RI&D, Scale and Speed for Green Hydrogen - Strengthening R&D Ecosystem to meet India's Ambitions

Chinnakonda S. Gopinath

CSIR- National Chemical Laboratory, Pune

Targets for Near, Mid and Long Terms

"Green Hydrogen will be India's biggest goal for providing a quantum jump to address climate change"

Aug. 15, 2021

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

India’s National Hydrogen Energy Mission (NHEM)

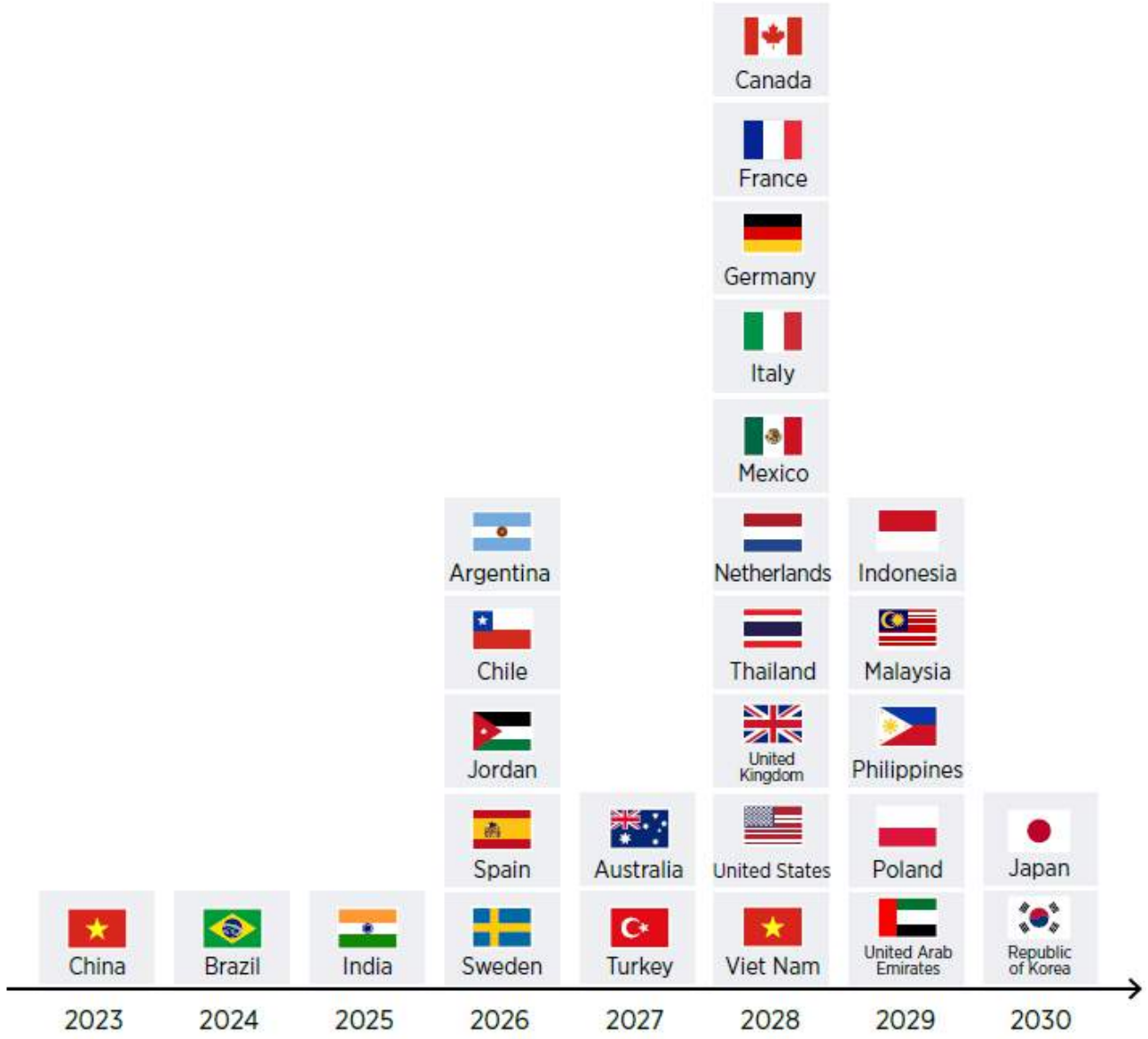
Aspirational Goal

Ensuring sustainability in each part of the hydrogen value chain

Hydrogen 212

- **Hydrogen generation at less than 2 $/kg,**
- **Storage-Distribution-Fuelling at less than 1 $/kg**
- **Replacing fossil tech. by H2 with ROI less than 2 years**

Countries where green H2 could become cheaper than blue H2



Courtesy: IRENA
Int. Renewable Energy Agency

- Lots of scope for RI&D to make H2 affordable, through Tech Devel.
- Pl. remember hardly 5 % of 330 Billion US$ announced is available on the ground.

Water Electrolysis

Stack efficiency and capex are critical for viability

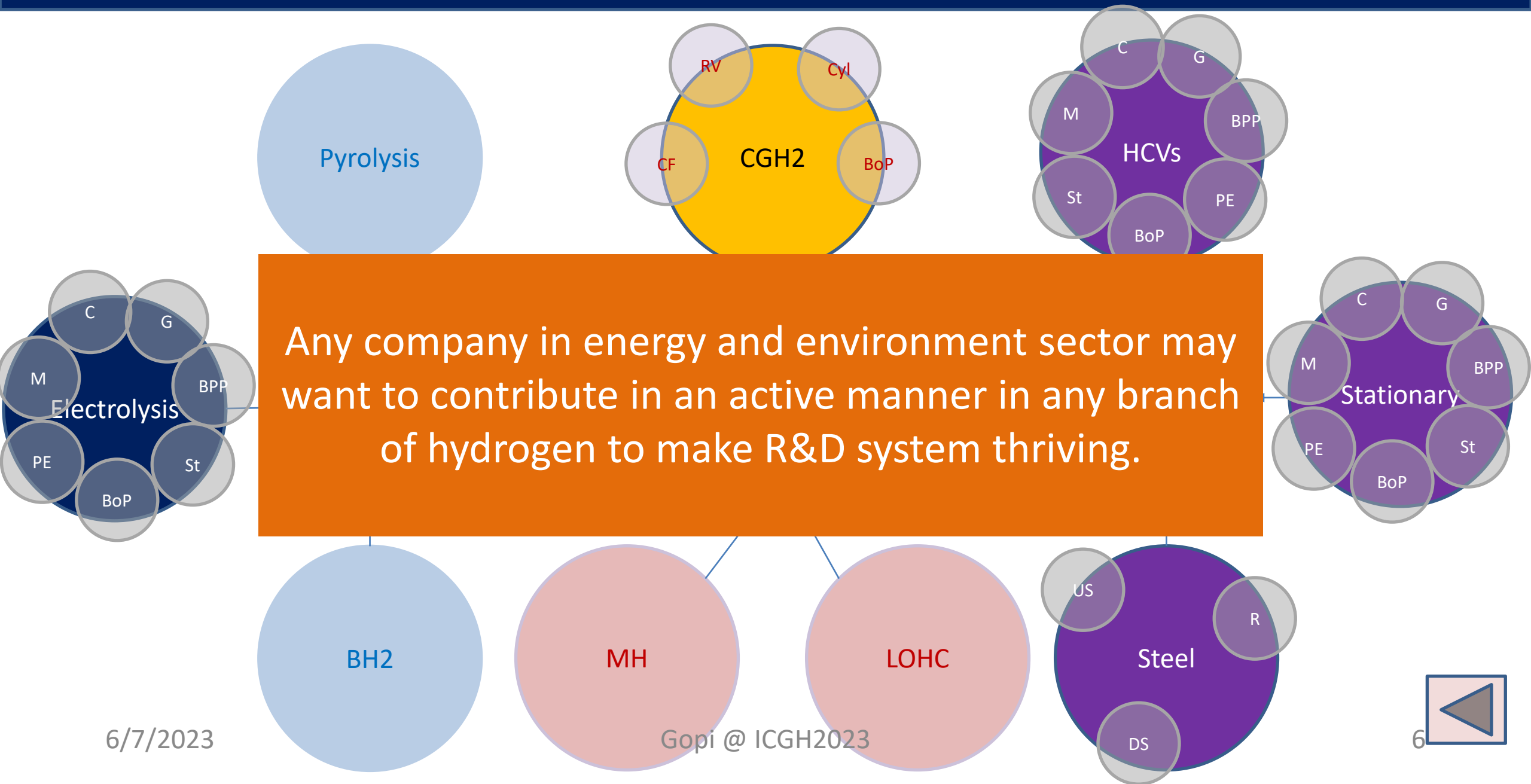
Red-Orange-Yellow-Green

Favoured Direction

Electricty Price (INR/kWh)	Plant Efficiency (%)	Plant cost ($/kW) CAPEX: 500				350				200				50			
		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	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	0.0	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	0.8	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	1.7	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

Plant load Factor (%)

Opportunities Across H_2 Value Chain



RI&D Challenges

Electrolyzers and Fuel Cells:

- Catalysts and their Scale-up
- Membranes and their scale-up
- Interfacial chemistry/physics for better performance
- Theory and Modeling
- Lots of Scale-up and Engineering challenges

Storage, Distribution and Others:

- Composite cylinders that contains recyclable carbon fibers
- Balance of plant
- Liners of composite cylinders
- All testing facilities related to H2

Highly Challenging, but rewarding (currently blue-sky) Projects

- Artificial photosynthesis for H2 and/or carbon recycling
- Water Electrolysis without OER at low potential – Totally different approach
- Sea water splitting with real sea-water and suppress Cl_2 evolution.

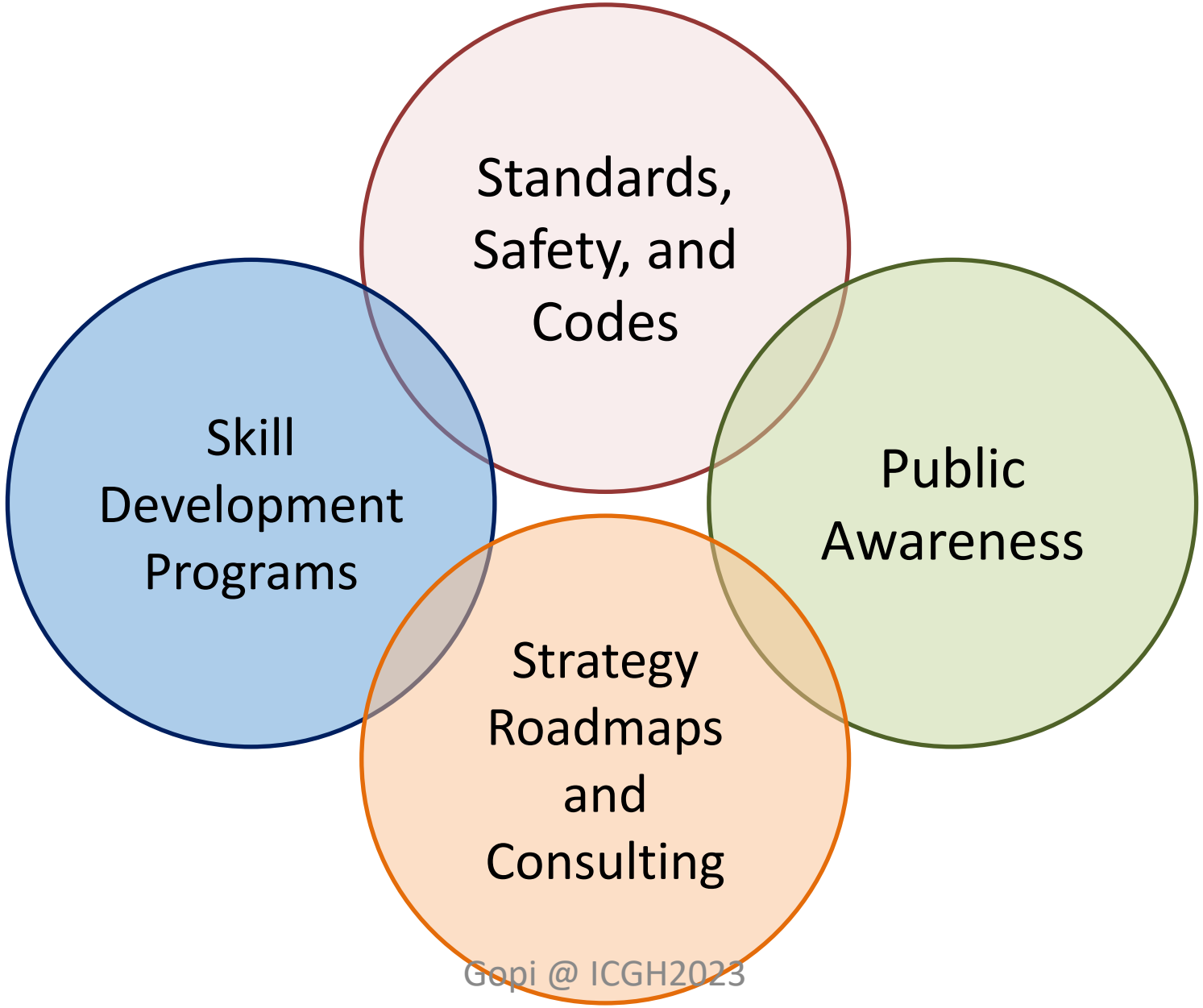
National Hydrogen Energy Mission of India

Mission Strategy:

1. **Creating demand** (blending H2 with NG, 10-year ramp up of green H2 usage in fertilizer and refinery)
2. **Pilots for niche applications** (RE integration & decentralization, HCVs, storage, pipelines, biomass, steel/ methanol)
3. Infrastructure development for storage & distribution **(Best to combine production and utilization locally)**
4. Hydrogen hubs (connecting production with local utilization with short range distribution)
5. **Regulations, codes and standards** (harmonize with intl. stds, timebound approvals for pilots, regulatory framework for vehicles/ storage/ refuelling, testing facilities for certification and validation, web database for regulations/ stds)
6. **Indigenous manufacturing** (incentives for Make-in-India, progressive indigenization across value chain)
7. **R&D** (applied research over short-term (0-5 yrs) and mid-term (5-10 yrs) and breakthrough research over long-term (10 yrs), support SMEs/ startups, PPP mechanism through SHIP, support creation of CoEs with industry consortium)
8. **Policy support** (facilitate open access RE, create demand through policy framework e.g. DG replacement)
9. HRD (skill development centers, course curricula)

Governance: National hydrogen expert group for tech advice/ gap analysis/ roadmapping/ assessment/ market analysis

Other R&D Contributions



Operational Models

Centers for translation and innovation (CTIs)

- Section 8 company
- Rapid translation of ideas into prototypes and commercial products through innovation
- De-risking technology commercialization through viability gap funding (TRL 2 to TRL 9)
- Connect academia, R&D institutions, industry, government agencies together
- Connect experts, facilities, funding and innovation tools
- Core team of scientists, engineers, business professionals
- Mission mode projects, Grand Challenge projects, Testing facili

RI&D to Technology, Scale-up with Speed is absolutely necessary to make H2 affordable

Centers of Excellence (CoEs)

- Co-located within R&D institutions, academia
- Development of new cutting edge and global IP creating techn
- Building new competencies, advanced scientific facilities
- Focusing on Grand challenge projects, Blue sky projects
- Focusing on TRL 0 to TRL 3 projects
- Connecting scientists and engineers across academic/ R&D institutions with CTIs
- Contribute to skill development, public awareness, standards and codes, consulting, strategy and roadmaps

CSIR Hydrogen Technology (H2T)

Key activities:

1. **Increase TRL for strategic raw materials, components and full systems → tech transfer and vendor development**
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**

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	One workshop conducted. More in pipeline
Catalysts for electrolysis & scale-up				
Compact reformer&H2 purification	Intermetallics, high entropy alloys and Metal hydrides	Catalyst, membranes, GDL, BPP, MEA, Stacks		
CH4 Pyrolysis (Plasma and Catalytic)			Analytics & informatics from URDIP	
Bio-H2/ Waste-to-H2	LOHC, MXenes	SOFC		
Artificial photosynthesis		HPSR (H2 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			

Dark-fermentation Process - Biohydrogen Production

Bio-H_2 from Waste/wastewater treatment using enriched anaerobic consortia as biocatalyst

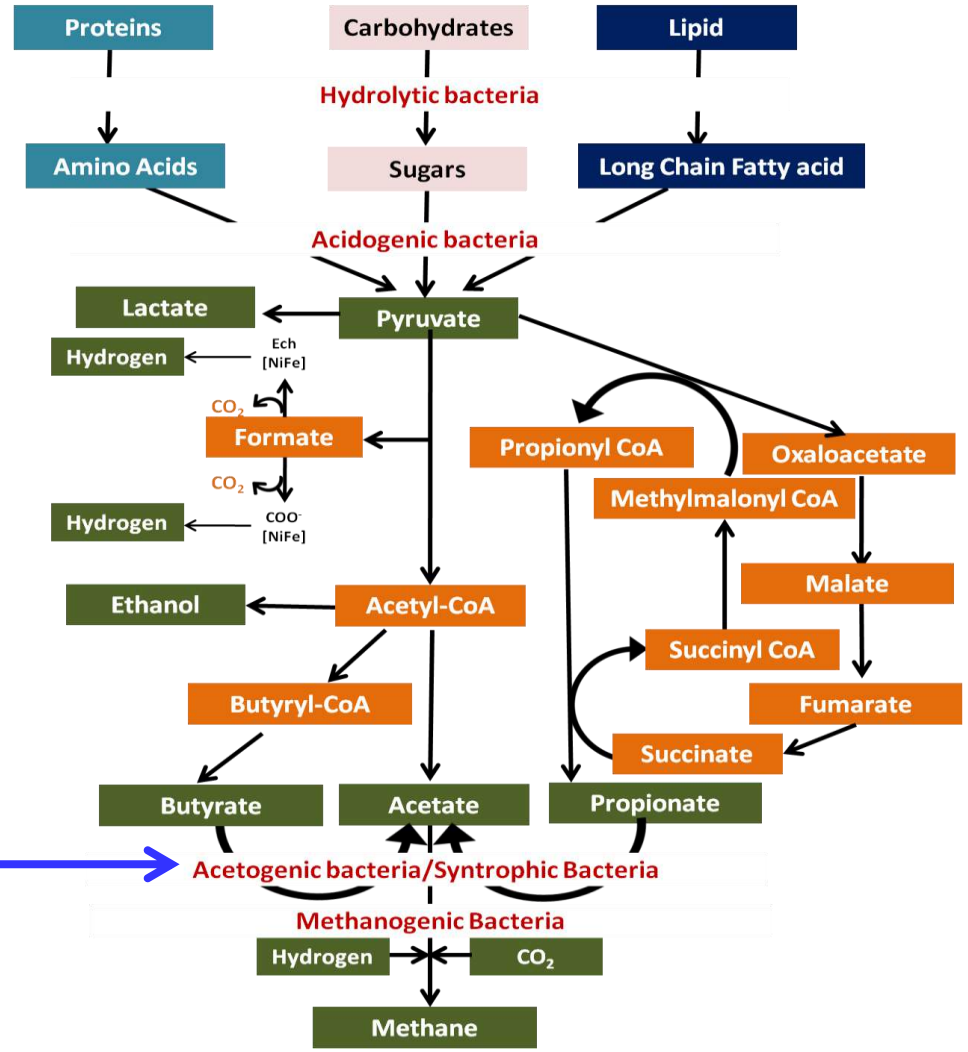
$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$

$C_6H_{12}O_6 + 2H_2O \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$

1 Kg COD = 20.93 mol H_2 = 468 L H_2 (0.042 Kg H_2)

Metabolic regulation

- Blocking of methanogenesis
- Selective enrichment of biocatalyst
- Operational conditions



Anaerobic Digestion Process

Focus of this work is to move more towards value added products along with Bio H2, by blocking CH4 formation.

Pilot Scale -Standalone H_2 production (50, 000 L H_2/day / 4.5 H_2 kg/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)

CSIR's Hydrogen Program: Today's Status

Demonstration of 3 kWe LT-PEMFC System for telecom tower applications

Demonstration of Fuel Cell Electric Vehicle (FCEV) on 07 Oct 2020 and Jan 2022

Demonstration of HTPEMFC based Combined Cooling & Power System

PEM electrolyzer at BARC

SOFC

H2 Plasma Reactor for Steel

Coal gasification pilot plant

Indian R&D institutions and academia are geared up to play an enabling role in building hydrogen economy in India

Indian talent in scientists and technologists must be leveraged for

- Strategic planning of important programs in NHEM
- Formulation of standards and codes
- Creation of centres for translating innovations and testing facilities

- Scale-up with speed is very critical to make H2 affordable.

Thank you