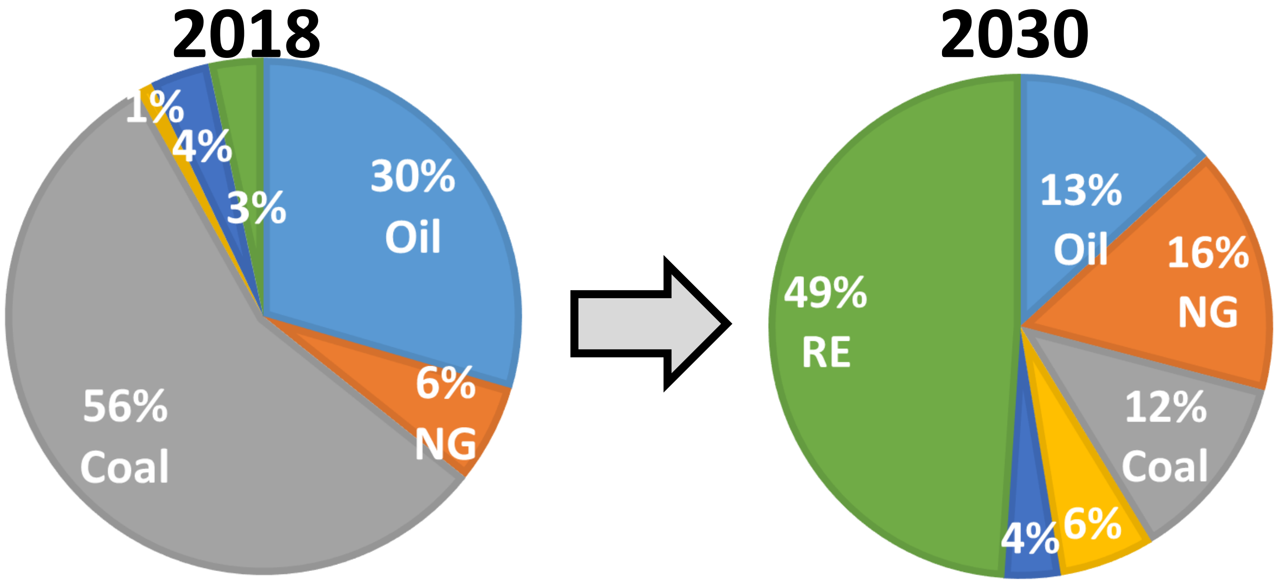
Green, Low Carbon and Carbon-Negative Technologies

Chinnakonda S. Gopinath
H2T Program Director, CSIR-National Chemical Laboratory, Pune

India’s aggressive push to address climate change



Panchamrit

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 $Gt_{CO2\ eq}$
Electricity	33%
Light transportation	5%
Agriculture	18%
Industry (refining, steel, fertilizers, cement, chemicals)	24%
Heavy transportation	5%
Others	15%

India's budget 2022-23 : Opportunities to achieve scale in RE

- 19,500 Cr PLI scheme for high efficiency PV modules
- 5-7% biomass firing in thermal power plants abating 38 MMTPA emissions
- Energy efficiency and savings measures
- Four pilot projects for coal gasification and conversion of coal into chemicals
- Promotion of R&D in this sunrise sector and policies to enable collaborations among academia, industry and public institutions
- Promotion of thematic funds for blended finance (20% Govt. share) in sunrise sectors including climate action

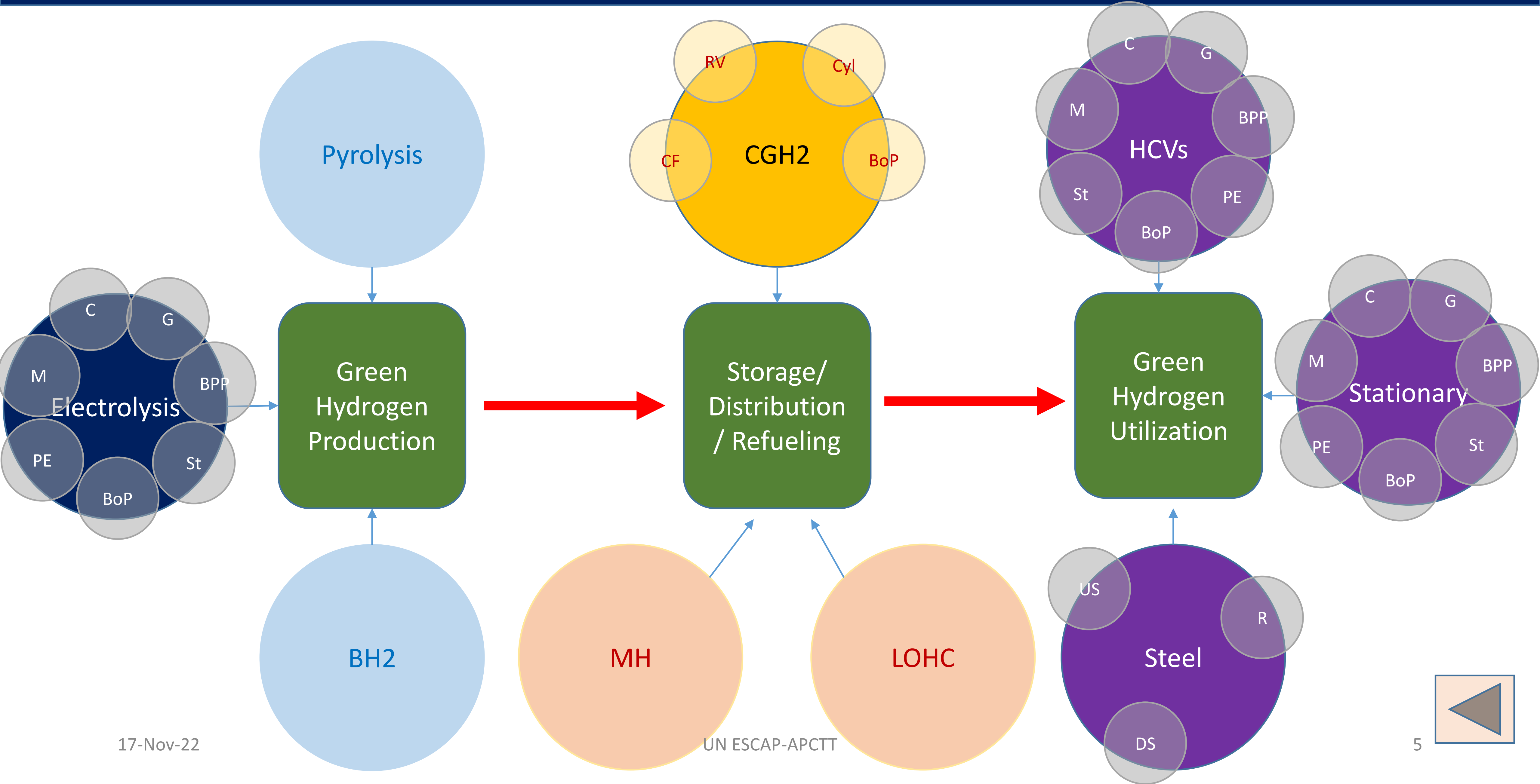
CSIR Hydrogen Technology (H2T) Program

Key activities:

1. **Increase TRL for strategic raw materials, components and systems → tech transfer & vendor devp.**
2. **Continuous R&D and innovation → help Indian companies to stay ahead of competition**
3. **Creating state-of-art testing facilities (in collaboration with other agencies where possible) → enable standardization, certification, quick prototyping, validation of PoCs and rapid scale-up to achieve higher TRLs**
4. **Skilling human resources (in collaboration with other agencies where possible)**
5. **Participating in policy research/ techno-economics/ market intelligence**
6. **Jointly conceiving, planning and monitoring large pilot projects for implementation in PPP mode**

Budget outlay: CSIR – 100 Cr

Mission Mode Technology Projects



H2T Proposals (Overview)

Hydrogen Generation	Hydrogen Storage/ Distribution	Hydrogen Utilization	Testing & IP	Skilling
Electrolysis (PEM/AEM/SOE)	**Type III/ Type IV cylinders**	**LTPEMFC and HTPEMFC**	EOI for testing	To start soon
Catalysts for electrolysis & scale-up				
Compact reformer&H_2 purification	Intermetallics, high entropy alloys and Metal hydrides	Catalyst, membranes, GDL, BPP, MEA, Stacks		
CH_4 Pyrolysis (Plasma and Catalytic)			Analytics & informatics from URDIP	
Bio-H_2/ Waste-to-H_2	LOHC, MXenes	SOFC		
Artificial photosynthesis		HPSR (H_2 plasma smelting reduction or green steel)		
Active industry participation is in place with majority of the project activities.		Modelling and simulations of fuel cell		
Missing	**Missing**	**Support role**	**Missing**	**Missing**
PTL and membrane for electrolysis	Pipes	Scale up of LTPEMFC and HTPEMFC	More testing centers; Market intelligence	Hands-on; Basic/ introductory
	Refuelling			

Exchange of RE among countries could increase the plant load factor to more than 50 %

Water Electrolysis

Stack efficiency and capex are critical for viability

Red-Orange-Yellow-Green

→ Favoured

Electricity Price (INR/kWh)	Plant Efficiency (%)	Plant cost ($/kW) CAPEX: 500				350				200				50			
	Plant load Factor (%) →	15	35	65	90	15	35	65	90	15	35	65	90	15	35	65	90
0.0	60	9.37	1.61	0.37	0.12	7.23	1.21	0.25	0.0[illegible]	5.10	0.82	0.14	0.01	2.96	0.43	0.03	0.00
	75	7.47	1.26	0.27	0.07	5.76	0.94	0.17	0.02	4.05	0.63	0.08	0.00	2.34	0.32	0.00	0.00
	90	6.20	1.02	0.20	0.04	4.78	0.76	0.12	0.00	3.35	0.50	0.05	0.00	1.93	0.24	0.00	0.00
1.0	60	10.15	2.39	1.15	0.91	8.02	2.00	1.04	0.85	5.88	1.61	0.92	0.79	3.75	1.22	0.81	0.73
	75	8.09	1.89	0.89	0.70	6.39	1.57	0.80	0.65	4.68	1.26	0.71	0.61	2.97	0.94	0.62	0.56
	90	6.72	1.55	0.72	0.56	5.30	1.29	0.65	0.52	3.88	1.03	0.57	0.48	2.45	0.76	0.49	0.44
2.0	60	10.94	3.18	1.94	1.70	8.80	2.79	1.82	1.64	6.67	2.39	1.71	1.58	4.54	2.00	1.60	1.52
	75	8.72	2.51	1.52	1.33	7.02	2.20	1.43	1.28	5.31	1.89	1.34	1.23	3.60	1.57	1.25	1.19
	90	7.25	2.07	1.25	1.08	5.82	1.81	1.17	1.04	4.40	1.55	1.09	1.00	2.98	1.29	1.02	0.97
3.0	60	11.72	3.96	2.72	2.48	9.59	3.57	2.61	2.42	7.46	3.18	2.50	2.36	5.32	2.79	2.38	2.30
	75	9.35	3.14	2.15	1.96	7.64	2.83	2.06	1.91	5.94	2.52	1.97	1.86	4.23	2.20	1.88	1.81
	90	7.77	2.60	1.77	1.61	6.35	2.33	1.69	1.57	4.92	2.07	1.62	1.53	3.50	1.81	1.54	1.49
4.0	60	12.51	4.75	3.51	3.27	10.38	4.36	3.40	3.21	8.24	3.97	3.28	3.15	6.11	3.57	3.17	3.09
	75	9.98	3.77	2.78	2.59	8.27	3.46	2.69	2.54	6.57	3.14	2.60	2.49	4.86	2.83	2.51	2.44
	90	8.29	3.12	2.29	2.13	6.87	2.86	2.22	2.09	5.45	2.60	2.14	2.05	4.02	2.34	2.07	2.01
5.0	60	13.30	5.54	4.30	4.05	11.16	5.14	4.18	3.99	9.03	4.75	4.07	3.93	6.89	4.36	3.95	3.88
	75	10.61	4.40	3.41	3.21	8.90	4.09	3.32	3.17	7.19	3.77	3.23	3.12	5.49	3.46	3.14	3.07
	90	8.82	3.64	2.82	2.66	7.39	3.38	2.74	2.62	5.97	3.12	2.67	2.58	4.55	2.86	2.59	2.54
6.0	60	14.08	6.32	5.08	4.84	11.95	5.93	4.97	4.78	9.81	5.54	4.85	4.72	7.68	5.14	4.74	4.66
	75	11.24	5.03	4.04	3.84	9.53	4.72	3.95	3.80	7.82	4.40	3.85	3.75	6.11	4.09	3.76	3.70
	90	9.34	4.17	3.34	3.18	7.92	3.91	3.26	3.14	6.50	3.64	3.19	3.10	5.07	3.38	3.11	3.06
7.0	60	14.87	7.11	5.87	5.62	12.73	6.71	5.75	5.57	10.60	6.32	5.64	5.51	8.46	5.93	5.53	5.45
	75	11.87	5.66	4.67	4.47	10.16	5.34	4.57	4.42	8.45	5.03	4.48	4.38	6.74	4.72	4.39	4.33
	90	9.87	4.69	3.86	3.70	8.44	4.43	3.79	3.66	7.02	4.17	3.71	3.62	5.60	3.91	3.64	3.58

UN ESCAP-APCTT Plant load Factor (%) 7

Sustainable Aviation Fuel (SAF)

- **Importance for India:**
  - Make-in-India SAF will help our aviation industry after mandatory participation in CORSIA post 2028
  - SAF will attract transit traffic through Indian airports
- **Globally patented and differentiated technology by CSIR-IIP:**
  - Our SAF is a 100% drop-in replacement of ATF
  - Lower opex due to cheaper catalyst and H2 consumption
  - Lower capex due to smart process technology
  - 600 litres biojet fuel production in lab-scale plant
  - 10% blend of biojet fuel demonstrated in Republic Day fly-off in 2019
  - 10% blend of biojet fuel demonstrated in IAF's flight to Leh
  - 25% blend of biojet fuel demonstrated in commercial Spicejet flight
- **Expected impact:**
  - 10% replacement of ATF will abate 1.6 million tons CO2

Scalable lipids supply is key: non-edible safflower (NCL), sewage-derived FOG (NEERI), CFTRI

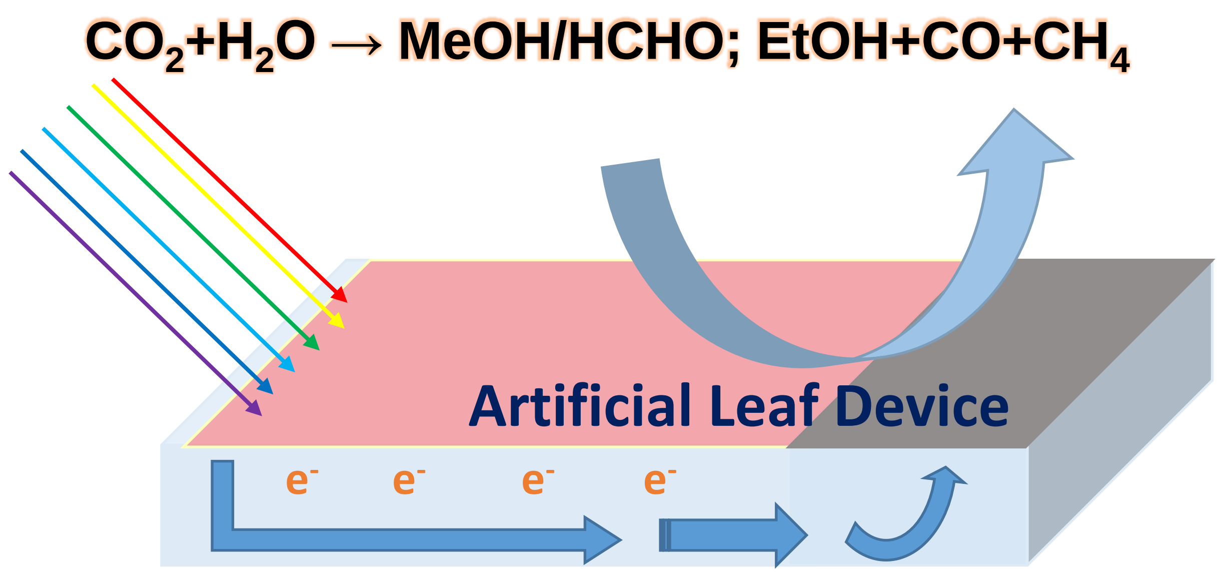
DME Technology

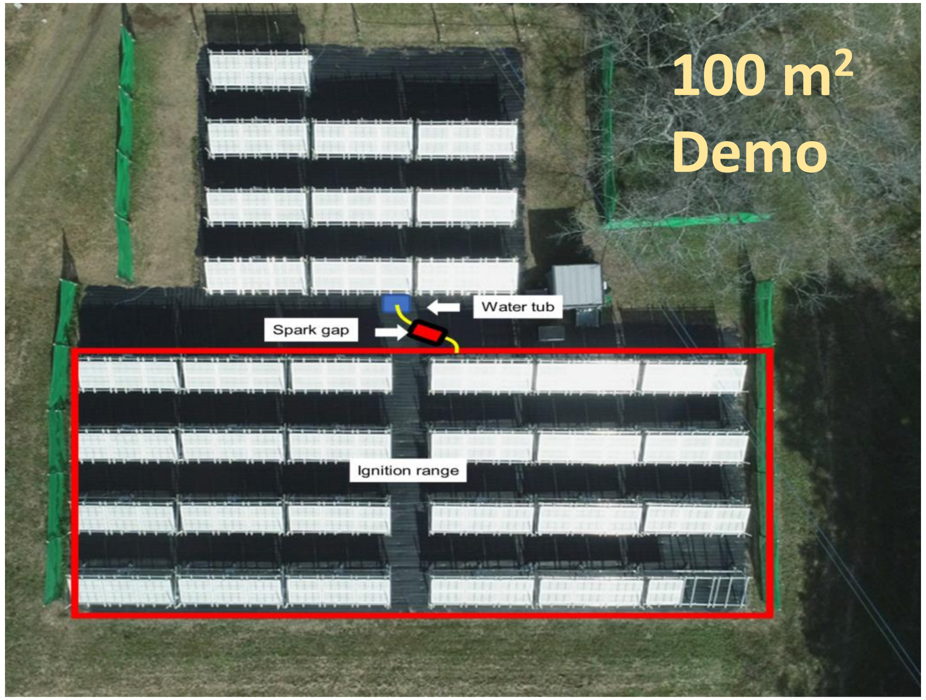
- **Importance for India:**
  - LPG and Diesel are imported fuels
  - DME is certified as a substitute for LPG and Diesel
  - Make-in-India DME will reduce imports
  - Big impact on Ujjwala Yojana
  - Easy retrofit to diesel engines, lower emissions
- **CSIR-NCL's differentiated technology offering:**
  - Globally benchmarked catalyst; 6 patents filed
  - 98.5% conversion; 99% selectivity, robust durability
  - 24 L/ day lab-demo plant, 4500 h continuous run
  - Demonstrated fuel for 2-wheelers (ARAI), cooking stove
- **Scale-up plans:**
  - 100 L/ day lab-pilot plant ready
  - Engineering designs for 2.5 ton/day plant in progress
  - EOI from 9 companies
- **Expected impact:**

  Can reduce 5 million ton LPG imports, reduce diesel imports

Fungible deployment model will be integrated with Methanol Economy effort

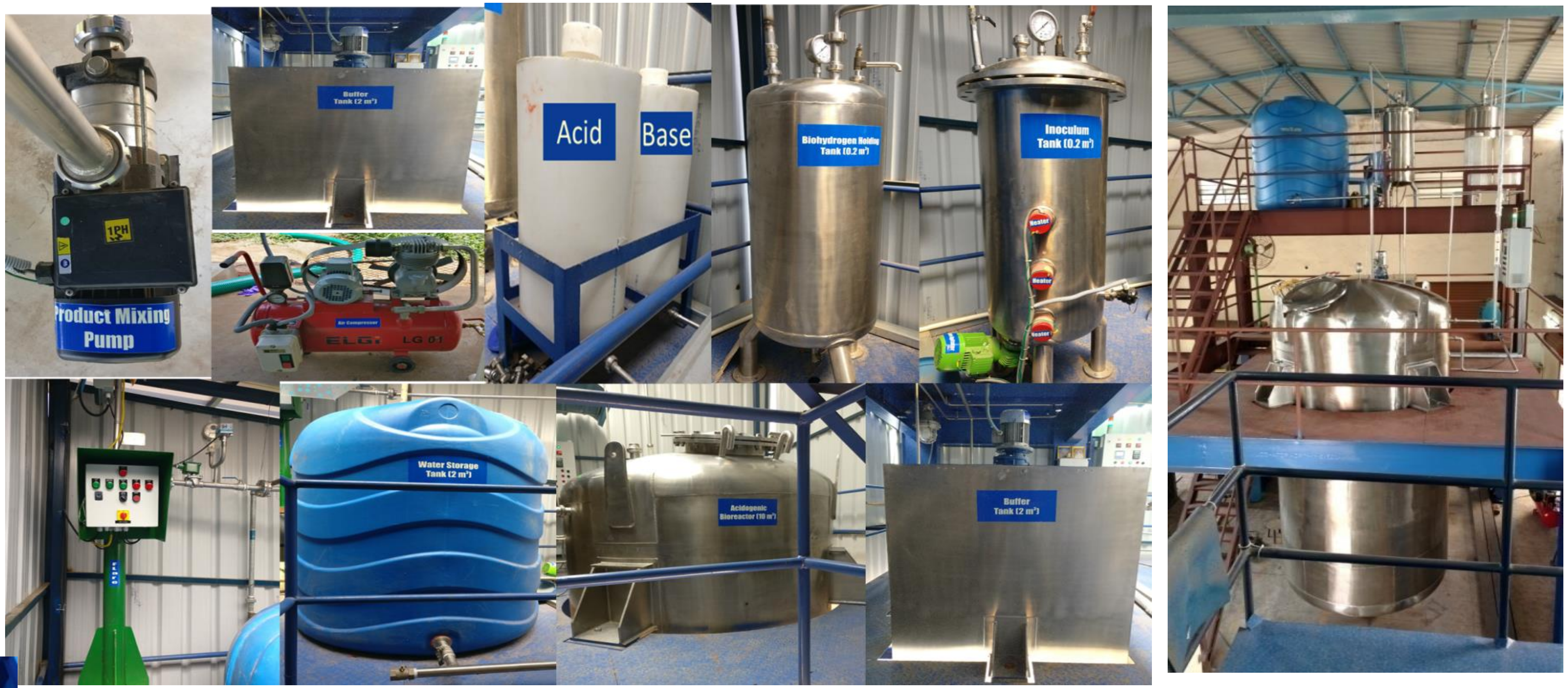
Artificial Leaf and CCU Concept for CO_2+H_2O to Methanol and/or Ethanol





- **Proof of concept available and scale-up work is in progress.**
- **Water splitting from 100 m^2 size device demonstrated by Domen et al.**
- **Could complete the carbon-cycling or carbon-neutral economy, by suitably combining with DME tech.**

Pilot Scale -Standalone H_2 production (50,000 L H_2/day)



Various Unit operations in Biohydrogen Pilot plant

Biohydrogen Pilot plant

- Biogenic Municipal Waste
- Food Waste
- Vegetable Waste
- Industrial wastewater
- Sludge
- Agro-biomass

Acidogenesis →

Biohydrogen (50%)
(50,000 liters/day)

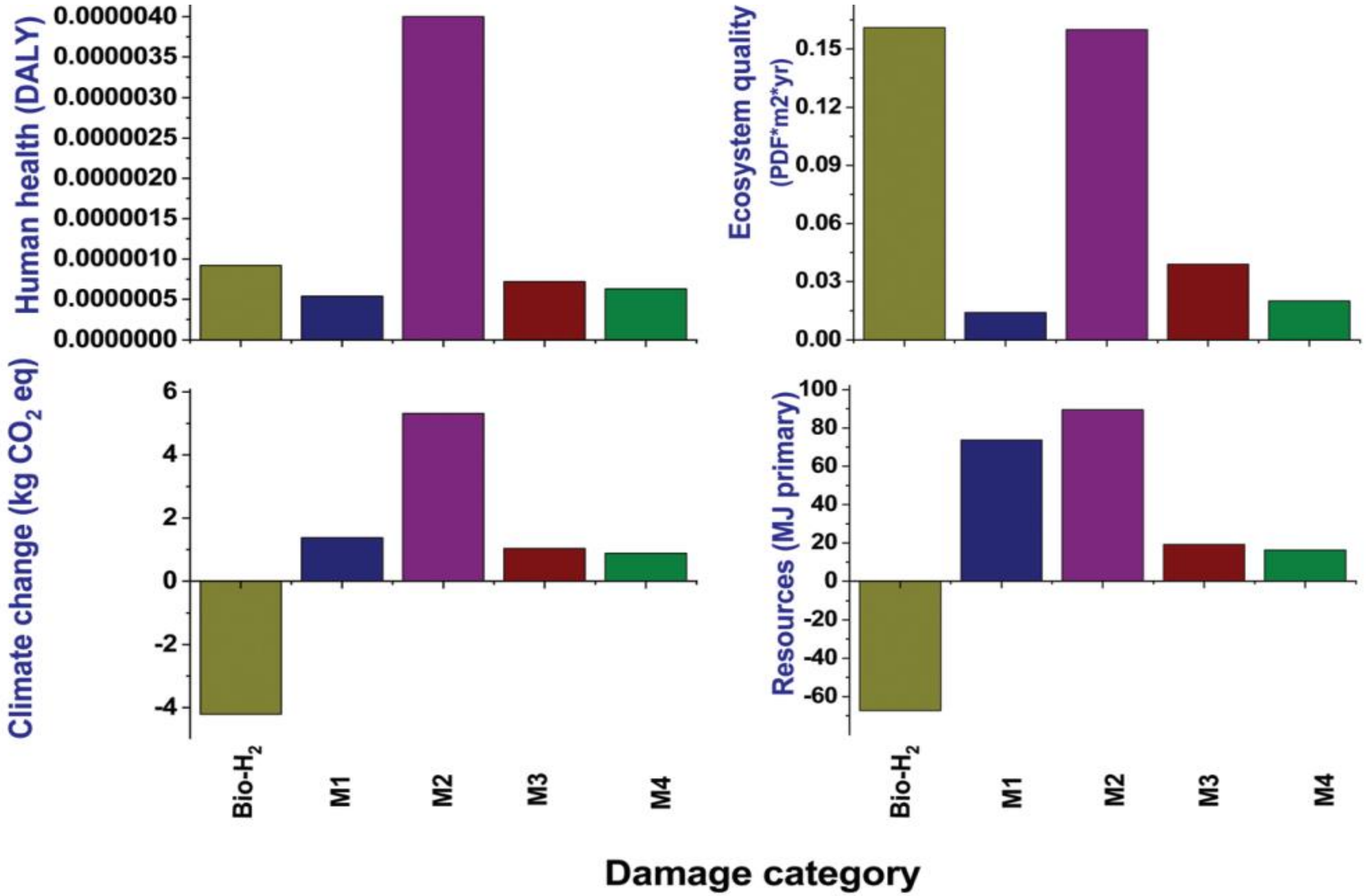
+

Fatty Acids+ Biohythane + Biofertilizer (By-products)

+

Remediation/Treatment
(70% COD removal)

Life Cycle Analysis - Environmental Sustainability



M1 - Ammonia cracking
M2 – Methane Steam Reforming
M3 – Sodium amalgam
M4 – Diaphragm technologies

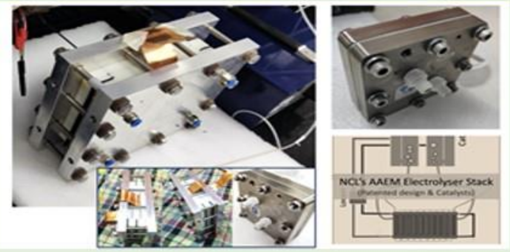
Standalone process with respect to endpoint (damage) categories

Green Chem.,23, 561-574, 2021

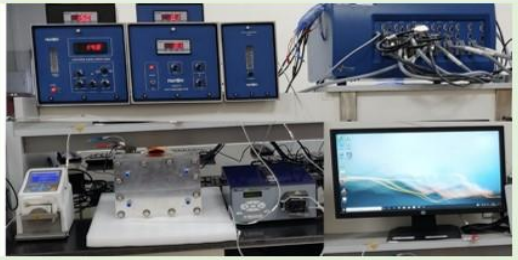
CSIR R&D Across Hydrogen Value Chain

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

Solar Powered Hydrogen Generator (500 L/h)



AEM Electrolyser (Non-precious catalysis)

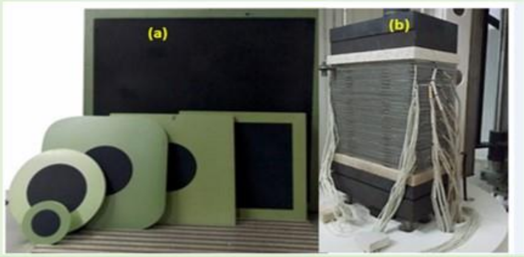


SHADE H_2 Electrolyser (10-1000 cm^2 stack)

Artificial Leaf for Solar to Chemical Conversion

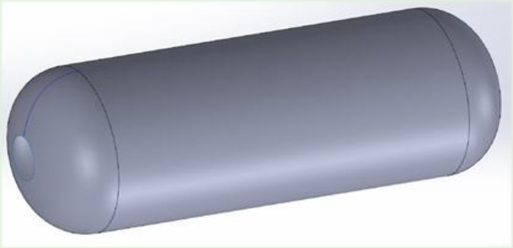
Photoelectrochemical Hydrogen Production

Photocatalytic Hydrogen Production

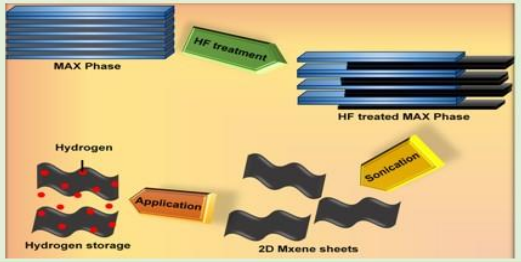


SOFC for High Temp. Steam Electrolyser

Fluidized Bed Gasification Pilot Plant

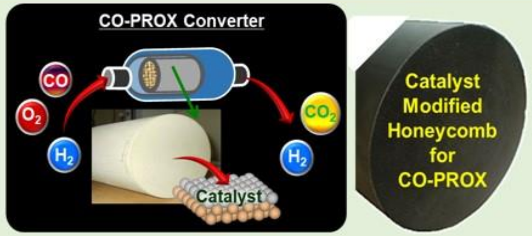


Type IV Hydrogen Storage Tank (CAD Model)

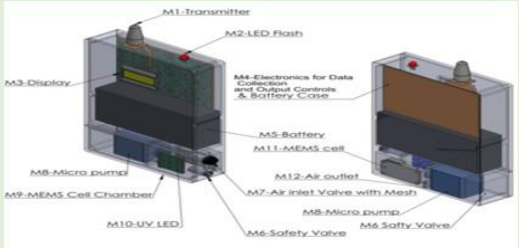


2D MXene based Hydrogen Storage Materials

MOF based Hydrogen Storage Materials

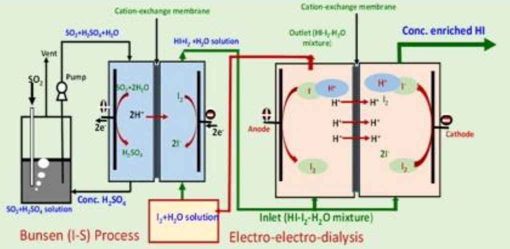


CO-PROX Converter & Catalyst



Hydrogen Detector

I-S Bunsen Cycle



I-S & EED Hybrid Process for HI Production

Thank You