The Role of Hydrogen in the Energy Transition

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R & D at CECRI

- Batteries, Supercapacitors & Fuel Cells
- Corrosion Science and Engineering
- Industrial Metal Finishing
- Electrometallurgy
- Electro-chemicals
- Electrodics and Electro-catalysis
- Electrochemical Materials Science & Functional Materials
- Electrochemical Instrumentation
- Pollution control
- Nanoelectrochemistry
- Educational Programs

↓

B Tech/M Tech Courses in Chem. & Electrochem. Engg. + Ph D

CECRI Madras Unit - Chennai

- Fuel Cells
- Lithium ion Batteries
- Futuristic Batteries

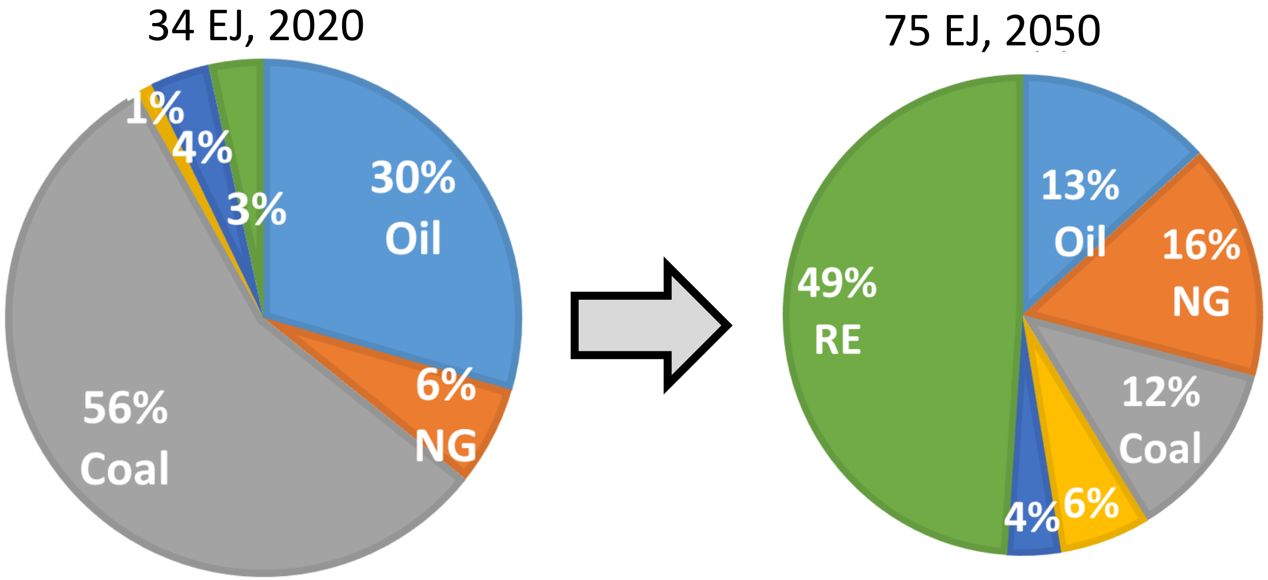
India's Evolving Energy Transition

- Energy demand will **double** from the present 34 EJ to 75 EJ by 2050
- Must achieve greater **end-to-end energy security**, from raw materials to energy generation processes
- As of today, India imports 350 million tons of carbon in the form of fossil energy
- 2.6 GT CO_2 is emitted from this carbon energy, making India world's 3rd largest GHG emitter
- Contrastingly, India has 110 billion tons of proven coal reserves, and an additional 450 million tons of carbonaceous resources in the form of **agro residues and MSW**
- Potential to increase **non-fossil clean energy** production from ~ 2.7 EJ today to ~ 26 EJ by 2050
- To achieve energy security with low carbon footprint, India must:
  - Reduce carbon demand through improving energy efficiency in all energy consuming processes
  - Move from thermal generation to integrated gasification combined cycle with Indian **coal gasification coupled with carbon capture utilization and storage**
  - **Increase clean power production from biomass, renewables, solar, wind, nuclear, hydroelectricity**
  - Explore energy storage options in the form of batteries, **hydrogen**, pumped hydro, gravity
  - Focus on technologies that offer greater prospects for end-to-end self reliance
  - Increase manufacturing across the energy generation, transmission, utilization value chains

India’s ambitious climate action plan

Panchamrit – India’s National Statement @ COP26

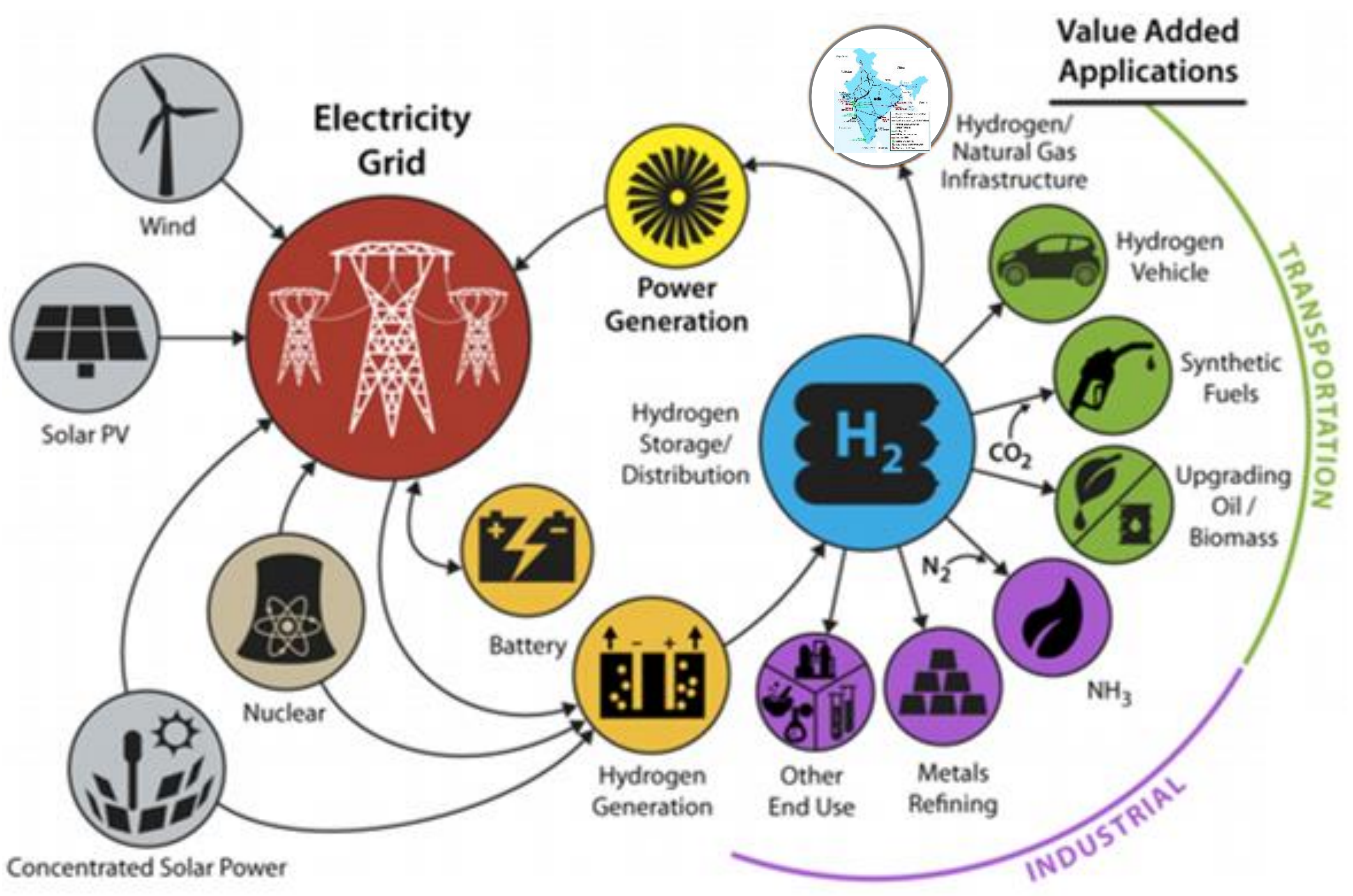
1. 500 GW RE installed capacity by 2030
2. 50% RE contribution to energy mix by 2030
3. Reduce CO2 emissions by 1 GT from now till 2030
4. Carbon intensity of GDP to be < 45% by 2030
5. Achieve net zero emissions by 2070



Total emissions (current)	2.6 $Gt_{CO2\ eq}$
Power	33%
Light transportation	5%
Agriculture	18%
Industry	24%
Heavy transportation	9%
Others	15%

H2 for India

Sector coupling energy vector critical to achieve deep decarbonisation of difficult sectors

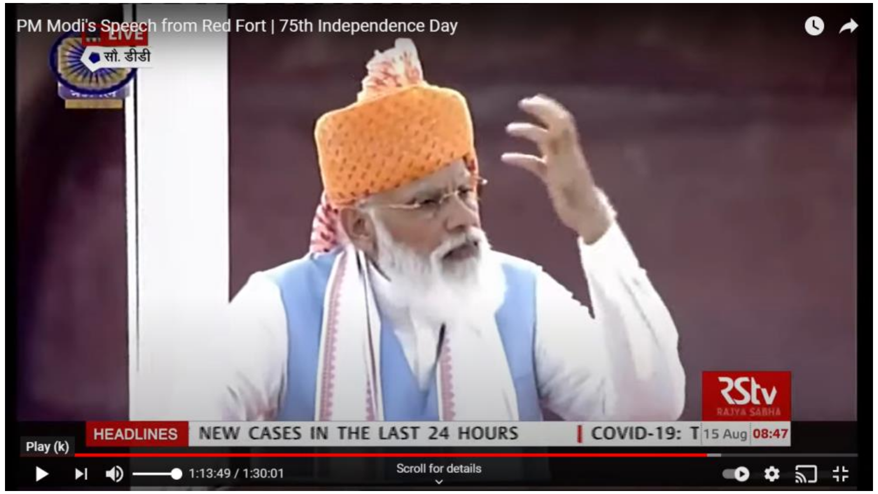


Abundant
Affordable
Atamanirbhar

Decentralization
Digitization
Deep Decarbonization

Enterprise
Exporter
Economy

H_2 Opportunity for India



“Green Hydrogen will be India’s biggest goal for providing a quantum jump to address climate change”

Near Term (2030-2035)

- Aim for 5 MMTPA green H2 (8% RE capacity)
- Phased replacement of grey in refining & fertilizer
- Green H2/ green NH3 hub for export, bunkering

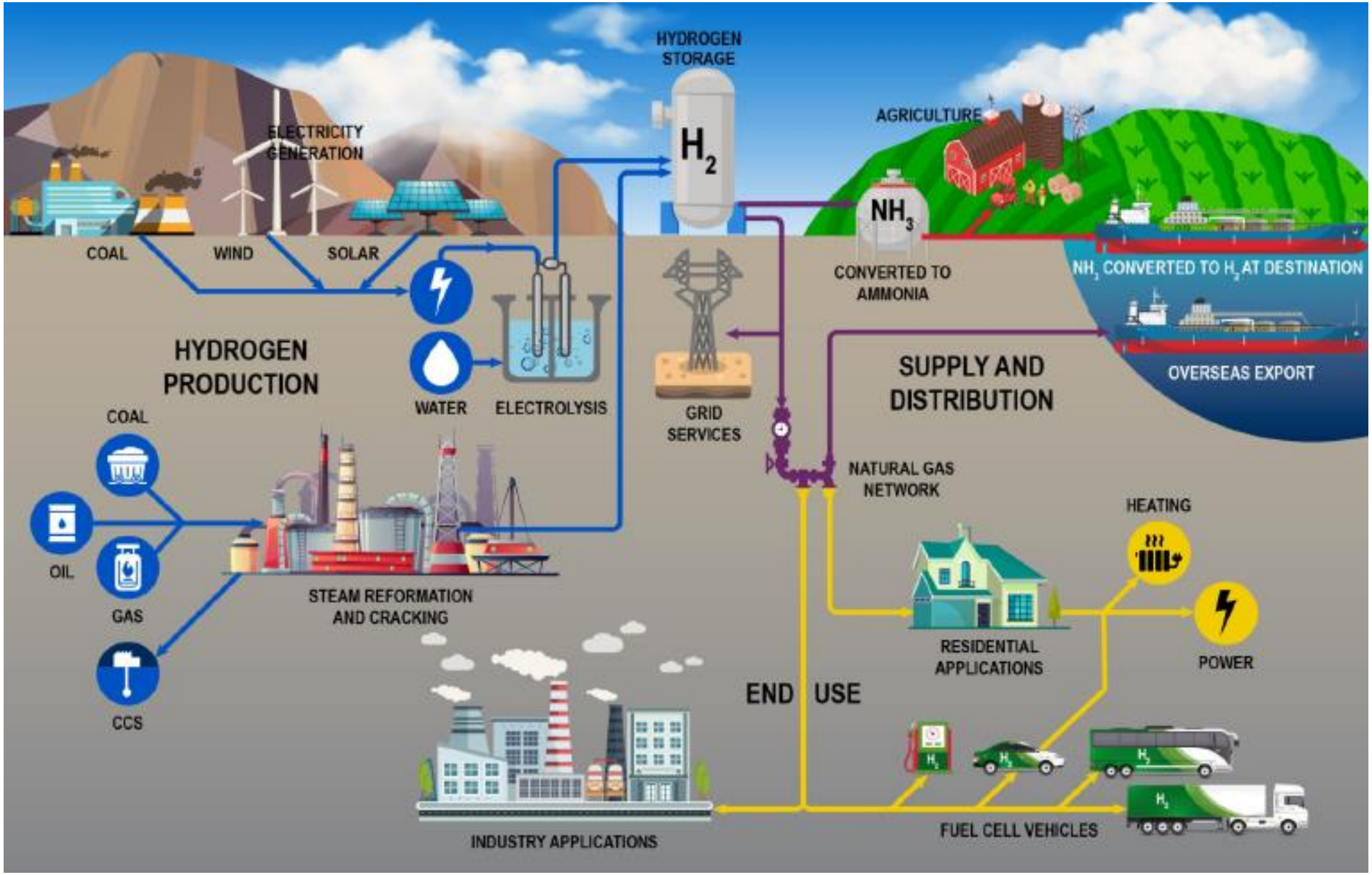
Mid Term (2040)

- Reach 12 MMTPA green H2 (20% of 500 GW RE)
- Shift diesel backup power generation to H2-FC/ ICE
- Shift HCVs to H2-ICE/ FCEV by 2045

Long Term (> 2050)

- At least 70 MMTPA commensurate with Indian economy
- Shift steel, cement to H2 technologies
- Grid balancing/ curtailed power

Opportunities Lie Across Hydrogen Value Chain



Production

Hydrogen Color Spectrum

GREEN HYDROGEN

Hydrogen produced by electrolysis of water, using electricity from renewable sources like hydropower, wind & solar. Zero carbon emissions are produced.

GREY HYDROGEN

Hydrogen produced using fossil fuels such as natural gas. This accounts from roughly 95% of the hydrogen produced in the world today.

BROWN HYDROGEN

Hydrogen extracted from fossil fuels and created through coal gasification.

BLUE HYDROGEN

Grey or brown hydrogen with its C02 sequestered or repurposed.

PINK/PURPLE/RED

Hydrogen obtained by electrolysis through an atomic current using nucle-ar power.

YELLOW HYDROGEN

Hydrogen made through electrolysis with solar power.

WHITE HYDROGEN

Hydrogen produced as a byproduct of industrial process.

TURQUOISE HYDROGEN

Hydrogen produced from natural gas using the molten metal pyrolysis tech-nology.

Hydrogen Rainbow – Indian Relevance

Grey	5 MMTPA (100% of H2) produced in India today, 10 T-CO2/T-H2
Brown	110 BnT coal reserves of India; Petcocke; Major thrust of gasification; CTH; 18 T-CO2/T-H2
Green	Basis for NHM for India; Water electrolysis using RE; 450 MnT biomass; < 1 T-CO2/T-H2
Blue	Needs major impetus on CCUS; Inertness/ costs/ safety; < 3 T-CO2/ T-H2
Turqu oise	Lower energy required than water electrolysis; C-sale credit; CBG pyrolysis; Carbon negative

Green hydrogen policy and implications

GOVERNMENT OF INDIA
MINISTRY OF POWER
सत्यमेव जयते

India's 2030 green H_2 production target

100 GW	40 GW	USD 100 billion*	=	5.0 MMTPA

Producing 5 MTPA of green hydrogen

50 MMT (1.6%)	68%	₹ 40,000 Cr
CO_2 reduction	LNG import reduction	Revenue saved

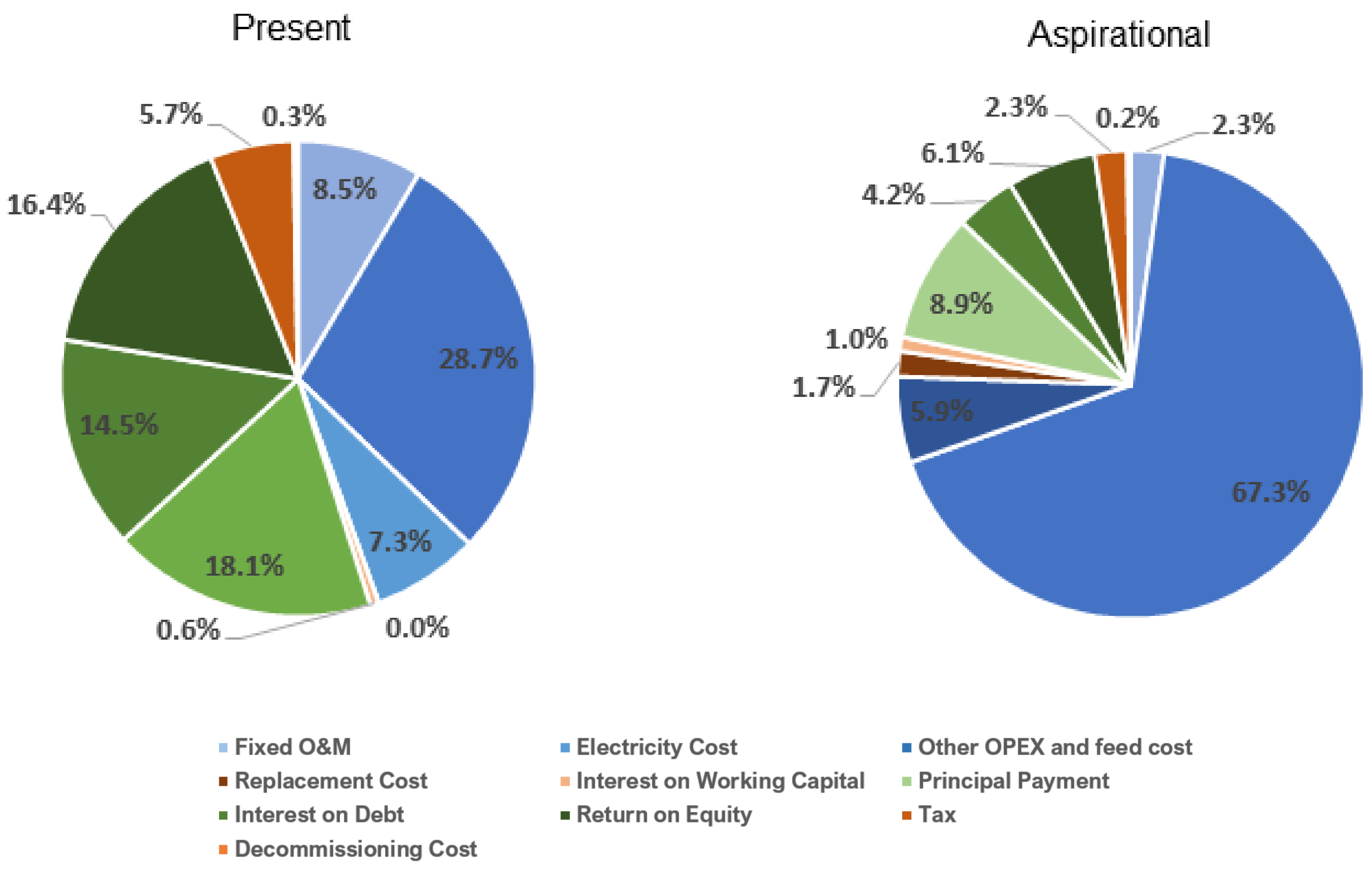
*Includes renewable energy, electrolyser and hydrogen storage costs | Source: CEEW analysis

The LCOH of Green Hydrogen

$$\text{LCOH} = \frac{\text{Net present value of total projected lifetime cost of GH2 production plant}}{\text{Net present projection of total hydrogen produced over lifetime}}$$

Parameters	UOM	Present (1 – 10s MW)	Near Term (100s MW)	Future (0.5-1 GW)	Aspiration ($1/kg)
LCOH	**$/kg**	**4.8**	**3.0**	**1.5**	**1.0**
Electrolyzer CUF	%	23	23	23	40
Specific Electricity Consump.	kWh/kg-H2	52	52	46	43.5
Electrolyzer Installed Capital Cost	$/kW	900	450	250	250
Electricity Cost (LCOE)	INR/kWh	2.1	2.1	1.5	1.5
Fixed O&M	% of capex	1.5	1.5	0.75	0.75
Variable OPEX	$/kW	1	1	0.5	0.5
Return on Equity	%	14	14	14	10
Interest on Loan/ Debt	%	8	8	8	5

The LCOH of Green Hydrogen



The LCOH of Green Hydrogen

Key take-aways: It is possible to achieve LCOH < 2 $/ kg for GH2 by electrolysis if:

1. The opex can be reduced by
   - Having access to LCOE of < 2 Rs/ kWh
     - This may be possible for an integrated solar-electrolysis plant at scale
     - Buying cheaper RE in off-peak hours instead of curtailing it
     - Improving CUF through solar-hybrids
     - Cheaper energy storage
   - Optimizing the sizing of solar and electrolysis plant for available CUF (without RE storage)
   - Reducing power consumption of electrolyzer per kg GH2 – emerging technologies, high operating pressure

2. The plant capex can be reduced through
   - Scale
   - Indigenization of BOP, PE and stack components

3. The cost of capital is reduced through
   - Policy intervention in the initial phase
   - Access to green capital

Unlocking H2 Potential

- ❑ Ukraine crises; NG prices soaring; EU doubling its H2 demand
- ❑ Major thrust for export
- ❑ Massive incentives in the initial phases by EU, US
- ❑ PLI, Interstate Transmission Charges Waiver, Free banking for 30 days
- ❑ Hydrogen valleys, major pilots
- ❑ Mapping H2 potential for India basis land, water, solar-wind potential, biomass, export potential
- ❑ RSC harmonization
- ❑ Significant R&D investments by all countries
- ❑ Make in India can't be just Assembled in India
- ❑ It has to be Invent + Make in India
- ❑ India must leverage its Enormous R &D Prowess

R&D Structure and Phased Plan

Mission Mode Projects
Short term (0 - 5 years)
Focus on end product development
Industry partnership
Aggregate and leverage existing capabilities and infrastructure

1200 Cr

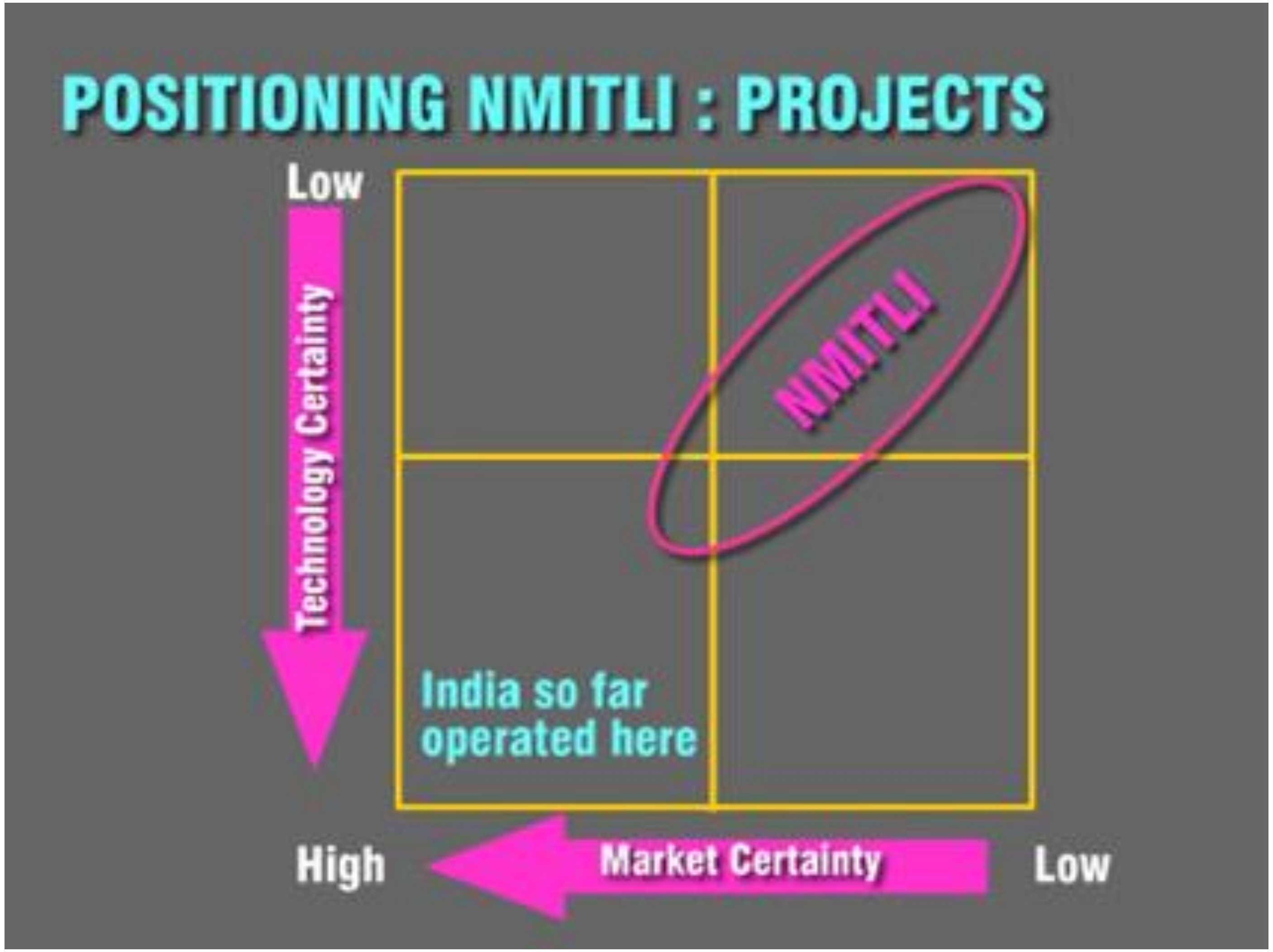
Grand Challenge Projects
Mid term (0 - 8 years)
Focus on critical technology to overcome license denials & supply constraints
Industry partnership in consortium mode
Augment existing capabilities and infrastructure, set up new models for fast translation

1000 Cr

Blue sky Projects
Long term (0 - 15 years)
Focus on global IP, competitive advantage
Special funding to attract best globally sourced Indian talent
Augment competencies and infrastructure in academia, R&D institutions

800 Cr

Genesis of CSIR's H2 Program



- 2002 NMITLI program on hydrogen conceived
- Industry participation from the beginning
- Methanol reformer for H2 production
- 2004 PEM electrolyzer program initiated
- 2005 Bio-H2 supported by DBT, MNRE
- 2009 PEMFC program initiated
- 2010 SOFC program initiated
- 2013 Hydrogen for steel program initiated
- 2014 Coal gasification PP was initiated

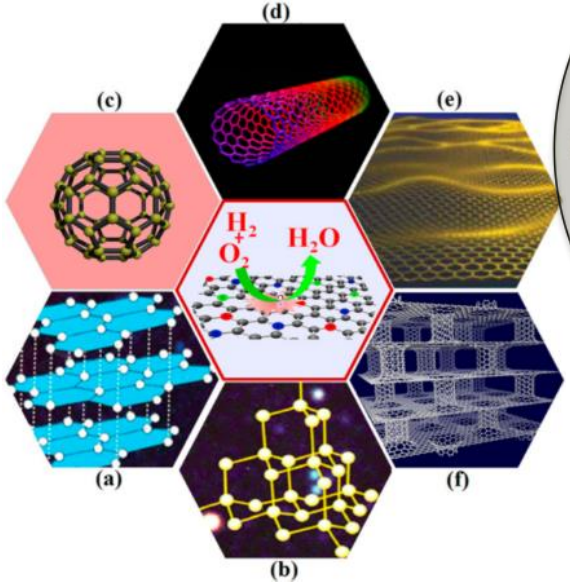
CORE STRENGTH

- ✓ Multidisciplinary expertise
- ✓ Fuel cell system development and demonstration
- ✓ IP and Know-How
- ✓ State-of-the-art facilities for fuel cells and public-private mode partnerships

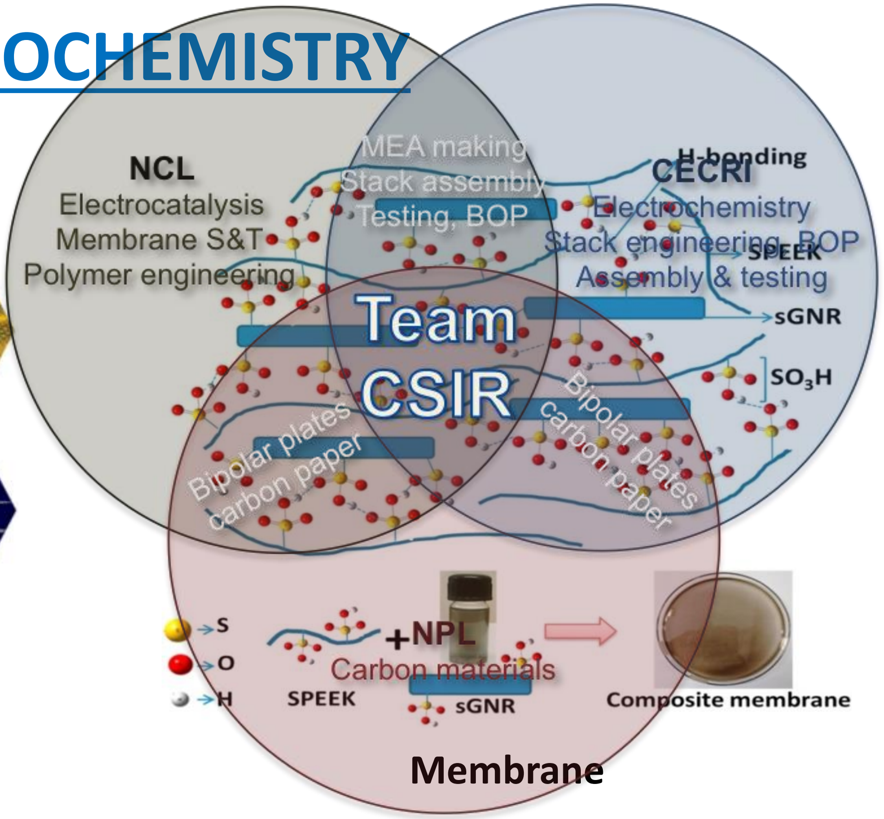
CSIR's PEMFC PROGRAM

CORE EXPERTISE

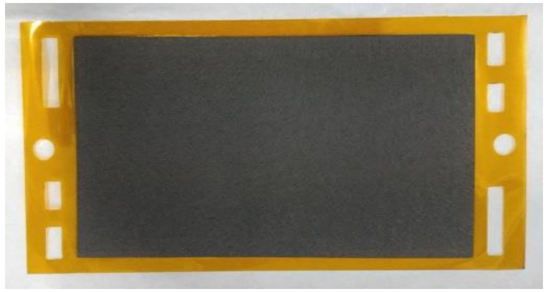
MATERIALS AND ELECTROCHEMISTRY



Catalyst and Catalyst Support



Membrane



Membrane Electrode Assembly

Challenges

Dependence on Import

Cost of Hydrogen

Lack of Infrastructure

System Robustness and Safety

HIGH COST

(Bottleneck in commercialization of fuel cell)

Opportunities

R&D

- ❖ Development of Cost-effective Materials & Process
- ❖ Improving System Efficiency
- ❖ Technology Indigenization
- ❖ Improved Engineering Design
- ❖ Reduce BOP Power Consumption

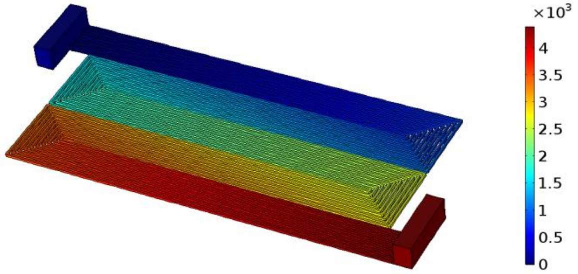
In-house developed fuel cell components and PEMFC stacks at CSIR

MEA fabrication

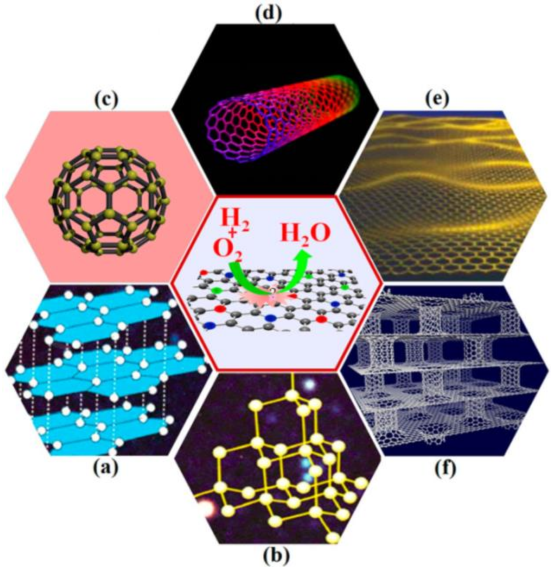
CCM

MEA

Composite membrane



Simulation of Flow-Field



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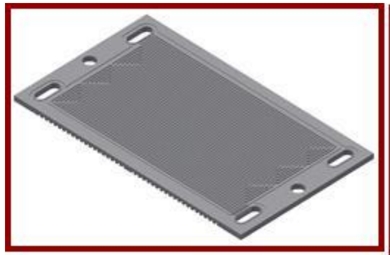
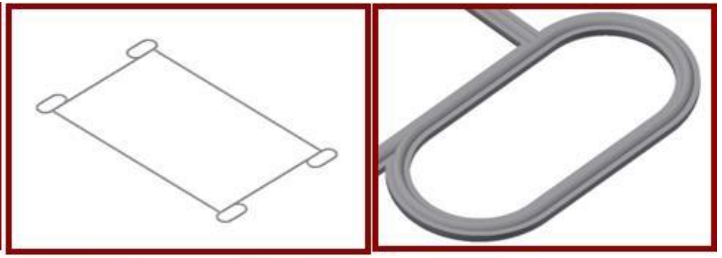
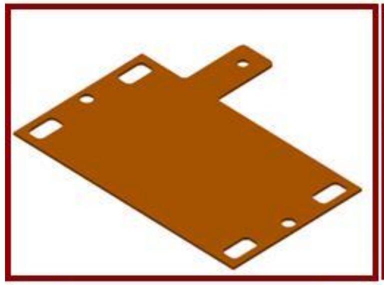


Flow pattern on graphite sheet



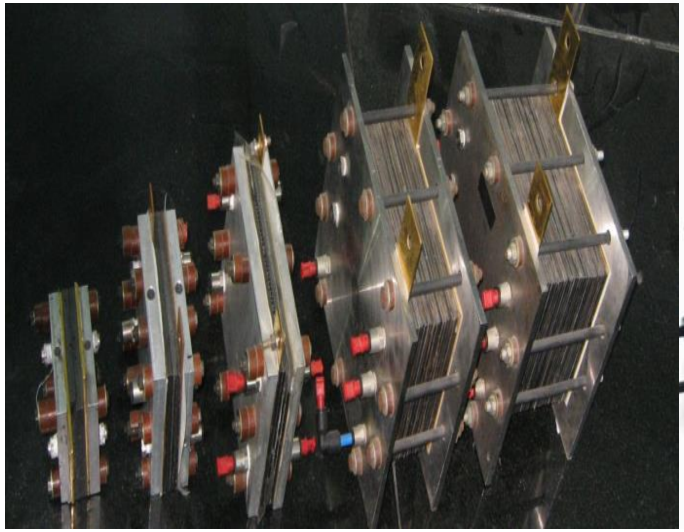
Silicone gaskets

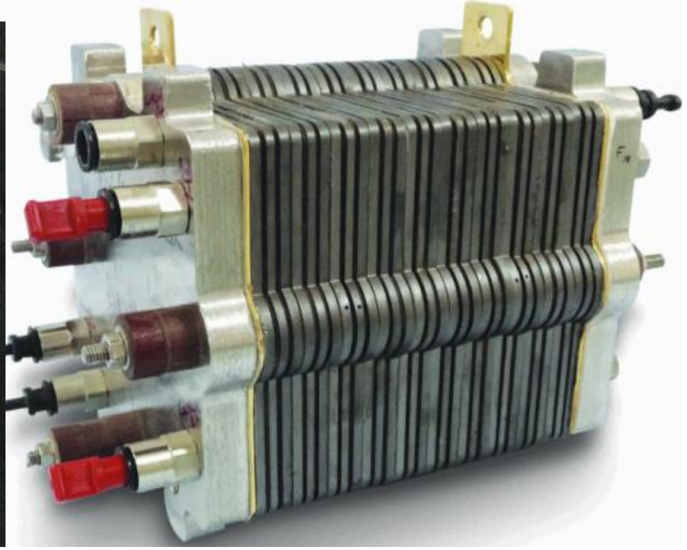


current collector

Al end plate

Coolant plate

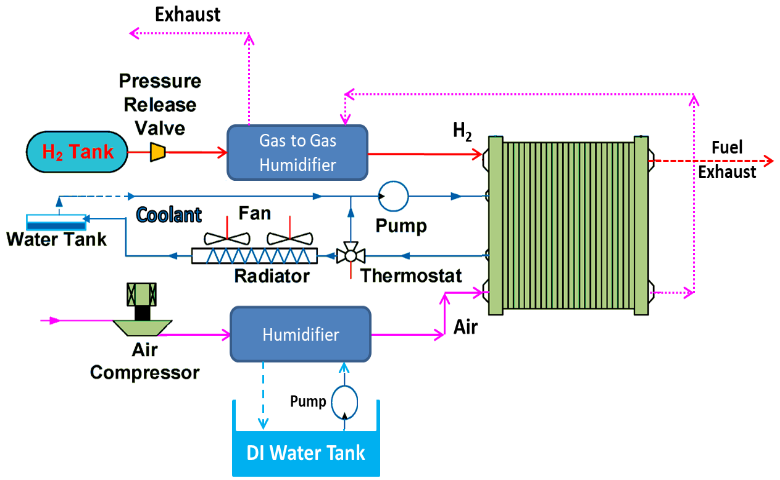


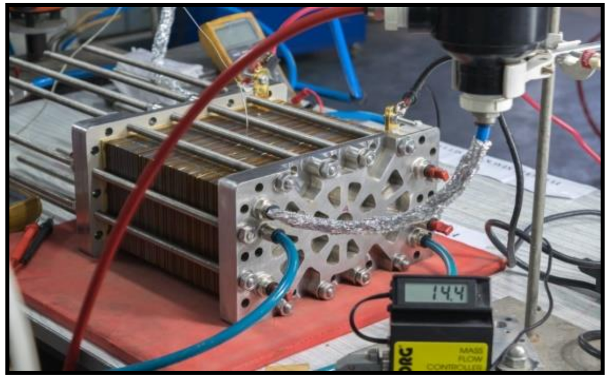


Fuel Cell Research Program for Real Time Application

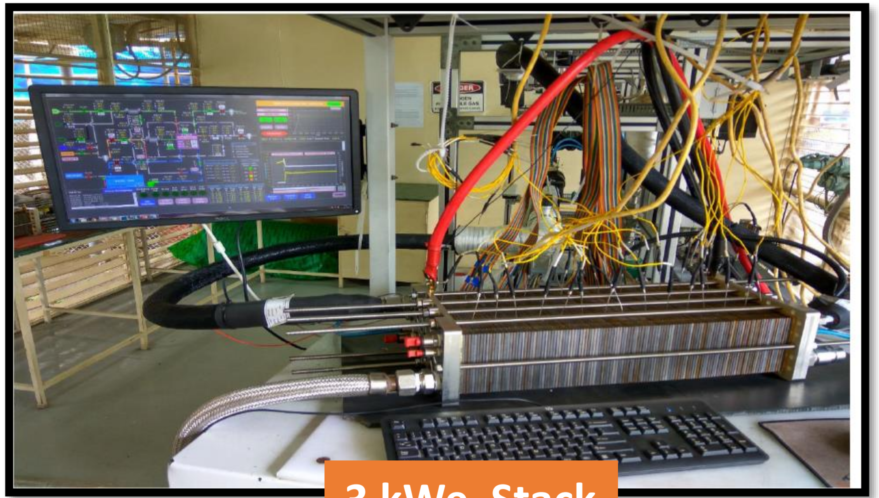
LT-PEM Fuel Cell for Stationary Power Application

Closed Cathode System

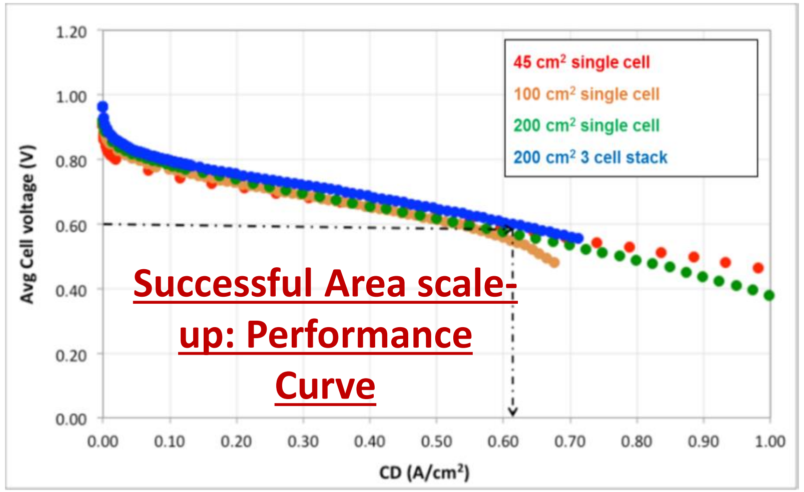


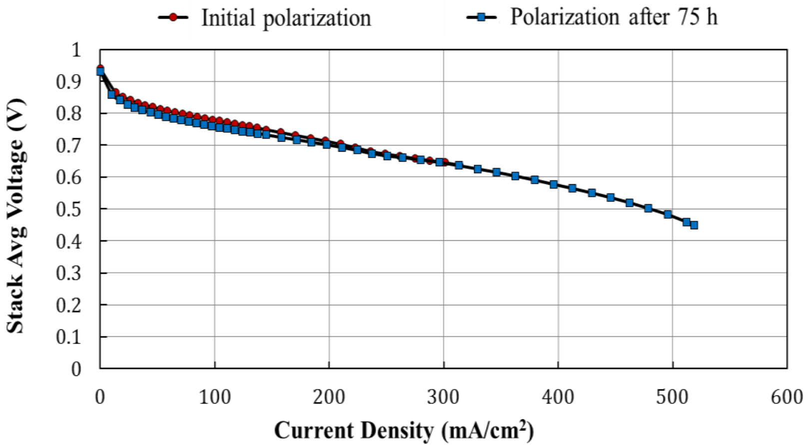


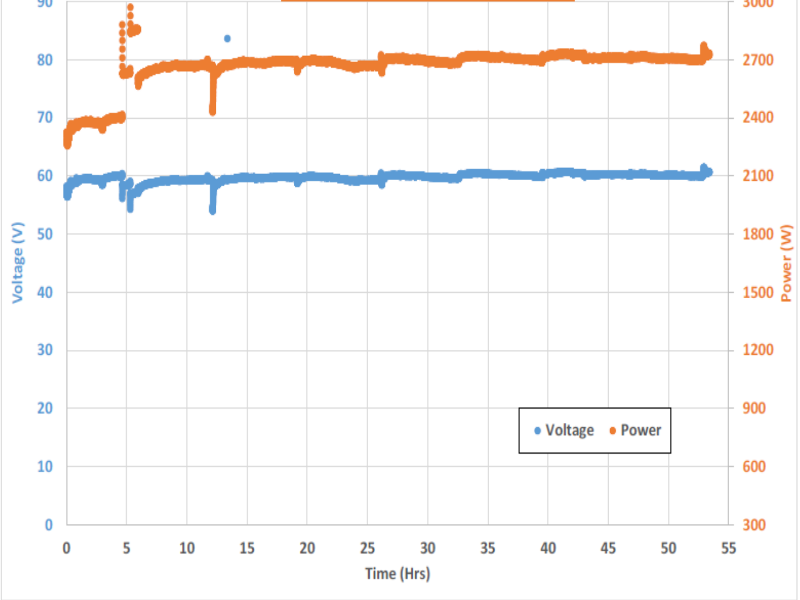
1 kW water cooled LT-PEMFC Stack



3 kWe Stack



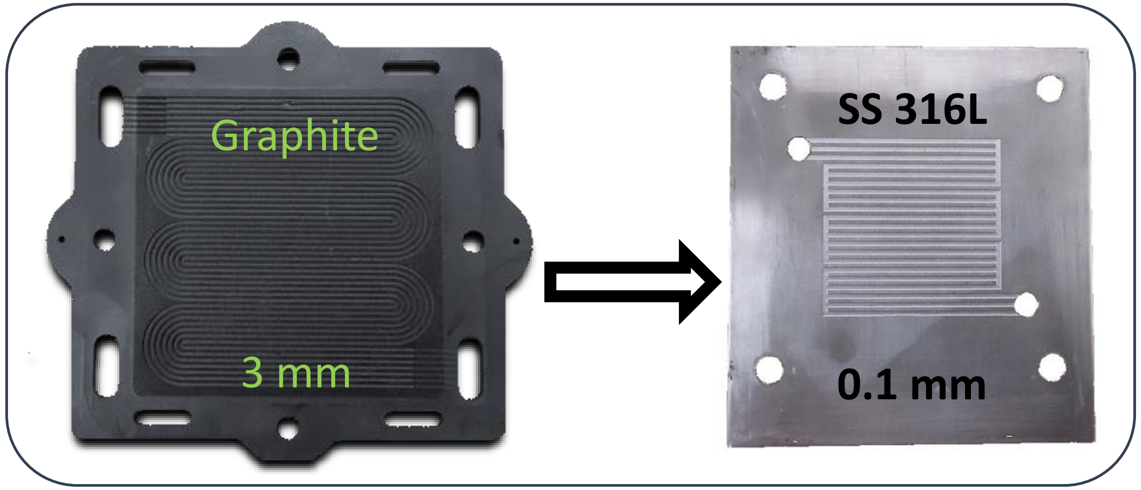




Making PEMFC affordable for Automotive Application

(By replacing graphite bipolar plate with metallic plate)

7-10 % reduction in stack cost



50 % reduction in stack size

6 times lighter for maximum output power

Problems

Low corrosion resistance,
High contact resistance

Solution

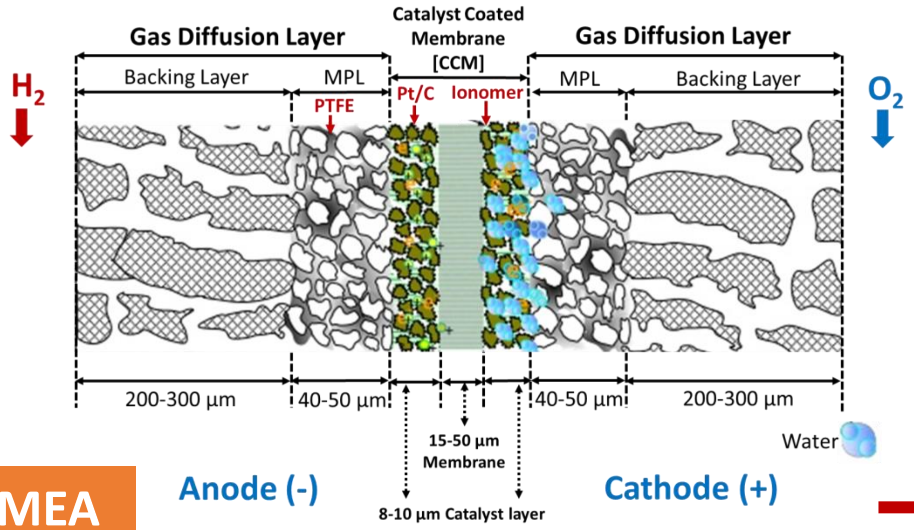
Coating /Surface Treatment
(TiN, Plasma Nitride, Gold)

<u>Processing of the plate</u>

consists of 3 steps

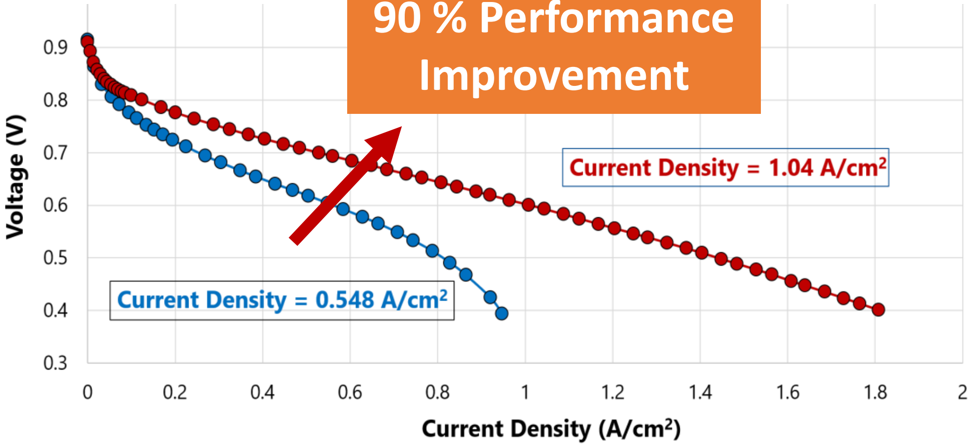
- **Fabrication of the plate**
- **Pre-treatment of the plate**
- **Coating process**

LT-PEM Fuel Cell for Automotive Application (Metallic Bipolar Plate)



MEA

90 % Performance Improvement



10 kW Stack

Prototype Demonstration Fuel Cell Car

CSIR, KPIT conduct successful trial runs of hydrogen fuel cell prototype car

HFC technology uses chemical reactions between hydrogen and oxygen (from air) to generate electrical energy, eliminating the use of fossil fuels.

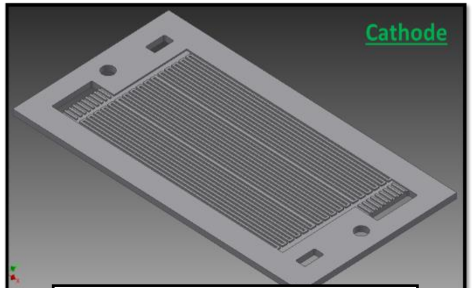
PTI • October 11, 2020, 08:56 IST

New Delhi: The Council of Scientific and Industrial Research (CSIR) and KPIT Technologies successfully ran trials of India's first Hydrogen Fuel Cell (HFC) prototype car running on an indigenously developed fuel cell stack, a statement said on Saturday.

High Temperature Proton Exchange Membrane Fuel Cell for CHP Application

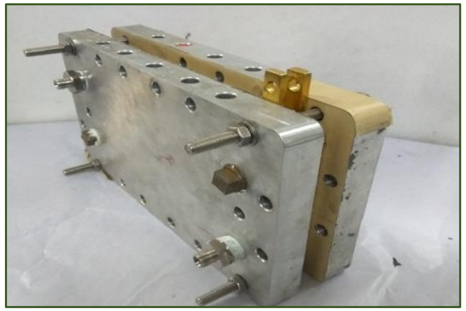
Indigenous Fuel Cell Design

Flow Field Design

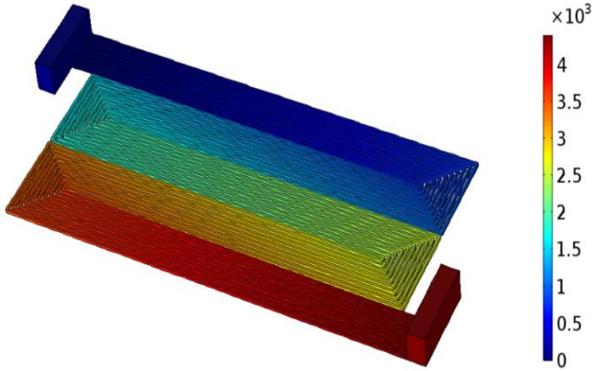


Interdigitated Flow Field

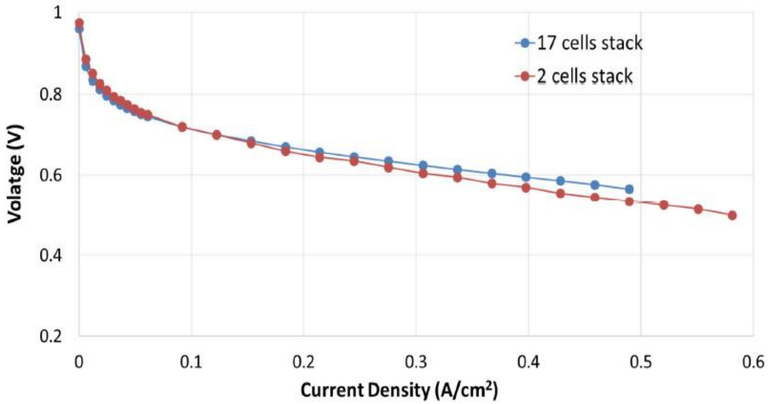
Single Cell Assembly



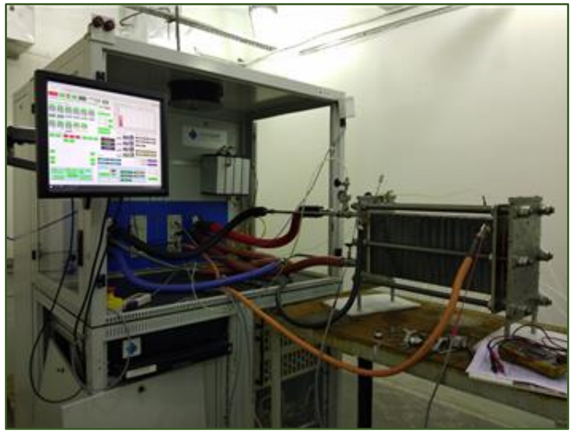
CFD Analysis



Performance Curve



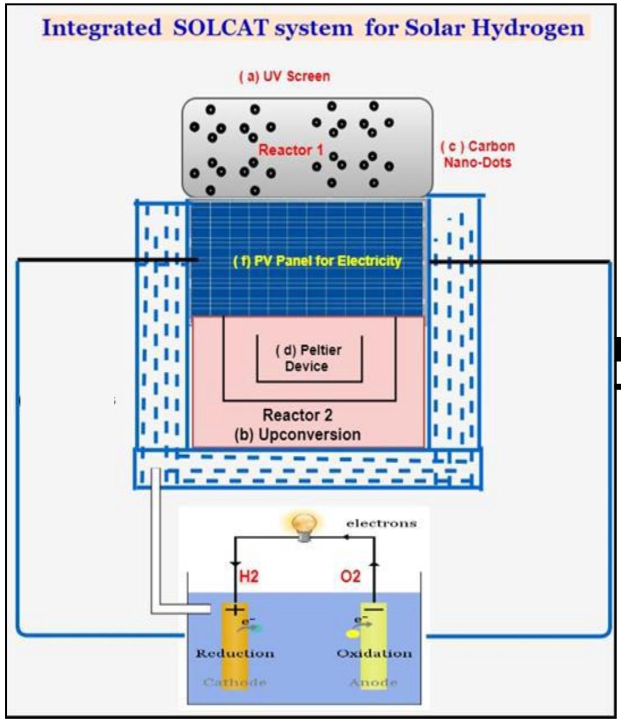
Lab Testing of 2.5-kWe Prototype



Developed 5-kW HT System Prototype

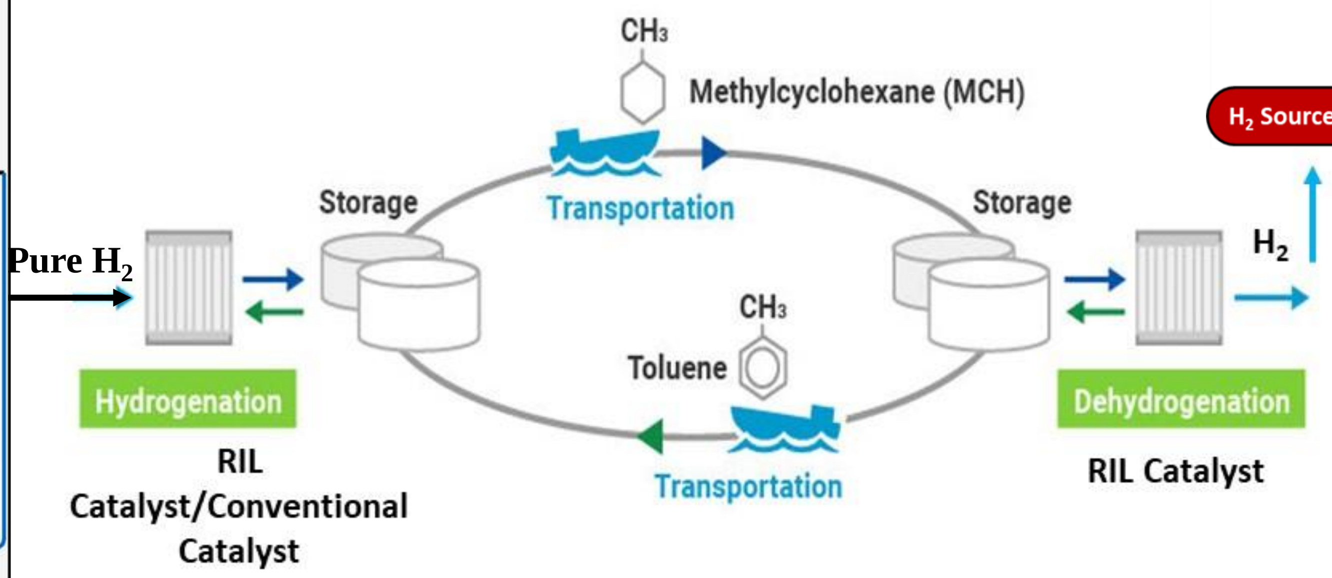
Development and Demonstration of a Hydrogen Eco System

[SOLCAT-HY device: Broad Band Absorption PV Cells and WE as unified standalone reactor]



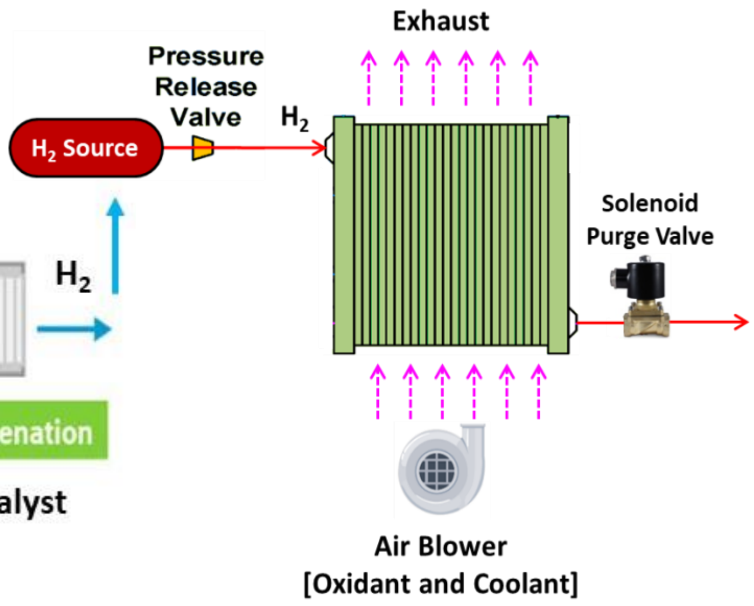
Hydrogen Generation

[LOHC]



Hydrogen Storage and Transporation

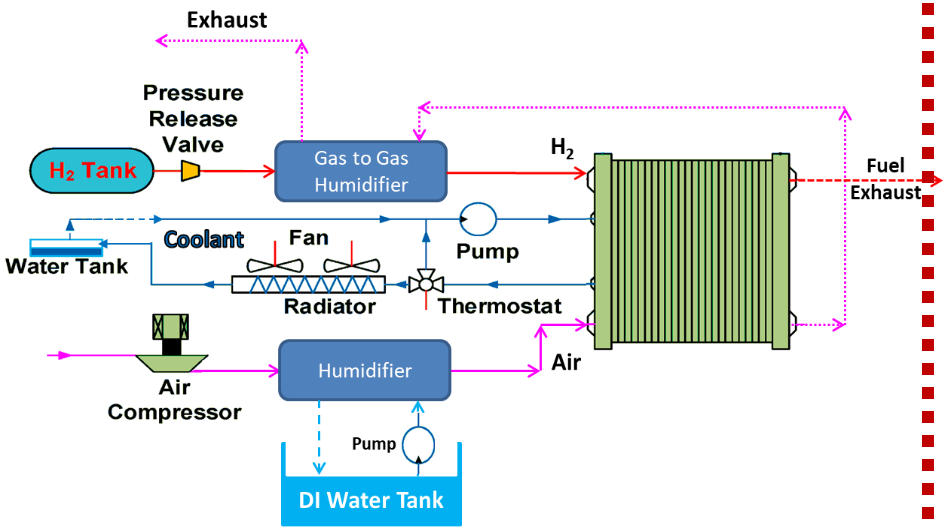
[Fuel Cell]



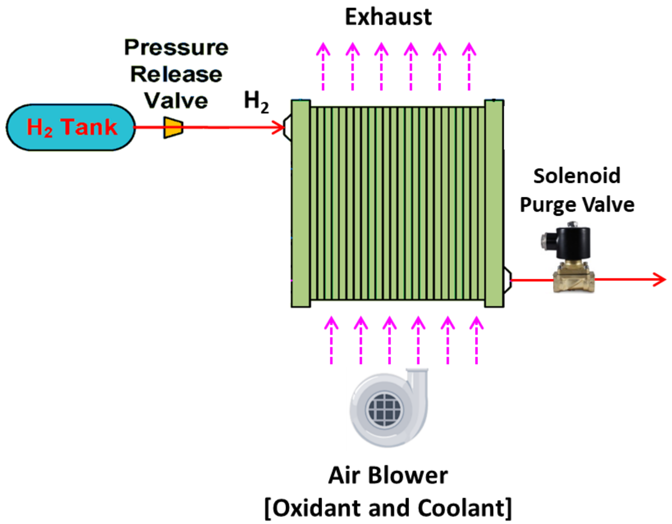
Hydrogen Utilization

Open Cathode PEM Fuel Cell – Backup Power Application

Conventional Fuel Cell System

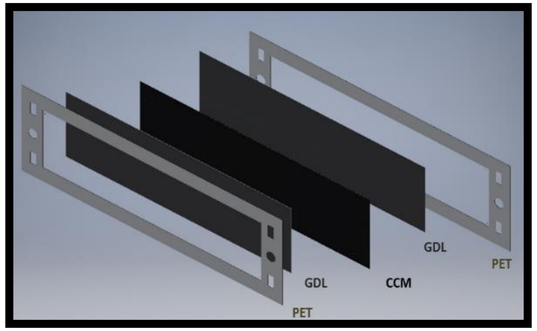


New Open Cathode System



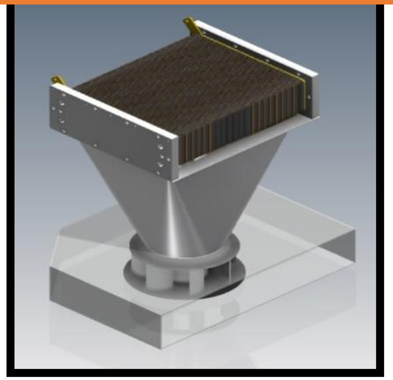
Indigenous Fuel Cell Design

MEA Assembly

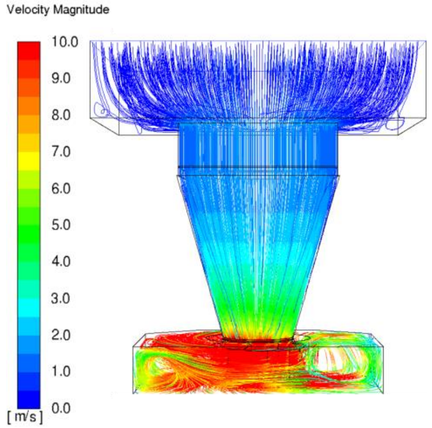


Single Cell Assembly

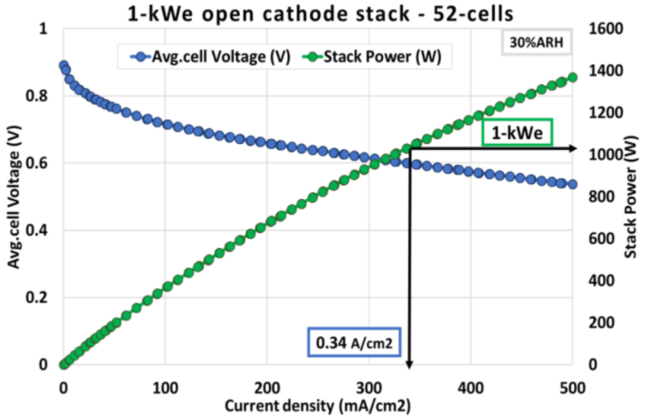
1-kWe Stack Model



CFD Analysis

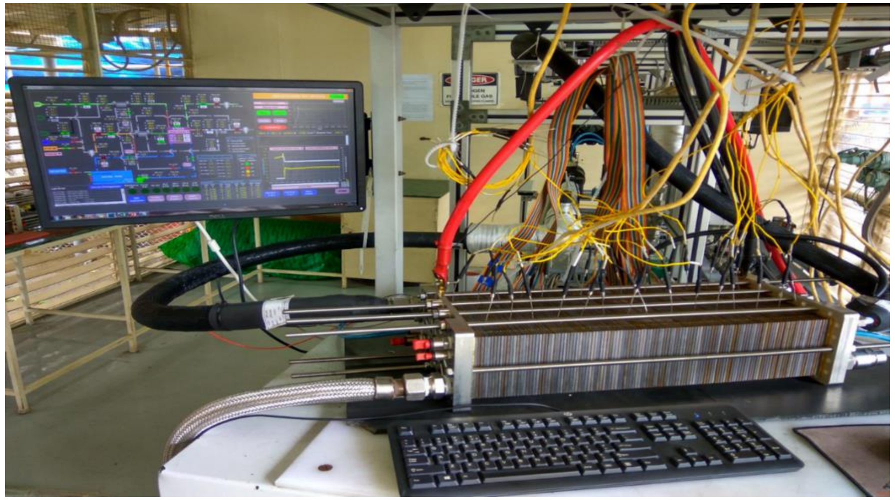


Demonstration of 1-kWe Prototype

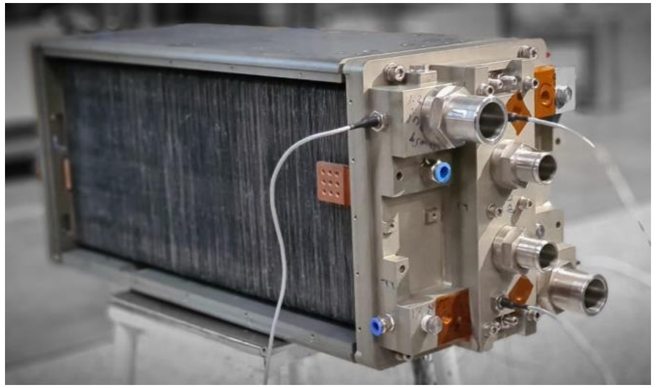


CSIR's Efforts - Fuel Cell Stack Test Protocols

CSIR-CECRI

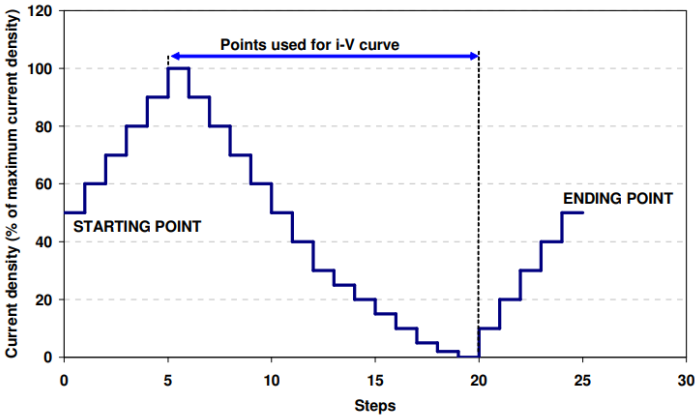


Stationary Grade Stack

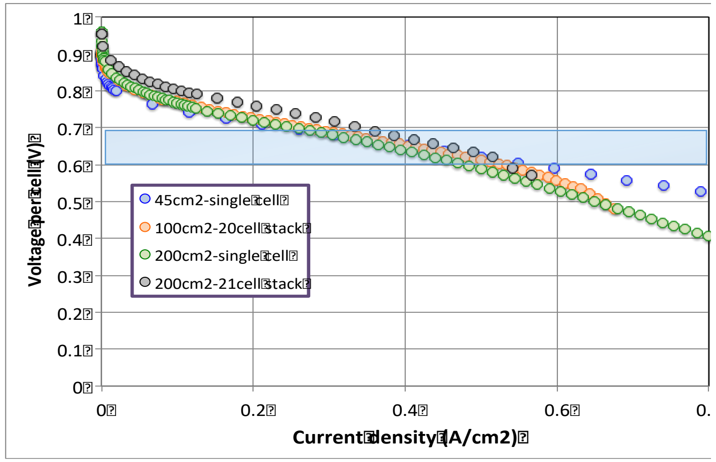


Automotive Grade Stack

Test Module TM PEFC ST 5-3
Version 30 04 2010



Performance Curve



6.3 Step 3: Carrying out the Long Term Durability Steady Test

During this test step, the static test inputs are to be maintained at their values within the specified ranges (see Table 4 or Table 5).
All the test inputs and outputs should be measured versus the test duration.
The main purpose of step 3 is to determine stack voltage (and the stack power) evolution of voltage in terms of V/hours when submitting the stack to a fixed load during a long period. A first value of the stack voltage at $i_{load\ nom}$ is measured when the operating conditions have all reached a stable value. The conclusion of the test referring to the qualification of the stack tested will partially be based on this initial value.
The long term durability test will include long term steady steps and polarization curves. The polarization curves will be performed at fixed intervals corresponding **t max/10** where **t max** is the maximum duration of the test as defined by the specific objective of the test module: t max can be fixed between 500 and 10,000 hours depending on the operating conditions and on the application concerned.
So the measurement step of the test will follow the sequence:

- Initial polarization curve starting at t = 0 after stabilization at i load
- Long term steady test phase n°1
- Polarization curve n°2 at t = t max/10
- Long term steady test phase n°2
- Polarization curve n°3 at t = 2 x t max/10 ...
- Long term steady test phase n°(n)
- Polarization curve n°(n+1) at t = n x t max/10 with 1 £ n £ 10

The comparison of the final polarization curve with the initial one will be used to qualify the performance loss of the stack on the entire range of current density in order to analyze the causes of performance degradation if any.

Note: other analytical methods can be applied during or after the end of the cycling step in order to help understanding the performance evolution. Recommended methods: Cyclic Voltammetry, Hydrogen cross-over, High Frequency, Resistance measurements and/or

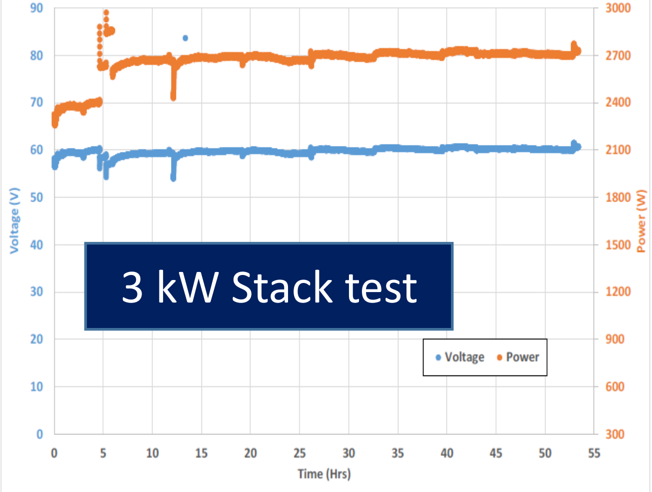
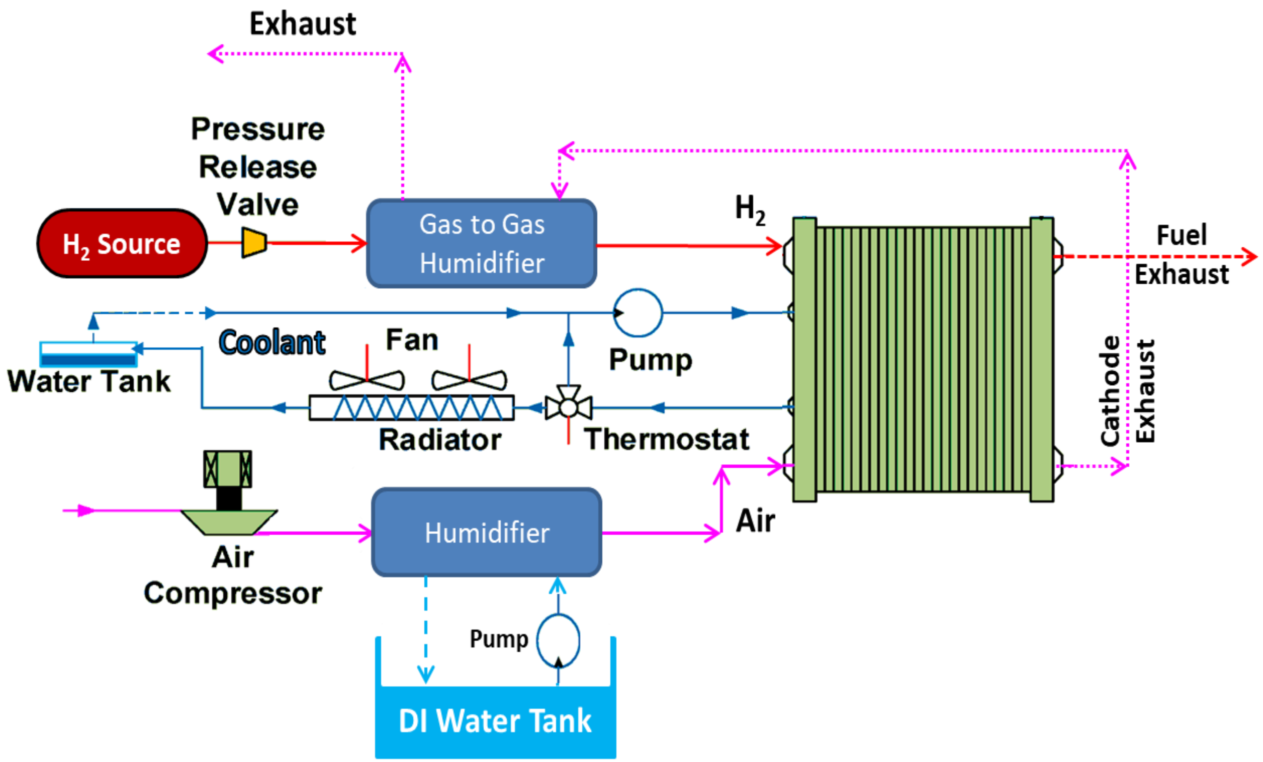
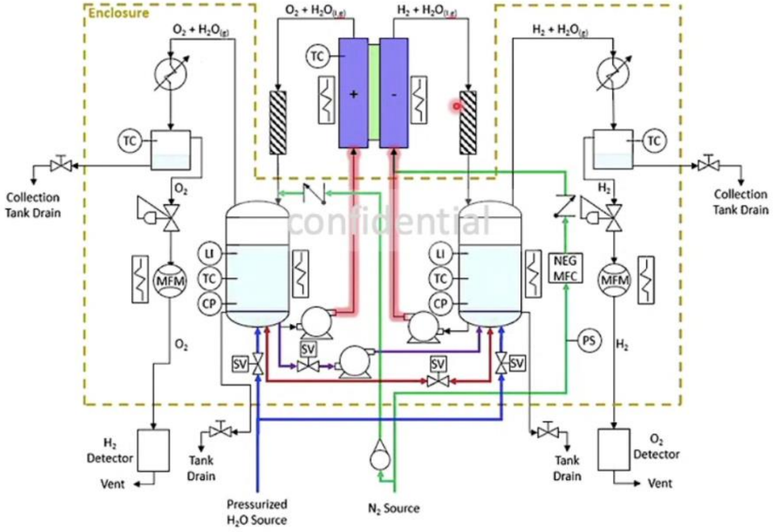


Fig 6.4: Life test (durability) data for 50+ hours with 7 shut-down/start-up sequences

Fuel Cell Test Station Standards and P&ID

Fuel cell Test Station developed by CSIR





P&ID with international safety standards for Hydrogen Fuel Cell (PEM) and Electrolyzer (PEM and AEM) test stations is available

CSIR Events for Hydrogen Technology in India

Prototype Demonstration Fuel Cell Car

CSIR, KPIT conduct successful trial runs of hydrogen fuel cell prototype car

HFC technology uses chemical reactions between hydrogen and oxygen (from air) to generate electrical energy, eliminating the use of fossil fuels.

PTI • October 11, 2020, 08:56 IST

New Delhi: The Council of Scientific and Industrial Research (CSIR) and KPIT Technologies successfully ran trials of India's first Hydrogen Fuel Cell (HFC) prototype car running on an indigenously developed fuel cell stack, a statement said on Saturday.

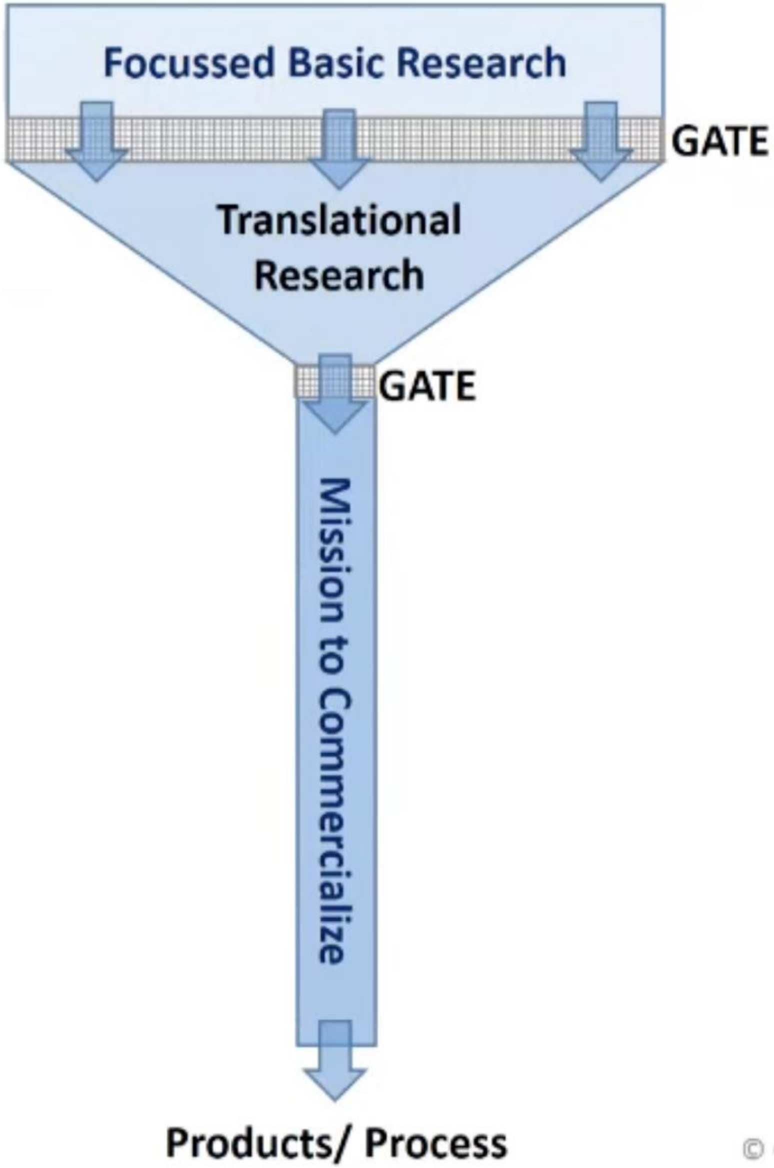
Demonstration of Fuel Cell Electric Vehicle (FCEV) on 07th Oct 2020

Demonstration of High Temperature PEMFC based Combined Cooling & Power System on 26th September 2019

Launch of India's First Indigenous Fuel Cell Bus December 15, 2021

CSIR H_2T Program Structure (2022-24)

- 100 Cr program
- 18 CSIR laboratories
- All 3 parts of the H2 value chain: Production/ Storage/ Utilization
- Structured to facilitate ideas to markets
- From component level to system level to products
- Focus on developing key strategic materials for H2 technologies
- India focussed, but globally benchmarked & globally competitive
- Deep partnerships with Indian industry
- Vendor development with SMEs
- Skill development programs
- Assist in development of RSCs (Regulations/ Standards/ Codes)
- National testing facilities
- Strategy and roadmaps for GoI and industry (Hubs, pilots)



Summary

- MNRE is leading the harmonization efforts in India (3 working groups)
- Indian R&D institutions and academia need to get better embedded in the RSC ecosystem
- Extensive testing facilities exist/ can be created in these institutions
- Deep understanding of technology is available
- Expertise on critical analysis such as LCA is available
- Collaborations/workshops with global SDOs will be beneficial

Fuel Cell Team

Prototype Demonstration Fuel Cell Bus

THANK YOU