architecture has interconnected carbon walls formed from the polymer-derived carbon layers.
- The Pt nanoparticles are well-dispersed with size in the range of 2-5 nm.
- The Pt particles are well-exposed and the open channels provide seamless pathways for reactant distribution.
- The unique texture of the catalyst helps for better dissipation of product water and thus improved water-management.

# PEMFC based on the 3D-Structured Catalyst (Pt/3DPDC)

## Single Cell Testing (45 $cm^2$); Nafion Membrane



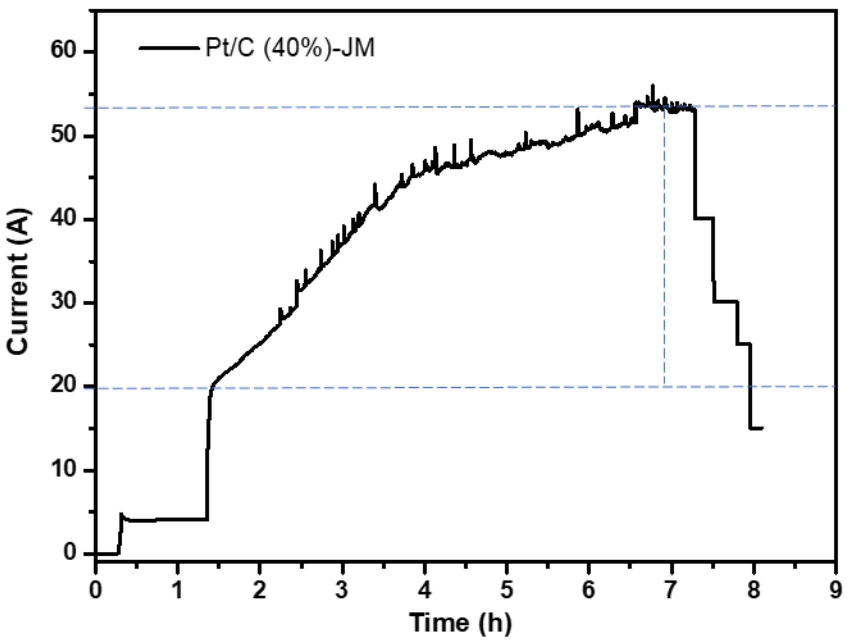


- The MEA based on Pt/3DPDC gives much better performance compared to that based on Pt/C (50.8 vs. 43.1 A $cm^{-2}$).

# Advantages of the Cells based on the 3D-Structred Catalysts

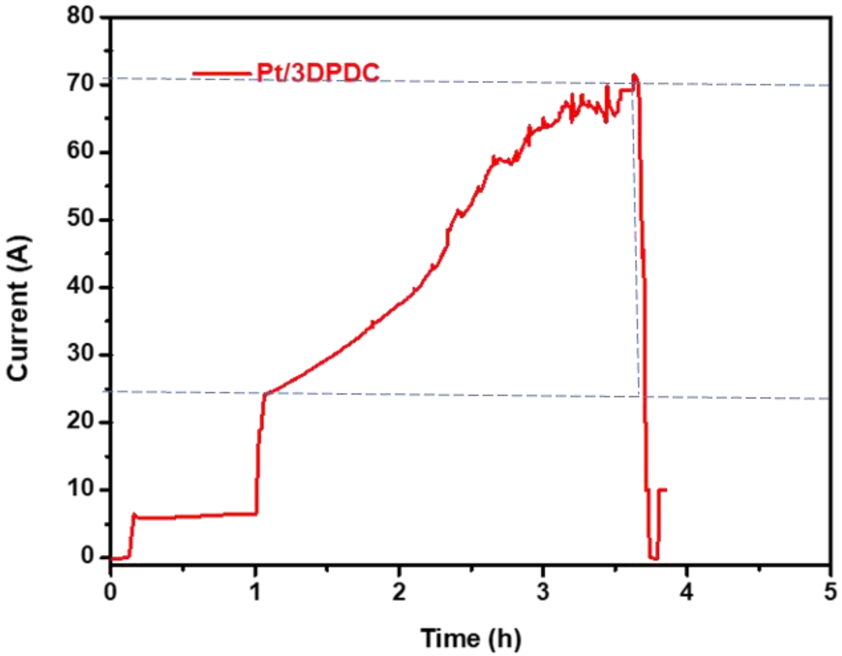
▪ Fast Activation ▪ High Performance ▪ Low Flooding

## Conventional MEA




- $\frac{dI}{dt} = 5.77\ Ah^{-1}$
- Slow activation; nearly 7 h
- Less current output; ~50 A
- More spikes due to water flooding

## Conventional MEA




- $\frac{dI}{dt} = 18.37\ Ah^{-1}$
- Fast activation; nearly 3.5 h
- High current output; ~70 A
- Less spikes due to water flooding

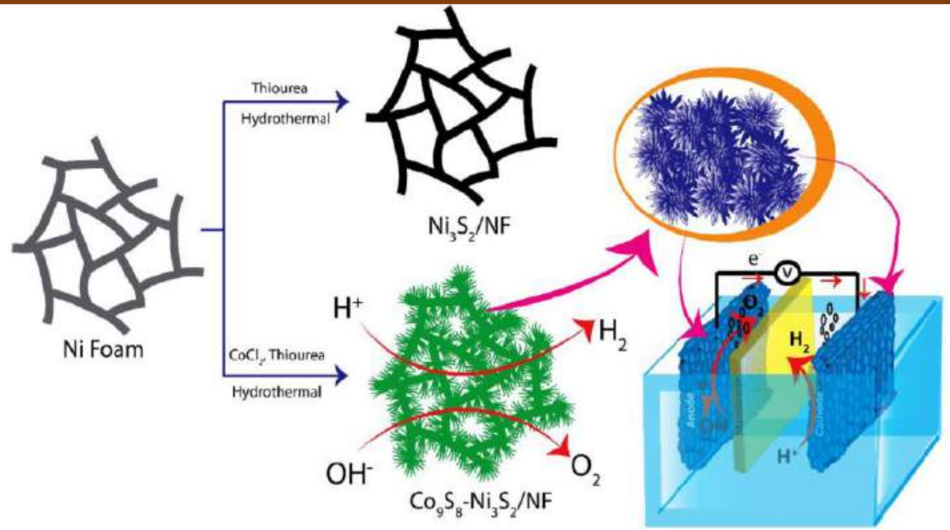
**Advantages of the 3DPDC MEA:**

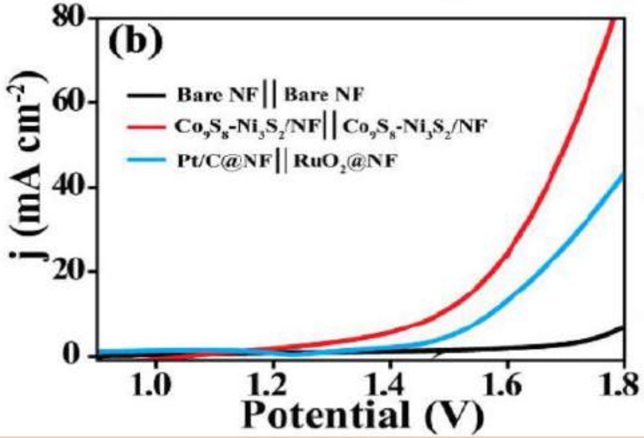
- Fast activation is possible due to the porous texture of the catalyst.
- High current output due to the better reactant distribution and exposure of the active sites.
- Better water-management since the porous texture assists water dissipation.
- Altogether, Pt/3DPDC provides more process-friendly electrodes.

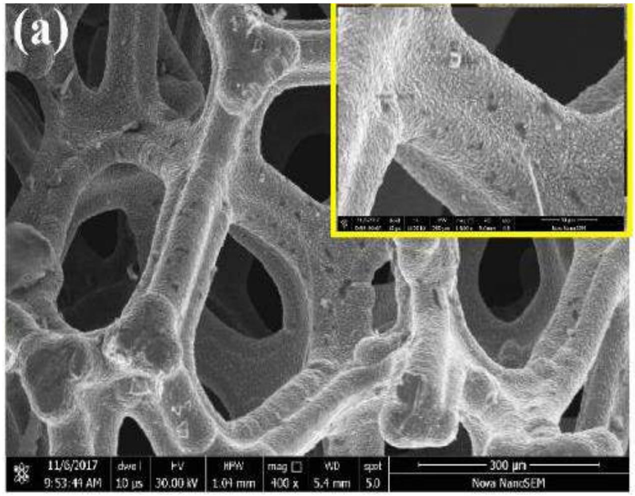
# 3D Structured Bi-functional Electrocatalysts for Water-Splitting

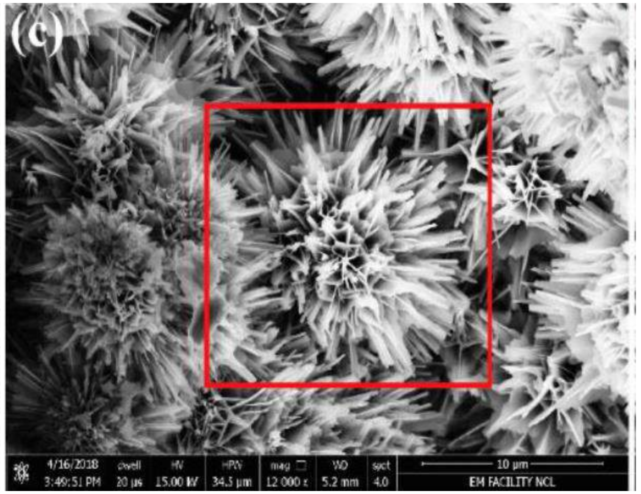
## Simultaneously OER & HER Active

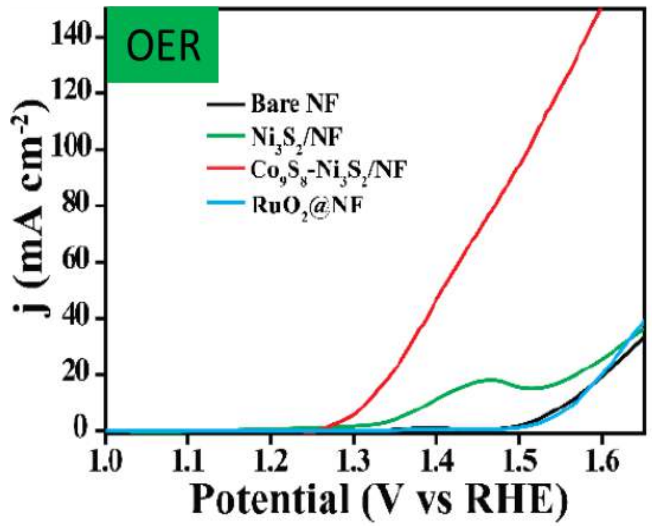
### 3D Structured OER/HER Bi-functional Catalyst

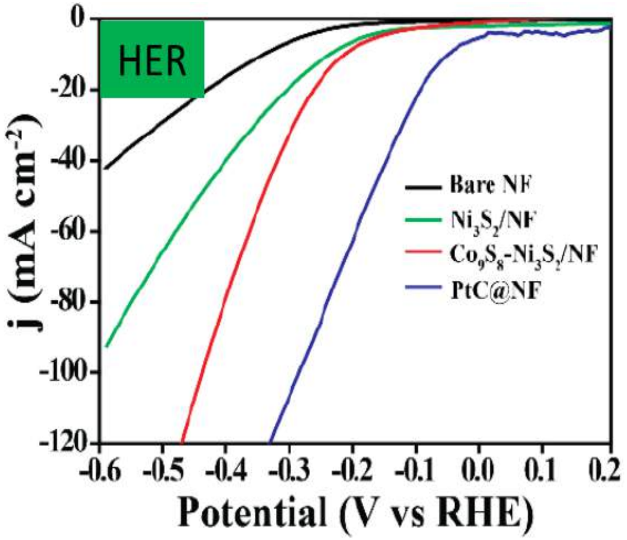


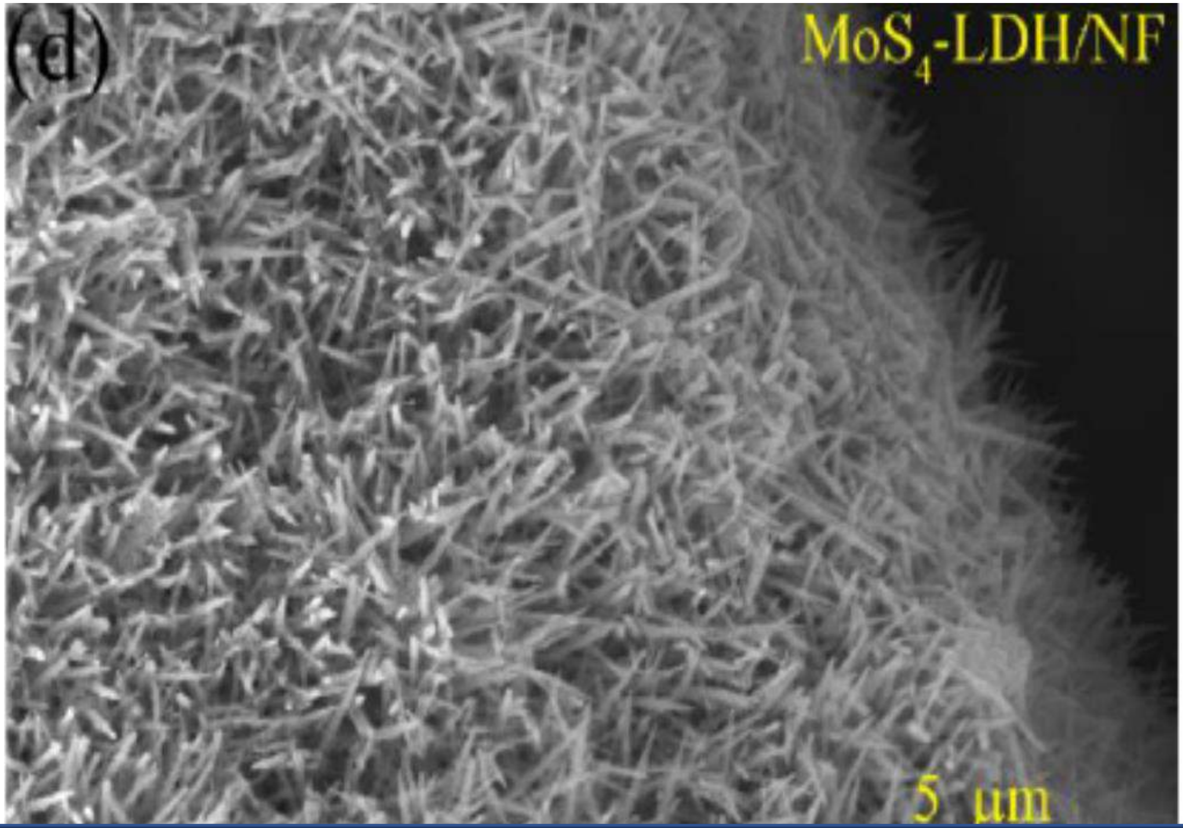



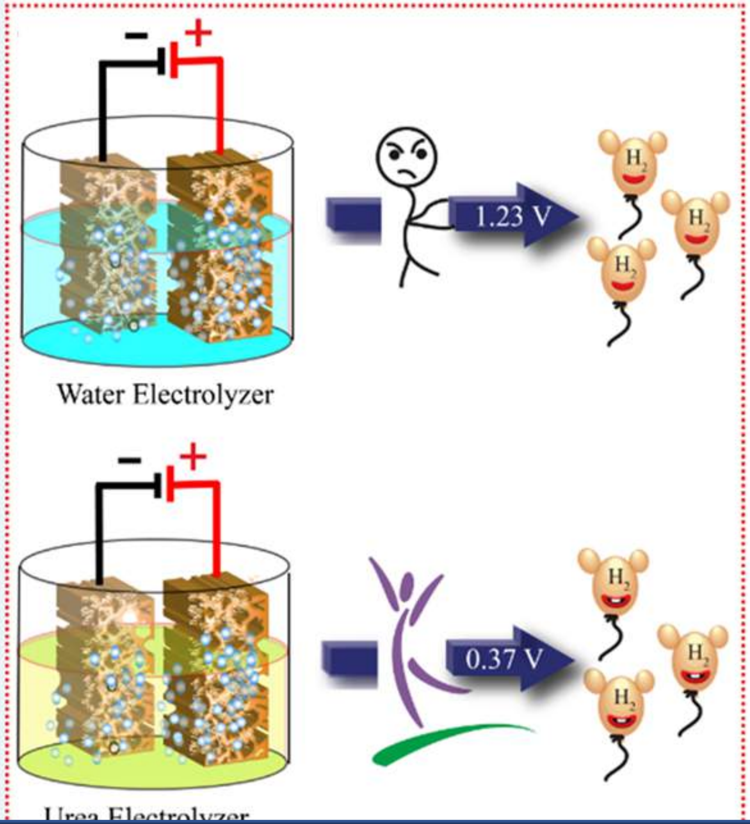

Chem. Eur. J, 2020. 26 (35), 7900

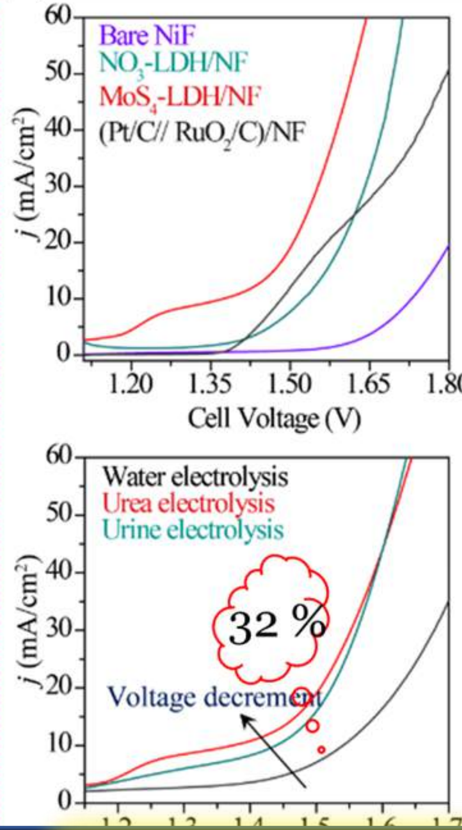
# 3D Structured Bi-functional Electrocatalysts for Water-Splitting

## Simultaneously OER & HER Active




ACS Appl. Mater. Interfaces, 2019, 11 (29), 25917 - 25927




**Same Catalyst for OER & HER** → **One Process for Electrode Fabrication** → **Same Electrode for the Anode & Cathode** → **More Feasible Anode Reaction** → **Less Processing Cost & Better Efficiency**

# Conclusions

CSIR HAS SET AN AMBITOUS ROADMAP TO MAKE THE ORGANIZATION AS THE TECHNOLOGY ENABLER FOR BUILDING AND MAINTAINING HYDROGEN ECONOMY FOR THE COUNTRY.

THE TRANSLATION OF THE INTRINSIC ACTIVITY OF THE CATALYST IN TERMS OF THE PERFORMANCE OF THE ELECTRODE DERIVED FROM THIS CATALYST REQUIRES COMPLEMENTARY AND WELL-MANGED FABRICATION PROTOCOLS.

THE IDEALLY BEST CHOICE IS TO DESIGN THE CATALYST THROUGH A 'BOTTOM-UP' APPROACH BY CAREFULLY INTEGRATING THE REQUIRED STRUCTURAL AND FUNCTIONAL ATTIBUTES WHILE BUILDING THE CATALYST ITSELF.

# Acknowledgement:

- Research scholars and project assistants in my group
- Fuel cell teams of the participating CSIR labs
- Industry partners
- CSIR and DST for project funding
- Director CSIR-NCL & Project Monitoring Committee Members
- Research collaborators in India and abroad

## Funding & Collaboration

CSIR-INDIA | Department of Sciences & Technology Government of India | THERMAX | Reliance Industries Limited | KPIT | Noritake JAPAN 1904

**Thank You!**